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COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT
HAZARDOUS MATERIALS AND WASTE MANAGEMENT DIVISION

PRELIMINARY ASSESSMENT

COLORADO SMELTER

PUEBLO, COLORADO

CERCLIS #: CON000802700

April 28, 2008

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ATTACHMENT

"Arsenic, Cadmium, Lead, and Mercury in surface soils, Pueblo, Colorado: implications for population health risk"

1.0 INTRODUCTION

This Preliminary Assessment (PA) of the former Colorado Smelter site located in Pueblo, Colorado, has been prepared to satisfy the requirements as set forth in a cooperative agreement between the United States Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE), Hazardous Materials and Waste Management Division. This PA was performed under authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA).

2.0 OBJECTIVES

The purpose of this investigation was to collect information concerning conditions at the former Colorado Smelter site with regard to the EPA's Hazard Ranking System (HRS) criteria, sufficient to assess the threat posed to human health and the environment, and to determine the need for additional CERCLA/SARA work or other appropriate action. Specific objectives include:

- Evaluating and summarizing existing site information and data;
- Identifying sources areas and source types;
- Approximating source volumes or area covered;
- Describing the pathways potentially impacted by the site;
- Identifying and describing targets within each pathway; and
- Identifying data gaps for additional CERCLA assessment.

3.0 SITE DESCRIPTION

3.1 Location

The remains of the 50-acre Colorado Smelter are located within a light industrial and residential neighborhood near the Arkansas River and the central business district of Pueblo, Colorado.

The site is located in the Southwest Quarter of the Northwest Quarter of Section 6, Township 21 South, Range 64 West. The approximate coordinates are 38° 14' 55" north latitude, 104° 36' 30" west longitude (USGS 1961).

The Colorado Smelter site is delimited by Santa Fe Avenue to the east, Agram Avenue to the south, Interstate 25 to the west, and the Arkansas River to the north. The smelter was constructed on the mesa of a large ravine. Waste slag was deposited in the ravine, which contained a significant stream of water (Fry 2000). The approximate location of the Colorado Smelter is identified on Figure 1 and the vegetated ravine, located west of the Colorado Smelter, may be seen on Figure 2.

The median income of Pueblo is $29,650. The average household population is 2.44. Forty-four percent of the population is Hispanic or Latino (US Census 2000). Recreational activities and amenities located within one quarter mile of the Colorado Smelter include a trail system and bike path, fishing, picnicking, parks and open space. Several ball fields are located between one quarter and one half miles of the site. Excursion boat cruises, retail shops and restaurants are located along the Historic Arkansas River Walk, approximately one mile north of the site.

The nearest residence is approximately 200 feet from the slagheap. Residences are located east of the site across South Santa Fe Avenue and south of the site across Agram Avenue. A park is located immediately south of the ravine.

Small businesses are located on-site. This includes Ace Enterprises, Top Notch Trailers, Domenic & Sons Paint & Body Shop, Chem Way Lawn Care, Meadow Gold Dairies, Northern Colorado Paper, and Ryder Truck Rental.

The Arkansas River valley, referred to as the Central Arkansas Playas, is located east of the site, approximately 2 miles away, and has been classified as a potential conservation area due to its high biodiversity. According to the Colorado Natural Heritage Program, several threatened or endangered species have been identified in Pueblo County. This includes the endangered Black-footed Ferret and the threatened Bald Eagle, Canada Lynx, and Mexican Spotted Owl (CNHP 2007).

The Runyon/Fountain Lake State Wildlife Area is located east-northeast of the Colorado Smelter, approximately one-quarter mile away (CDOW 2007).

3.2 Regional History

Between the 1880's and 1920's, six smelters operated in the City of Pueblo and its nearby subdivisions. During the peak of operation, these smelters produced approximately 2000 tons of metal daily. One smelter, the Rocky Mountain Steel Mill, continues to operate (CDPHE 1995).

The proliferation of smelters in Pueblo was due to the nearby availability of coal and limestone, and the service of the area by two railroads, the Denver & Rio Grande (D&RG), and the Atchison, Topeka and Santa Fe. The source of ore was mines located in the mountains west of Pueblo, the Wet Mountain Valley, the upper Arkansas Valley, the San Juan Mountains, and Leadville (Fry 1990).

3.2.1 Other Historic Smelters

Between 1878 and 1921, four other smelters operated in the Pueblo area. These included the Pueblo Smelting and Refining Company smelter (Pueblo Smelter), the New England & Colorado Smelting Company (aka Massachusetts) smelter, the Philadelphia Smelting and Refining Company smelter, and the United States Zinc Company (aka Blende)

smelter. Remnants of these smelters, and their associated waste piles, are visible in many areas. Their approximate locations are presented in Figure 2.

3.2.2 Colorado Coal & Iron Steel Works

The Colorado Coal & Iron Company (CC&I) steel works began operating in September 1881. In 1892, CC&I merged with the Colorado Fuel Company to form Colorado Fuel & Iron (CF&I). CF&I filed for Chapter 11 bankruptcy in 1990. In 1993 the mill was purchased by Oregon Steel Mills Inc. and renamed Rocky Mountain Steel Mills (Porter 2006).

The mill continues to operate under a state Resource Conservation and Recovery Act permit (CO-05-09-29-01) and a Clean Air Act Title V Operating Permit (95OPPB086). A press release was issued in November 2006 to announce the future acquisition of Oregon Steel Mills by the Russian firm Evraz Group SA.

3.3 Colorado Smelter (aka Boston Smelter) History

The Colorado Smelting Company Smelter (also known as Colorado Smelter, Boston Smelter, Boston & Colorado Smelter, and Eilers Smelter) began operating four furnaces in 1883. It was constructed in a ravine between Santa Fe Avenue and the D&RG tracks. The owners of the Madonna Mine, located in Monarch, built the Colorado Smelter in order to smelt the extracted silver-lead ore in a cost effective manner (Fry 1990).

Four more blast furnaces were added in 1889. In addition to the eight blast furnaces, the Colorado Smelter operated two calcining furnaces for desulphurization of ores and one fusing furnace used to slag the flue dust. Twenty kilns were used to desulphur crushed matte from the blast furnaces (Fry 1990).

The Colorado Smelter was consolidated into ASARCO (formerly American Smelting and Refining Company) in 1899 and closed in 1908. Some of the slag was used as track ballast for the D&RG track constructed between Florence and Canon City. In 1923, bricks from the blast furnace smoke stack were used to construct the St. Mary School (Fry 1990).

At present, there are remnants of destroyed buildings and large slag piles at the Colorado Smelter site. Current site conditions are documented in Photos 1 through 7.

3.4 Previous Area Investigations

Several previous investigations have been performed at the Colorado Smelter site and at nearby locations. This work was performed by CDPHE, by the EPA contractors URS Consultants Inc. (URS) and Ecology and Environment Inc. (E&E), and by other entities. The results of these investigations were documented in reports as detailed below:

July 1991	CDPHE	Preliminary Assessment, Santa Fe Bridge Culvert
February 1994	CDPHE	Sample Report, Screening Site Inspection, Santa Fe Avenue Bridge Culvert
June 1995	CDPHE	Analytical Results Report, Expanded Site Inspection, Santa Fe Avenue Bridge Culvert
July 1995	E&E	Analytical Results Report, Boston Smelter
October 1995	E&E	Site Screening Report, Boston Smelter
1995	Pueblo County Health Dept.	"GuardCare '95" Blood Lead Screening
2006	Diawara, et al	Arsenic, Cadmium, Lead and Mercury in surface soils, Pueblo, Colorado: implications for population health risk

In 1989, a citizen contacted the Pueblo City-County Health Department regarding a colored discharge flowing from a pipe into the Arkansas River. The 18-inch culvert extended from the concrete levee wall along the south side of the river, directly under the Santa Fe Street Bridge. Reddish-orange stains were visible where the liquid flowed overland, suggesting the presence of elevated iron concentrations. Pueblo County collected a grab sample of the discharge on September 26, 1989. Analysis of the sample showed elevated concentrations of several metals, including iron. Based on this result, the Water Quality Control Division (WQCD) of the Colorado Department of Public Health and Environment was notified (CDPHE HMWMD 1995).

A WQCD representative visited the site and noted what appeared to be a natural topographic low filled with slag located behind the levee wall. Presumably, the metal contaminated discharge observed flowing from the Santa Fe Bridge culvert resulted from surface or ground waters seeping through the slag. The pipe discharge was not permitted by WQCD. A current owner or operator of the slag pile was not identified, and the Hazardous Materials and Waste Management Division (HMWMD) of the Colorado Department of Public Health and Environment was notified.

In January 1990, the site was entered into the Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) database. The site was named the Santa Fe (Bridge) Culvert and given the Environmental Protection Agency identification number (EPA ID) COD982572513.

In 1991, CDPHE conducted a preliminary assessment (PA) of the Santa Fe Bridge Culvert site. In performing the PA, it was discovered that several smelters had operated in the vicinity of the site between 1878 and 1921. Large slag piles remained, including some located in areas where residential development had occurred. Concerned that these slag piles were a potential source of contaminants, CDPHE expanded the area of

investigation from a focus solely on the culvert to include an evaluation of these additional source areas (CDPHE HMWMD 1994).

The focus for this 2007 PA is to describe Colorado Smelter (Boston Smelter) sources in addition to pathways and targets that may be impacted by the site.

3.5 Site Characteristics

3.5.1 Geology and Hydrogeology

Artificial fill and Quaternary Piney Creek and Post Piney Creek alluvium comprise the surficial deposits. The artificial fill consists of gravel, silt, clay, concrete waste, and smelter waste and slag. The Piney Creek alluvium is 10 to 46 feet thick and consists of yellowish-gray to medium-brown silt, clay, sand and gravel. It has a hydraulic conductivity of approximately 27 feet per day (CDPHE HMWMD 1992).

The alluvium lies over sedimentary bedrock composed of chalk and shale beds of the Cretaceous Pierre Shale and the Smokey Hill Shale Member of the Niobara Formation. These strata have a total thickness of approximately 3500 feet and are relatively impermeable, acting as aquatards preventing the downward migration of groundwater.

The uppermost major aquifer is the Dakota Sandstone. It is approximately 3500 feet to the top of the aquifer in the Pueblo area (USGS 1978).

3.5.2 Hydrology

Downtown Pueblo was constructed along the banks of the Arkansas River. On June 3, 1921, a sudden rainstorm flooded both the Arkansas River and Fountain Creek. The flood destroyed approximately one third of the downtown area, and caused the closure of the Pueblo and Blende smelters. Between 1921 and 1926, cement banks and dikes were constructed to reroute the Arkansas River to its present location and protect the city from future flooding. The original 1921 waterway was restored in the mid 1990's, and now channels low volumes of water. Redevelopment along its banks serves as a tourist attraction.

The Arkansas River is channeled by dikes through the stretch that is adjacent to the site of the former Colorado Smelter slagheap. Flow is from northwest to southeast. Gullies on the slag bluffs south of the river serve as conduits for intermittent overland flow. It is possible this intermittent overland flow may be impacted by contact with the waste slag pile present in this area. Stream flow in the Arkansas River varies dramatically from below 20 cubic feet per second (cfs) in December and January to over 4000 cfs in June. Average annual flow of the Arkansas River in Pueblo is 573 cfs, while average annual flow in Fountain Creek is 97 cfs (USGS 2005).

3.5.3 Climate

Pueblo temperatures fluctuate seasonally, with an average of 160 days of below freezing lows and 64 days of above 90°F highs. Annual precipitation averages 11.2 inches, of which over half falls as rain between the months of May and August. Relative humidity is fairly low, typically 45 to 60 percent (ClimateZone). The 2-year 24-hour rainfall event is 2.0 inches (CDOT 2005).

Average wind speed is 7.7 miles per hour and predominately flows from the west-northwest, although occasional upslope conditions cause a reversal in wind direction (WebMET).

The remains of the Colorado Smelter and the slag pile are located in an area designated Flood Zone C by the Federal Emergency Management Agency (FEMA), and are therefore outside of the 500 year flood plain.

4.0 PRELIMINARY PATHWAY ANALYSIS

4.1 Waste Characteristics

The waste piles located at the former Colorado Smelter sites contains slag ranging in size from very coarse gravelly materials to silt. The Colorado Smelter slag pile forms a thirty-foot high escarpment visible from of Santa Fe Avenue. The slag appears to have been deposited in a low area. The Denver & Rio Grande railroad tracks, and possibly portions of Interstate 25, appear to have been constructed on the slag dump. There are numerous reports that smelter waste was used as ballast material for miles of railroad track in Colorado (CDPHE HMWMD 1995).

Pueblo historian Eleanor Fry recounted the history of the Colorado Smelter waste pile. According to her 1990 article in the *Pueblo Lore*, the "slag dumps of the old Eiler smelter were disappearing during the spring of 1927. Hundreds of carloads of slag were loaded and hauled to all parts of the West and Southwest to ballast railroad tracks. Trainloads also were being hauled to the Mississippi Valley to repair flood damage to railroad rights of way. The solid cliffs of slag were broken up by blasting and steam shovels loaded the loose material into the railroad cars. Twenty five to fifty cars were shipped out daily."

Emissions from smelting operations often contain inorganic constituents such as lead and arsenic. Soils contaminated with cadmium, arsenic, lead and zinc may be found in residential areas surrounding smelter plant sites. Ingestion of soil and inhalation of wind blown soil are potential human exposure pathways of concern and may occur due to the extent of off-site contamination in surface soils near the site (ATSDR 2006).

In April 1992, CDPHE collected a grab sample from the remaining slag pile located at the site of the former Colorado Smelter. The slagheap forms a thirty-foot high escarpment and covers approximately 25 acres, for a total volume of 50,000 cubic yards of slag (June 2007 site visit, Photos 1-4). The source sample (SF-SS-3) contained several metals, including arsenic, barium, copper, lead, manganese, silver and zinc (CDPHE HMWMD 1994). Results of analysis of this sample (SF-SS-3) are presented in Table 1 and sample locations are shown on Figure 6.

Based on the results of the 1992 sampling effort, CDPHE performed additional sampling in September 1994. Thirteen source samples were collected. Two of the source samples were collected from the Colorado Smelter slag pile (Samples SS-7 and SS-8). The remaining source samples were collected from other former smelter locations and slag piles (CDPHE HMWMD 1995). Source sample locations are shown on Figure 3, and results are presented in Table 2. In addition to the source samples, 39 soil samples were collected, including four background samples (SO-1, SO-2, SO-3 and SO-4) and 35 samples located within 200 feet of a residence. The samples were located throughout the Pueblo area to evaluate overall residential soil impacts of the historic smelter operations. Twenty-one samples were located within one mile of the Colorado Smelter. Residential soil sample locations are illustrated on Figure 7, and analytical results are presented in Table 6.

The Colorado Smelter source samples contained concentrations of arsenic and manganese that exceeded the soil benchmarks of the 1993 version (and subsequently the 2004 version) of the Superfund Chemical Data Matrix (SCDM). Based on a site visits performed by CDPHE during June and November 2007, access to the source locations are not restricted by fencing or other physical barriers.

Eight of the residential soil samples located within one mile of the Colorado Smelter contained Level I concentrations of arsenic. Based on the average household occupancy of 2.44, there are an estimated 20 people occupying residences within 200 feet of known contamination. Contamination is inferred between the sampling locations with high arsenic values. The polygon of inferred contamination is illustrated on Figure 7. It covers an area of approximately 960 acres. There are an estimated 800 homes located within the area of inferred contamination, which equates to an estimated 1,952 residents.

On May 10, 1995, an EPA contractor (Ecology & Environment) performed in situ x-ray fluorescence (XRF) spectrophotometeric lead and arsenic analysis on the slag pile located at the former Colorado Smelter site. The results are documented in a July 1995 report (E&E 1995a). Analysis was conducted at eight locations of the slag pile. Results are presented in Table 7; sampling locations are shown on Figure 7. None of the slag samples indicated concentrations of arsenic above the detection limit. However, the detection limit for the XRF for arsenic was reported at 67 mg/kg, significantly above the SCDM benchmarks for cancer (0.43 mg/kg) and non-cancer risk (23 mg/kg), and is therefore unusable.

The estimated accuracy of the XRF data for lead was plus or minus 30 percent. A wide variation in the concentration of lead in the slag samples was observed. The reported lead concentrations ranged from less than 100 mg/kg to 9700 mg/kg. This is likely the result of the heterogeneous nature of the slag material. Two of the slag samples had reported lead concentrations greater than 400 mg/kg, the screening level recommended in EPA's OSWER Directive 9355.4-12 and CDPHE's Residential Soil Cleanup Table Value Standard (EPA 1994, CDPHE HMWMD 1997).

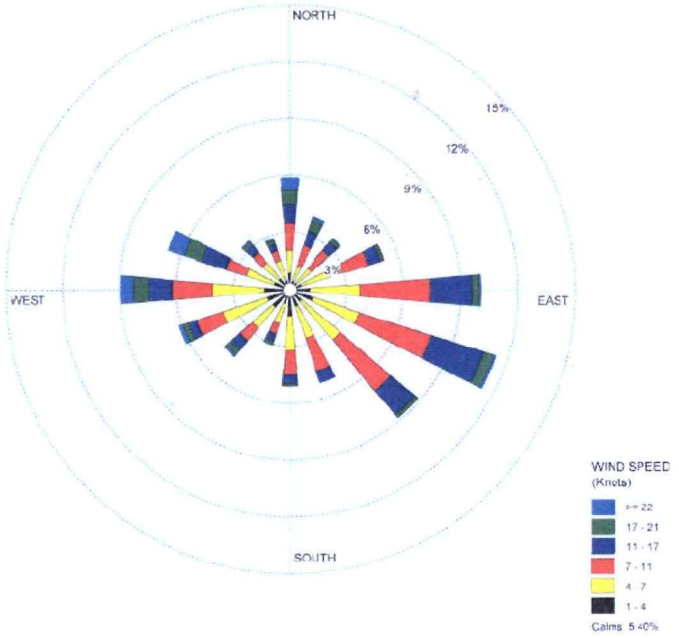
On August 16, 1995, Ecology and Environment conducted a systematic grid sampling of the slag pile and adjacent soils. The results are documented in an October 1995 report. The property was split into five sampling areas, designated A through E, based on the natural topography of the site. A total of 88 samples were collected and brought to Denver for analysis. Sample locations are illustrated on Figure 4, and results are presented in Table 3. The samples were analyzed for arsenic, cadmium and lead using an X-ray fluorescence spectrometer (XRF). Seventeen samples were sent to a laboratory for confirmatory analysis. Very poor correlation was observed between the XRF analysis and laboratory analysis for both arsenic and cadmium, therefore the XRF generated data for arsenic and cadmium is of little value. However, the XRF lead analysis correlated well with the laboratory lead analysis (E&E 1995b).

The observed concentration of lead in the slag pile ranged from an estimated 56 mg/kg to a high of 9300 mg/kg. A total of 59 of the 88 samples collected exceeded 400 mg/kg lead. The highest concentrations were found in the samples analyzed in sampling area C, averaging 3323 mg/kg. Samples located at the northern end of the pile (Section A) generally contained lower concentrations of lead.

4.2 Air Pathway

During smelter operations, heavy metal contaminants were likely exhausted through the smoke stacks and dispersed through the air pathway. The blast furnace smokestack was 132 feet high. The stack from the fusing and calcining furnaces was 95 feet high. The desulphuring kilns were vented from a stack 65 feet high (Fry 1990).

A wind rose plot generated from the meteorological monitoring site located at the Pueblo Municipal Airport provides information on wind speed and direction near the Colorado Smelter site. Wind speeds in Pueblo average seven to eight miles per hour, and range from calm (5.4 % of the time) to gusts exceeding 20 miles per hour (3.5% of the time). Predominant winds are from the west-northwest, although occasional upslope conditions result in gusty eastern winds (WebMET).



Inhalation of wind blown soils historically contaminated with lead and arsenic may still pose a risk to human health and the environment. The resident population within the target distance limits was estimated from the Environmental Justice Geographic Assessment Tool maintained by EPA (EJ 2007). The nearest residence is located approximately 200 feet from the slagheap.

Distance	Estimated Number of Persons
0 – ¼ mile	628
¼ - ½ mile	1,375
½ - 1 mile	5,235
1 – 2 miles	20,925
2 – 3 miles	33,304
3 – 4 miles	31,707
Total	93,174

An estimated 3,500 acres of wetlands are located within four miles of the site. This includes Riverine and Palustrine wetlands associated with the Arkansas River and Fountain Creek. Lake Minnequa, Runyon Lake and other bodies of water supporting Lacustrine wetlands are also present within four miles of the Colorado Smelter (FWS, 1974). Runyon/Fountain Lake is a designated State Wildlife Area, and is located between one quarter and one-mile east-northeast of the site (CDOW 2007).

The Arkansas River valley, referred to as the Central Arkansas Playas, is located east of the site, approximately 2 miles away, and has been classified as a potential conservation area due to its high biodiversity. According to the Colorado Natural Heritage Program, several threatened or endangered species have been identified in Pueblo County. This

includes the endangered Black-footed Ferret and the threatened Bald Eagle, Canada Lynx, and Mexican Spotted Owl (CNHP 2007).

4.3 Groundwater Pathway

The top of the uppermost major confined aquifer, the Dakota Sandstone, is approximately 3500 feet below ground surface, making its use limited. Considering the low permeability and tremendous thickness of the Pierre Shale, cross contamination by the shallow alluvial aquifer to the confined Dakota Sandstone aquifer is unlikely (CDPHE HMWMD 1995).

The discontinuous sandstone lenses of the overlying Pierre Shale are not an important source of drinking water due to their poor water quality (CDPHE HMWMD 1995). However, sources are not contained with regard to the groundwater pathway. The seep observed on the slagheap during previous site visits may indicate a hydraulic connection between groundwater and surface water. Both the seep and the Santa Fe Avenue Bridge culvert may serve as conveyances of shallow groundwater to the surface water of the Arkansas River.

Data on the number of groundwater wells permitted by the State Engineer's Office in the vicinity of the site is presented below. These wells are completed in the shallow alluvial aquifer. The classification or use of the wells has not been determined, although it is assumed none of the wells are used for drinking water since there is a municipal supplier.

Distance	Number of Wells	Number of Persons
0 - ¼ mile	9	22
¼ - ½ mile	11	27
½ - 1 mile	51	124
1 - 2 miles	268	654
2 - 3 miles	371	905
3 - 4 miles	586	1,430
Total	1,296	3,162

As of 2007, the St. Charles Mesa Water District operates two surface water intakes and four groundwater wells that are under the influence of surface water. The four wells are located between 2 and 3 miles east-southeast of the site and appear to be in a different drainage. The wells are not likely to be impacted by the Colorado Smelter site.

Sources are uncontained with regard to the groundwater pathway. However, it is unlikely shallow groundwater in the vicinity of the site is used as a drinking water source since the area is serviced with a municipal water supply. Contamination of the Dakota aquifer is unlikely given the low permeability of the overlying Pierre Shale. It is therefore probable there are no targets for the groundwater pathway.

4.4 Surface Water Pathway

4.4.1 Hydrologic Setting

The buildings of the Colorado Smelter were located on a bluff adjacent to a ravine that carried a significant flow of water. Slag from the smelter process was deposited into the ravine (Fry 2000). Water flowing through the ravine was not observed during the November 27 2007 site visit. It is probable that flow increases during the spring due to snow melt and during summer rains. A wetland was observed along the base of the ravine. Channels are present along the banks of the slagheap. The site is not located within the 500-year floodplain (Pueblo Assessor 2007).

Three probable points of entry (PPE), located within a 500 foot stretch of the Arkansas River, were observed during the November 27, 2007 site visit. A large storm water culvert is located at the northwestern corner of the site (Photo 8). The culvert discharges into a ditch that transports water from multiple locations to the Arkansas River. At the southeastern corner of the site, a small grate collects surface water into a storm water pipe (Photo 10). The pipe travels in a northeasterly direction towards the Arkansas River, although the discharge point was not observed.

The Santa Fe Avenue Bridge culvert is located between the other two PPE locations. This culvert conveys orange water directly into the Arkansas River (Photo 9). The inlet to the culvert could not be found, and it is possible it does not daylight but instead drains alluvial groundwater from beneath the slagheap.

4.4.2 Surface Water Targets

The Arkansas River is classified as a warm water fishery. An estimated 124 pounds of fish per acre are present in the Pueblo area (CDPHE HMWMD 1995). The predominant species are long nosed sucker and white sucker. Other species present include fathead minnow, orange spotted sunfish, small mouth bass, green sunfish, rainbow and brown trout, and walleye. No threatened and endangered species are known or suspected to be present (CDOW 2007). The Arkansas River is also classified for use as a water supply, for agriculture, and for recreation (CDPHE WQCC 2005).

Wetlands appear to intermittently line both banks of the Arkansas River. These are generally palustrine with emergent, scrub and shrub, or forest coverage. Roughly 12 miles of the 15-mile target distance limit contain wetlands (FWS 1974). Approximately 3,387 square feet of wetlands are located on site, in the base of the ravine (E&E 1995b).

The Arkansas River valley, referred to as the Central Arkansas Playas, is located east of the site, approximately 2 miles away, and has been classified as a potential conservation area due to its high biodiversity. According to the Colorado Natural Heritage Program, several threatened or endangered species have been identified in Pueblo County. This

includes the endangered Black-footed Ferret and the threatened Bald Eagle, Canada Lynx, and Mexican Spotted Owl (CNHP 2007).

In 1991, a preliminary assessment (PA) of the Santa Fe Avenue Bridge Culvert site was conducted. The PA documented that the St. Charles Mesa Water District (PWSID 151750) surface water intake is located about 100 yards downstream of the discharging culvert. The intake is located on the same side (south) of the river as the culvert discharge. In 1991, the intake removed approximately 3 acre-feet per day of surface water from the Arkansas River between November 15 and March 15 each year (CDPHE HMWMD 1991).

As of 2007, the St. Charles Mesa Water District operates two surface water intakes (from the Arkansas River approximately 100 yards downstream of the Santa Fe Avenue Bridge Culvert, and from the Bessemer Ditch, located over four miles southeast of the site in Lombard Village) and four groundwater wells that are under the influence of surface water. All of these public drinking water sources are active. The St. Charles Mesa Water District obtains 92% of its water from surface sources and 8% from groundwater. The population that is served by this system is 11,992 (CDPHE WQCD 2007a). The proportion of water obtained from each of the surface water intakes is unknown, and therefore assumed to be equal. The apportioned number of people served by the surface water intake located within the target distance limit is calculated to be 5,516. St. Charles Mesa water sources are identified on Figure 5.

The two surface water sources of the St. Charles Mesa Water District were given a susceptibility rating of moderately high by the CDPHE Source Water Assessment and Protection Program (CDPHE WQCD 2007c).

4.4.3 Previous Sampling

During the October 1995 source sampling conducted by Ecology and Environment, an on-site wetland area of approximately 3,387 square feet was identified. The wetland area was labeled sampling area B and is shown on Figure 4. The source of the wetland appeared to be a natural spring located between sample areas B and C. Three sediment samples were collected and analyzed. Lead concentrations in these sediments (SE-01, SE-02, and SE-09) were 640, 830, and 1200 mg/kg, respectively. All three lead values were above 400 mg/kg, the screening value recommended by EPA's OSWER Directive 9355.4-12 and CDPHE's Residential Soil Cleanup Table Value Standard (EPA 1994, CDPHE HMWMD 1997, E&E 1995b).

A seep was observed on the Colorado Smelter slagheap during the 1991 Santa Fe Avenue Bridge Culvert PA site visit and again during the 1992 sampling event conducted by CDPHE and documented in the 1994 report. It was located approximately one-quarter mile up gradient of the culvert. The seep flowed as a surface water feature for several hundred yards then disappeared back into the subsurface. The flow of the seep was estimated at roughly five gallons per minute. On April 14, 1992, a sample of the seep

was collected and identified as SF-SW-6. The location of the sample is illustrated on Figure 5. As shown in Table 4, the seep contained a concentration of antimony above the Maximum Contaminant Level (MCL) and the Superfund Chemical Data Matrix (SCDM) benchmarks for drinking water (CDPHE HMWMD 1994).

The Arkansas River is located approximately one half mile north northeast of the slag pile. Erosion channels visible on the sides of the slag pile indicate contaminant transport to the Arkansas River caused by unrestrained runoff. Therefore, along with the seep sampling, surface water samples were collected from four locations in the Arkansas River. An upstream sample, SF-SW-1, was collected from above the confluence of Dry Creek and the Arkansas River to serve as a background sample. A second sample, SF-SW-2, was collected approximately one hundred yards upstream of the culvert and was considered to be potentially impacted by the slagheap. Sample SF-SW-3 was collected at the Santa Fe Avenue culvert discharge. Sample SF-SW-4 and duplicate sample SF-SW-5 were collected at the St. Charles Mesa water intake (CDPHE HMWMD 1994). Analytical results for these samples are shown in Table 4. Sample locations are shown on Figure 5. One of the samples collected at the St. Charles Mesa intake exhibited cadmium at a concentration that exceeded the MCL standard. However, the duplicate sample did not confirm this result. Additionally, cadmium was also detected in the upstream sample at a concentration greater than standards.

During the Expanded Site Investigation conducted in 1994, six additional surface water samples were collected. Concentrations of heavy metals in the surface water sample collected at the St. Charles Mesa water intake (sample SW-3) were not elevated with regard to the background sample (SW-1) collected approximately one and three quarter miles upstream (CDPHE HMWMD 1995). Sample locations are depicted on Figure 5 and sampling results are presented in Table 5.

The United States Geological Survey (USGS) performed a three-year study in the Arkansas River basin between 1990 and 1993. One sampling point was located at the Moffat Street footbridge, approximately 20 yards downstream of the St. Charles Mesa surface water intake (USGS07099970). The USGS analysis indicated the water quality near the intake was within the stream standards (USGS 2007).

The USGS data also indicated the concentrations of metals were within threshold values established by the SCDM of 2004, and within the Maximum Contaminant Levels (MCL) and/or Maximum Contaminant Level Goals (MCLG) for drinking water established in the Safe Drinking Water Act (EPA 2004). Based on the USGS sampling results, it appears the St. Charles Mesa water intake was not impacted by the Colorado Smelter.

Moffat Street 07099970			
Dissolved Metal Concentration (μg/L)	Sampling Results 1990-1993	2004 SCDM non-cancer	MCL or MCLG
Cadmium	< 0.1	18	5
Chromium	< 1.0	110	100
Copper	1.8	-	1300
Iron	6.5	-	-
Lead	< 0.5	-	15
Manganese	13.5	5100	-
Nickel	2.0	730	-
Silver	< 1.0	180	-
Zinc	3.4	1100	-
Selenium	6.3	180	50

In 2006, the St. Charles Mesa Water District reported a 90th percentile lead concentration of 4.2 μg/L, in excess of the action level of 1.5 μg/L established by the Safe Drinking Water Act. This concentration of lead may be from corrosion of household plumbing systems, from erosion of natural deposits, or from other sources (St. Charles Mesa 2007).

4.4.4 Conclusions

Contaminated groundwater in the shallow alluvium may discharge to surface water via the Santa Fe Avenue Bridge culvert. An observed release from the culvert was seen during the November 27 2007 site visit.

The seep that was observed discharging from the slag pile during the 1991 Santa Fe Avenue Bridge Culvert PA site visit and again during the 1992 sampling event conducted by CDPHE and documented in the 1994 report may contribute contaminants such as antimony, selenium, and zinc to the Arkansas River via overland flow to the two other storm water culverts.

A municipal water intake that serves an estimated 5,516 people is located approximately 100 feet downstream, on the same side of the river. Samples collected in 1992 and 1994 indicate no elevated concentrations of heavy metals in the Arkansas River at the intake compared to background (Tables 4 and 5).

A wetland area of approximately 3,387 square feet is located onsite. Wetlands also line roughly 12 miles of the 15-mile target distance limit downstream of the PPE to the Arkansas River.

4.5 Soil Exposure Pathway

The site is situated in a combined industrial and residential use setting. The resident population within the target distance limits was estimated from the Environmental Justice

Geographic Assessment Tool maintained by EPA (EJ 2007). The nearest residence is located approximately 200 feet from the slagheap.

Distance	Estimated Number of Persons	Estimated Number of Children Under 5
0 - ¼ mile	628	67
¼ - ½ mile	1,375	209
½ - 1 mile	5,235	666
Total	7,238	942

Small businesses are located on-site. This includes Ace Enterprises, Top Notch Trailers, Domenic & Sons Paint & Body Shop, Chem Way Lawn Care, Meadow Gold Dairies, Northern Colorado Paper, and Ryder Truck Rental. There are an estimated 50 workers located onsite.

In 1992, CDPHE collected five residential soil samples for the Santa Fe Bridge Culvert site characterization. A background sample was collected approximately ¾ mile west of the slag pile. The remaining four samples were collected on residential properties within 200 feet of a residence, and were located east and within ½ mile of the slagheap. Sample locations are shown on Figure 6, and analytical results are presented in Table 1. Arsenic concentrations in the residential soils were greater than three times the background concentration and exceeded the Superfund Chemical Data Matrix (SCDM) benchmark for cancer risk (0.43 mg/kg) (EPA 2004). Copper, lead, nickel and selenium concentrations were also elevated in at least one of the residential soils (CDPHE HMWMD 1994).

In support of the Expanded Site Investigation (CDPHE HMWMD 1995), during September 1994 CDPHE sampled residential soils in addition to the previously discussed source and residential soil samples. Residential exposure to contaminated soils was evaluated by collecting a total of 39 soil samples, including four background samples (SO-1, SO-2, SO-3 and SO-4) and 35 samples located within 200 feet of a residence. The samples were located throughout the Pueblo area to evaluate overall residential soil impacts of the historic smelter operations. Three samples were located within a quarter mile of the Colorado Smelter (SO-13, SO-15 and SO-36). Eight residential soil samples were located between one-quarter mile and one-half mile of the site (SO-12, SO-14, SO-16, SO-24, SO-25, SO-26, SO-38 and SO-39). Ten samples were located between one-half and one mile of the site (SO-10, SO-17, SO-27, SO-28, SO-29, SO-30, SO-31, SO-34, SO-35, and SO-37). Soil sampling locations are illustrated on Figure 7, and analytical results are presented in Table 6.

Arsenic exceeded the SCDM benchmark for cancer risk (0.43 mg/kg) in each of the 35 residential soil samples. However, the arsenic concentrations in residential soils reached analytical significance in only eleven samples, where the concentrations exceeded three times background. Eight of these samples were located within one mile of the Colorado Smelter (SO-13, SO-15, SO-29, SO-31, SO-36, SO-37, SO-38, and SO-39).

Based on Expanded Site Investigation sample data, eight residential properties located within one mile of the Colorado Smelter contain Level I concentrations of arsenic. Based on the average household occupancy of 2.44, there are an estimated 20 people occupying residences within 200 feet of known contamination.

Contamination is inferred between the sampling locations with high arsenic values. The polygon of inferred contamination is illustrated on Figure 7. It covers an area of approximately 960 acres. There are an estimated 800 homes located within the area of inferred contamination, which equates to an estimated 1,952 residents.

On May 10, 1995, an EPA contractor performed in situ x-ray fluorescence (XRF) spectrophotometeric lead and arsenic analysis on forty-five residential soil samples, in addition to the eight slag samples already discussed. Thirty samples were collected within one mile of the Colorado Smelter. The remaining samples (XRF-39 through XRF-53) were collected in the proximity of the Blende Smelter (E&E 1995a). Sample locations are shown on Figure 7. Results are presented in Table 7.

Only three of the thirty Colorado Smelter residential soil samples analyzed for arsenic indicated concentrations above the detection limit. However, the detection limit for the XRF for arsenic was reported at 67 mg/kg, significantly above the SCDM benchmarks for cancer (0.43 mg/kg) and non-cancer risk (23 mg/kg), and the residential Soil Cleanup Table Value Standard established by CDPHE in 1997 (0.21 mg/kg). This high detection limit, coupled with the potential for sample inference due to other metals, renders the arsenic data essentially useless.

The estimated accuracy of the XRF data for lead was plus or minus 30 percent. Results for the residential soil samples located near the Colorado Smelter were variable, ranging from non-detect (at 52 mg/kg) to 4900 mg/kg. Seven of the 30 residential soil samples exceeded 400 mg/kg for lead, the screening level recommended in EPA's 1994 OSWER Directive 9355.4-12, and CDPHE's 1997 Residential Soil Cleanup Table Value Standard.

Following the soil sampling activities, CDPHE recommended that a study be conducted to survey blood lead levels in children six months to six years from an area surrounding the Blende Smelter. Young children are especially vulnerable and sensitive to the effects of lead exposure. The neighborhoods around the Blende Smelter were targeted due to elevated lead levels in soil. The Pueblo City-County Health Department (PCCHD), in collaboration with CDPHE, coordinated the blood lead survey by visiting homes in the area to inform residents of the study and to encourage them to have their children participate in the testing. The testing was conducted at no charge through a program called "GuardCare 95". After GuardCare, PCCHD mailed packets with health education materials concerning lead and offered another blood lead check in the target area.

Twenty-one Pueblo children (0-13 years) had lead screening conducted through GuardCare. Of the total number tested, 11 children lived in the area around the Blende

Smelter, which is located about two miles east of the Colorado Smelter site. According to census studies, there were approximately 70 children under the age of six years in the Blende target area (PCCHD 1995). A few more children were tested as a result of the mailing in the area. None of the persons tested showed abnormal blood lead levels (PCCHD 1996).

In preparing this Preliminary Assessment report, CDPHE was not able to determine based upon its records whether any of the children tested during the GuardCare program lived near the Colorado Smelter site or whether the children who participated in GuardCare or the follow up blood lead survey resided in households with elevated lead concentrations in yard soils.

Sampling of surface soils in the Pueblo region was also conducted by affiliates of the Colorado State University in Pueblo. Sixty-eight soil samples were collected at 33 locations and analyzed for arsenic, cadmium, lead and mercury. The results of the sampling effort were presented in the August 2006 publication of *Environmental Geochemistry and Health*. Samples were collected every two kilometers along four parallel transects running northwest to southeast across the city limits. Eight samples were located within one mile of the Colorado Smelter site (19A, 19B, 20A, 20B, 21A, 21B, 3A, and 3B).

All 68 samples exceeded the carcinogenic risk SCDM benchmark for arsenic, although only eight samples contained concentrations of arsenic greater than three times background levels. The background levels used for comparison ranged from 5.0 mg/kg to 6.1 mg/kg for arsenic. None of the soil samples exceeded 400 mg/kg for lead. The overall average concentration for lead and arsenic was 88 and 12.5 mg/kg respectively. The concentration of lead and arsenic for the samples collected within one mile of the Colorado Smelter site was 194 and 8.6 mg/kg. The background levels used for comparison ranged from 13.9 to 32.5 mg/kg for lead. The study concluded that a higher-density geochemical survey is needed to identify smaller and possibly higher amplitude "hotspots" within the city (Diawara 2006). A copy of the paper is included as an appendix to this report.

5.0 SUMMARY

The Colorado Smelter operated from 1883 to 1908, and was dismantled in 1915. A large slag pile remains situated in a ravine near Santa Fe Avenue and Interstate 25. The site encompasses approximately 50 acres, and includes a slagheap estimated at a volume of 50,000 cubic yards. Slag often contains inorganic constituents such as lead and arsenic. The slag pile is uncontained.

Although several previous investigations have been performed at the site, uncertainties remain in determining whether or not a potential human health risk exists.

5.1 Air Pathway

During operations, it is likely the emissions from the smoke stacks produced widespread contamination of surficial soils with heavy metals. Inhalation of wind blown soils historically contaminated with lead and arsenic may still pose a risk to human health and the environment. The resident population within the target distance limit of 4 miles is estimated at 93,174 (EJ 2007). An estimated 3,500 acres of wetlands are located within four miles of the site (FWS 1974). Runyon/Fountain Lake is a designated State Wildlife Area, and is located between one quarter and one-mile east-northeast of the site (CDOW 2007). The Arkansas River valley, referred to as the Central Arkansas Playas, is located east of the site, approximately 2 miles away, and has been classified as a potential conservation area due to its high biodiversity. According to the Colorado Natural Heritage Program, several threatened or endangered species have been identified in Pueblo County (CNHP 2007).

5.2 Groundwater Pathway

Sources are uncontained with regard to the groundwater pathway. However, it is unlikely shallow groundwater is used as a drinking water source since the area is serviced with a municipal water supply. Four municipal groundwater wells are located between 2 and 3 miles east-southeast of the site. The wells appear to be in a different hydrogeologic zone and are likely not impacted by the Colorado Smelter site. Contamination of the Dakota aquifer is unlikely given the low permeability of the overlying Pierre Shale. It is probable there are no targets for the groundwater pathway.

The seep observed on the slagheap during previous site visits may indicate a hydraulic connection between groundwater and surface water. Both the seep and the Santa Fe Avenue Bridge Culvert may serve as conveyances of shallow groundwater to the surface water of the Arkansas River.

5.3 Surface Water Pathway

The slag pile is uncontained and may be a contributor of heavy metals to surface water. Portions of the slag pile are in contact with surface water. Erosion channels on the sides of the slag pile indicate contaminant transport to the Arkansas River caused by unrestrained runoff. The Arkansas River is designated a Class I Warm Water Aquatic Life and Domestic Water Supply surface water. An observed release via the Santa Fe Avenue Bridge culvert was witnessed on the November 27, 2007 site visit. A municipal water intake that serves an estimated 5,516 people is located approximately 100 feet downstream, on the same side of the river.

The seep discharging from the slag pile may also contribute contaminants such as antimony, selenium, and zinc to the Arkansas River via overland flow to the two other storm water culverts.

A wetland area of approximately 3,387 square feet is located onsite. Wetlands also line roughly 12 miles of the 15-mile target distance limit downstream of the PPE to the Arkansas River.

5.4 Soil Exposure Pathway

It is likely the emissions from the smoke stacks resulted in widespread contamination of surficial soils with heavy metals. Soils contaminated with cadmium, arsenic, lead and zinc may be found in residential areas surrounding former smelter plant sites. Soil sampling of the area surrounding the Colorado Smelter showed lead and arsenic concentrations in some residential yards in excess of EPA benchmarks.

Approximately 942 residents live within one mile of the Colorado Smelter site. The nearest residence is located approximately 200 feet from the slagheap. An estimated 50 workers are located onsite.

An estimated 20 people are occupying residences located within 200 feet of Level I contamination. An additional 1,952 estimated residents live within a 960 acre area of inferred contamination. This has the potential to result in residents being exposed to elevated levels of arsenic and lead through the soil pathway or through the air pathway via windblown soil.

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TABLES

Table 1
1992 Source and Residential Soil Sample Results (mg/kg)
[CDPHE 1994 Screening Site Inspection]

	2004 SCDM	Background Soil SF-SO-1	Colorado Slag SF-SS-3	Culvert Sediment SF-SS-2	Residential Soil SF-SO-2	Residential Soil SF-SO-3	Residential Soil SF-SO-4	Residential Soil SF-SO-5
Aluminum		6730	16900	2800	10400	6700	4330	4100
Antimony	31	13.2 J	8.8 UJ	23.3 J	9.7 J	9.5 J	13.7 J	10.1 UJ
Arsenic	23	5.2	21.2	8.0	29.7	22.6	23.7	28
Barium	5500	170	3750	150	371	187	216	214
Beryllium	160	0.24 U	0.88	0.44 U	0.99 UJ	0.66 UJ	0.70 UJ	0.68 UJ
Cadmium	39	2.6	7.2	3.6	4.3	4.3	7.3	7.0
Calcium		35000 J	50500 J	66700 J	25400 J	34000 J	143000 J	137000 J
Chromium	230	12.9	11.9	13.9	8.2	9.5	8.4	6.8
Cobalt		4.7	14.1	1.8 U	5.5	6.8	11.6	9.4
Copper		29.6	856	28.3	34.5	65.8	99.9	31
Iron		17100 J	12300 J	41600 J	47400 J	21400 J	20900 J	20300 J
Lead		111	1950	122	239	336	152	34.4
Magnesium		3340	7050	2510	2360	3550	4530	5440
Manganese	11000	336 J	18300 J	527 J	589 J	668 J	300 J	156 J
Mercury	23	0.23	0.1 U	0.34	0.28	0.19	0.13 U	0.11 U
Nickel	1600	16.1 J	19.8 UJ	17.8 UJ	16.2 UJ	21.6 UJ	55.6	51
Potassium		4720	9710	822	1660	1920	1860	1850
Selenium	390	1.2 U	0.34	3.9	1.4	1.6	9.1	8.3
Silver	390	0.96 U	12.8	1.8 U	2.0	1.0	1.2	0.92 U
Sodium		172	1410	529	368	165	251	274
Thallium		0.28	0.22	0.71	0.24	0.35	1.2	1.9
Vanadium	550	34.5	46.1	37.7	34.7	35.3	61.4	65.8
Zinc	23000	254	18500 J	303 J	196 J	558 J	354 J	177 J

SCDM – Superfund Chemical Data Matrix residential soil standard for non-cancer risk
U –analyte not detected at the reported limit.
J – analyte detected above the instrument detection limit but below the analytical reporting limit
Shaded cells indicate a concentration at least three times background
Sample locations presented on Figure 6

Table 2
1994 Source Sample Results (mg/kg)
[CDPHE 1995 Expanded Site Inspection]

	CF&I South SS-1	CF&I South SS-2	Colo. West SS-3	Colo. West SS-4	Pueblo SS-5	Pueblo SS-6	**Colo. SS-7**	**Colo. SS-8**	Phil. SS-9	Phil. SS-10	New England SS-11	New England SS-12	Blende SS-13
Aluminum	17000j	19300j	10300j	13600j	23000j	5600j	**26400j**	**16000j**	8780j	56300j	6760	17500	5020
Antimony	5.7uj	7.0uj	5.6uj	5.5uj	1520j	6.1j	**29.4j**	**5.7uj**	5.2uj	5.2uj	5.6j	5.2r	5.2r
Arsenic	0.48j	8.2j	3.9j	10.0j	3.6r	37.8j	**79.4j**	**10.7j**	0.97j	2.4uj	14.6j	6.1j	4.8j
Barium	528j	313j	162j	273j	847j	208j	**6520j**	**1570j**	271j	736j	232	346	129
Beryllium	3.1	3.5	0.43	0.86	1.8	0.22	**1.4**	**1.3**	1.2	15.2	0.75	0.75	0.38uj
Cadmium	0.86u	1.1uj	1.4	4.0	0.80uj	9.1	**1.1**	**1.4**	0.8u	0.79uj	0.81u	0.80u	3.6
Calcium	27500j	102000j	31900j	25800j	81900j	222000j	**72300j**	**35400j**	4670j	206000j	2221000	189000	13600
Chromium	7.6	91.0	14.2	16.4	59.0	13.4	**9.3**	**5.9**	12.7	8.4	659	2960	7.7
Cobalt	4.4	10.9	6.9	8.9	22.6	13.5	**22.7**	**6.9**	6.8	1.8	18.6	9.0	4.1
Copper	35.7	137	22.6	91.8	200	43.9	**1720**	**132**	45.0	5.0j	100	166	23.4
Iron	7590j	75500j	20100j	21700j	105000j	26100j	**237000j**	**21000j**	8530j	4660j	146000	114000	8880
Lead	33.6	110	123	318	213	22.0	**7640**	**598**	24.5j	11.2	54.4	41.5	201
Magnesium	8310j	12500j	3610j	3930j	26900j	4230j	**14200j**	**2500j**	3000j	30800j	31000	16100	2470
Manganese	920j	2830j	263j	515j	1510j	89.3j	**15500j**	**1610j**	80.9j	7390j	20100j	16400j	288j
Mercury	0.11u	0.14u	0.11u	1.4	0.18	0.11u	**0.10u**	**0.11u**	0.10u	0.10u	0.10u	0.10u	0.10
Nickel	5.2	35.5	10.3	17.2	96.6	78.9	**33.3**	**10.1**	13.4	3.4u	19.9	35.1	8.1
Potassium	4820	4130	2090	2430	3940	2100	**19900**	**1690**	2320	21900	1030	1000	1530
Selenium	2.0	0.92j	0.33	1.4	22.8j	21.0	**2.2**	**0.46j**	1.5	4.4	0.50j	1.0	0.39j
Silver	0.80u	3.7	0.79u	1.9	4.7	1.1	**23.6**	**1.8**	0.74u	1.1	11.8	10.1	1.7uj
Sodium	255	584	189	365	7080	355	**2130**	**1010**	703	1340	626	307	110
Thallium	0.20u	0.29j	0.20u	0.19u	1.9u	1.5j	**1.8uj**	**0.20uj**	0.18uj	0.18u	1.9uj	1.8u	0.18u
Vanadium	13.9j	64.6j	52.3j	41.3j	148j	150j	**45.2j**	**28.9j**	19.4j	37.4j	1240	242	19.8
Zinc	74.0j	467j	110j	598j	923j	182j	**37400j**	**2460j**	74.4j	34.1j	182	124	829

u –analyte not detected at the reported limit.
j – analyte detected above the instrument detection limit but below the analytical reporting limit
Bold font indicates Colorado Smelter source samples
Sample locations presented on Figure 3

Table 3
1995 XRF Source Sample Results (mg/kg)
[E&E 1995b Site Screening Report]

Sample Area	Sample ID	As	Pb	Cd	Sample Area	Sample ID	As	Pb	Cd
A	BS-SO-AA1	45 J	56 J	270 U	B	BS-SO-14WT	36 U	920	270 U
	BS-SO-AA2	43 J	78	270 U		BS-SO-15WT	120	1600	270 U
	BS-SO-AA3	36 U	470	270 U		BS-SO-16WT	36 U	360	270 U
	BS-SO-AA4	36 U	1000	270 U		BS-SO-17WT	36 U	350	270 U
	BS-SO-AB1	36 U	510	270 U		AVERAGE		798	
	BS-SO-AB2	41 J	940	270 U					
	BS-SO-AB3	36 U	330	270 U	C	BS-SO-A1	27 U	20 U	190 U
	BS-SO-AB4	36 U	910	270 U		BS-SO-A2	27 U	110	190 U
	BS-SO-AC1	36 U	160	270 U		BS-SO-A3	27 U	490	190 U
	BS-SO-AC2	36 U	390	270 U		BS-SO-A4	27 U	190	190 U
	BS-SO-AC3	36 U	990	270 U		BS-SO-B1	27 U	1200	190 U
	BS-SO-AC4	27 U	300	190 U		BS-SO-B2	86 J	7500	250 J
	AVERAGE		511			BS-SO-B3	27 U	3300	190 U
						BS-SO-B4	90 J	2500	190 U
B	BS-SE-01WT	36 U	640	270 U		BS-SO-C1	36 U	5000	270 U
	BS-SE-2WT	36 U	830	270 U		BS-SO-C2	230	6400	190 U
	BS-SO-03WT	36 U	660	270 U		BS-SO-C3	27 U	5100	190 U
	BS-SO-04WT	36 U	190	270 U		BS-SO-C4	27 U	230	190 U
	BS-SO-04WT	36 U	200	270 U		BS-SO-D1	27 U	4500	190 U
	BS-SO-5WT	36 U	1100	270 U		BS-SO-D2	210	9300	190 U
	BS-SO-6WT	36 U	130	270 U		BS-SO-D3	130	3200	190 U
	BS-SO-7WT	73 J	520	270 U		BS-SO-D4	3400	4100	190 U
	BS-SO-8WT	36 U	180	270 U		BS-SO-E1	27 U	1900	190 U
	BS-SE-9WT	99 J	1200	270 U		BS-SO-E2	27 U	4300	190 U
	BS-SO-10WT	36 U	790	270 U		BS-SO-E3	49 J	3800	190 U
	BS-SO-11WT	36 U	3500	270 U		AVERAGE		3323	
	BS-SO-12WT	36 U	1100	270 U					
	BS-SO-13WT	45 J	96	270 U					

Sample locations are presented on Figure 4

Table 3 cont.
1995 XRF Source Sample Results (mg/kg)
[E&E 1995b Site Screening Report]

Sample Area	Sample ID	As	Pb	Cd	Sample Area	Sample ID	As	Pb	Cd
D	BS-SO-U1	27 U	5200	190 U	E	BS-SO-O1	36 U	1500	270 U
	BS-SO-U2	27 U	160	190 U		BS-SO-P1	27 U	220	190 U
	BS-SO-U3	27 U	320	190 U		BS-SO-Q1	27 U	720	190 U
	BS-SO-V1	27 U	1600	190 U		BS-SO-Q2	27 U	4600	190 U
	BS-SO-V2	27 U	920	190 U		BS-SO-Q3	27 U	510	190 U
	BS-SO-V3	29 J	590	190 U		BS-SO-R1	27 U	2400	190 U
	BS-SO-V4	76 J	570	190 U		BS-SO-R2	27 U	1600	190 U
	BS-SO-W1	27 U	1300	190 U		BS-SO-S1	75 J	660	280 J
	BS-SO-W2	27 U	600	190 U		BS-SO-S2	50 J	490	190 U
	BS-SO-W3	27 U	290	190 U		BS-SO-S3	27 U	620	190 U
	BS-SO-W4	27 U	510	190 U		BS-SO-S4	46 J	320	190 U
	BS-SO-X1	46 J	1300	190 U		BS-SO-T1	48 J	340	190 U
	BS-SO-X2	160	2300	190 U		BS-SO-T2	27 U	1300	190 U
	BS-SO-X3	27 U	200	190 U		BS-SO-T3	27 U	450	190 U
	BS-SO-X4	27 U	480	190 U		AVERAGE		1124	
	BS-SO-Y1	27 U	2700	190 U					
	BS-SO-Y2	27 U	190	190 U	SLAG PILE	BS-SO-SGN	27 U	310	190 U
	BS-SO-Y3	39 J	220	190 U		BS-SO-SGC	27 U	270	190 U
	BS-SO-Y4	27 U	420	190 U		BS-SO-SGS	27 U	1400	190 U
	BS-SO-Z1	27 U	4300	190 U		AVERAGE		660	
	BS-SO-Z2	27 U	2800	190 U					
	BS-SO-Z3	27 U	390	190 U					
	AVERAGE		1244						

Sample locations are presented on Figure 4

Table 4
1992 Surface Water Sample Results (ug/L)
[CDPHE 1994 Screening Site Inspection]

	MCL (Maximum Contaminant Level)	2004 SCDM for drinking water	Background Surface Water SF-SW-1	Culvert Discharge SF-SS-1	Slag Pile Seep SF-SW-6	Arkansas River 100 yd Upstream of Culvert SF-SW-2	Arkansas River at Culvert Discharge SF-SW-3	Arkansas River at St Charles Mesa Intake SF-SW-4	Arkansas River at St Charles Mesa Intake Duplicate SF-SW-5
Aluminum			99.5	26.7 U	464	275	193	164	104
Antimony	6	15	46.9 U	48.9 U	59.1	48.9 U	48.9 U	48.9 U	48.9 U
Arsenic	50	11/0.057	1.1 U	1.1 UJ	1.1 UJ	1.1 U	1.1 U	1.1 U	9.4
Barium	2000	2600	53	18.7	36.6	56	53.8	56.0	51.6
Beryllium	4	73	5.4 UJ	3.6 UJ	3.6 UJ	4.5 UJ	3.6 UJ	4.5 UJ	3.6 UJ
Cadmium	5	18	6.4	4.4 U	4.4 U	4.4 U	4.4 U	8.0	4.4 U
Calcium			63200 J	391000 J	358000 J	75000 J	869000 J	79100 J	75900 J
Chromium	100	110	7.8 U	7.8 U	7.8 U	7.8 U	7.8 U	7.8 U	7.8 U
Cobalt			4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U	4.4 U
Copper	1300		4.4 U	4.4 U	12.7 UJ	4.4 U	4.4 U	4.4 U	4.4 U
Iron			31.3 UJ	14500 J	216 J	158 UJ	431 J	89.3 UJ	79.9 UJ
Lead	15		1.1 UJ	11.1 U	11.1 UJ	1.1 UJ	1.1 UJ	1.1 UJ	1.1 UJ
Magnesium			17900	110000	105000	21700	25800	23700	22500
Manganese		5100	13.5 UJ	572 J	11 UJ	16.1 J	20.3 J	15.2 J	13.4 UJ
Mercury	2	11	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U
Nickel	100	730	18.9 U	18.9 U	18.9 U	18.9 U	28.9 U	18.9 U	18.9 U
Potassium			3350	16000	9360	3520	3220	3400	3230
Selenium	50	180	2.6 J	2.7 J	44.9 J	4.8 J	11.6 J	6.8 J	9.9 J
Silver		180	4.4 U	4.4 U	4.4 U	4.4 U	4.8	4.4 U	4.4 U
Sodium			27100	185000	182000	34400	42000	39400	36300
Thallium	0.5		1.1 U	1.1 UJ	1.1 UJ	1.1 U	1.1 U	1.1 U	1.1 U
Vanadium		260	5.6 U	5.6	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U
Zinc		11000	5.6 U	128	333	5.6 U	9.6 UJ	5.6 U	5.6 U

U – analyte not detected at the reported limit.
J – analyte detected above the instrument detection limit but below the analytical reporting limit
UJ – analyte not detected at the reported limit, however the reported limit is only approximate because quality control criteria were not met.
Shaded cells indicate an exceedance of standard
Sample locations are presented on Figure 5

Table 5
1994 Surface Water Sample Results (ug/L)
[CDPHE 1995 Expanded Site Inspection]

	MCL (Maximum Contaminant Level)	2004 SCDM for drinking water	Background Above Dry Creek Confluence SW-1	Arkansas River at Culvert Discharge SW-2	Arkansas River at St. Charles Mesa Intake SW-3	Arkansas River at St. Charles Mesa Intake Duplicate SW-6	Arkansas River at Hwy 227 SW-4	Arkansas River at Nielson Street SW-5
Aluminum			1240	312	351	402	1050	4870 J
Antimony	6	15	25.6 U	25.6 U	29.9 UJ	25.6 U	27.4 UJ	25.6 UJ
Arsenic	50	11/0.057	1.2 UJ	1.2 UJ	1.2 UJ	1.2 U	1.2 UJ	2.5 J
Barium	2000	2600	84.0	68.2	70.2	71.1	69.9	138 J
Beryllium	4	73	0.30 U	0.30 U	0.30 U	0.30 U	0.42	0.48 J
Cadmium	5	18	3.9 U	3.9 U	3.9 U	3.9 U	3.9 U	3.9 UJ
Calcium			64900	72800	71200	71300	87300	75800 J
Chromium	100	110	3.7 U	3.7 U	3.7 U	3.7 U	3.7 U	6.4 J
Cobalt			4.6 U	4.6 U	4.6 U	4.6 U	4.6 U	4.8 J
Copper	1300		4.2 UJ	3.0 UJ	3.0 UJ	5.3 UJ	5.4 UJ	14.7 J
Iron			1340	504	380	380	1430	7680 J
Lead	15		5.6 J	2.8 J	4.5 J	2.5 J	4.5 J	18.2 J
Magnesium			16600	20100	19600	19400	32300	26800 J
Manganese		5100	148	38.5	43.0	45.9	63.9	372 J
Mercury	2	11	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 UJ
Nickel	100	730	16.7 U	16.7 U	16.7 U	16.7 U	16.7 U	20.5 UJ
Potassium			2970	3010	2980	2920	1560	5150 J
Selenium	50	180	4.7 J	10.0 J	9.0 J	9.3 J	20.3 J	7.6 J
Silver		180	3.6 U	3.6 U	3.6 U	3.6 U	3.6 U	3.6 UJ
Sodium			22300	30800	29700	29600	81800	44000 J
Thallium	2		0.90 U	0.90 U	0.90 U	0.90 UJ	0.90 U	0.90 UJ
Vanadium		260	7.5	4.7	5.6	5.1	5.6	17.8 J
Zinc		11000	20.0	5.3	9.4	7.3	10.5	56.7 J

U – analyte not detected at the reported limit.
J – analyte detected above the instrument detection limit but below the analytical reporting limit
UJ – analyte not detected at the reported limit, however the reported limit is only approximate because quality control criteria were not met.
Shaded cells indicate an exceedance of standard
Sample locations are presented on Figure 5

Table 6
1994 Residential Soil Sample Results (mg/kg)
[CDPHE 1995 Expanded Site Inspection]

	SCDM	SO-1[a]	SO-2[a]	SO-3[a]	SO-4[a]	SO-5	SO-6	SO-7	SO-8	SO-9	**SO-10[b]**	SO-11	**SO-12[b]**	**SO-13[b]**	**SO-14[b]**
Aluminum		14500	15400	12800	16400	4500	5840	13500	9140	6780	4780	14600	4860	9220	7480
Antimony	31	5.6r	6.1r	5.4r	5.7r	5.5r	5.4r	5.8r	6.2r	6.1r	5.4r	6.9r	9.5j	5.6u	5.5r
Arsenic	23	5.5j	5.0j	6.1j	15.5j	10.0j	8.6j	9.3j	18.5j	10.0j	8.4j	9.0j	1.0j	19.4j	5.0j
Barium	5500	184	166	196	217	182	105	196	245	199	279	375	147	146	171
Beryllium	160	0.74	0.75	0.66	0.72	0.34uj	0.37	0.73	0.58	0.51	0.43	1.1	0.83u	0.72	0.49
Cadmium	39	0.85u	0.93u	0.83u	0.87u	2.2	1.3	1.8	2.7	1.4	3.2	3.0	0.98	2.1	2.0
Calcium		39200	32600	88100	13200	13600	15400	26100	30000	27700	28000	31200	13300	19700	27700
Chromium	230	13.2	12.3	11.6	22.5	9.8	7.3	14.1	10.2	7.4	7.6	39.2j	2.8j	9.8j	8.3j
Cobalt		8.9	8.0	8.3	12.5	4.3	3.7	7.9	6.3	5.4	4.9	12.5	5.5	6.0	5.0
Copper		22.4	18.1	21.1	38.1	34.2	26.6	32.6	46.9	40.1	93.2	85.8	18.3j	41.3	34.4
Iron		17900	17100	14700	27000	9560	9810	17700	15500	11100	11000	21400	4790j	15500	12900
Lead		32.5	13.9	28.2	29.3	240	142	93.3	322	124	303	553	23.8j	155j	111j
Magnesium		6120	5000	5060	9100	2160	1780	4510	3280	2130	2450	6650	910	3520	3690
Manganese	11000	381j	424j	333j	567j	179j	171j	326j	281j	207j	368j	657	103	429	396
Mercury	23	0.11u	0.12u	0.11u	0.11u	0.13	0.11u	0.11u	0.19	0.12u	0.26	0.30	0.13u	0.14	0.12
Nickel	1600	15.5	15.8	21.1	30.6	11.1	8.5	17.9	31.1	12.5	13.4	24.9	7.1	12.8	8.5
Potassium		4100	4830	3640	4030	1220	1560	3490	2940	1940	1760	3580	738	2330	1790
Selenium	390	0.60j	0.71j	0.56j	1.6j	1.2j	1.1j	1.1j	1.6j	1.5j	1.5j	1.5j	0.90j	0.81j	0.40
Silver	390	1.5uj	1.3uj	1.4uj	2.1uj	0.88uj	1.9	2.1	2.3	1.6	2.2	2.2	0.91u	1.0	0.98
Sodium		184	152	123	169	87.9	192	162	215	224	235	197	1190	195	203
Thallium		0.20uj	0.21uj	0.26j	0.20uj	0.25j	0.19u	0.20	0.22u	0.21u	0.19u	0.24u	0.23u	0.38	0.19
Vanadium	550	48.0	46.3	53.9	58.7	27.1	31.7	49.9	42.6	31.2	20.9	43.7	18.1	33.7	27.0
Zinc	23000	81.4	66.9	73.5	120	211	95.4	154	230	154	421	912	38.3	268	269

SCDM – Superfund Chemical Data Matrix residential soil standard for non-cancer risk
[a] – background sample
[b] – sample located within one mile of Colorado Smelter
u –analyte not detected at the reported limit
j – analyte detected above the instrument detection limit but below the analytical reporting limit
Shaded cells indicate concentration at least three times background and in excess of screening benchmark
Sample locations are presented on Figure 7

Table 6 cont.
1994 Residential Soil Sample Results (mg/kg)
[CDPHE 1995 Expanded Site Inspection]

	SCDM	**SO-15[b]**	**SO-16[b]**	**SO-17[b]**	SO-18	SO-19	SO-20	SO-21	SO-22	SO-23	**SO-24[b]**	**SO-25[b]**	**SO-26[b]**	**SO-27[b]**
Aluminum		7360	7790	7490	6050	7820	10500	9880j	9420j	16900j	9170j	5540j	6530j	7400j
Antimony	31	7.8j	5.7r	5.4r	6.6j	9.4j	7.0j	5.4uj	5.5j	5.5uj	5.6uj	5.2uj	5.3uj	5.4uj
Arsenic	23	44.0j	10.7j	13.2j	8.0j	13.5j	10.6j	7.3j	38.9j	22.9j	7.9j	5.4j	5.7j	4.1j
Barium	5500	299	202	165	154	123	214	140j	558j	247j	363j	133j	270j	115j
Beryllium	160	0.81	0.54	0.49	0.42uj	0.39uj	0.90	0.40	0.75	0.84	0.89	0.36	0.41	0.38
Cadmium	39	12.7	4.9	3.2	1.6	4.8	6.1	2.0uj	46.1	24.1	1.8uj	1.5uj	1.4	0.83u
Calcium		25000	50700	27500	29200	16300	33900	35700j	28300j	25500j	25600j	18300j	31100j	32000j
Chromium	230	7.8j	18.9j	10.4j	7.0j	10.7j	9.6j	16.2	11.7	17.7	13.9	7.2	10.5	10.1
Cobalt		6.9	7.1	7.4	4.0	7.4	5.8	5.6	7.7	10.7	7.2	3.8	4.4	4.6
Copper		131j	60.8j	49.7j	23.8j	174j	31.1j	29.2	228	107	56.2	43.5	37.9	30.1
Iron		13700	17100	16800	9750	17700	14000	15400j	17700j	24300j	17100j	11100j	10900j	11400j
Lead		692j	175j	164j	77.6j	336j	169j	102	2130	968	605	187	136	81.9
Magnesium		2950	5260	4030	2520	3210	6590	3170j	4240j	6600j	2780j	2310j	2960j	3510j
Manganese	11000	578	309	287	265	328	519	322j	555j	682j	409j	289j	261j	258j
Mercury	23	0.81	0.19	0.14	0.11	0.13	0.12	0.11u	7.5	0.80	0.64	0.11	0.10u	0.11u
Nickel	1600	12.8	23.9	22.1	9.6	11.4	13.8	14.8	11.9	18.0	10.2	7.9	9.2	9.1
Potassium		1070	2400	3300	1840	2170	2900	2220	1850	4410	1980	1520	1710	1540
Selenium	390	0.43j	2.7j	1.8j	0.62j	0.38j	0.82j	0.65	1.6	0.81	0.80	0.73	0.81	0.57
Silver	390	3.9	1.1	1.6	0.78u	5.0	1.1	0.76u	11.1	5.0	1.3	0.88	0.75u	0.76u
Sodium		436	359	206	113	91.9	266	180	325	218	393	106	147	180
Thallium		0.35	0.61	0.49uj	0.20u	0.21uj	0.20uj	0.24j	0.19uj	0.19uj	0.20u	0.18u	0.19u	0.19u
Vanadium	550	25.2	50.4	53.6	24.7	39.0	34.1	55.2j	35.2j	51.7j	30.8j	22.0j	25.1j	28.1j
Zinc	23000	616	390	258	153	2430	590	268j	6910j	2920j	718j	272j	220j	149j

SCDM – Superfund Chemical Data Matrix residential soil standard for non-cancer risk
[b] – sample located within one mile of Colorado Smelter
u –analyte not detected at the reported limit
j – analyte detected above the instrument detection limit but below the analytical reporting limit
Shaded cells indicate concentration at least three times background and in excess of screening benchmark
Sample locations are presented on Figure 7

Table 6 cont.
1994 Residential Soil Sample Results (mg/kg)
[CDPHE 1995 Expanded Site Inspection]

	SCDM	**SO-28[b]**	**SO-29[b]**	**SO-30[b]**	**SO-31[b]**	SO-32	SO-33	**SO-34[b]**	**SO-35[b]**	**SO-36[b]**	**SO-37[b]**	**SO-38[b]**	**SO-39[b]**
Aluminum		9080j	11500j	9120j	9120	6380	9060	5750	6730	10400	6700	4330	4100
Antimony	31	5.3uj	5.4uj	5.5uj	5.4uj	5.3r	5.7r	5.3r	13.2j	9.7j	9.5j	13.7j	10.1uj
Arsenic	23	9.8j	66.6j	10.8j	20.3j	16.8j	6.1j	8.3j	5.2	29.7	22.6	23.7	28
Barium	5500	185j	266j	173j	151	111	131	137	170	371	187	216	214
Beryllium	160	0.50	0.81	0.49	0.55	0.48	0.55	0.40uj	0.24u	0.99uj	0.66uj	0.70uj	0.68uj
Cadmium	39	2.8	2.8	0.85u	1.4	0.81u	1.9	1.8	2.6	4.3	4.3	7.3	7
Calcium		32900j	36800j	43900j	29800	19600	19600	25600	35000j	25400j	34000j	143000j	137000j
Chromium	230	23.7	13.5	10.8	14.5	7.6	10.1	7.3j	12.9	8.2	9.5	8.4	6.8
Cobalt		6.9	7.8	5.8	6.1	5.2	7.1	4.7	4.7	5.5	6.8	11.6	9.4
Copper		36.2	88.1	36.3	60.7	38.1	37.4	29.0j	29.6	34.5	65.8	99.9	31
Iron		17400j	20700j	14800j	20200	9780	14700	9400	17100j	47400j	21400j	20900j	20300j
Lead		248	276	122	250j	89.0	67.0	124j	111	239	336	152	34.4
Magnesium		3450j	3630j	3970j	3520	3040	4210	3310	3340	2360	3550	4530	5440
Manganese	11000	302j	567j	313j	439	309j	338j	295	336j	589j	668j	300j	156j
Mercury	23	0.28	0.24	0.11u	0.15	0.10	0.11u	0.14	0.23	0.28	0.19	0.13u	0.11u
Nickel	1600	13.9	15.6	13.7	13.0	13.5	13.9	11.0	16.1j	16.2uj	21.6uj	55.6	51
Potassium		2250	2150	2250	1810	2540	2540	1840	4720	1660	1920	1860	1850
Selenium	390	0.75	0.91	0.48	0.99	1.6j	0.98j	0.48j	1.2u	1.4	1.6	9.1	8.3
Silver	390	1.3	1.6	0.78u	1.6	2.1uj	1.7uj	0.75u	0.96u	2	1	1.2	0.92u
Sodium		182	349	116	132	103	179	94.4	172	368	165	251	274
Thallium		0.20	0.19uj	0.20u	0.19u	0.19u	0.39j	0.19u	0.28	0.24	0.35	1.2	1.9
Vanadium	550	43.3j	35.5j	36.8j	40.7	22.2	32.5	23.3	34.5	34.7	35.3	61.4	65.8
Zinc	23000	296j	657j	234j	417j	180	191	157	254	196j	558j	354j	177j

SCDM – Superfund Chemical Data Matrix residential soil standard for non-cancer risk
[b] – sample located within one mile of Colorado Smelter
u –analyte not detected at the reported limit
j – analyte detected above the instrument detection limit but below the analytical reporting limit
Shaded cells indicate concentration at least three times background and in excess of screening benchmark
Sample locations are presented on Figure 7

Table 7
1995 XRF Source and Residential Soil Sample Results (mg/kg)
[E&E 1995a Analytical Results Report]

	Slag XRF-001	Slag XRF-002	Slag XRF-003	Slag XRF-004	Slag XRF-005	Slag XRF-006	XRF-007	XRF-008	XRF-009	XRF-010	Slag XRF-011	Slag XRF-012	XRF-013
Arsenic	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U	140 J	67 U	67 U	67 U
Lead	88 J	190	210	360	420	180	52 U	610	2400	4900	9700	180	52 J

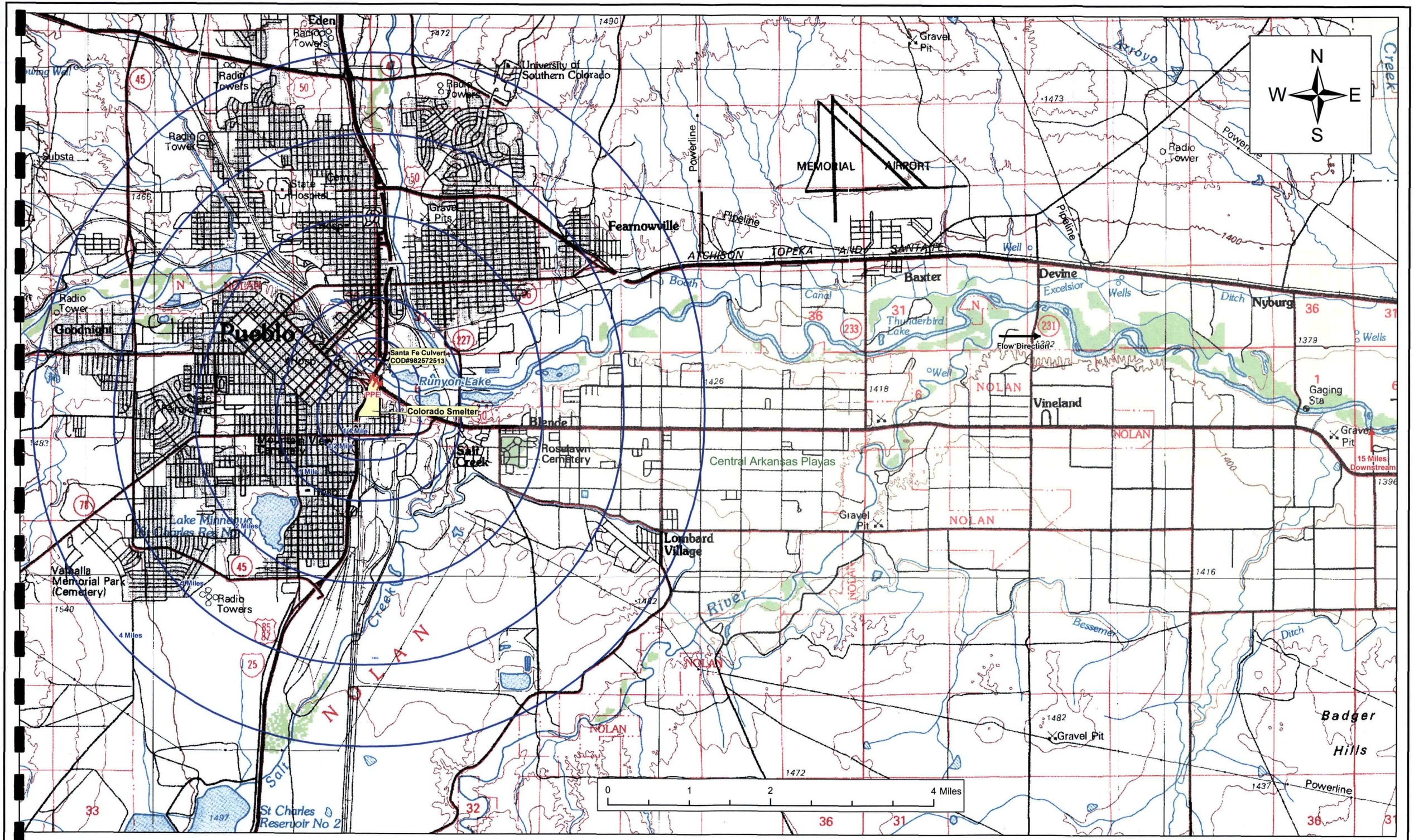
	XRF-014	XRF-015	XRF-016	XRF-017	XRF-018	XRF-019	XRF-020	XRF-021	XRF-022	XRF-023	XRF-024	XRF-025	XRF-026
Arsenic	67 U	130 J	67 U	67 U	67 U	67 U	67 U	67 U	67 U	75 J	67 U	67 U	67 U
Lead	120 J	330	140 J	260	200	340	240	340	160 J	590	520	860	87 J

	XRF-027	XRF-028	XRF-029	XRF-030	XRF-031	XRF-032	XRF-033	XRF-034	XRF-035	XRF-036	XRF-037	XRF-038
Arsenic	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U	67 U
Lead	170 J	200	210	81 J	52 U	270	700	260	100 J	240	52 U	200

U –analyte not detected at the reported limit.
J – analyte detected above the instrument detection limit but below the analytical reporting limit
Shaded cells indicate concentration in excess of screening benchmark
Sample locations are presented on Figure 7

Note: Arsenic detection limit of 67 mg/kg is significantly greater than existing health-based benchmarks.

FIGURES

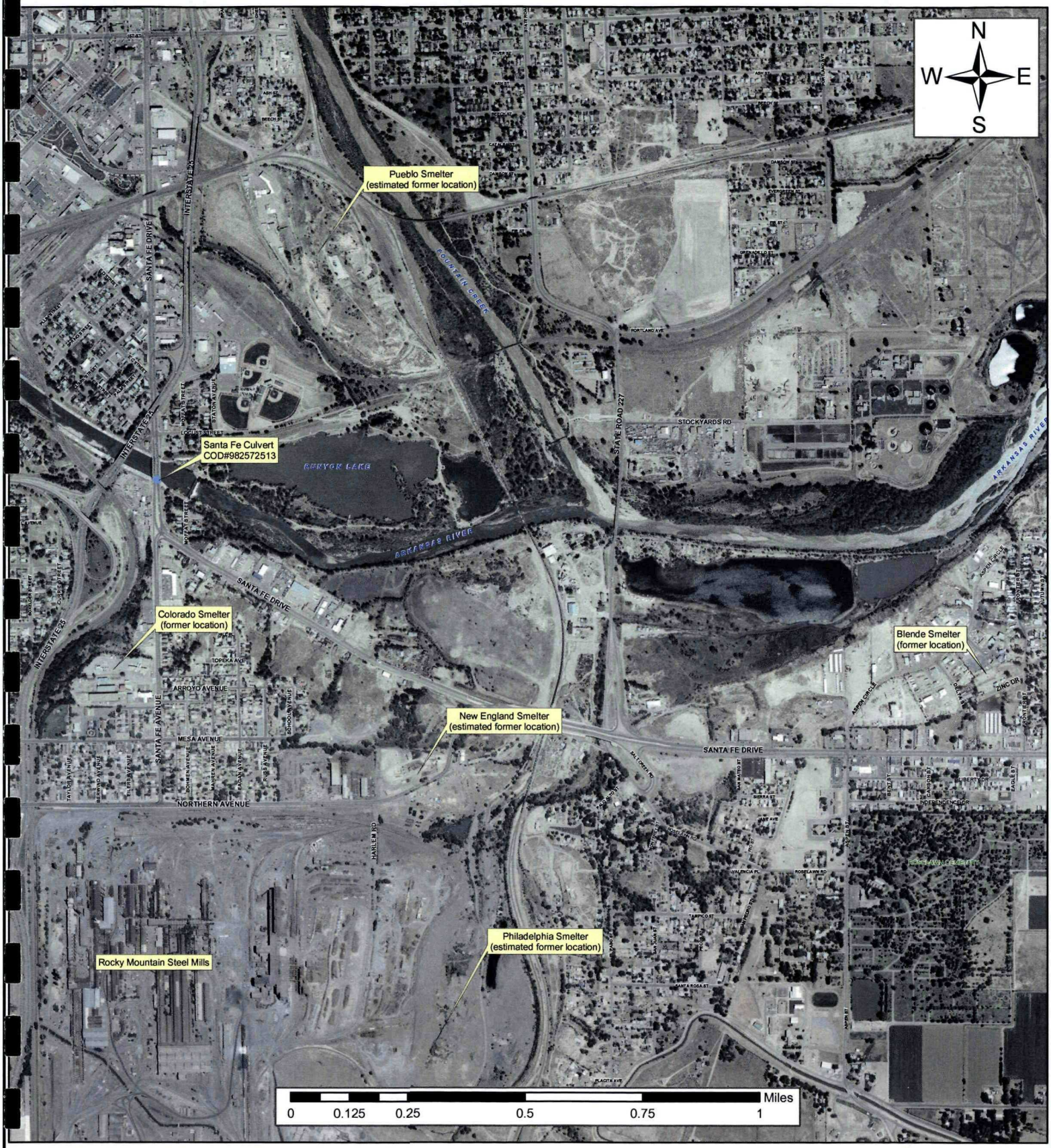


Colorado Smelter
Preliminary Assessment
April 28, 2008

Site Location and Area of Influence

Base map from USGS 1to24 topographic quadrangle (1977)

Figure 1

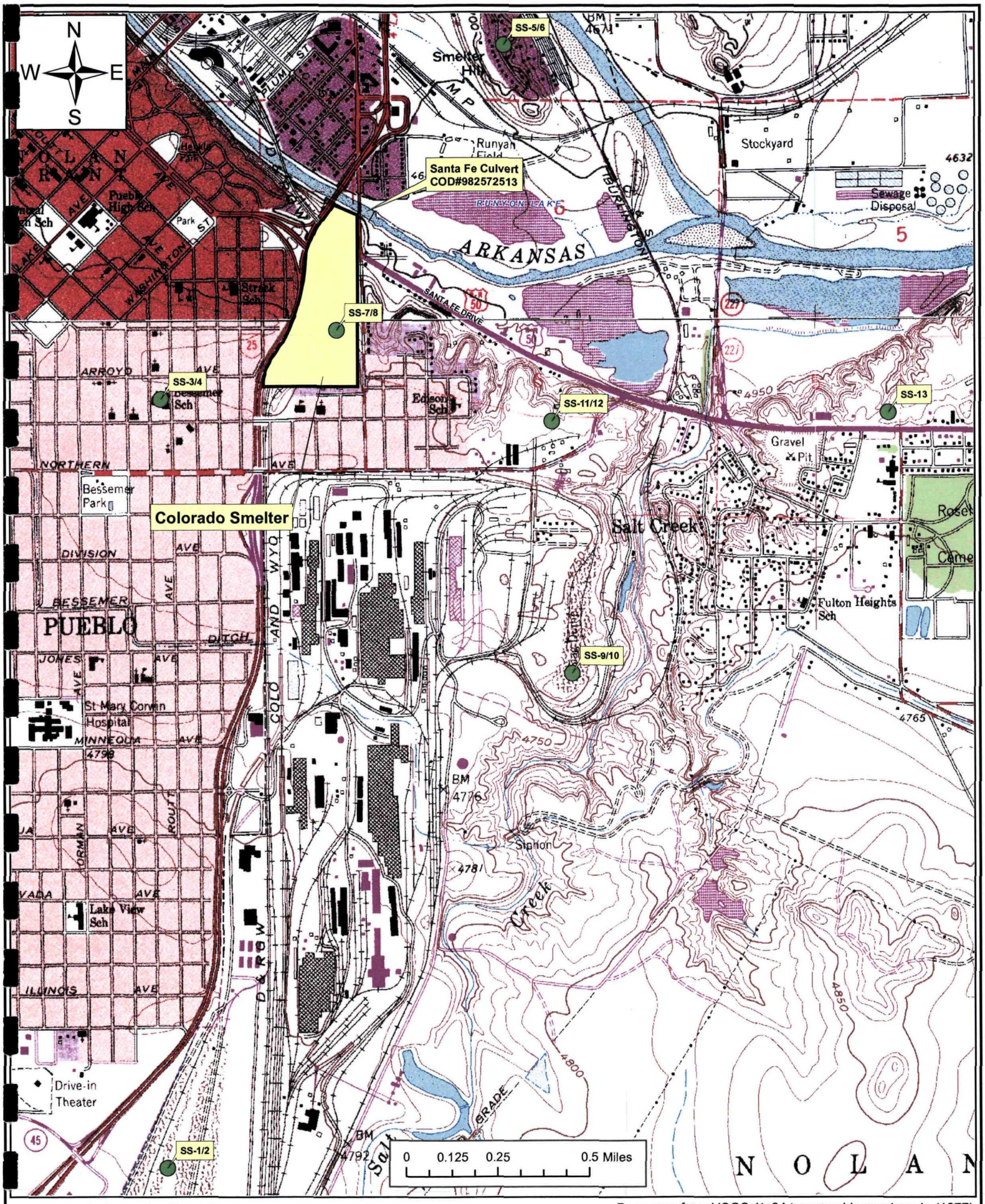


Aerial photograph from USDA NAIP (2005)

Colorado Smelter
Preliminary Assessment
April 28, 008

Historic Smelter Locations

Figure 2



Base map from USGS 1to24 topographic quadrangle (1977)

Colorado Smelter
Preliminary Assessment
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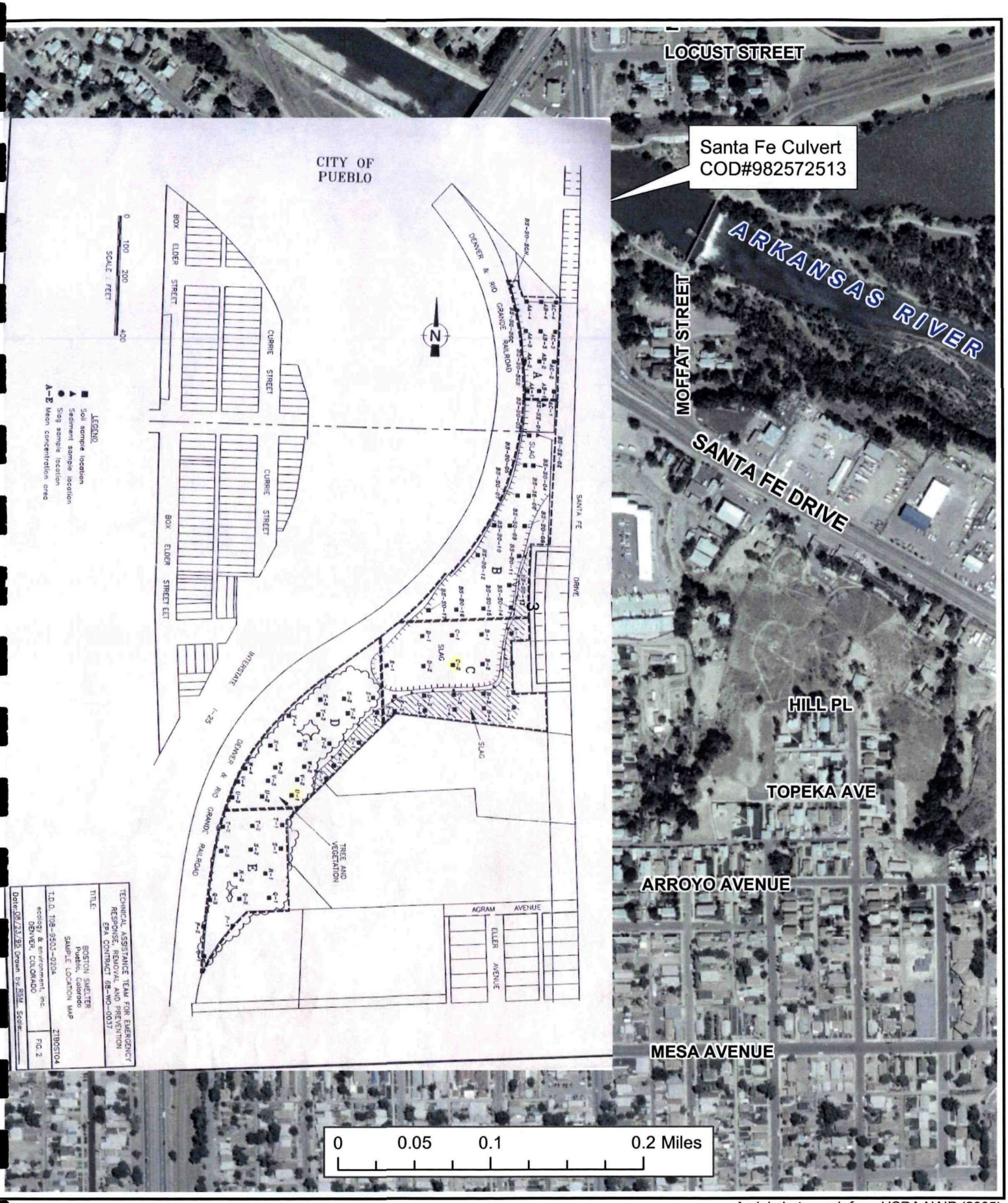
1994 Source Sample Locations
[CDPHE 1995 Expanded Site Inspection]

Figure 3

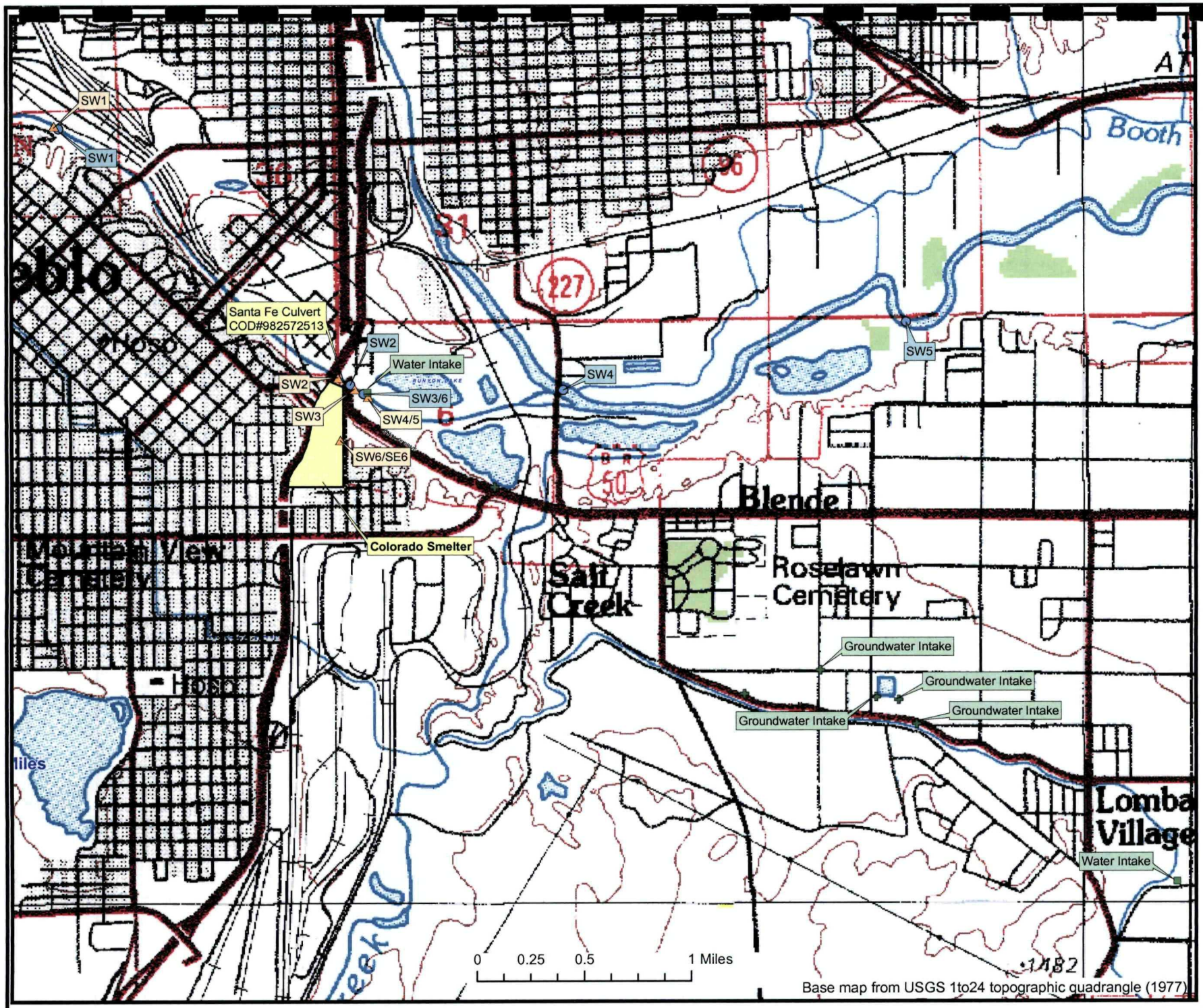


Aerial photograph from USDA NAIP (2005)

Colorado Smelter
Preliminary Assessment
April 28, 2008

1995 E&E Source and Sediment Sample
[E&E 1995b Site Screening Report]

Figure 4



Colorado Smelter
Preliminary
Assessment
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N
W E
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Surface Water
and Sediment
Sample Locations
and
Municipal Drinking
Water Intakes

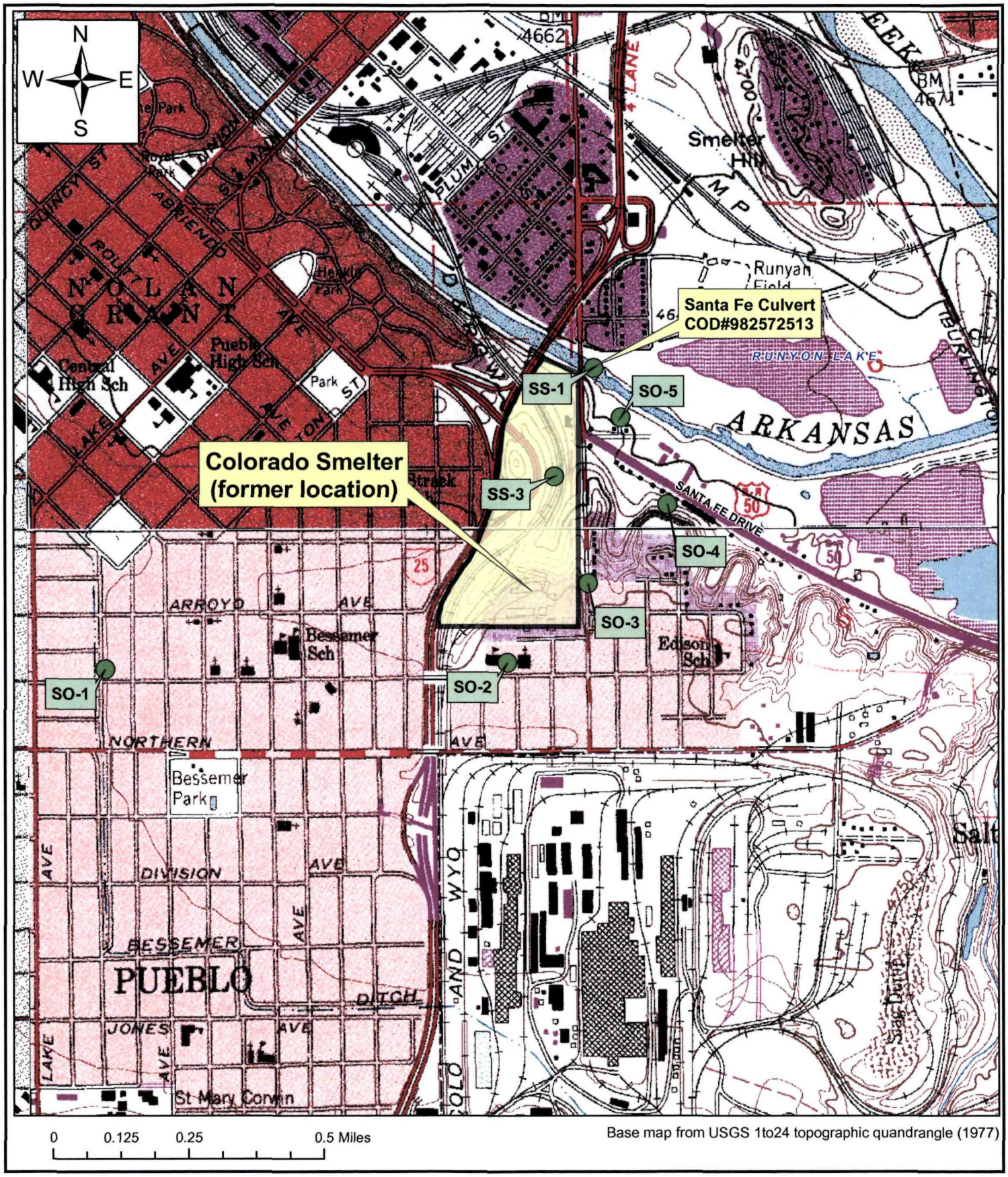
Figure 5

1992 Surface Water and Sediment Samples [CDPHE 1994 Screening Site Inspection]

1994 Surface Water Samples [CDPHE 1995 Expanded Site Inspection]

St. Charles Mesa Surface Water Intakes

St. Charles Mesa Groundwater Intakes



Base map from USGS 1to24 topographic quandrangle (1977)

Colorado Smelter
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1992 Source and Residential Soil Sample Locations
[CDPHE 1994 Screening Site Inspection]

Figure 6

Aerial photograph from USDA NAIP (2007)

Colorado Smelter
Preliminary Assessment
April 28, 2008

CDPHE Sept 1994 Soil Samples
[CDPHE 1995 Expanded Site Inspection]

E&E May 1995 Soil Sample
[E&E 1995a Analytical Results Report]

1994 and 1995
Residential Soil
Sample Locations

Figure 7

PHOTOS

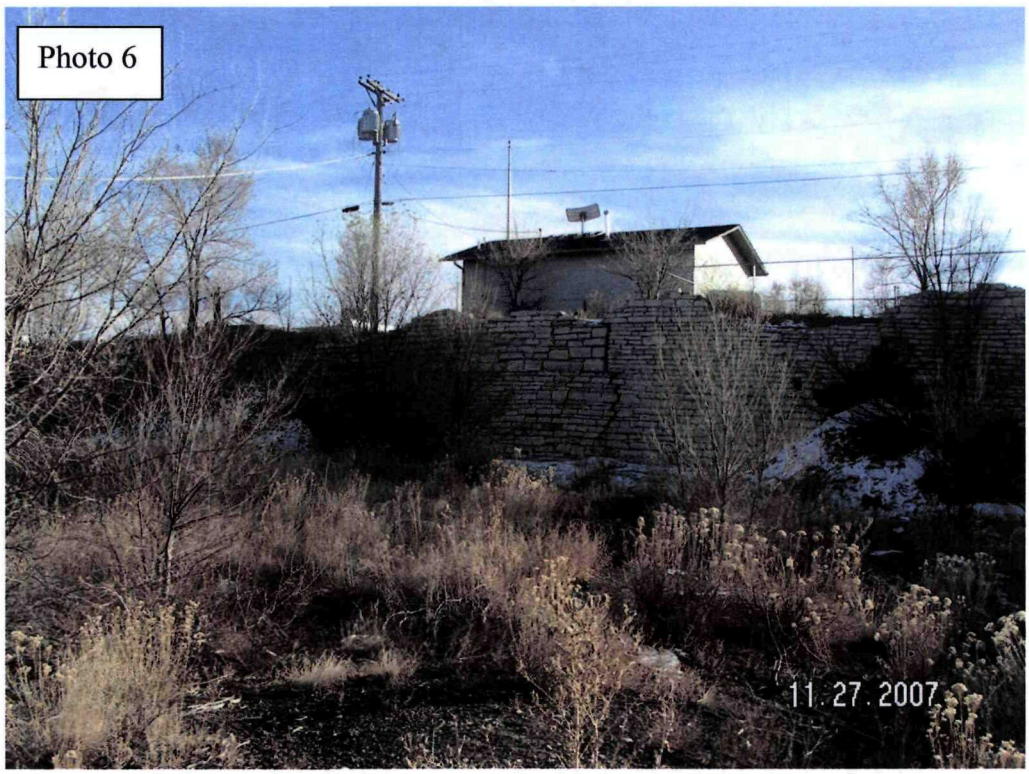
Colorado Smelter slagheap
looking southwest from Santa Fe Ave

Colorado Smelter slag

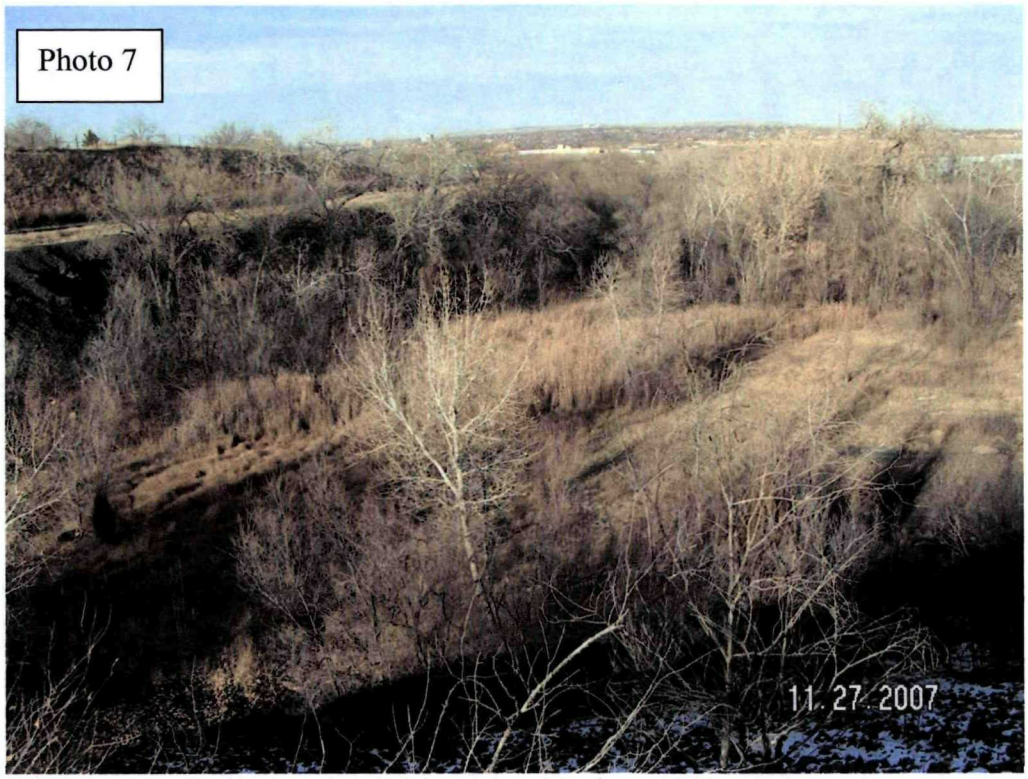
Colorado Smelter slagheap and railroad grade
looking northwest in the ravine

Fox observed on slagheap, looking west across the ravine

Colorado Smelter building foundation remnants
looking south in the ravine



Colorado Smelter remnants, looking west from the ravine

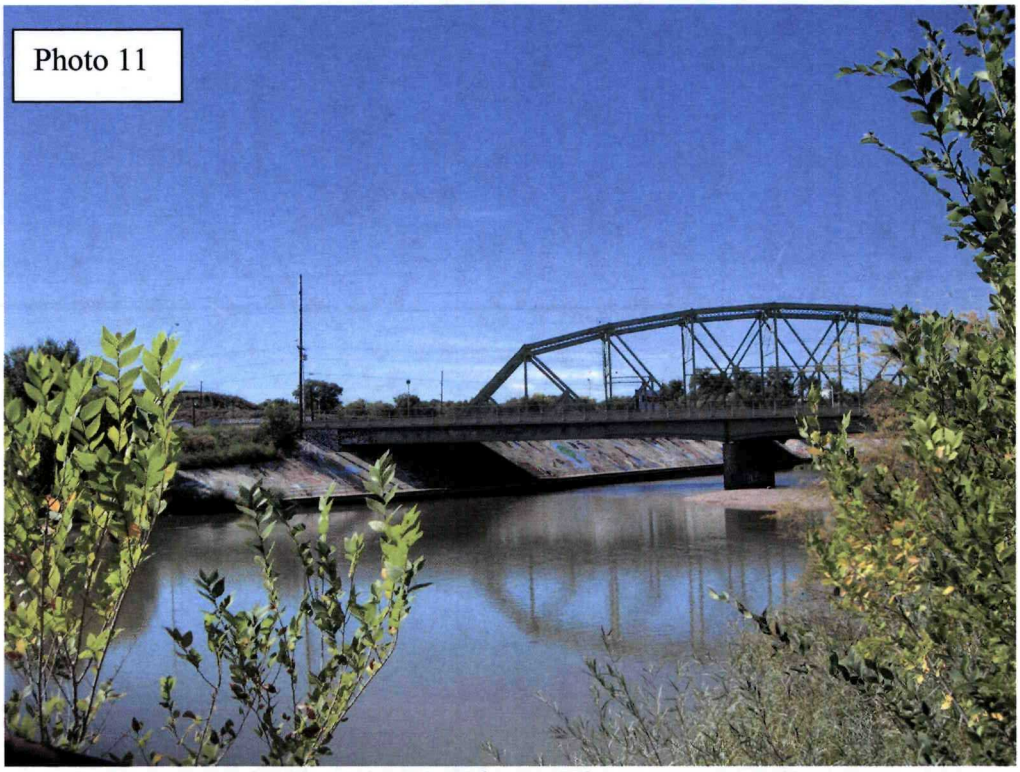


Wetland located in base of ravine, looking north

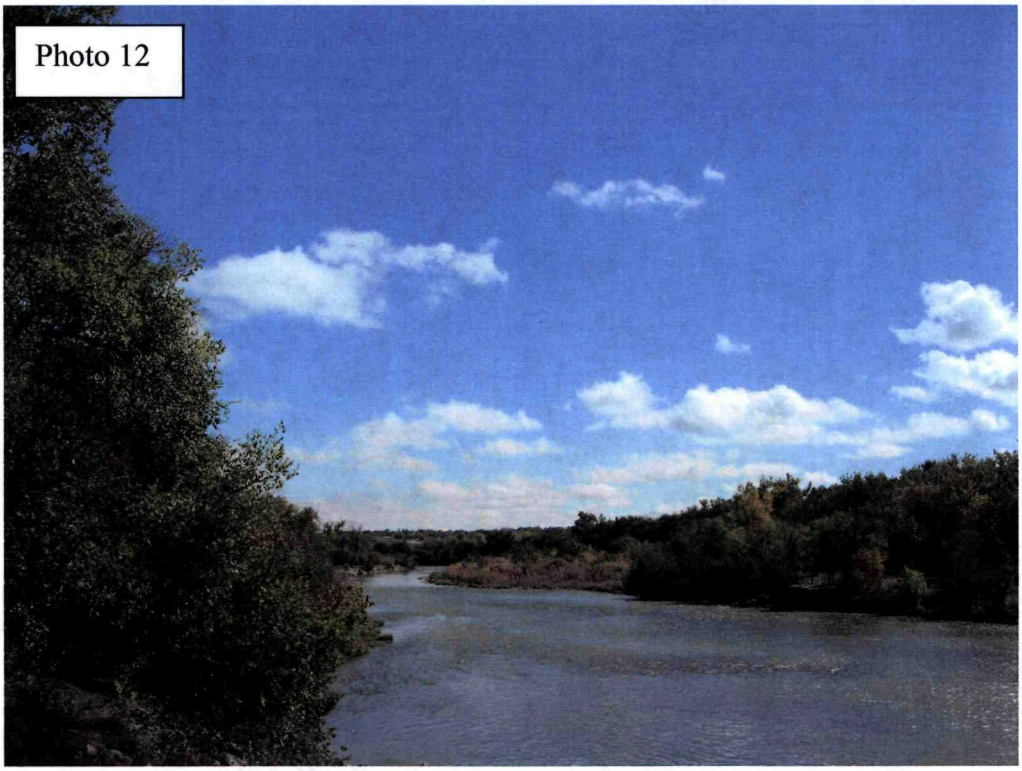
Western storm water culvert located behind the Ace Enterprises building (possible PPE)

Santa Fe Avenue Bridge Culvert (main PPE)

Eastern storm water collection drain, located in front of vacant A&W / Kentucky Fried Chicken building (possible PPE)



Arkansas River looking southwest (upstream)



Arkansas River looking southeast (downstream)

St. Charles Mesa Water intake location, looking south towards Santa Fe Avenue bridge

Runyon Lake

ATTACHMENT

Environmental Geochemistry and Health (2006) 28:297–315
DOI 10.1007/s10653-005-9000-6
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Arsenic, Cadmium, Lead, and Mercury in surface soils, Pueblo, Colorado: implications for population health risk

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Received 27 July 2004 Accepted 27 June 2005

Key words: arsenic, cadmium, cancer risks, environmental contamination, ESDA, GPS coordinates, lead, mercury, spatial statistics, urban geochemistry

Abstract

Decades of intensive industrial and agricultural practices as well as rapid urbanization have left communities like Pueblo, Colorado facing potential health threats from pollution of its soils, air, water and food supply. To address such concerns about environmental contamination, we conducted an urban geochemical study of the city of Pueblo to offer insights into the potential chemical hazards in soil and inform priorities for future health studies and population interventions aimed at reducing exposures to inorganic substances. The current study characterizes the environmental landscape of Pueblo in terms of heavy metals, and relates this to population distributions. Soil was sampled within the city along transects and analyzed for arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb). We also profiled Pueblo's communities in terms of their socioeconomic status and demographics. ArcGIS 9.0 was used to perform exploratory spatial data analysis and generate community profiles and prediction maps. The topsoil in Pueblo contains more As, Cd, Hg and Pb than national soil averages, although average Hg content in Pueblo was within reported baseline ranges. The highest levels of As concentrations ranged between 56.6 and 66.5 ppm. Lead concentrations exceeded 300 ppm in several of Pueblo's residential communities. Elevated levels of lead are concentrated in low-income Hispanic and African-American communities. Areas of excessively high Cd concentration exist around Pueblo, including low income and minority communities, raising additional health and environmental justice concerns. Although the distribution patterns vary by element and may reflect both industrial and non-industrial sources, the study confirms that there is environmental contamination around Pueblo and underscores the need for a comprehensive public health approach to address environmental threats in urban communities.

Introduction

Although the carcinogenic mechanism(s) of heavy metals and other trace elements remains unclear in many cases, laboratory studies using animal models (Goyer 1996; De Boeck *et al.* 2003; Waalkes 2003; Fontana *et al.* 2004) as well as epidemiological studies (Boice *et al.* 2003; Guillamet *et al.* 2004; Pinkerton *et al.* 2004; Tchounwou *et al.* 2004) have established relationships between heavy metals and various forms of cancer as well as other health endpoints including neurological disorders

and developmental disabilities. The surface soil content of heavy metals and other trace elements in a region depends, in part, on the nature of bedrock, on abiotic factors such as weather conditions, and on biotic factors such as microbial populations. However, topsoil contamination by heavy metals and other organic and inorganic compounds comes mainly from anthropogenic sources (Zakrzewski 1997; Adriano 2001). Activities that promote such contamination include agricultural inputs from fertilizers and pesticides, waste incineration, emissions from point sources such as industrial plants and non-point sources such as automobiles, and biosolids such as municipal waste and sludge (Adriano 2001; Onianwa *et al.* 2001). Communities such as Pueblo in southern Colorado, where the aforementioned practices are pervasive, engender concern about environmental contamination and its potential role in shaping cancer risk.

The city of Pueblo, Colorado has a long history of activities that could compromise environmental quality and thus community health. Because of its proximity to large coal and lime deposits and its access to a reliable railroad system, Pueblo has long provided an ideal location for smelters to process various ores (Buckingham 1995). From the 1890s to 1921, six smelters operated in the central area of the city: the Blend Zinc Smelter, the Colorado Fuel and Iron Co. (CF&I) Smelter, the Colorado Smelting Company, the Massachusetts Smelting Company, the Philadelphia Smelting and Refining Company, and the Pueblo Smelting and Refining Company. Although five of the six were either destroyed by flood or dismantled by 1921, the CF&I (now renamed Rocky Mountain Steel Mill-RMSM) Smelter is still in operation, with a contamination site (waste area) reportedly much larger than that of all the other five smelters combined (Buckingham 1995).

At the beginning of its operations in the late 1800s, the CF&I processed pig iron as main raw material to make steel and iron products, using coal in a coke plant (BHS 2004). The pig iron contained primarily iron ore, carbon and various metals, including heavy metals, as impurities. The first annual report of CF&I was published in August 1893 and summarized activities from November 1892 to August 1893 (BHS 2004). During this period, the iron and steel plant covered over 41 km^2 and operated three blast furnaces with a daily production capacity of 400 tons of pig iron, one converter with a daily capacity of 500 tons of steel ingots, one blooming and rail mill producing 500 tons of blooms and 300 tons of rails, and other equipments of smaller capacity. By 1937 (the last year with an available production statement), the CF&I processing and production capacity had increased substantially. This year the plant used 714,578 tons of iron ore and 1,555,774 tons of coal to produce 362,728 tons of pig iron, 615,481 tons of ingots, 165,787 tons of rails, 70,318 tons of rail accessories, 290,875 tons of limestone and dolomite, 454,513 tons of coke, and 268,398 tons of other steel products plus a good amount of coke by-products. Since the 1980s, the CF&I plant has been processing scrap materials to make various steel products.

The residential houses around CF&I were built from mid 1800s to early 1900s in order to accommodate the workers, and the land use patterns have not significantly changed around the mill since the beginning of operations, although many residents have relocated over the years. Although this central industrial area is also adjacent to some of Pueblo's poorest neighborhoods according to 2000 US Census data (GeoLytics 2002), potential health risks to Pueblo's residents have yet to be determined.

To date, some small-scale sampling efforts have been carried out in Pueblo (Buckingham 1995), but they are too limited in scope to allow for their generalization to the entire city. The most recent of these soil studies was conducted between 1992 and 1995 (Buckingham 1995) through selective sampling at suspected waste areas of smelters and in nearby residential areas. These analyses showed that, although most of the smelters ceased operation by 1921, levels of antimony (Sb), arsenic (As), chromium (Cr) and manganese (Mn) still exceeded Superfund Chemical Data Matrix (SCDM) benchmark levels at some of the sites (http://www.epa.gov/superfund/sites/npl/hrsres/tools/scdm.htm). SCDM is a source for factor values and benchmark values applied when evaluating potential National Priority List (NPL) sites using the Hazard Ranking System (HRS). Benchmarks are environment- or health-based substance concentration limits developed by or used in other EPA regulatory programs. SCDM contains HRS factor values and benchmark values

for hazardous substances that are frequently found at sites evaluated using the HRS. In this study of suspected waste sites of Pueblo, the concentrations of other elements in top soil, including lead (Pb) and mercury (Hg), in topsoil of these suspected waste sites in Pueblo were also above regional and national baseline levels. Some 22.6% (7 of 31) of samples taken at residences around the smelters had As-level above the SCDM benchmark. The current study expands this preliminary analysis by systematically surveying the geochemistry of Pueblo's soils to provide a data set that has implications for the public health community. This information will allow researchers to make limited comparisons of different communities within Pueblo and, where data exist, with other areas of the state, region, and county. It will establish a basis for setting priorities for subsequent epidemiological studies and surveillance of potentially harmful substances in the environment. Additionally, these reconnaissance baseline data will allow us to identify hot spots (those large enough to be identified at the sample density of the current survey) and areas that may pose potential risks to the residents of Pueblo, Colorado.

In this paper, we characterize the environmental landscape of Pueblo, Colorado in terms of four potentially toxic elements (i.e., Pb, As, Hg and Cd) and relate this to population distributions. Information about the abundance and spatial distribution of these inorganic substances across industrial, commercial, and residential areas of Pueblo, Colorado may play an important role in examining health trends in this community, and will give us the ability to determine which communities live within or near environmentally contaminated areas.

Materials and methods

Area of study

Soil was sampled within the geographical zone of the city of Pueblo, Colorado. For comparison purposes, the study zone also included parts of the relatively newly established community of Pueblo West and areas south of Pueblo around the Comanche Power Plant, both of which are outside the city limits. A demographic analysis of key socioeconomic indicators was conducted using data from the 2000 United States Census (GeoLytics 2002). The aim of the demographic analysis was to provide insight into the population characteristics of Pueblo's residents and to inform the design of the environmental sampling and any subsequent health surveys.

Sampling method

Soil samples were collected along 4 transects, 3 km apart (Figure 1). The position of these transects was based on demography, street index and other socio-economic parameters. For example, one transect goes through the Santa Fe Culvert (Figure 1, sites 2 A/B, 3 A/B, 18 A/B), a zone with a past history of heavy industrial activities and environmental contamination (Buckingham 1995). A few additional samples were collected from traditionally low-income areas, such as Bessemer (sites 20 A/B), Dog Patch (sites 25 A/B) and Sunset Park (sites 6 A/B). Transects were oriented parallel to general wind patterns in the region (northwest to southeast) to determine potential wind impact on heavy metal distribution. Sampling sites were chosen every 2 km on each of the four transects. Each site was referenced according to Geographical Positioning System (GPS) information and by street index. Each of the 33 sampling sites was marked by two 25 cm×25 cm collection areas. These areas were chosen haphazardly 50 to 100 m apart such that 66 soil samples were taken along side walks, in the front and/or backyard of residences, on empty lots, school yards, and playgrounds. Samples were taken from the top 5-cm of soil and placed in freezer bags. For each sample a subset was sieved to particles less than 2 mm in diameter and stored in glass containers for chemical analysis.

Chemical analysis

The samples were analyzed in the laboratories of the U.S. Geological Survey, Denver, Colorado. Cadmium (Cd) and lead (Pb) were determined by inductively coupled plasma – mass spectrometry after digestion of the samples by a four-acid protocol (Briggs & Meier 1999). Briefly, 0.200 g sample was weighed into a 30-mL Teflon vessel for chemical analysis. Samples were rinsed from the side walls of the Teflon vessel with minimum amount of DI water. Afterward, 3 mL of concentrated HCl and 2 mL of HNO_3 were added and

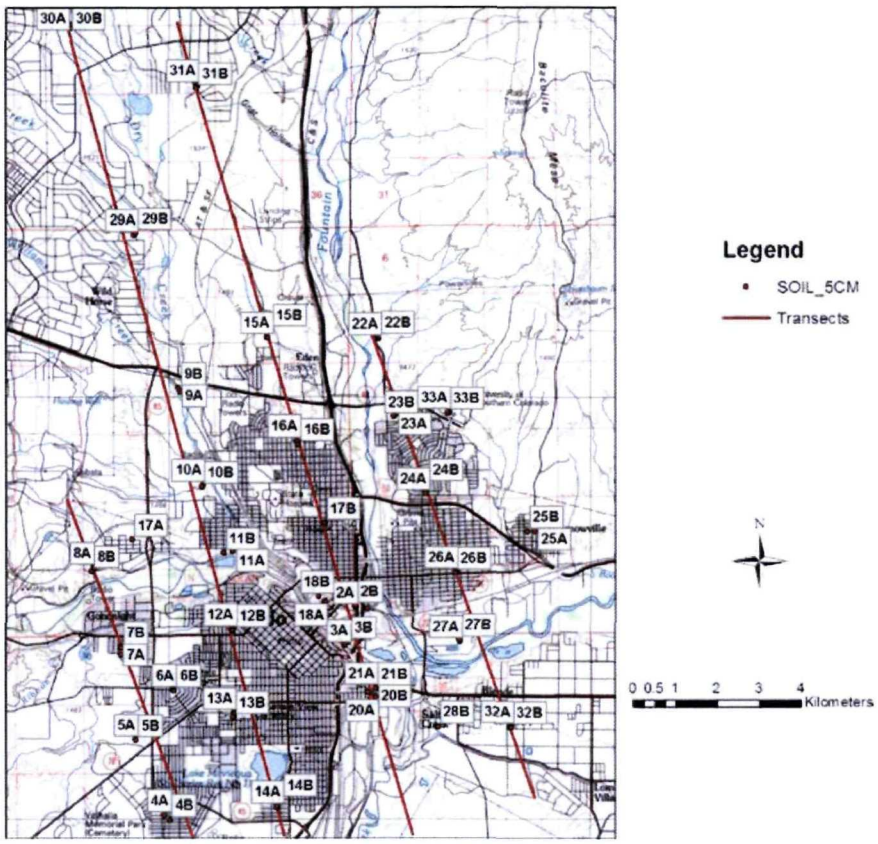

Fig. 1. Sampling sites for the exploratory spatial analysis of heavy metals in topsoil of Pueblo, Colorado.

samples were allowed to subside. Concentrated $HClO_4$ (1 mL) and concentrated HF (2 mL) were then added. Teflon vessels were placed on aluminum heating block preset at 110 °C and heated to incipient dryness. The temperature was subsequently raised to 160 °C to bring samples to complete dryness, and the Teflon vessels were removed from the heating block. Concentrated $HClO_4$ (1 mL) was then added and samples were again brought to complete dryness at 160 °C and allowed to cool. At this point, 1 mL concentrated HNO_3 and two drops of H_2O_2 were added to samples and reactions were allowed to subside. 19 mL of 1% HNO_3 were then added and the vessels were capped and heated for 30 min in drying oven preset at 100 °C. A 1:10 dilution of each sample in 1% HNO_3 was then prepared and stored in polypropylene test tube for ICP-MS analysis. Arsenic was determined by hydride-generation atomic absorption spectrometry (Hagemen & Welsch 1996) and mercury was analyzed by cold-vapor atomic absorption spectrometry (O'Leary *et al.*, 1996). Rigorous quality assurance/quality control protocols (Crock *et al.* 1983) in place at the U.S. Geological Survey were followed, including insertion of "blind" standard reference materials for determination of the accuracy of the methods, and analytical duplicates to allow estimation of the precision of the method.

Statistical analysis

The four elements of interest (As, Cd, Hg, and Pb) were selected because of their implications for human health based on toxicological and epidemiological data. For each element, levels in Pueblo's industrial area were compared to levels from sites at varying distances away using pair-wise comparison (ANOVA, Minitab 2000). A Pearson correlation was used to determine the relationship between the various elements. Geochemical data were mapped via satellite-generated coordinates (GPS bearings) for ease of future reference. A database was constructed matching GPS data to soil data on heavy metals gathered at 66 sampling sites in and around Pueblo, Colorado. ArcGIS

9.0 was used to perform an exploratory spatial data analysis (ESDA, ESRI 2000) and to construct prediction maps of levels of the elements of interest.

The prediction maps were generated using "ordinary kriging." This process involves a set of statistical methods that sample the nearest neighbors of a data set and use the results to interpolate a surface area that represents a prediction of the values based on a theoretical data point that lies between a set of actually measured data points. A log transformation was used to help normalize the distribution and aid in the construction of the kriging model for each element. Scientists at the US Geological Survey recently used techniques somewhat similar to develop prediction color maps for 22 chemical elements from data collected during a nationwide surficial soil survey conducted from 1961–1975 (Gustavsson *et al.* 2001). Although ESDA has its limitations, it enables the researcher to easily determine variations and large-scale trends in the geographical distribution of the elements of interest. ArcGIS 9.0 (ESRI 2000) was used to analyze the population distributions in the study area, based on the 2000 US Census data (GeoLytics 2002). ArcGIS allows the simultaneous consideration of all major variables of interest, including the geochemical data, city zoning information and population distributions by ethnic group and by income.

Results

Surface soil concentration of As, Cd, Hg, and Pb

The levels of As, Cd and Pb in the surface soils of Pueblo, Colorado are, on average, higher than baseline values reported in the literature for soils of the conterminous United States (Shacklette & Boerngen 1984) and for the Front Range Urban Corridor of Colorado (Severson & Tourtelot 1994; Table 1). The concentrations of these elements are also higher than the "background" levels for Pueblo reported by Buckingham (1995; Table 1). However, caution should be used when comparing the levels of elements in the top 5 cm of surface of the current study to results reported elsewhere due to differences in sampling depth and other methods. For instance, Shacklette & Boerngen (1984) sampled 0–20 cm; Severson & Tourtelot (1994) sampled 0–15 cm. In addition, information about the same compounds around the conterminous United Stated found in the nationwide background baseline data was generated from samples collected more than 20 years ago (1961–1975) and relied on a relatively small sample size per surface area (1 sample per 600 km^2; 1248–1319 samples for each heavy metal). The studies reported herein for the Pueblo region, a relatively very small area in southern Colorado are based on 66 sampling sites; this corresponds to 1 sample per 6 km^2. Nevertheless, it is instructive to compare the current data to national data to provide context for the environmental conditions in Pueblo. Based on our observations, levels for the various trace elements are higher today in the southern region of Pueblo than the background levels recorded for these heavy metals in the same region during the USGS survey.

The prediction maps generated by the ordinary kriging technique provide hypothetical distributions for the heavy metals of interest. Goodness of fit statistics suggest that these maps are reasonably accurate for lead which is the most problematic from an environmental justice standpoint. The error plots also illustrate a good fit with our ESDA model for the other elements analyzed, as explained below for each element.

Cross Validation results for the Pb model indicate that the model actually overestimates variability in the data (Figure 2; Table 2). The over estimation is indicated by the larger Average Standard Error (ASE) when compared to the Root Mean Square (RMS) value. The Mean Error (ME) greater than 1 is probably due to the large variations in the lead data. The Mean Standardized (MS) is near zero indicating a good fit of the model to the data. The Root Mean Square Standardized (RMSS) value of 0.7128 indicates a relatively good fit to the data and also indicates that the model's predicted values tend to overestimate the actual data. The variability in the data may be due to some local effects that may not be readily apparent without further extensive sampling and research into past activities of other pollution sources. Relatively high Pb levels were recorded in surface soils around Pueblo during the survey, and the surface distribution of Pb in the survey area followed a well-defined pattern (Figure 3). These high-Pb zones (112–318 ppm) are concentrated primarily around the RMSM manufacturing plant

Table 1. Concentration of the heavy metal arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) in topsoil in Pueblo, Colorado.

	Background Average* US	Background Range* US	Background Range** Pueblo	Site 1A	Site 1B	Site 2A	Site 2B	Site 3A	Site 3B
GIS References									
Latitude				38.26657	38.26445	38.26477	38.26502	38.25666	38.25730
Longitude				−104.60198	−104.60419	−104.60745	−104.60749	−104.61031	−104.60914
Mineral (ppm)									
Arsenic	7.2	< 0.01–97	5.0–6.1	31.3	23.1	8.3	10.6	9.9	13.9
Cadmium	0.26	0.03–2	0.83–0.93	4.9	4.9	1.6	2.2	2.4	3.1
Mercury	0.09	< 0.01–4.6	0.11–0.12	0.15	0.06	0.06	0.11	0.09	0.09
Lead	19	< 10–700	13.9–32.5	312	61	77	213	154	316
	Site 4A	Site 4B	Site 5A	Site 5B	Site 6A	Site 6B	Site 7A	Site 7B	Site 8A
GIS References									
Latitude	38.22044	38.21947	38.23666	38.23651	38.24726	38.24712	38.25482	38.25640	38.27341
Longitude	−104.65929	−104.65804	−104.66720	−104.66707	−104.65682	−104.65653	−104.67101	−104.67097	−104.67835
Mineral (ppm)									
Arsenic	16.6	7.1	6.3	5	6.1	4.2	3.1	4.1	21.9
Cadmium	6.5	2.4	0.8	1.3	1.3	0.8	0.6	1.7	4.2
Mercury	2.45	1.26	< 0.02	0.02	0.09	0.02	< 0.02	0.42	0.07
Lead	310	132	26	40	73	34	43	69	99
	Site 8B	Site 9A	Site 9B	Site 10A	Site 10B	Site 11A	Site 11B	Site 12A	Site 12B
GIS References									
Latitude	38.27264	38.31074	38.31163	38.29113	38.29060	38.27688	38.27644	38.26016	38.25998
Longitude	−104.67899	−104.65479	−104.65503	−104.64841	−104.64883	−104.64048	−104.64309	−104.64073	−104.64037
Mineral (ppm)									
Arsenic	14.1	7.1	7	8	7.6	10.3	18.9	8.5	5.7
Cadmium	4.2	3.5	2.5	2.8	2.0	4.1	5.4	2.1	2.4
Mercury	0.06	0.02	0.02	< 0.02	< 0.02	0.09	0.04	0.04	0.06
Lead	100	48	36	22	28	53	30	76	134
	Site 13A	Site 13B	Site 14A	Site 14B	Site 15A	Site 15B	Site 16A	Site 16B	Site 17A
GIS References									
Latitude	38.24218	38.24135	38.22219	38.22363	38.32248	38.32415	38.30040	38.29957	38.27938
Longitude	−104.64028	−104.64050	−104.62880	−104.62762	−104.63097	−104.63001	−104.62282	−104.62270	−104.66797
Mineral (ppm)									
Arsenic	5.8	5.3	25.4	6.4	11.1	14.9	11.1	16.3	9.4
Cadmium	1.6	1.0	4.4	0.9	2.5	2.7	2.3	1.9	2.5
Mercury	0.13	0.03	0.08	0.02	0.04	0.04	0.28	0.06	0.16
Lead	85	55	84	27	28	61	57	35	221

	Site 17B	Site 18A	Site 18B	Site 19A	Site 19B	Site 20A	Site 20B	Site 21A	Site 21B
GIS References									
Latitude	38.28280	38.26600	38.26708	38.24660	38.24406	38.24548	38.24561	38.24745	38.24734
Longitude	−104.61564	−104.61555	−104.61726	−104.60420	−104.60349	−104.60319	−104.60195	−104.60137	−104.60204
Mineral (ppm)									
Arsenic	30	11	5.1	10.5	7.4	9.9	10	6.3	2.5
Cadmium	2.1	1.6	1.1	3.9	1.7	2.4	1.5	1.6	0.4
Mercury	0.29	0.04	0.02	0.17	0.05	0.09	0.06	0.05	0.07
Lead	129	112	68	287	177	228	149	168	74
	Site 22A	Site 22B	Site 23A	Site 23B	Site 24A	Site 24B	Site 25A	Site 25B	Site 26A
GIS References									
Latitude	38.32216	38.32245	38.30595	38.30538	38.28906	38.29098	38.28104	38.28088	38.27218
Longitude	−104.60071	−104.60067	−104.59628	−104.59668	−104.58827	−104.58784	−104.55858	−104.56073	−104.58005
Mineral (ppm)									
Arsenic	14.1	12.8	14.4	11.4	6.1	5.6	56.6	66.5	7.4
Cadmium	0.5	0.3	2.2	1.9	0.8	1.9	5.3	10.6	1.2
Mercury	0.03	0.03	0.02	< 0.02	0.03	< 0.02	0.08	0.09	0.08
Lead	26	25	35	33	59	22	47	70	145
	Site 26B	Site 27A	Site 27B	Site 28A	Site 28B	Site 29A	Site 29B	Site 30A	Site 30B
GIS References									
Latitude	38.27208	38.25740	38.25772	38.24079	38.23915	38.34459	38.34492	38.38965	38.38888
Longitude	−104.58043	−104.57893	−104.57918	−104.58304	−104.58517	−104.66710	−104.66648	−104.68368	−104.68443
Mineral (ppm)									
Arsenic	4.5	2.8	5.2	11.8	10.5	10.3	11.3	23.3	20.6
Cadmium	1.0	1.1	1.8	1.7	2.0	3.7	3.2	7.0	5.8
Mercury	0.05	0.25	0.21	0.03	0.04	0.03	0.02	0.02	0.02
Lead	81	50	83	51	86	38	23	31	29
	Site 31A	Site 31B	Site 32A	Site 32B	Site 33A	Site 33B		Playground at Site 11	Playground at Site 28
GIS References									
Latitude	38.37668	38.37599	38.23911	38.23898	38.30626	38.30614		38.27688	38.24079
Longitude	−104.64954	−104.64985	−104.56565	−104.56535	−104.58161	−104.58214		−104.64048	−104.58304
Mineral (ppm)									
Arsenic	13.2	14.7	13.8	11.5	24.2	22.6		2.1	1.8
Cadmium	1.6	2.1	5.0	3.0	1.5	2.3		0.2	0.2
Mercury	0.05	0.02	0.11	0.06	0.03	0.03		< 0.02	< 0.02
Lead	18	30	201	118	29	63		20	25

Sources: *Shackelette Boerngen 1984, Adriano 2001, Gustavsson *et al.* 2001; ** see Buckingham 1995.

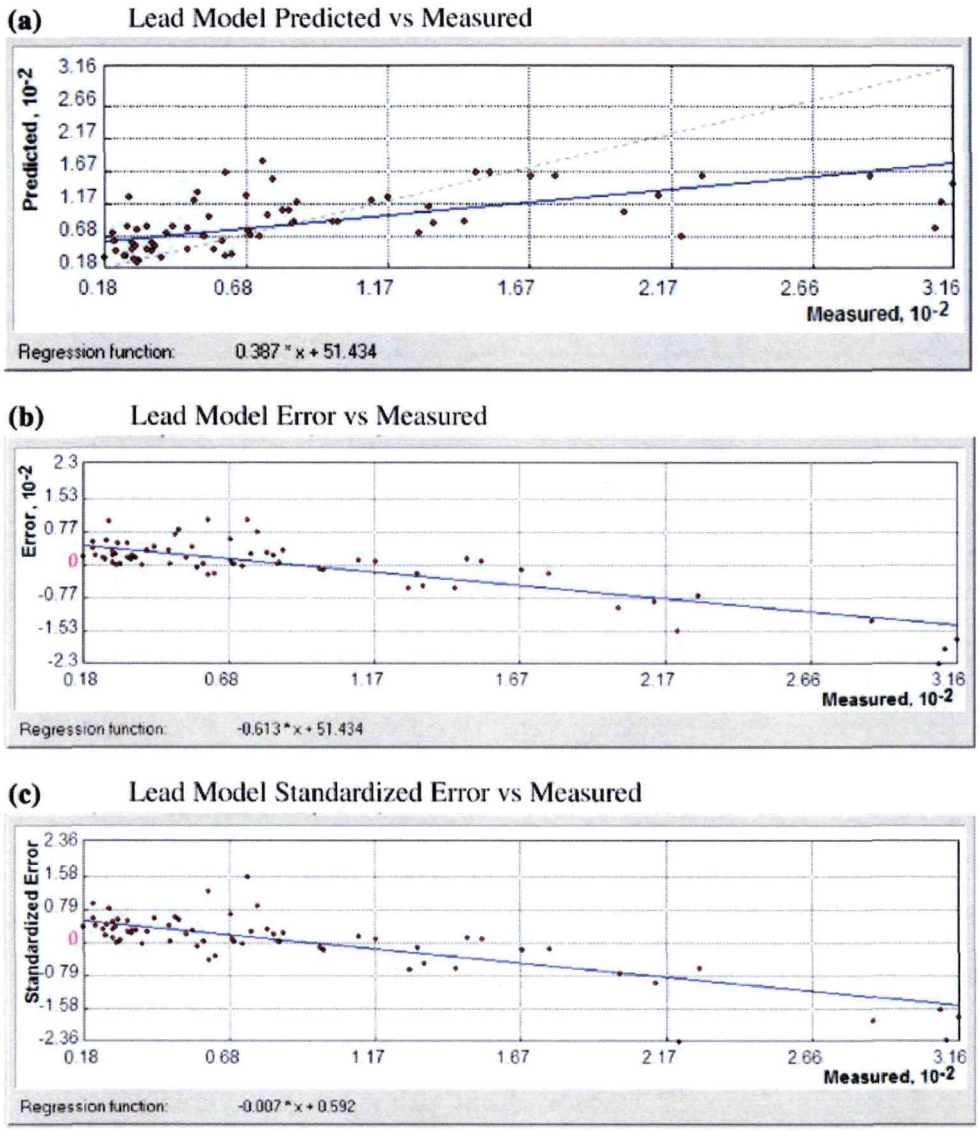

Fig. 2. Cross-validation prediction error graphs for the exploratory spatial analysis of lead (Pb) in topsoil of Pueblo, Colorado: (a) Pb model predicted versus measured, (b) Pb model error versus measured, (c) Pb model standardized error versus measured.

(just south of sites 20 A/B) and the old smelters (sites 3 A/B, 19 A/B, and 21 A/B). The average Pb content of surface soil in Pueblo is 87.7 ppm, over five times the average for the conterminous US of 16 ppm (Shacklette & Boerngen 1984). It is also over twice what Severson & Tourtelot (1994) report for average Pb concentrations (35 ppm) in soils of the Front Range Urban Corridor of Colorado.

Table 2. Cross-validation prediction model errors of the exploratory spatial analysis of heavy metals arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) in topsoil in Pueblo, Colorado.

Prediction model errors	As	Cd	Pb	Hg
Mean	−0.2727	−0.03155	−1.194	−0.006615
Root Mean Square	6.377	1.587	63.89	0.2452
Average Standard Error	6.097	1.711	92.28	0.304
Mean Standardized	−0.02516	−0.0151	−0.001335	−0.01809
Root Mean Square Standardized	0.982	0.9203	0.7128	0.787
Samples	66 of 66	66 of 66	66 of 66	66 of 66

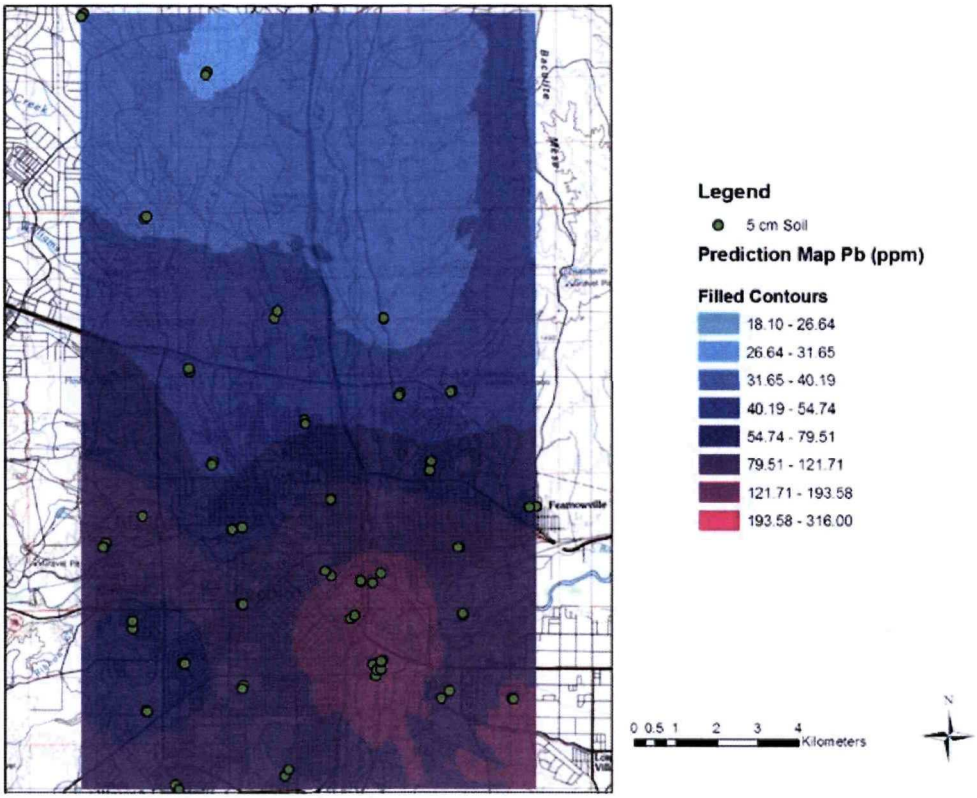

Fig. 3. Exploratory spatial prediction map of lead (Pb) distribution in topsoil of Pueblo, Colorado.

Based on the general northwest to southeast wind pattern in the region, this factor did not prove to have impacted the spatial distribution of Pb or any of the other elements of interest.

The Arsenic model fits the data very well. This is indicated by several factors: the RMS and AVS values are close indicating that the model accurately represents the variability of the data (Figure 4; Table 2). The MS value indicates a good fit and it is close to zero indicating a rather small error in estimation of our predicted values. The RMSS value of 0.982 is near the optimum value of 1 that also indicates a good fit of the arsenic predicted model with the data collected. In general, the distribution of As in surface soils around Pueblo, Colorado does not appear to be related to smelter location (Figure 5). Neither the RMSM smelting operations nor the presence of old smelters (sites 3 A/B, 20 A/B, 21 A/B) appear to have had a direct influence on soil As concentrations (Figures 1 and 5). However, elevated As levels (23.1–31.3 ppm) were recorded in the proximity of Goat Hill near an old smelter (sites 1 A/B). The highest concentrations of As were recorded at the two sites at the Dog Patch (Figure 1, sites 25 A/B), with concentrations as high as 56.6–66.5 ppm (Figure 5). Other hot spots include the location of Colorado State University-Pueblo (22.6–24.2 ppm, sites 33 A/B).

For Cadmium, the model fits the data well also as evidenced by close values for RMS and AVS (Figure 6; Table 2); these show that the model accurately represents the variability of the Cd data. The MS value is close to zero, indicating small error in estimation of our predicted values. The RMSS value of 0.9203 is near optimum 1 that also indicates a good fit of the Cd model to the data collected. The surface model of Cd shows isolated areas of elevated Cd concentration in Dog Patch (sites 25 A/B), Pueblo West (sites 29 A/B, 30 A/B), and Highland Park (sites 4 A/B), but Cd distribution follows no particular geographic pattern (Figure 7). Cadmium in surface soil in Pueblo varied between 0.3 ppm and 10.6 ppm, with an average value of 2.53 ppm.

The numerical scale of the mercury numbers as a whole is small; this is evident in the ME that is close to zero (Figure 8; Table 2). The RMS and

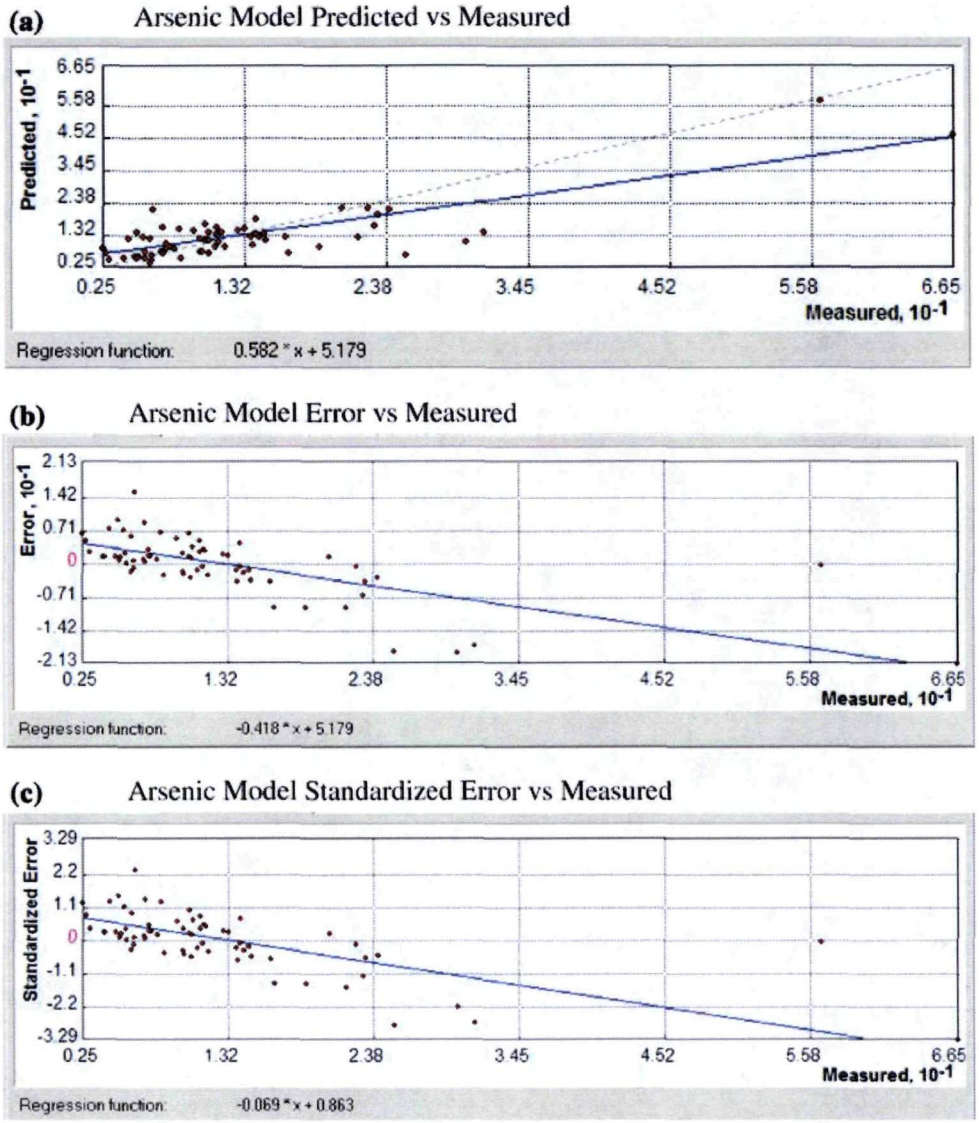

Fig. 4. Cross-validation prediction error graphs for the exploratory spatial analysis of arsenic (As) in topsoil of Pueblo, Colorado: (a) As model predicted versus measured, (b) As model error versus measured, (c) As model standardized error versus measured.

higher ASE suggest that the model overestimates the variability in the data. The MS value is also close to zero and the RMSS is relatively high. These factors support the fit of the model to the data. Further sampling would strengthen the model as the over estimation of variability is probably due to local effects in the data, as expressed in the prediction map (Figure 9). Hg level in Pueblo soils varied from <0.01 ppm to 2.45 ppm; with the mean concentration being 0.12 ppm (Table 1).

Of all of the models represented, the arsenic model exhibits the greatest degree of autocorrelation followed by the lead model. The cadmium model exhibits the least amount of auto correlation indicating that the source of cadmium in the Pueblo area is most likely due to a non-point source type of pollution while the arsenic and lead models indicate some degree of point source pollution involvement. The mercury model does not show a strong autocorrelation.

The Pearson correlations show a positive significant interdependence between As and Cd (0.732; $p = 0.000$), and between Hg and Pb (0.419; $p = 0.000$). No statistically significant correlations were found between the pairs As/Hg (0.021; $p = 0.868$), As/Pb (0.040; $p = 0.751$), Cd/Pb (0.211; $p = 0.089$) and Cd/Hg (0.231; $p = 0.061$).

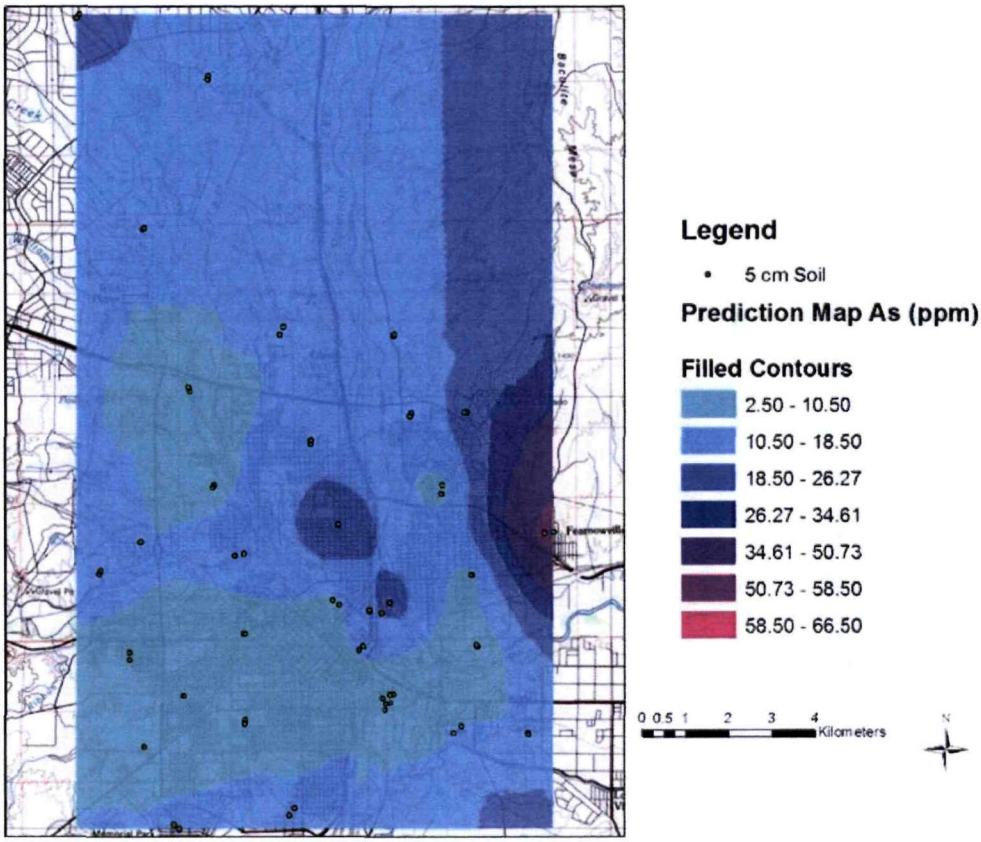

Fig. 5. Exploratory spatial prediction map of arsenic (As) distribution in topsoil of Pueblo, Colorado.

The reasons for these correlations (As/Cd; Hg/Pb) are unclear. As a natural constituent of bedrocks that are rich in several other minerals (Cu, Au, Pb and Zn), arsenic is very ubiquitous. Among the major sources for Cd contamination by atmospheric deposition are smelting, burning of plastic, burning of fossil fuel and steel mill plants. Use of phosphate fertilizers and municipal sludge also contribute to increasing soil Cd content. The past history and current industrial activities in the city explain, in part, why Cd levels are so high compared to topsoil in other residential areas in North America. As explained above, the surface distribution of As and that of Cd in topsoil around Pueblo, Colorado do not follow clearly defined spatial patterns, and their interdependence is difficult to explain. Pb is found only in small quantities in nature, (13–16 ppm, Adriano 2001). Yet, very high levels of Pb were recorded in topsoil around Pueblo during the survey, and the surface distribution of Pb in the study area followed a well-defined pattern (Figure 3), suggesting point source pollution. Hg or liquid silver usually occurs in elemental Hg vapor form in the atmosphere, and in the form of inorganic salts or organic complexes in soil/sediments, water, and living organisms (Adriano 2001). Normal soils have Hg concentration of less than 0.01 ppm. Since Hg spatial distribution follows no pattern similar to that of lead, the correlation between the two elements is rather coincidental. In general, the trend of independent occurrence patterns observed here, which is consistent with previous reports (Shacklette & Boerngen 1984, Gustavsson *et al.* 2001), explains in part the variation in scale of autocorrelation between metals based on their sources.

Implications for population health risk

Ethnicity group classifications were obtained from the 2000 US Census Bureau database, where the classification in a particular group is based on standard self-definition. Where Pb levels are highest (Figure 3), the populations with greatest

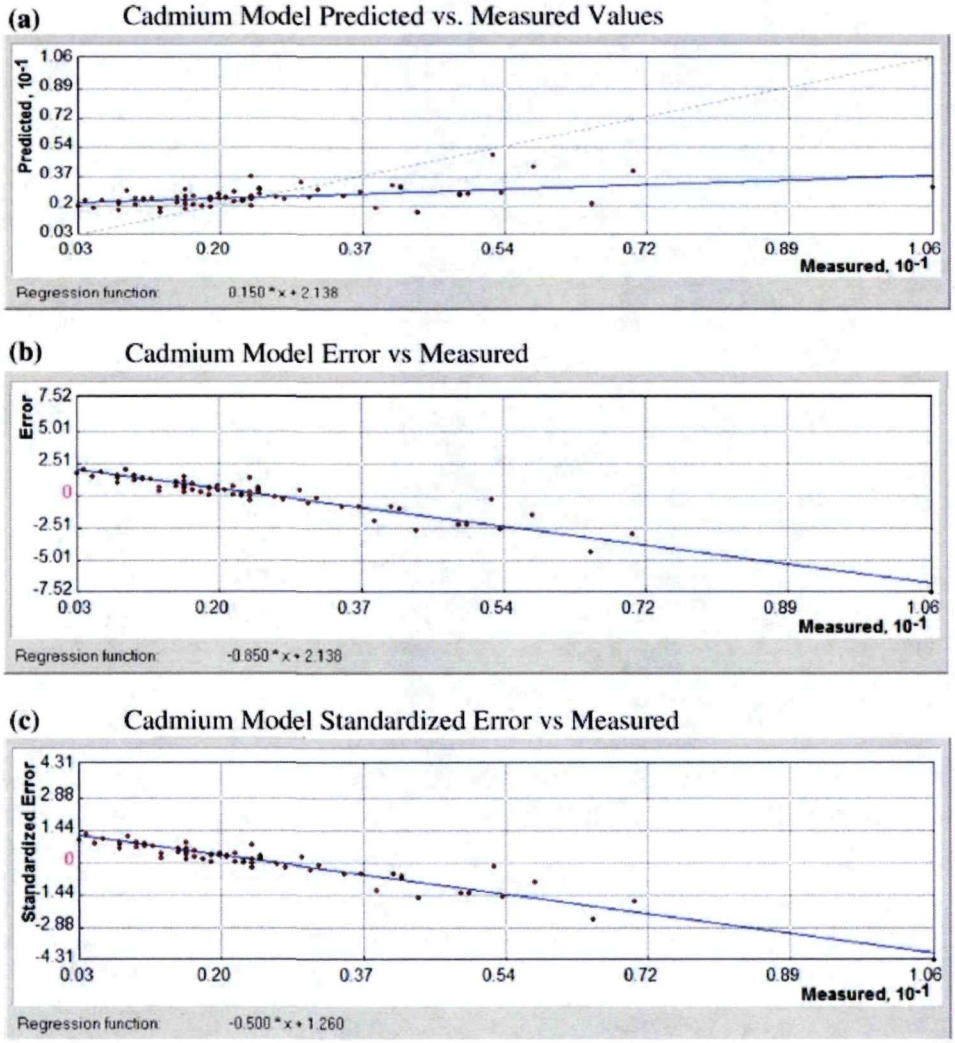

Fig. 6. Cross-validation prediction error graphs for the exploratory spatial analysis of cadmium (Cd) in topsoil of Pueblo, Colorado: (a) Cd model predicted versus measured, (b) Cd model error versus measured, (c) Cd model standardized error versus measured.

exposure are primarily Hispanics (Figure 10). This is further evidenced by graphing the range of Pb levels found in the survey zone versus the percentage of each ethnic group associated with Pb by Census block (Figure 11). The data set used to develop the graph was created by first merging the prediction map layer created by ordinary kriging with the population map indicating the census tract block data. The merged layer was then intersected with the measured data gathered in the field. The measured data formed the basis for the x-axis of the graph while the proportional composition of the census data formed the basis of the y-axis. For example, of the total population group of the Census block living around the lowest 18.1 ppm Pb range on the graph nearly 80% is non-Hispanic White, 10% Hispanic, and 1% African-American. This graph shows that the proportion of Hispanics increases significantly with higher topsoil concentration of Pb (% Hispanic = 12.0 + 0.0445 ppm Pb; $r = 0.27$; $p = 0.029$). To the contrary, as Pb levels increase in Census blocks, the proportion of non-Hispanic Whites tends to decrease (% Non-Hispanic White = 81.9–0.0345 ppm Pb; $r = -0.22$; $p = 0.077$). The trend for African-Americans (African-American = 1.48–0.00244 ppm Pb; $r = -0.07$; $p = 0.561$) is compromised by their relatively low percentage within the general population (Figure 12). According to the population

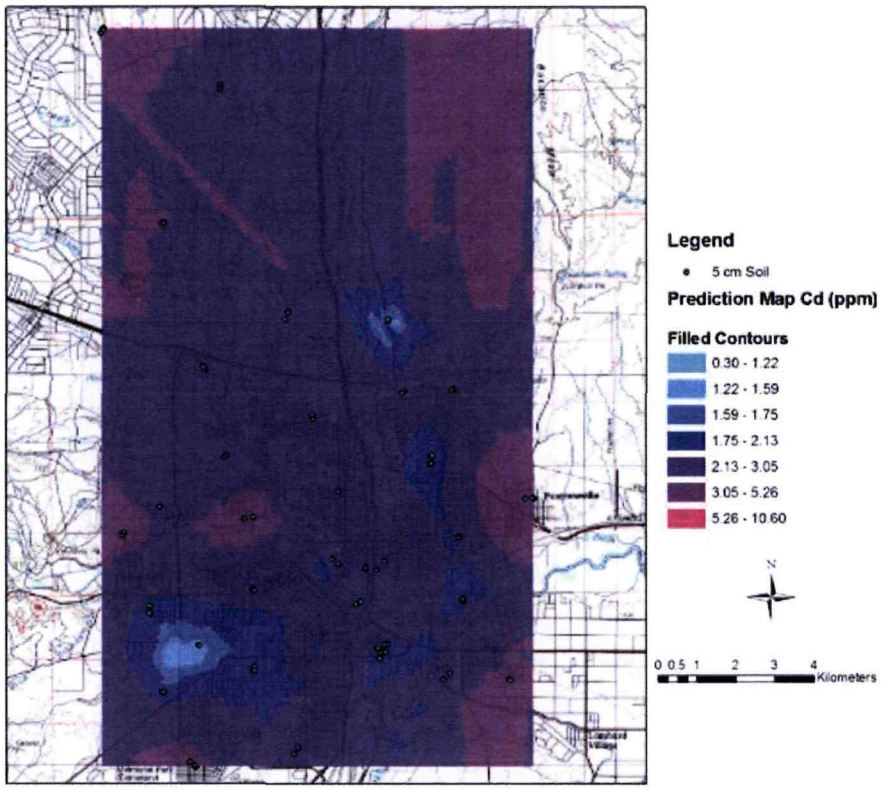

Fig. 7. Exploratory spatial prediction map of cadmium (Cd) distribution in topsoil of Pueblo, Colorado.

distribution maps for Hispanics (Figure 10) and non-Hispanic Whites (Figure 13) in the surveyed zone versus the spatial distribution of As (Figure 5), the low-income (Figure 14) Dog Patch neighborhood (sites 25 A/B) with high As levels may be of concern. However, aside from this case, no relationships were found between As and population distribution by ethnicity or household income. In terms of cadmium exposure, there are no apparent correlations between population distribution by ethnicity or income in Pueblo and Cd levels (Figures 7, 10, 12–14), although like As, high levels of Cd were observed in the low-income Dog Patch area (sites 25 A/B). The maps of population distribution show no relationship between the spatial distribution of Hg (Figure 9) and ethnicity or income level (Figures 10, 12–14).

Discussion

The level of arsenic in surface soils around Pueblo is on average 2.4 times higher than geometric mean baseline level in the conterminous US (12.6 ppm versus 5.2 ppm; Shacklette & Borengen 1984) and 3.6 times the baseline level for the Front Range Urban Corridor of Colorado (12.6 ppm versus 3.5 ppm; Severson & Tourtelot 1994). More importantly, this arsenic value is 60 times higher than the soil cleanup standard of 0.21 ppm for residential property as established in Colorado (CDPHE 1997). That being said, it should be pointed out that this cleanup standard was developed by back-calculation of a soil concentration equivalent to a 10^{-6} cumulative cancer risk. These types of calculations often lead to standards that are actually below the normal background levels for arsenic in soil. Nevertheless, because it is found in soil and groundwater, and because long-term exposure to As is known to cause cancer of the skin, lungs, urinary bladder, and kidney (Goyer 1996), careful monitoring of this element is important.

Though the range of Pb found in Pueblo (18 ppm to 316 ppm) falls below the soil cleanup standard of 400 ppm for residential areas (CDPHE 1997; EPA 2001), the levels of Pb found in parts of the city are high enough to raise concerns. Pb levels at many sites in Pueblo exceed

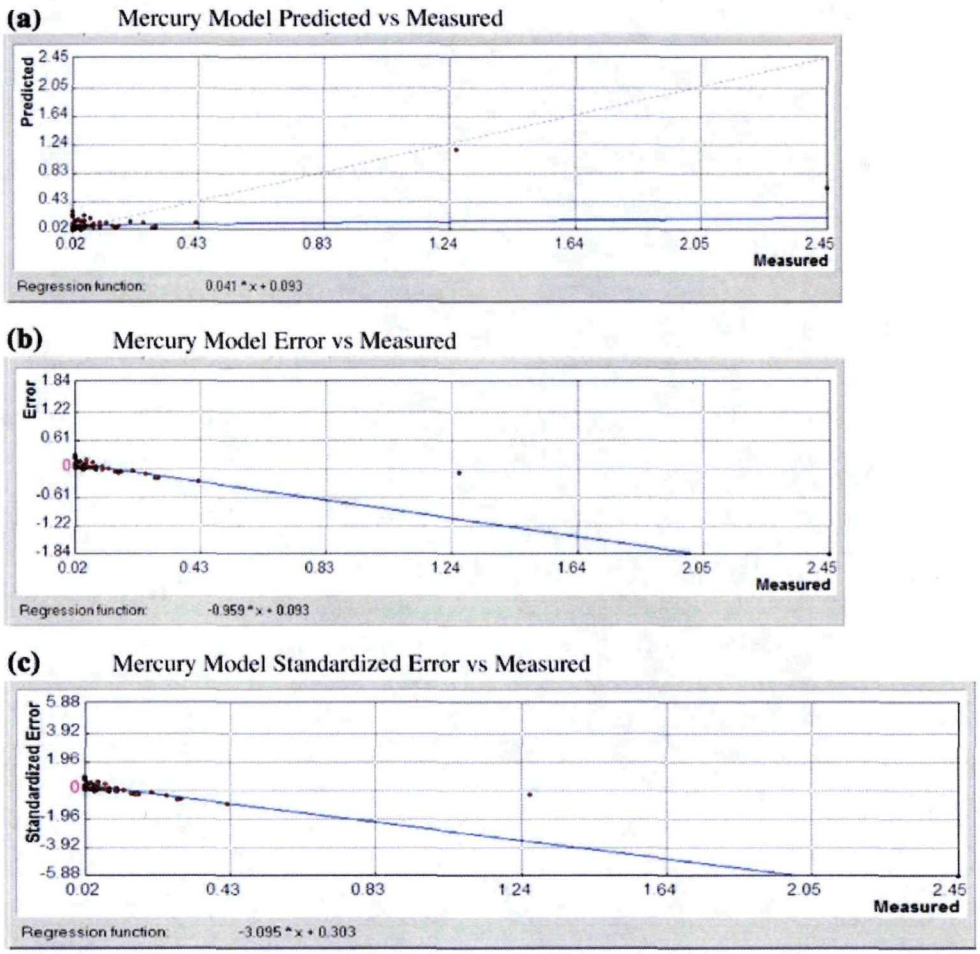

Fig. 8. Cross-validation prediction error graphs for the exploratory spatial analysis of mercury (Hg) in topsoil of Pueblo, Colorado: (a) Hg model predicted versus measured, (b) Hg model error versus measured, (c) Hg model standardized error versus measured.

the 140 ppm and 260 ppm Canadian limits for residential area and commercial zones, respectively (Adriano 2001). In addition, the average soil Pb content of 87.7 ppm in Pueblo is greater than the ecological soil screening levels established by EPA (2003a) of 16 ppm for avian wildlife and 59 ppm for mammalian wildlife. Given the relatively widespread elevation in Pb levels in parts of the survey zone, high Pb levels observed in Pueblo soils related to industrial activities (e.g., smelting operations) in the region may contribute to the exposure of, for example, small children. Pb poisoning, which is especially problematic during the key periods of child development (Goyer 1996), is of global interest and should be elevated as an important public health priority in Pueblo. Considering recent cases of Pb poisoning among residents in other contaminated areas as a result of emissions by Pb-processing plants (Fontana *et al.* 2004), the high levels of heavy metals in topsoil around Pueblo, Colorado justify preventive action by the public health community. Phytoremediation or the addition of turf or other ground cover around playgrounds, backyards, etc. may be warranted. Improved technology to reduce source emissions could also be contemplated.

The average level of Cd in Pueblo topsoil (2.53 ppm) exceeds the ecological soil screening level established by the EPA (2003b) of 1.0 ppm for avian wildlife and 0.38 ppm for mammalian wildlife. The natural topsoil content of Cd is usually less than 1 ppm (Adriano 2001). As explained earlier, past history and current

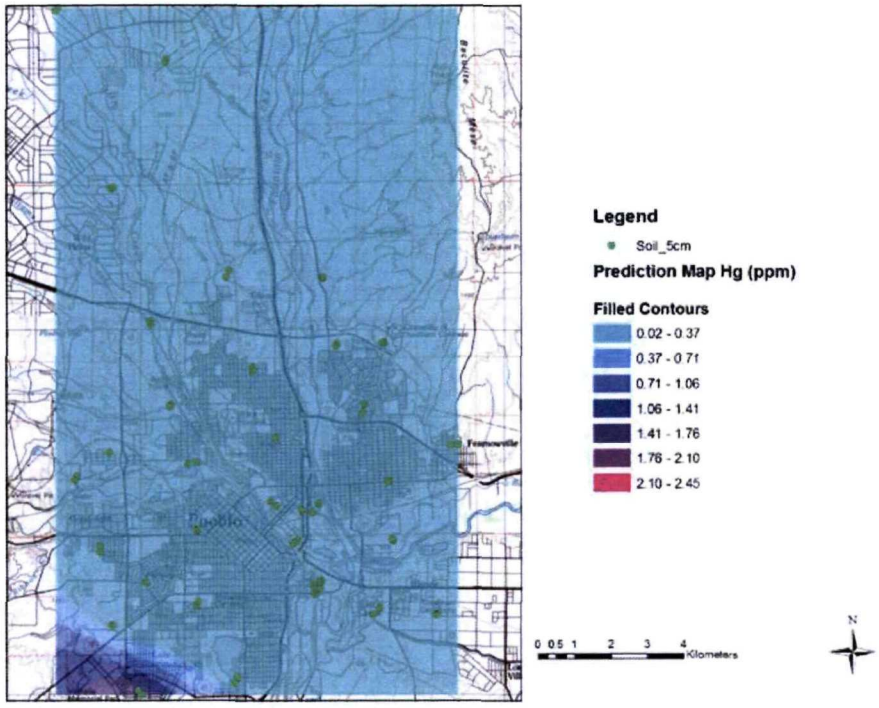

Fig. 9. Exploratory spatial prediction map of mercury (Hg) distribution in topsoil of Pueblo, Colorado.

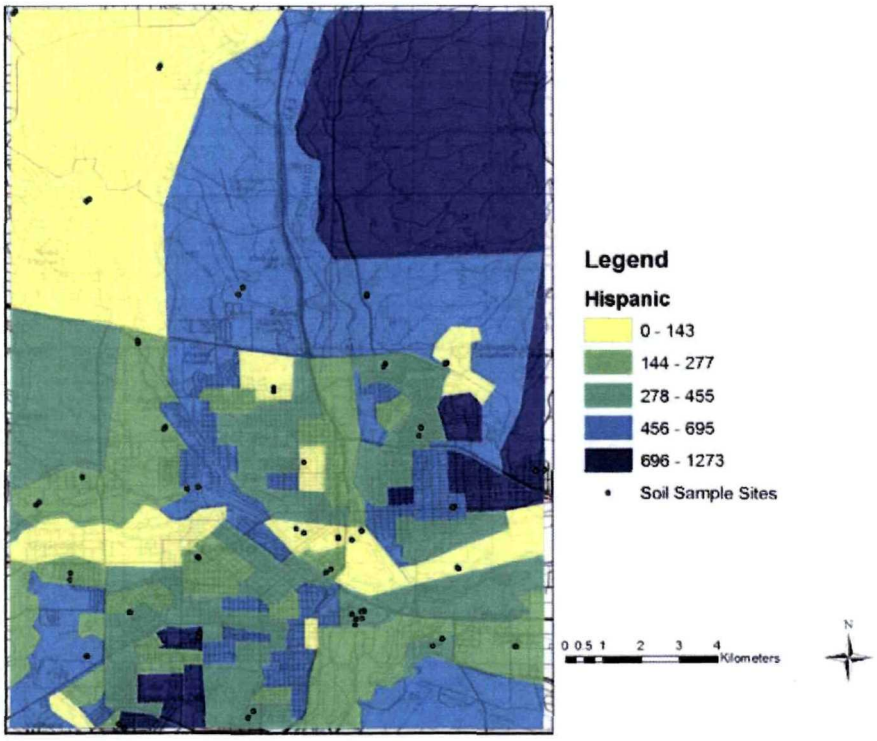

Fig. 10. Population distribution of Hispanics in Pueblo, Colorado. *Source*: GeoLytics Inc. 2002. United States Census CD 2000 Long Form SF3. East Brunswick, New Jersey.

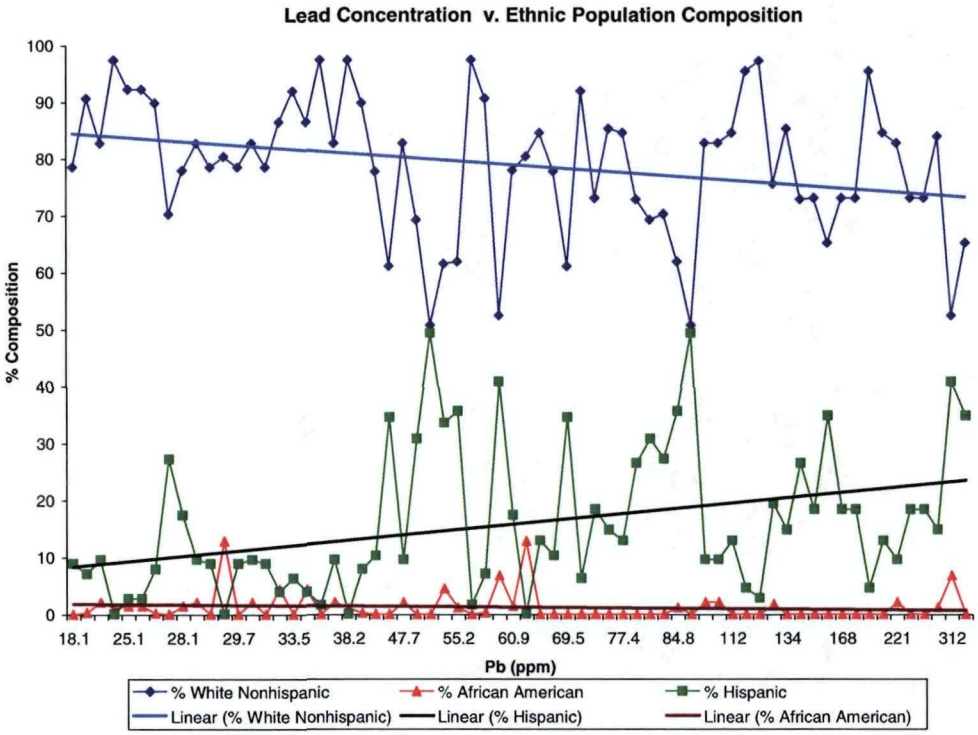

Fig. 11. Graph of average lead (Pb) concentration in topsoil of Peublo, Colorado versus ethnic group population distribution by census block.

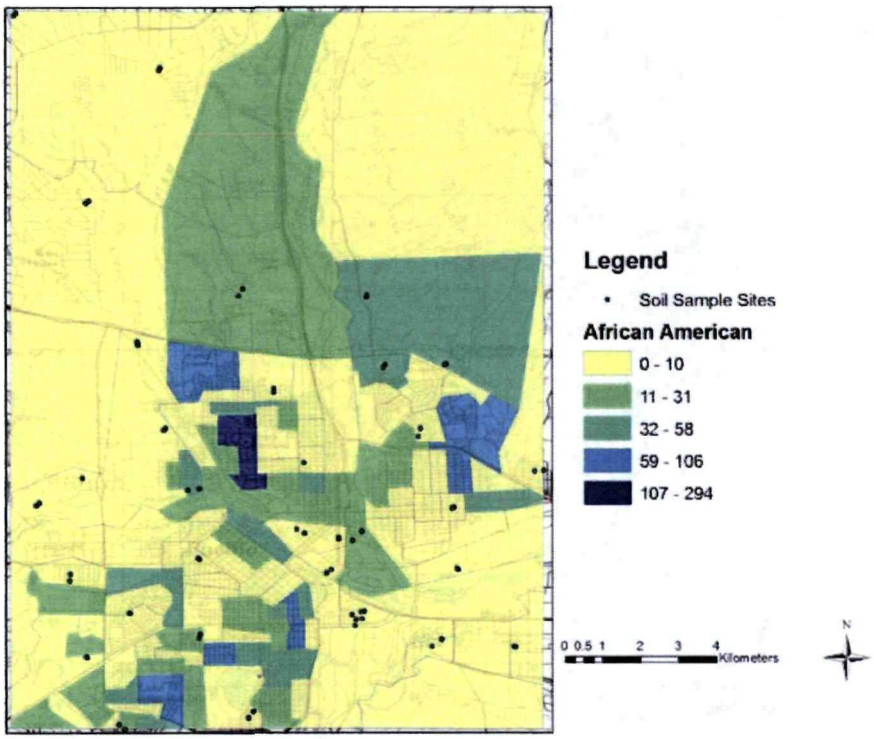

Fig. 12. Population distribution of African Americans in Pueblo, Colorado. *Source*: Geolytics, Inc. 2002. United States Census CD 2000 Long Form SF3. East Brunswick, New Jersey.

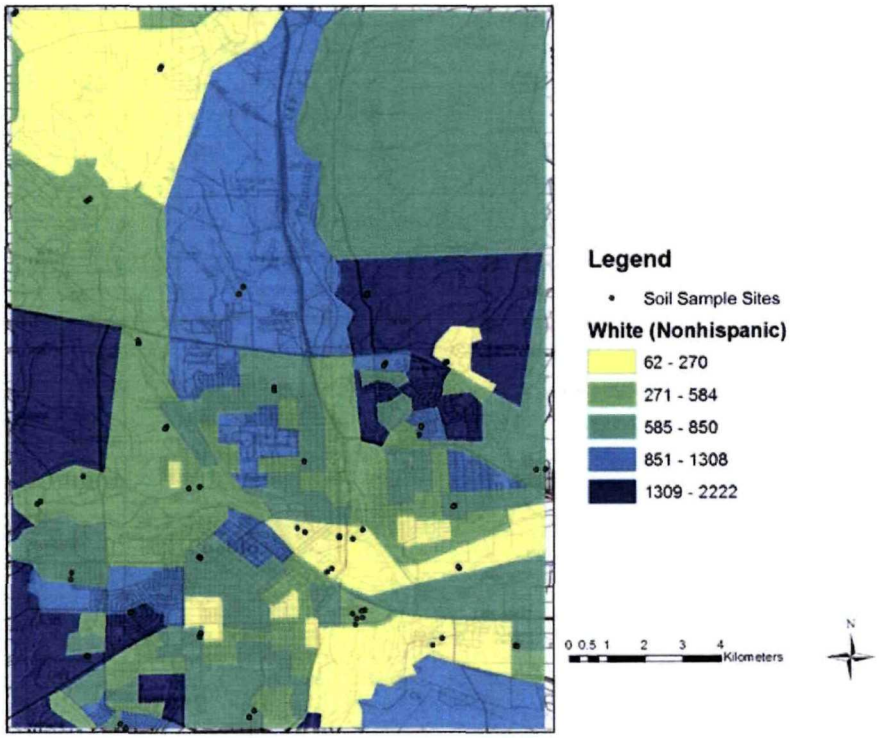

Fig. 13 Population distribution of non-Hispanic Whites in Pueblo, Colorado. Source: GeoLytics Inc. 2002. United States Census CD 2000 Long Form SF3. East Brunswick, New Jersey.

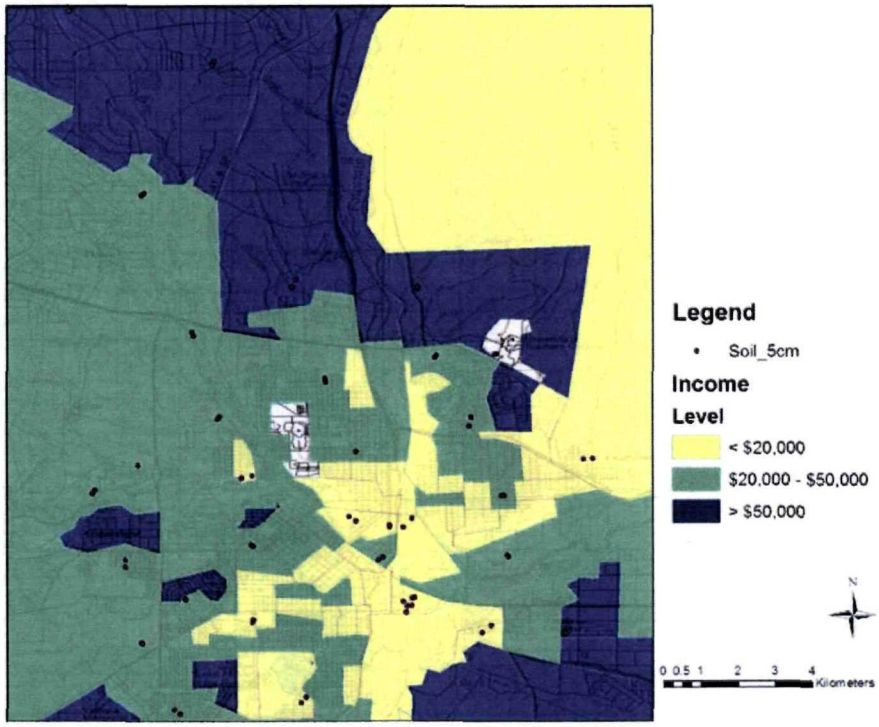

Fig. 14. Distribution of household income in Pueblo, Colorado. Source: GeoLytics Inc.2002. United States Census CD 2000 Long Form SF3. East Brunswick, New Jersey.

industrial activities in the city may explain in part why Cd levels are elevated in Pueblo. Cadmium is a known human carcinogen (Waalkes 2003) and has been reported to cause reproductive toxicity (Sarabia *et al.* 2003) and pulmonary diseases (Goyer 1996), and to disrupt renal function (Goyer 1996). In addition, Matsuda and others (2003) found that long-term exposure to Cd reduced the longevity of residents in a river basin in Japan. Since the compound's half-life in the body may reach as long as 30 years following exposure (Goyer 1996), the degree of contamination observed around Pueblo warrants efforts to minimize atmospheric releases and consequent accumulation in soil.

The Hg content of Pueblo topsoil was within the ranges reported by Shacklette & Boerngen for average levels within the conterminous US (1984; Table 1). Even the highest value of 2.45 ppm found in the El Camino area (Figure 1, site 4 A/B) is well below the soil cleanup standard of 17.66 ppm established for inorganic mercury in Colorado (CDPHE 1997).

In conclusion, the study shows the value of understanding the abundance and spatial distribution of potentially toxic elements in an urban setting and confirms previous reports (e.g., Buckingham 1995) that elevated levels of certain heavy metals remain a concern for communities in Pueblo, Colorado. The distribution patterns vary by element and may reflect both industrial and non-industrial sources. A higher-density geochemical soil survey is needed to identify smaller and possibly higher amplitude "hotpots" within the city. The levels of Pb and Cd observed around Pueblo justify concerns expressed by segments of the population and by community leaders about preventing further environmental degradation and determining population health consequences. Our Pb and Cd data suggest that a higher proportion of low-income communities live in close proximity to contaminated areas (around sites 3 A/B, 20 A/B, 21 A/B) and thus may be exposed to excess levels of these heavy metals. Given the variability of the elements found in this reconnaissance soil geochemical survey of Pueblo and the range of populations at potential risk, next steps will include dissemination of these findings to communities and public health officials and further assessment of the population's exposure to these substances using biomonitoring.

Acknowledgements

We thank Heather Miao at the Pueblo County Department of Public Health and Environment, Dr. Dave Lehmpuhl, Susakul P. Na Ayudthaya and Felicia Garcia at Colorado State University-Pueblo, Georgia Lozinsky at Makeminemagic, Inc., Maria Sanchez-Kennedy and Beverly Allen at the Bessemer Historical Society in Pueblo, and everyone in Dr. Jodi Flaws' lab at the University of Maryland Baltimore for their helpful technical assistance. This work was supported by the National Institutes of Health grant (1P20CA91489-01A1, the US Geological Survey Denver, the National Institutes of Health grant (R25 CA49981 and Colorado State University-Pueblo.

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AND ENVIRONMENT

HAZARDOUS MATERIALS AND WASTE MANAGEMENT DIVISION

PRELIMINARY ASSESSMENT

COLORADO SMELTER

PUEBLO, COLORADO

CERCLIS #: CON000802700

April 28, 2008