Preliminary Evaluation of Mining-Related Injuries in the Cherokee County Superfund Site, Cherokee County, KS

Prepared for:

Kansas Department of Health and Environment
U.S. Department of the Interior

Prepared by:

Stratus Consulting Inc.
PO Box 4059
Boulder, CO 80306-4059
(303) 381-8000

Contact:

P. David Allen II

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Acronyms and Abbreviations

ALAD	aminolevulinic acid dehydratase
ALC	aquatic life criteria
AWQC	ambient water quality criteria
CCC	criteria continuous concentration
Cd	cadmium
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMC	criteria maximum concentration
Cu	copper
CWA	Clean Water Act
DRG	digital raster graphics
FDA	Food and Drug Administration
FS	feasibility study
FWS	U.S. Fish and Wildlife Service
GIS	geographical information systems
GMAV	genus mean acute value
GMCV	genus mean chronic value
KDHE	Kansas Department of Health and Environment
MCL	maximum contaminant level
MCLG	maximum contaminant level goals
NEC	high no effect concentration
Ni	nickel
NPL	National Priorities List
NRDA	natural resource damage assessment
OU	operating unit
Pb	lead
PEC	probable effect concentration

RI	remedial investigation
RMS	root mean squared
RODs	Records of Decisions
SDWA	Safe Drinking Water Act
Se	selenium
SMCL	secondary maximum contaminant level
T&E	threatened and endangered
TDS	total dissolved solids
TEC	threshold effect concentration
TOC	total organic carbon
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
Zn	zinc

1. Introduction

1.1 Report Objectives

This report presents a preliminary evaluation of natural resource injuries in the Cherokee County Superfund Site of southeast Kansas resulting from releases of hazardous substances from Tri-State Mining District locations. This report was prepared to assist the U.S. Fish and Wildlife Service (FWS) and State of Kansas (collectively “trustees”) in planning for natural resource damage assessment (NRDA) activities. This report is based on information available in 1999 relevant to releases, pathways, and injuries within all three states of the Tri-State Mining District (Kansas, Missouri, and Oklahoma). Consequently, more recent information that may have become available is not included in this report.

This report details the results of our preliminary evaluation of available information related to natural resource injuries, and its main purpose is to evaluate the extent to which existing information can be used to satisfy the main elements of an NRDA (identification of sources and releases of hazardous substances, identification of environmental pathways of exposure, and determination and quantification of injuries to natural resources). It includes information documenting releases of hazardous substances from mining facilities, identification of environmental exposure pathways through which these hazardous substances have been transported from their sources and have come to be located in the environment, and information describing injuries to groundwater, surface water, sediments, soils, vegetation, wildlife habitat, and aquatic biota in Kansas that have resulted from exposure to the hazardous substances.

The objective of the preliminary evaluation of natural resource injuries and damages is to:

- Use existing data to evaluate the likelihood that the elements of a future NRDA can be satisfied
- Provide the trustees with initial estimates — based on a review of readily available information — of the potential scope of the natural resource damages
- Facilitate planning regarding NRDA activities and to help inform discussions regarding the future directions of the assessment

Finally, it is emphasized that this document is not designed to serve as a final evaluation of natural resources injuries. Rather, it presents preliminary conclusions based on a review of the information available in 1999, including remedial investigation (RI) reports and state agency documents. The conclusions that are expressed in this report therefore may change if and when new data are considered.

1.2 Description of Site, Chronology of Mining, and Regulatory Actions

The Kansas portion of the Tri-State Mining District is primarily in Cherokee County in southeastern Kansas. Figure 1.1 shows the entire Tri-State Mining District for context, which is an area of about 300 square miles stretching from the northwest edge of the Ozark Uplift in Missouri west and south to the eastern fringe of the Great Plains. Cherokee County in Kansas lies mainly on the Osage Plains, and is characterized by a flat terrain with shallow stream valleys and elevations of 800-900 feet above sea level.

The Spring River flows generally southwest through Missouri, entering Kansas and Cherokee County about 10 miles north of Galena. The Spring River continues to flow south through Cherokee County where its main tributaries are Shawnee Creek, Brush Creek, Willow Creek, Short Creek and Shoal Creek. It then crosses the Oklahoma State line just south of Baxter Springs and flows south through Oklahoma to join the Neosho River at Grand Lake. The mining area in Cherokee County is also drained by Tar Creek, which flows south to its confluence with the Neosho River.

The predominant land use in the Tri-State Mining District is arable agriculture (mainly wheat, sorghum, corn, soybeans, and hay). Agriculture accounts for approximately 60-70% of land use in Cherokee County. The remaining land uses are mining-related, urban, and unimpacted natural land.

Lead and zinc mining began in the mid-19th century (Dames & Moore, 1995). Mine production peaked in Missouri in about 1916, and then shifted to Kansas and Oklahoma. Diminishing production led to the closure of the mining industry in Missouri by 1957. Output from the Cherokee County mines peaked in the 1920s and 1930s and diminished thereafter, until it ceased entirely in the 1970s (Dames & Moore, 1995). The number of operating mines in the early 1900s was estimated to be in the hundreds (Stock and Teet, 1969; Stewart, 1990, 1991; Dames & Moore, 1993b).

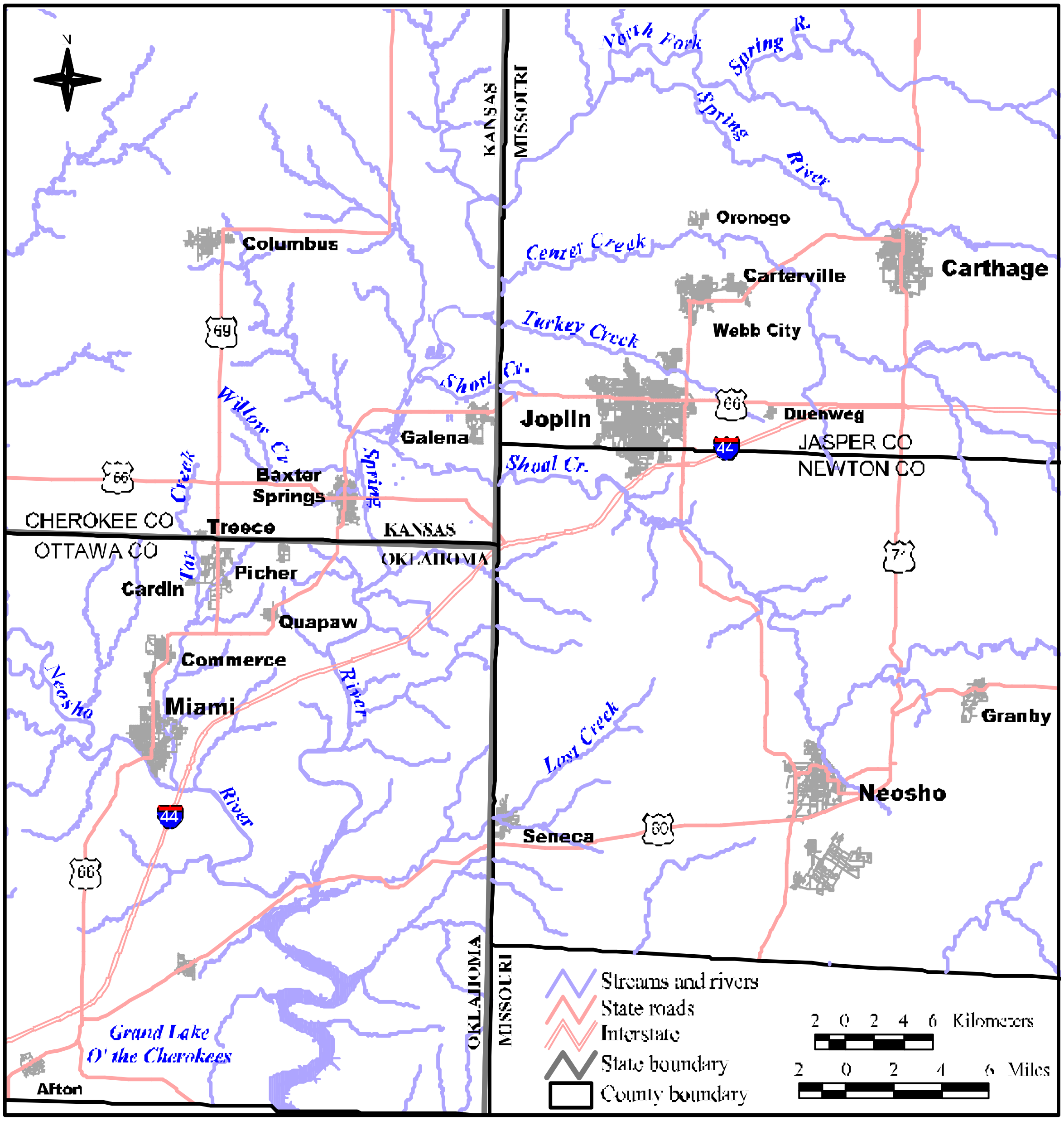

Figure 1.1. The Tri-State Mining District.

Mining operations in the Tri-State Mining District were principally underground and involved sinking shafts to subsurface ore bodies (Dames & Moore, 1995). At the surface, the raw ore was crushed in stages and the metals were separated by gravity separation or, later, flotation. Waste rock, development rock, chat, and tailings materials were dumped at the surface in waste piles. Many wastes were re-milled as more efficient separation techniques became available.

Ores were also smelted. Initially there may have been crude log smelters associated with each mine (Dames & Moore, 1995). However, these were later consolidated. A smelter was established at Galena in Cherokee County in about 1920, and it remained in operation until 1970.

After 150 years of mining and smelting, chat piles, tailings sites, development and waste rock piles, and subsidence ponds were prominent features of the landscape. Much of the total volume of surface mine wastes has been removed over the last few decades to provide materials for building and roads. Sears (1989) estimated that 94% of Kansas wastes have been removed. However, thousands of acres of wastes still remain on the ground surface. Much of this waste is highly contaminated with hazardous substances, including cadmium (Cd), lead (Pb), zinc (Zn), nickel (Ni), copper (Cu), and selenium (Se). Of these, cadmium, lead, and zinc are the main focus of this preliminary evaluation of injuries because of their relative volume, concentration, and toxicity.

Within the Tri-State Mining District are three Superfund sites, as determined under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In 1983, the Cherokee County Superfund site was added to the National Priorities List (NPL).

The Cherokee County Superfund site has been divided into seven mining areas, referred to as subsites: Baxter Springs, Treece, Galena, Badger, Lawton, Waco, and Crestline (see Figure 1.2). To date, three of these subsites, Baxter Springs, Treece, and Galena, have been through the remedial investigation and feasibility study (RI/FS) process. Investigations at Galena were initiated in 1984 by the U.S. Environmental Protection Agency (U.S. EPA), and the RI was completed in 1987. Following an Administrative Order of Consent between the U.S. EPA and the Baxter Springs/Treece Participating Group (including Amax, Inc.; Gold Fields American Corporation; ASARCO, Inc.; NL Industries, Inc.; Sun Company, Inc.; Eagle-Picher Industries, Inc.; and St. Joe Minerals Corporation) in 1990, an RI was initiated for the Baxter Springs and Treece subsites. The combined results were completed in 1993 (Dames & Moore, 1993b).

Seven operating units (OUs) were identified within the Cherokee County Superfund site, and Records of Decisions (RODs) were issued for Galena (groundwater/surface water, alternative water supply, and residential soils) and for Baxter Springs and Treece combined (U.S. EPA, 1989; Sverdrup Environmental, 1996; U.S. EPA, 1997). For the Galena subsite, requirements pertaining to groundwater and surface water (OU #1, #5) included providing an alternative water

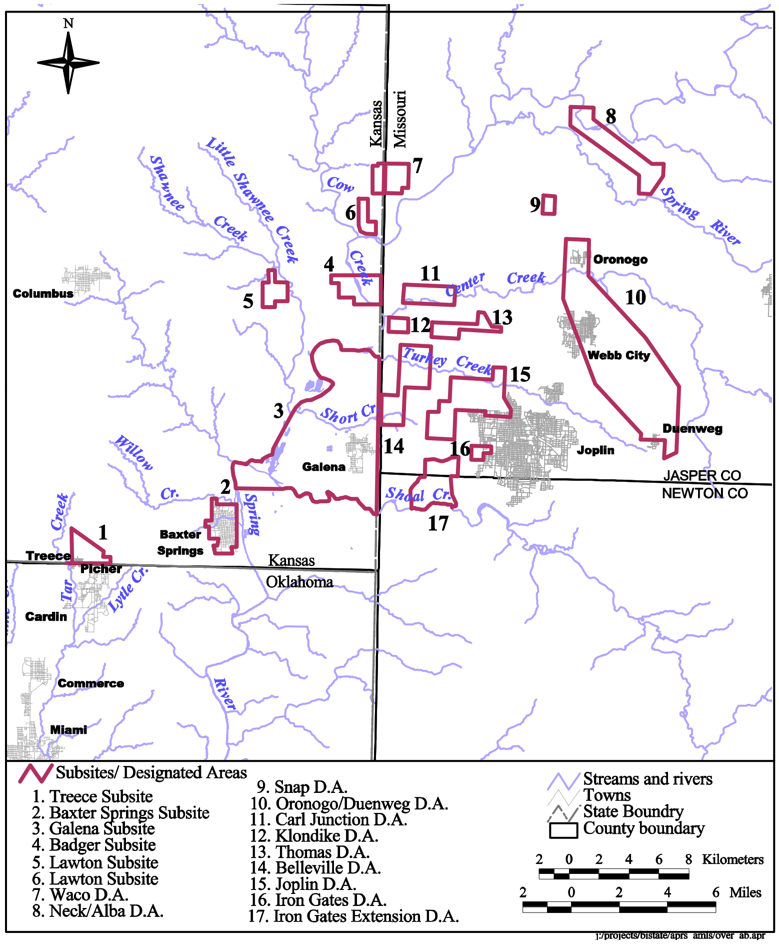

Figure 1.2. Subsites and designated areas in the Tri-State Mining District.

supply for households relying on the shallow aquifer for domestic water, removing and relocating surficial mine and mill wastes, diverting and rechanneling streams, recontouring and revegetating former waste areas, and remediation of contaminated deep aquifer wells (Sverdrup Environmental, 1996). The ROD for residential yards (OU #7) mandated the excavation and disposal of contaminated residential soils, in addition to health education, institutional controls, maintenance of remedies, and additional treatability studies (U.S. EPA, 1996b). Issued in 1997, the ROD for the Baxter Springs and Treece subsites contained similar remedies to those issued for the Galena subsite (U.S. EPA, 1997). The Crestline subsite was also delineated in Cherokee County. However, since we have received no data, this site is not considered further in this preliminary evaluation.

1.3 Report Focus

Throughout this report we evaluate injuries and damages for those areas for which data were readily available. In general, these are areas where RI or other investigations had been completed at the time that we completed our review and analysis. There are additional areas that may be injured but for which data were not available (for example, where the RI process had not been completed for the Crestline subsite). We have not evaluated injuries or damages for such areas. However, subsequent inclusion of these areas could influence estimates of injuries and damages.

We also have focused on the most obvious and readily addressed injuries. For example, we present an analysis of injury to terrestrial resources at largely devegetated chat piles. However, it is known that areas of chat exist that may be vegetated but that still may be injured. Also, in many areas, chat has been removed from its original location, leaving soils that may be contaminated with hazardous substances and that could cause injury to biological resources. The large commitment of resources necessary to identify and quantify less obvious injuries is beyond the scope of a preliminary evaluation. Nevertheless, such injuries may well exist and their inclusion in subsequent stages of the NRDA could increase estimates of both injury and damages.

Subsequent to producing the first draft of this evaluation, the trustees identified additional data that could have been included in a preliminary evaluation. These data sets indicate that injuries to surface water, mollusks, and other invertebrates in the Kansas reaches of the Spring River could be more severe and widespread than had been indicated absent these data. It should be noted that, because these (and possible other) data were not available to us during the writing of this report, our preliminary evaluation may underestimate the degree and extent of natural resource injuries. Where practicable, we identify possible instances of such underestimation in the text of this report.

1.4 Structure of Report

In Chapter 2 of this report we identify sources of hazardous substances (particularly cadmium, lead, and zinc) and evaluate information on their release into the environment. Chapter 3 describes the environmental pathways through which hazardous substances have been and are being transported from their sources to exposed natural resources. Chapter 4 describes injuries to the natural resources, and Chapter 5 presents a summary of results and conclusions. Chapter 6 contains references cited in this report. Where the data allow, we have described natural resource injuries by designated area or operable unit.

2. Sources and Releases of Hazardous Substances

This chapter identifies sources of hazardous substances in the Tri-State Mining District, and discusses releases of hazardous substances from these sources to Cherokee County in Kansas. We focus primarily on cadmium, lead, and zinc in this evaluation because these are the hazardous substances for which the most comprehensive data sets exist and which (because of the concentrations reported) are most likely to have resulted in injuries to exposed natural resources (based on volume, concentration, and toxicity). However, where data exist for other hazardous substances (e.g., selenium and copper), they are also reported.

2.1 The Mining Process and Sources of Hazardous Substances

Sources of hazardous substances in the Tri-State Mining District include subsurface sources associated with underground mine workings, and surface sources associated with emplacement and disposal of mine wastes. Underground mine workings have exposed mineralized areas to the environment, leading to the contamination of groundwater as it has come into contact with ore and subsurface wastes. Contaminated groundwater, in turn, serves as a surficial source as seeps. Other surficial sources include mixed waste piles, waste rock, tailings, and chat (see Section 2.2 for definitions).

This chapter discusses releases of hazardous substances into the Tri-State environment for these various source types. We first address surficial sources (waste rock, tailings, chat) (Section 2.2) and then subsurface and aquatic sources (Section 2.3).

2.2 Waste Rock, Tailings, Chat, and Soils

Waste rock, chat, tailings, and contaminated soils in the Tri-State Mining District are all sources of hazardous substances. Definitions of these waste types are given below. These definitions are derived from RI documents (Dames & Moore, 1993b, 1995) for the Cherokee County NPL site.

- **Waste rock** is defined as cobble- to boulder-sized rocks that have been excavated but not milled. This includes “country” rock overlying an ore body, rock removed in the creation of air shafts, and mined rock containing very little usable ore. Overburden, country rock, and “bull” rock are all types of waste rock.

- **Chat** is defined as a mixture of gravel- to fine-sized mill waste, often mixed with sand-sized particles. Chat is the discarded waste after the initial milling (jigging, tabling, and shaking) of the mined rock. Chat piles are a dominant geographic feature in the Tri-State Mining District (Figures 2.1 and 2.2). Much of the gravel-sized chat has been removed, washed, and sold as fill for roadbeds, etc.

- **Vegetated chat** is defined as chat or excavated chat covering at least 2,500 square feet and with at least 50% cover of vegetation. Most of the vegetated chat appears to be chat piles that have been partially excavated, with the remaining mixed chat and soil supporting some vegetation.

- **Tailings** are defined as fine-grained mine waste, the leftover rock after the final milling of the ore and the flotation of the metals from crushed rock. Some tailings-sized wastes were also created as a by-product of washing chat. Tailings are 35-60% silt size fraction, and the remainder is generally sand-sized particles. Tailings were usually sluiced into a dammed pond in a water slurry; thus many tailings piles contain ponded water.

Figure 2.1 shows illustrates the geographically widespread extent of mine wastes throughout the Tri-State Mining District.

Evaluation of whether these waste types act as sources of hazardous substances is performed in this report by comparing concentrations of metals in the wastes with background soil concentrations (Table 2.1). These background concentrations from areas of Kansas and Missouri unaffected by mining activities are based on a review of the literature. In addition, we present U.S. average concentrations in soils for comparative purposes (Table 2.1). Waste piles or soils in the Tri-State Mining District that contain hazardous substances at concentrations substantially exceeding the background concentrations reported in Table 2.1 were considered to be sources of hazardous substances.

Based on the data in Table 2.1, approximate representative background concentrations of the above hazardous substances are 0.5 mg/kg Cd, 15 mg/kg Cu, 20 mg/kg Pb, 0.5 mg/kg Se, and 50 mg/kg Zn. The mine waste and contaminated soils described in the following sections contain concentrations of some or all of these hazardous substances that are up to several orders of magnitude greater than the background concentrations.

2.2.1 Cherokee County, Kansas

Much of the mine waste data for Cherokee County comes from RI/FS (Dames & Moore, 1993b) and Ecological Risk Assessment (Dames & Moore, 1993a) work in the Baxter Springs/Treece subsites of the Cherokee County NPL site. In addition, the U.S. EPA (1988b), CH2M Hill (1989), and Veith et al. (1994) published some data from the Galena subsite.

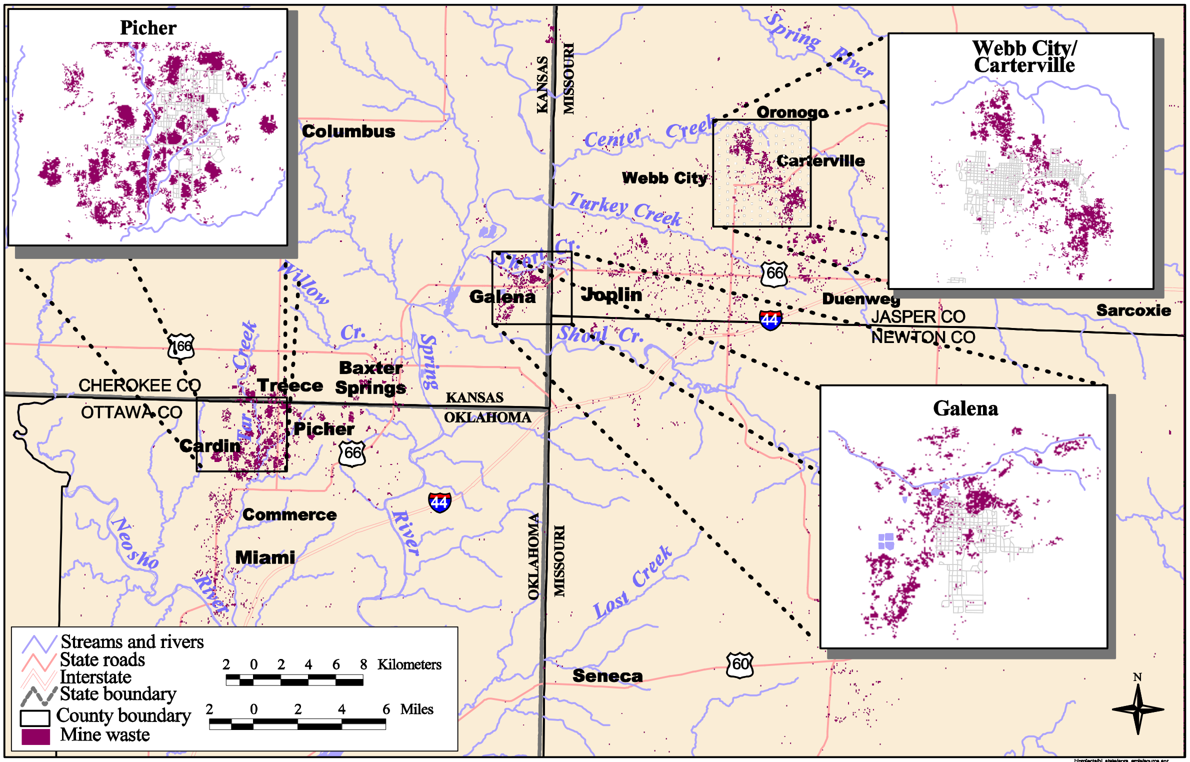

Figure 2.1. Distribution of mine waste piles in the Tri-State Mining District, showing three of the principal mining areas in greater detail. The distributions of waste piles were obtained from satellite imagery (see Section 4.4.3).

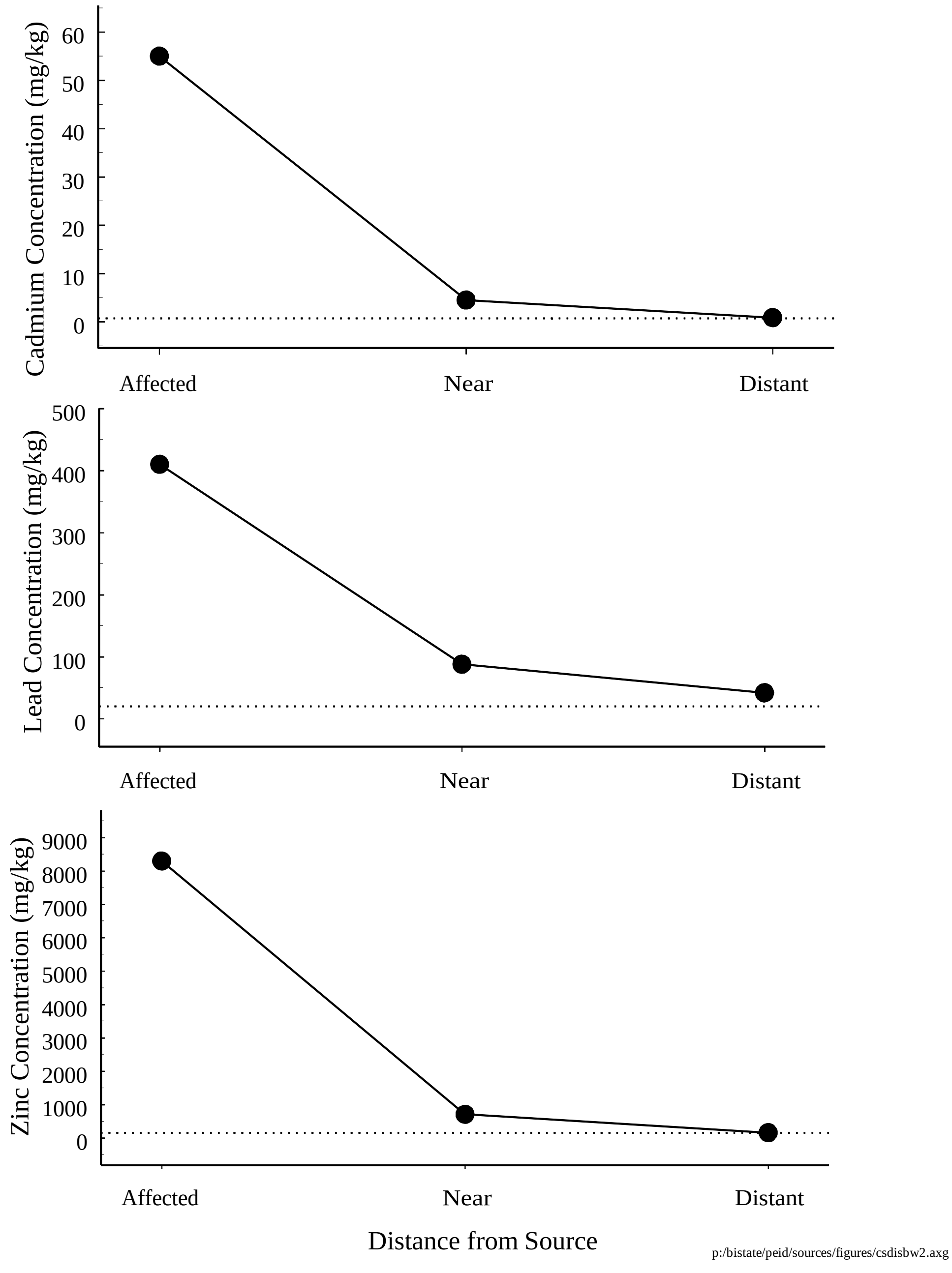

Figure 2.2. Concentrations of hazardous substances in soil in Cherokee County with increasing distance from the source (Dames & Moore, 1993b). Affected soils are soils containing visible mine waste fragments, near soils are within 300 feet of mine wastes, and distant soils are >300 feet away from a mine waste pile. The dotted lines represent background concentrations.

Table 2.1. Background concentrations of hazardous substances (mg/kg)

Metal	Kansas[a]	Missouri[b]	U.S.[c] average values
Cadmium	0.4	<1.0	0.53
Copper	11	13	20-30
Lead	17	20	32
Selenium	0.5	0.28	0.5-1.5
Zinc	44	49	64

a. Dames & Moore, 1993b.
b. Tidball, 1983.
c. Based on Alloway, 1990, and Kabata-Pendias and Pendias, 1992.

Waste Rock, Tailings, and Chat

The classifications of mine waste in the Cherokee County NPL site sometimes include only general terminology, such as "surface mine waste," which may cover all types of mine waste. In other cases, bulk chat and surface chat are distinguished, where bulk chat is a composite sample taken from a core that may extend deep into the chat pile and surface chat refers to the upper 12 inches of chat at the surface of the pile. The classification of bulk and surface tailings is the same as for chat.

Table 2.2 shows that average and maximum concentrations of Cd, Pb, and Zn in Cherokee County mine wastes greatly exceed background soil concentrations. In the Galena subsite, U.S. EPA (1988b) reported Cd concentrations as high as 60 mg/kg, Pb as high as 3,880 mg/kg, and Zn as high as 9,320 mg/kg in unspecified surface mine waste. These concentrations are 120-195 times greater than background concentrations.

Average concentrations of Cd, Pb, and Zn in chat piles from the Galena, Baxter Springs, and Treece subsites all exceed background concentrations by at least an order of magnitude (Table 2.2). Average Cd concentrations were similar in several studies, ranging from 26 to 46 mg/kg. The maximum Cd concentrations from chat pile studies ranged from 38 to 89 mg/kg, over two orders of magnitude greater than background concentrations.

Pb concentrations in chat piles were more variable than Cd, but still highly elevated above background (Table 2.2). CH2M Hill (1989) reported a maximum Pb concentration from their three Galena chat samples of 95 mg/kg, more than an order of magnitude lower than all the other reported maximum Pb concentrations, but still nearly five times greater than background. Also at

Table 2.2. Mean concentrations of hazardous substances in Cherokee County mine waste

Material[a]	Metal (mg/kg)			Source
	Cd	Pb	Zn	
Background concentration	0.5	20	50	See Table 2.1
Surface mine waste (n = 8)	35 (60)	1,820 (3,880)	5,710 (9,320)	U.S. EPA, 1988b
Chat: Galena	26 (38)	63 (95)	6,033 (8,500)	CH2M Hill, 1989
Surface chat: Galena	28	603	13,688	Veith et al., 1994
Bulk chat[a]: Baxter Springs/Treece	46 (89)	750 (1,660)	8,300 (13,000)	Dames & Moore, 1993b
Surface chat[a]: Baxter Springs		450 (610)	6,400 (6,800)	
Surface chat: Treece		700 (1,500)	10,000 (13,000)	
Bulk tailings: Baxter Springs/Treece	124 (540)	3,800 (13,000)	21,600 (64,000)	
Surface tailings: Baxter Springs		1,700 (3,200)	17,000 (39,000)	
Surface tailings: Treece		2,700 (5,900)	19,000 (64,000)	

Numbers in parentheses are maximum concentrations.

a. “Bulk” refers to vertically composited samples; “surface” refers to samples from upper 12 in. of material.

Galena, Veith (1994) reported average Pb concentrations in chat of 603 mg/kg. In the Baxter Springs/Treece subsites, average Pb concentrations ranged from 450 to 750 mg/kg, with a maximum Pb concentration of 1,660 mg/kg (Dames & Moore, 1993b). This maximum Pb concentration is over 80 times greater than background Pb concentrations.

Zn concentrations in the Cherokee County chat are uniformly over two orders of magnitude greater than background soil concentrations. Average Zn concentrations in chat ranged from over 6,000 mg/kg to more than 10,000 mg/kg (Table 2.2), and maximum concentrations were 13,000 mg/kg (CH2M Hill, 1989; Dames & Moore, 1993b). Veith et al. (1994) reported average Zn concentrations near 13,700 mg/kg, nearly 275 times higher than background.

Concentrations of Cd, Pb, and Zn in Cherokee County tailings were higher than the concentrations in chat. All of the tailings data are from the Dames & Moore (1993b) RI report for Baxter Springs and Treece subsites. They reported Cd concentrations averaging 124 mg/kg, with a maximum concentration of 540 mg/kg, two orders of magnitude greater than background soil concentrations. Pb concentrations on average were 1,700 to 3,800 mg/kg. The maximum Pb concentration of 13,000 mg/kg exceeded background by 650 times. Average Zn concentrations ranged from 17,000 to 21,600 mg/kg. The maximum Zn concentrations were 64,000 mg/kg, over three orders of magnitude greater than background soil Zn concentrations (Table 2.2).

Contaminated Soils

In Cherokee County data sources, "mine-site soils" include all soils within a mine site from disturbed or affected areas that contained visible mine waste. "Near-pile soils" are located within 300 feet of a mine waste pile in nonagricultural areas and that contained no visible mine waste fragments.

It is known that areas of chat or tailings have been removed in Cherokee County. This likely resulted in areas where the soils suffer residual contamination due to their contact with the hazardous substances in the mine wastes. It is also likely that this residual contamination persists to the present. Addressing these areas of residual contamination is beyond the scope of this report; however, their future inclusion could result in extending the spatial extent of injury.

Concentrations of Cd, Pb, and Zn in both soil types indicate that they are a source of hazardous substances in Cherokee County. The mine-site soils from Baxter Springs/Treece contained an average of 55 mg/kg Cd, 410 mg/kg Pb, and 8,300 mg/kg Zn. The maximum concentrations were 87 mg/kg, 570 mg/kg, and 14,000 mg/kg for Cd, Pb, and Zn, respectively (Table 2.3). These concentrations are at least two orders of magnitude greater than background concentrations. The average cadmium concentration in the 12 near-pile soil samples was 4.5 mg/kg, with a maximum of 21 mg/kg (Table 2.3), some 40 times greater than background Cd concentrations. Average Pb was 88 mg/kg, with a maximum of 300 mg/kg, and average Zn was 710 mg/kg, with a maximum of 2,900 mg/kg. The maximum Pb concentration is over 35 times greater than background, and the maximum Zn concentration is 58 times greater than background.

These data indicate that hazardous substances from mine waste have migrated from the waste piles to the nearby soils, contaminating the soils to such an extent that the soils, in turn, have become sources of hazardous substances.

Table 2.3. Mean concentrations of hazardous substances in Cherokee County, Kansas, soils

	Metal (mg/kg)			
Type of waste[a]	**Cd**	**Pb**	**Zn**	**Source**
Background concentration	0.5	20	50	See Table 2.1
Mine-site soils (n = 4)	55 (87)	410 (570)	8,300 (14,000)	Dames & Moore, 1993a,b
Near-pile soils (n = 12)	4.5 (21)	88.1 (300)	710 (2,900)	Dames & Moore, 1993a

Numbers in parentheses are maximum concentrations.

a. Near-pile soils refer to soils within 300 ft of mine waste; mine-site soils refer to soils directly atop a mine site, often including a visible mix of chat or tailings.

Dames & Moore (1993a,b) compared the concentrations of hazardous substances in near-pile soils to concentrations in B-horizon soils, which can be used to represent background. Concentrations of Cd, Pb, and Zn were significantly higher (one tailed t-test, $P = 0.05$) in the near-pile soils than in background soils (below detection limit, 17.4 mg/kg, and 44 mg/kg, respectively). In addition, near-pile soil concentrations of cobalt and manganese were also significantly higher than the background B-horizon soils in the area. Mean cobalt was 15.6 mg/kg in near-pile soils versus 7.0 in B-horizon soils; mean manganese was 947 in near-pile soils versus 134 in B-horizon soils (Dames & Moore, 1993b).

Spatial Extent of Contamination

Dames & Moore (1993b) estimated that there are 1,195 acres of mine waste and contaminated soils in the Baxter Springs and Treece subsites (Table 2.4). Andes (1988) measured 710 acres of mine waste areas in the Galena subsite, including approximately 80 acres of devegetated dry stream sediments. Andes (1988) classified 320 acres of the Galena mine waste as waste rock, and Dames & Moore classified only 18 acres as waste rock in Baxter Springs/Treece. Also, Dames & Moore (1993b) measured 212 acres of tailings in Baxter Springs/Treece, and Andes (1988) reported none in Galena. It is likely that the authors of these documents classified similar mine waste into different categories. Finally, it should be noted that Andes (1988) provides no estimate of the extent of contaminated soils in the Galena subsite. Stratus Consulting also estimated the spatial extent of unvegetated mine waste in all of Cherokee County, estimating 874 acres using a more conservative approach, and 1,416 acres using a less restrictive approach. It should be noted that since these estimates do not include vegetated mine wastes (i.e., >30% cover) or areas where wastes have been removed, they likely could underestimate the actual extent of contamination.

Table 2.4. Acres of mine waste in Cherokee County, Kansas

Subsite	Waste rock/ overburden	Chat	Tailings	Near-site soils	Total
Galena	320	312			710[a]
Baxter Springs/Treece	18	324	212	641	1,195
Total	338	636	212	641	1,905

a. Andes (1988) may have classified chat as waste rock, and tailings as chat. He characterized chat as a "fine-grained material" and did not characterize any of the waste as tailings. In addition, Andes (1988) stated that mine waste covers approximately 710 acres in the Galena subsite, including stream sediments. This estimate may not include near-site soils.

Sources: Galena: Andes, 1988; Baxter Springs/Treece: Dames & Moore, 1993b.

Cadmium, lead, and zinc concentrations in the soil decrease with increasing distance from the source (Dames & Moore, 1993b) (Figure 2.2). In addition, soil at more than 300 feet from the source has two to three times the concentrations of these metals than found in background soils. The significantly higher concentrations in affected soil, as defined earlier, shows mine wastes to be a source of cadmium, lead, and zinc, and the transport of the metals to the surrounding soils creates a new source of hazardous substances.

The vertical distribution of metals in soils is another important factor in determining whether the elevated concentrations found in the soil are a result of mining or are derived directly from the ore bodies. As shown in Figure 2.3, lead concentrations in soils downwind (as determined by Ecology & Environment, 1995) of the Galena Smelter decrease with depth. If the metals were naturally elevated in the soil, the concentrations would be relatively uniform throughout the soil profile. Thus these data confirm that the metals have come from an external source, in this case from the smelter and other mining activities, rather than occurring naturally.

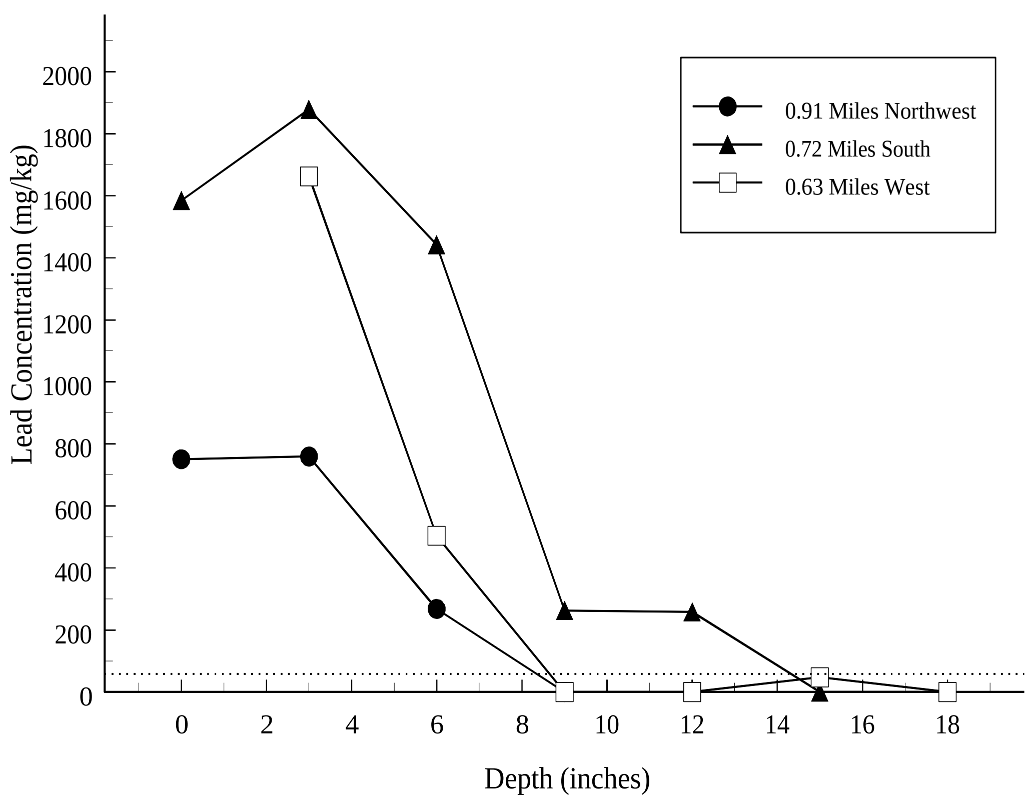

Figure 2.3. Lead concentrations at increasing soil depths downwind of a smelter in Galena, Kansas (Ecology & Environment, 1995). The dotted line represents the background concentration.

2.3 Mine Water, Seeps, Ponds

This section focuses specifically on groundwater contamination at, near, or under mine sites in the Tri-State Mining District. This includes shallow aquifer groundwater, groundwater from within mine shafts, streams flowing from mine shaft openings, saturated tailings ponds, and ponds formed as a result of collapsed mine shafts (subsidence ponds). Since each of these sources entirely or almost entirely originates in groundwater, concentrations of hazardous substances in the sources are compared to background groundwater concentrations in the Tri-State Mining District.

Dames & Moore (1993b, 1995) characterized background contaminant concentrations in shallow groundwater in the Missouri part of the Tri-State Mining District (Table 2.5). In general, concentrations of hazardous substances in groundwater are reported in the dissolved (<0.45 µm) fraction, and concentrations in ponds are total recoverable (unfiltered). Based on the data in Table 2.5, approximate representative background concentrations are on the order of 1 µg/L (Cd), 5 µg/L (Pb), and 150 µg/L (Zn).

In Chapter 3 (pathways) and Chapter 4 (injury evaluation) of this report, we discuss concentrations of hazardous substances in groundwater and surface water, highlighting the marked increase in hazardous substance concentrations downstream/downgradient of mine sites. In this section, we highlight only those concentrations of hazardous substances in waters directly at the source of contamination — mine water, seeps, and ponds — and by doing so show that these sites are sources of contamination.

Table 2.5. Background concentrations[a] of hazardous substances (µg/L) in groundwater, Missouri

Metal	Groundwater	Ponds
Cadmium	0.2	Average = 1
Lead	2.0	Average = 9
Zinc	160	Average = 53

a. Dissolved concentrations in groundwater, and total recoverable in ponds.

Source: Dames & Moore, 1995.

2.3.1 Cherokee County, Kansas

Most of the data on contaminated mine waters in Cherokee County come from the RI/FS (Dames & Moore, 1993b), with a few samples from Parkhurst (1987). Table 2.6 shows concentrations of hazardous substances in mine-related ponds within the NPL site. Each of the sites in Table 2.6 contains elevated concentrations of Zn, seven of eight contain elevated Cd concentrations, and five of eight contain elevated Pb concentrations. The water from the Sunflower Mine subsidence pond (Parkhurst, 1987) contained dissolved Pb at 190 µg/L, Ni at 360 µg/L, and Zn at 48,000 µg/L. The Pb and Ni concentrations are over 35 times greater than background, and the Zn concentration is some 320 times greater than background.

Of the six ponds where Dames & Moore (1993c) found elevated Cd concentrations, the average concentration was 16 µg/L, and the maximum was 32 µg/L, over 30 times greater than background. The four ponds with elevated Pb concentrations contained an average concentration of 42 µg/L, with a maximum of 100 µg/L, 20 times greater than background. The average Zn concentration in the seven ponds in Baxter Springs and Treece was 2,280 µg/L, and the maximum concentration was 9,700 µg/L, nearly 65 times greater than background.

Dames & Moore (1993c) analyzed water from the Ballard East tailings pond in Cherokee County. At the time of the sampling, the Ballard East pond received water from a chat washing operation, where much of the water in the pond was recycled in the chat washing process. The chat washing may have contributed to the highly elevated hazardous substance concentrations in the pond: the Cd concentration was 350 µg/L, the Pb concentration was 120 µg/L, and the Zn concentration was 7,900 µg/L (Dames & Moore, 1993c).

Table 2.6. Concentrations of hazardous substances in water from mine-related ponds, Cherokee County, Kansas

Location	Cd (µg/L)	Pb (µg/L)	Ni (µg/L)	Zn (µg/L)	Source
Background concentration	1	5	10	150	
Sunflower Mine Collapse	3	190	360	48,000	Parkhurst, 1987
Pond 2 in Baxter Springs				320	Dames & Moore, 1993c
Pond 4 in Baxter Springs	10			1,300	
Pond 1 in Treece	24			2,600	
Pond 2 in Treece	32	25		9,700	
Pond 3 in Treece	22	13		390	
Pond 4 in Treece	7	100		1,200	
Pond 5 in Treece	2.5	31		450	

Metals concentrations from Sunflower Mine are dissolved; all others are total recoverable.

Dames & Moore (1993b) also analyzed groundwater in old mine shafts in Cherokee County. All of the samples from the mine shafts contained highly elevated concentrations of Zn, and several contained elevated concentrations of Cd, Pb, and/or Ni (Table 2.7). Some of the mine shafts contained extremely high concentrations of hazardous substances. For example, the shaft below the Ballard Mine contained average concentrations of 2,100 µg/L Cd, 1,450 µg/L Pb, 5,500 µg/L Ni, and 1,200,000 µg/L Zn. The maximum Cd concentration is 3,100 times greater than background, and the maximum Zn concentration is four orders of magnitude greater than background. As described previously, the Ballard Mine area was the site of a chat washing operation when these samples were collected, so these highly elevated concentrations may reflect the concentration of hazardous substances in the water as it was re-used to wash metals-laden chat.

Table 2.7. Average concentrations of hazardous substances in mine shaft waters, Cherokee County, Kansas

Location	Cd (µg/L)	Pb (µg/L)	Ni (µg/L)	Zn (µg/L)	Source
Background concentration	1	5	10	150	
Upper zone of mine openings					Dames & Moore, 1993b
Ballard	23 (51)	139 (340)		5,075 (11,000)	
Big John #6		21 (54)		298 (750)	
Bruger #8			213 (310)	6,375 (8,600)	
English O			318 (360)	3,375 (4,000)	
Paxson	15 (21)			3,225 (3,800)	
Lower zone of mine openings					
McCullough well	1,300	160	160	59,000	
Ballard	2,100 (3,100)	1,450 (1,700)	5,500 (6,400)	1,200,000 (1,500,000)	
Big John #6			987 (990)	13,800 (14,000)	
Bruger #8				11,300 (14,000)	
English O	23 (70)	19 (39)	1,860 (5,300)	103,000 (304,000)	
Paxson		10.4 (21)	383 (510)	19,800 (27,000)	

Numbers in parentheses are maximum concentrations.
Metals concentrations from Sunflower Mine are dissolved; all others are total recoverable.

The McCullough well also contained very high concentrations of hazardous substances, with 1,300 µg/L Cd, 160 µg/L Pb and Ni, and 59,000 µg/L Zn (Table 2.7). These concentrations are 16-1,300 times greater than background concentrations. Other examples of highly elevated concentrations include Ni and Zn from the English "O" mine, where Ni was as high as

5,300 µg/L, and Zn as high as 304,000 µg/L. Although other mine shafts did not have concentrations that were many orders of magnitude greater than background, each of the shafts in Table 2.7 contained highly elevated concentrations of some hazardous substances. Thus, these mine sites clearly serve as sources of hazardous substances to the Cherokee County area.

2.4 Spatial Distribution of Contaminants in Streams

Spatial patterns of contaminants concentrations in streams in the Tri-State Mining District are also helpful in source identification. Figure 2.4 shows that as Short Creek flows past mine sites and waste in Missouri and Kansas, the concentrations of metals in its surface waters increase. This indicates that the sources of these metals are associated with the mining operations. This is also true for Tar Creek as it flows past Treece and Picher (Figure 2.5) in Kansas and Oklahoma. Figures 2.4 and 2.5 combine data from studies carried out over 20 years and therefore, temporal changes in contaminant concentrations could contribute to the patterns obvious in the figures. However, that the concentration peaks are also due to mine wastes is confirmed by the fact that the same patterns may also be observed within studies (e.g., Dames & Moore, 1995).

2.5 Conclusions

The data presented in this chapter support the following conclusions about sources and releases of hazardous substances in the Tri-State Mining District.

Mine Waste, Chat, Tailings, Contaminated Soils

Mine waste, chat, tailings, and contaminated soils in the Tri-State Mining District are all sources of hazardous substances to the environment. This is confirmed by:

- Unvegetated and partially vegetated mine wastes cover nearly 1,200 acres of Cherokee County, Kansas. Concentrations of Cd, Pb, and Zn are on average one to three orders of magnitude greater than background soil concentrations.

- Soils within 300 ft of Cherokee County mine waste piles contain Cd, Pb, and Zn concentrations that are on average several times greater than background soils, with maximum concentrations more than two orders of magnitude greater than background. These mine-site and near-pile soils cover almost 650 acres in the Baxter Springs and Treece subsites in Cherokee County.

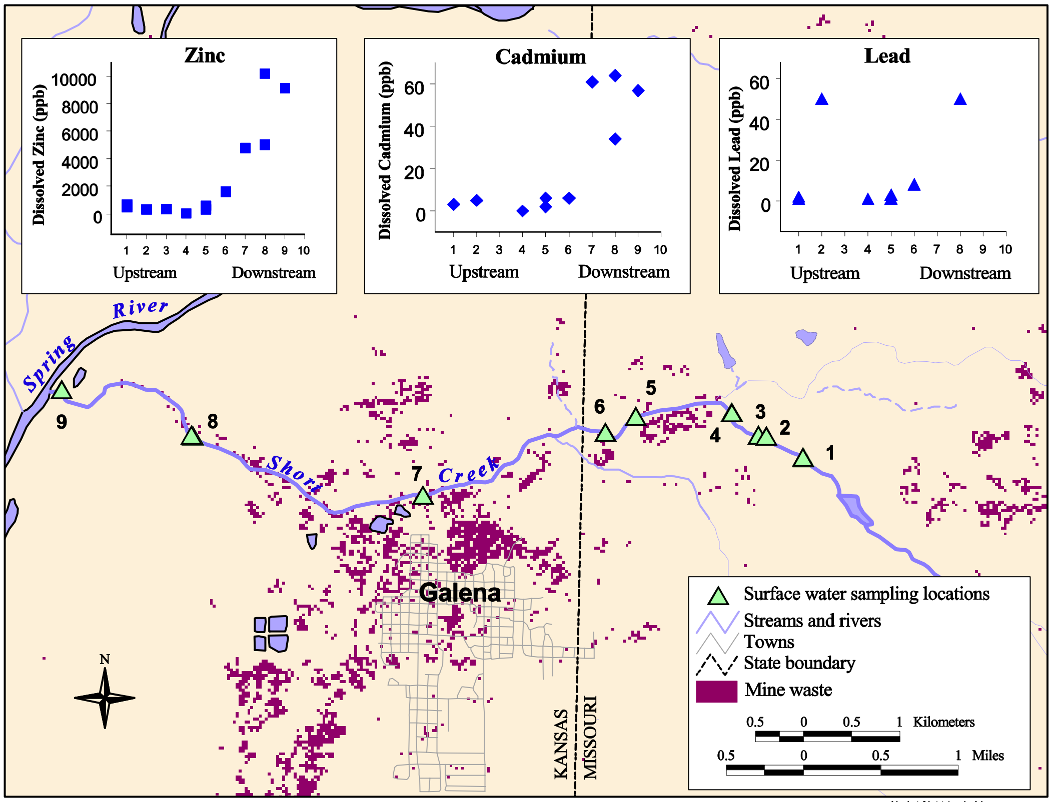

Figure 2.4. Metals concentrations in surface water in Short Creek relative to mining and waste disposal operations.

Sources: Barks, 1977; Dames & Moore, 1995; Author unknown, 1997; Ferrington, date unknown.

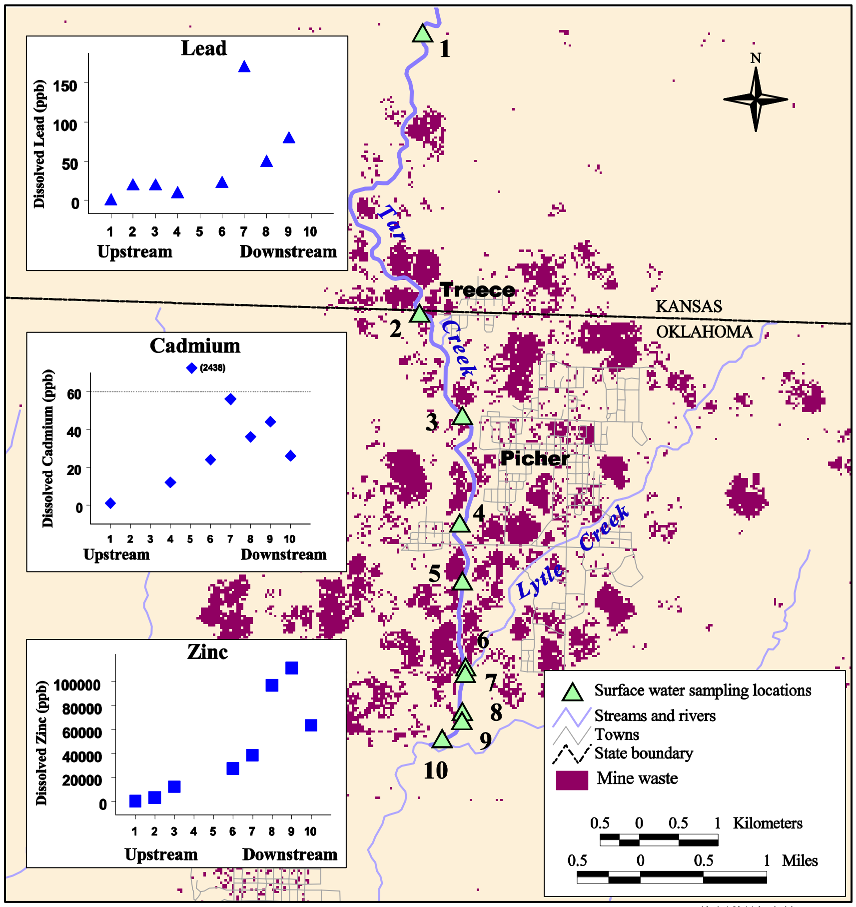

Figure 2.5. Metals concentrations in surface water in Tar Creek relative to mining and waste disposal operations.

Sources: Adams, 1980; OWRB, 1983a; Parkhurst, 1987.

Mine Water, Seeps, Ponds

Mine water, seeps, and ponds are all sources of the hazardous substances Cd, Pb, and Zn to the Tri-State Mining District environment. This conclusion is supported by the following:

- In Cherokee County, Kansas, flooded mine shafts contain highly elevated concentrations of hazardous substances. At least five different flooded mine shafts have been identified, with water samples collected in the upper shaft and lower shaft areas. Each of the mine shafts contained Zn concentrations several times greater than background. In addition, most mine shafts also contained highly elevated concentrations of Cd, Ni, and/or Pb.

- Several tailings ponds and subsidence ponds were identified in Cherokee County, Kansas. These ponds contained concentrations of Zn several times greater than background. Some samples also contained highly elevated concentrations of Cd, Ni, and/or Pb.

In summary, the available data show that the hazardous substances Cd, Pd, and Zn and other metals in large volumes of mine wastes have been and are being released to the environment of Cherokee County, Kansas. Past and current sources of these hazardous substances include waste rock piles, chat, tailings, mine water, seeps, and ponds.

3. Pathways

3.1 Introduction

Chapter 2 demonstrated that surficial mine wastes, soils, and groundwater all act as sources of hazardous substances (including Cd, Pb, and Zn) to the Tri-State Mining District environment. This chapter identifies the pathways by which natural resources in the district come to be exposed to hazardous substances released from these sources. As described in federal regulations at 43 CFR Part 11, pathways may be determined by demonstrating the presence of the hazardous substances in the pathway resources, or by using a model that demonstrates the routes of exposure [43 CFR § 11.63 (a)(2)]. In this analysis, the former approach is taken to demonstrate that the mining-related hazardous substances Cd, Pb, and Zn are not confined to the immediate vicinity of their sources but have been extensively transported from these sources, resulting in exposure to and contamination of natural resources.

Section 3.2 of this chapter presents a conceptual model of the Tri-State Mining District environmental pathways and identifies those pathway components that are likely to have transported hazardous substances from their sources to natural resources. Section 3.3 confirms that all of the pathway components identified in the previous section have indeed been contaminated by mining-related hazardous substances, confirming their transport from the sources to exposed natural resources.

3.2 Potential Transport Pathways

This section describes potential pathways of contaminant transport both from sources to particular media and between affected media. Figure 3.1 shows a conceptual model of these transport pathways for the Tri-State Mining District. This model is based on the known fate and transport characteristics of metals in the environment; our knowledge of typical transport pathways at mine sites elsewhere; our knowledge of the mine wastes, geomorphology, and ecology of the Tri-State Mining District; and the types of natural and ecological resources that exist on and adjacent to the sources of hazardous substances.

Hazardous substances can be released directly from the sources into the air, groundwater, surface water, and soils. Smelters can release metals directly into the air, where they can potentially be moved and later deposited in another location. In addition, air can entrain metals as it flows over fugitive dust sources such as chat piles.

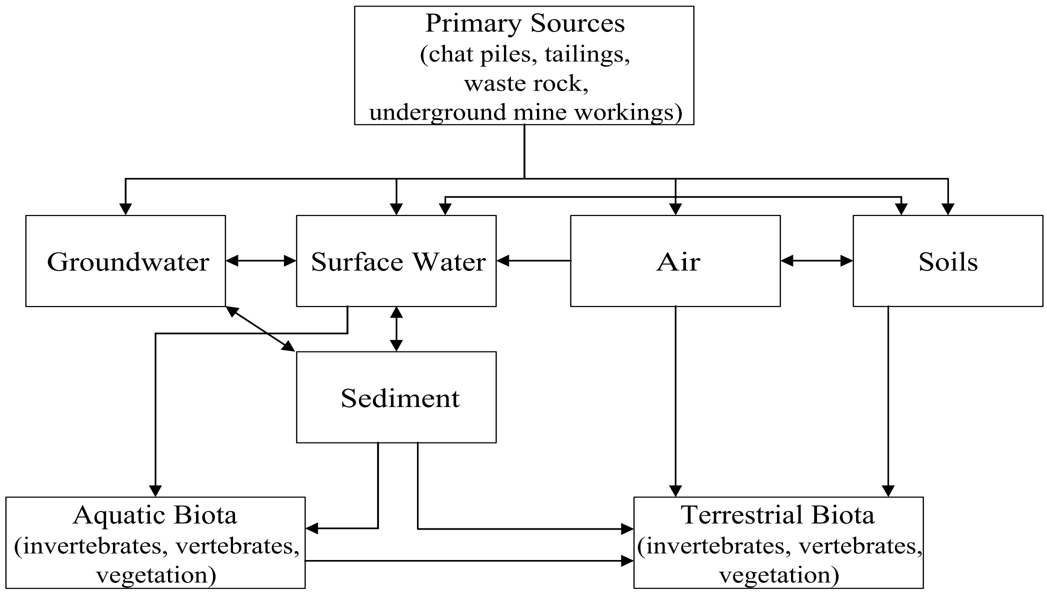

Figure 3.1. Environmental pathways through which mining-related hazardous substances may be transported from their sources to natural resources in the Tri-State Mining District.

Rain water percolating through the mine waste piles can leach hazardous substances into the soil beneath the waste pile. The result may be infiltration of contaminated water into the shallow aquifer. Groundwater can also be affected as it flows through underground mine workings and comes into contact with exposed ore bodies.

Surface water can receive hazardous substances directly from sources via erosion of various types of mine waste products during runoff. In addition, infiltration of water into waste piles can mobilize hazardous substances into solution, resulting in contaminated runoff to surface water.

Air, groundwater, surface water, and soils may receive hazardous substances not only directly from the sources, but also from each other. Air can transport hazardous substances and deposit them directly into surface water or onto soils. Hazardous substances can also move back and forth between ground and surface water through discharge and recharge.

Terrestrial and aquatic biota may be exposed to contaminants in environmental media either directly (for example, plants exposed directly to hazardous substances in soils) or indirectly through food chain transfer.

3.3 Transport Pathways by Media

Section 3.2 of this chapter identified the likely environmental pathway components through which hazardous substances could be transported from mining sources in the Tri-State Mining District. In this section we present data obtained from the literature to show that natural resources in the district have indeed been exposed to mining-related hazardous substances via these pathways. We do so by presenting measured concentrations of hazardous substances in the pathway components identified in Figure 3.1 and by comparing these concentrations with background concentrations from nonmining areas of Kansas, Missouri, Oklahoma, or the United States in general, and with site-specific background concentrations. These include data from areas within the assessment area but upstream or upwind of mining facilities. Appropriate Tri-State sample sites that were included in characterizing background concentrations were determined using geographical information systems (GIS), printed maps, and published information.

Data presented in this section were collected between 1961 and 1998. Groundwater data were collected between 1976 and 1997, surface water data between 1963 and 1994, sediment data between 1981 and 1994, air data between 1970 and 1993, soil data between 1971 and 1998, aquatic biota data between 1988 and 1994, and terrestrial biota data between 1971 and 1998. These data have been compiled from a variety of sources (identified in the text), many of which have not been thoroughly examined for quality and validity. In addition, the data presented are selective: they do not represent a comprehensive analysis of all data currently available. In our selection of data for inclusion in this report we evaluated data sets for their completeness, the existence of adequate geographical location information, the adequacy of laboratory and field methods in the collection and analysis of samples, the uncertainty associated with the data, and the relevance of the data to the main elements of an NRDA.[1]

1. The methods of calculation and treatment of values below the detection limit varied between data sources, and often was not specified. As a result, values below detection limit may have been treated as zeroes, 1/2 the detection limit, or the detection limit itself.

3.3.1 Groundwater

Chapter 2 (Section 2.2) of this report demonstrated that groundwater below mine waste piles and in flooded mine shafts is highly contaminated with Cd, Pb, and Zn. In the following analysis we evaluate contaminant concentrations in groundwater that are more distant from mining activity to determine whether these metals are being transported from the sites where they initially enter the groundwater.

Table 3.1 lists selected examples of Cd, Pb, and Zn concentrations in groundwater in Cherokee County in Kansas. Concentrations in groundwater from specific subsites or designated areas, as well as regions, are included in the table. Estimates of background concentrations were obtained from the shallow aquifer (Boone aquifer, also known as the Mississippian aquifer; see Chapter 4 for a detailed description of the aquifer) wells upgradient of mining activity in Jasper County (Dames & Moore, 1995) and from the deep aquifer (Roubidoux aquifer) upgradient of mining activities in Ottawa County (Christenson, 1995).

Table 3.1 presents metals concentrations in Cherokee County groundwater, including wells from the Galena and Treece subsites, the area north of the Galena subsite, and the area north of Shoal Creek. The background concentrations used for Cherokee County were those determined by Dames & Moore (1995) to be baseline groundwater concentrations in Jasper County. In addition, groundwater metal concentrations are compared to those in the deep aquifer, upgradient of known mining activity (Christenson, 1995).

Total and dissolved concentrations for all three metals were as high as one order of magnitude greater than background concentrations (Table 3.2). Average Cd concentrations ranged from 7.8 :g/L dissolved to 9.67 :g/L total (U.S. EPA, 1987b; Author unknown, 1989), almost 10 times greater than background concentrations. A maximum dissolved Cd concentration of 180 :g/L (U.S. EPA, 1987b) was 900 times greater than background. Average Pb concentrations were 9 to 14 times greater than background concentrations, and a maximum dissolved Pb concentration of 230 :g/L was two orders of magnitude greater than background concentrations (U.S. EPA, 1987b; Author unknown, 1989).

Private wells on the Galena subsite had a maximum Zn concentration of 15,000 :g/L, more than 90 times greater than background concentrations (U.S. EPA, 1987b). The average total Zn concentration in the Treece subsite was 1,550 :g/L, an order of magnitude greater than background concentrations.

Table 3.1. Mean metals concentrations in shallow aquifer groundwater in Cherokee County, Kansas, compared to background concentrations in Cherokee County

			Concentration (: g/L)			Mean background concentration (: g/L)		
Area sampled	**Years sampled**	**Number of samples**	**Cd**	**Pb**	**Zn**	**Cd**	**Pb**	**Zn**
Private wells in Galena subsite	1986-1987		7.8[b] 180 (max)	28[b] 230 (max)	980[b] 15,000 (max)	0.2[a,f] (<dl-0.6)	2[a,f] (<dl-5)	160[a,f] (14-748)
Area north of Galena subsite	1988	5 Cd 13 Pb	8.28[c] (5.5-14)	18.28[c] (1.2-68)		<1.6-2.9[h]	<1.4-12.8[h]	<3.2-18.6[h]
		6 Cd 12 Pb	9.67[a,c] (5.7-15)	23.73[a,c] (1.8-110)				
Blue Mound and McCullough wells (Treece subsite)	1997	7			1,550[a,d,g] (30-3,300)			
Eastern area wells (north of Shoal Creek)	Year unknown	9			540[e,g] (20-1,500)			

Mean is followed by range in parentheses. All dissolved concentrations, unless otherwise noted; dl = detection limit.

a. Total recoverable.
b. U.S. EPA, 1987b.
c. Author Unknown, 1989.
d. Dames & Moore, 1993b.
e. Spruill, 1984.
f. Dames & Moore, 1995.
g. Median.
h. Christenson, 1995 (Roubidoux aquifer upgradient of mining).

Table 3.2. Mean metals concentrations in surface water in Cherokee County, Kansas, compared to background concentrations

Mine-affected sampled area	Years sampled	Number of samples	Concentration (: g/L)			Mean background concentration (: g/L)		
			Cd	Pb	Zn	Cd	Pb	Zn
Short Creek and tributaries	1976	1	6[b]	8[b]	1,600[b]	1.27[l]	4.53[l]	61.1[l]
	1976-1982	13			85,000[c] (1,800-200,000)	(<dl-3)	(<dl-20)	(<dl-1,190)
	1976-1982	14		3,538[a,c] 24,000(max)	87,000[a,c] (6,900-200,000)	1.42[a,m] (<dl-2)	12.0[a,m] (<dl-25)	61.5[a,m] (4-330)
	1985-1987	24	77.0[d] (nd-170)	77.94[d] (nd-1,600)	14,302[d] (nd-53,000)	1.27[l] (<dl-3)	4.53[l] (<dl-20)	61.1[l] (<dl-1,190)
	1985-1987	24	83.7[a,d] (nd-190)	296.2[a,d] (nd-1,700)	13,925[a,d] (nd-55,000)	1.42[a,m] (<dl-2)	12.0[a,m] (<dl-25)	61.5[a,m] (4-330)
	1993-1994	48	63.7[e]		9,459[e]	1.27[l] (<dl-3)	4.53[l] (<dl-20)	61.1[l] (<dl-1,190)
	1997	3	67.3[f] (28-140)	42.3[f] (<50-77)	9,105[f] (2,185-20,111)	1.27[l] (<dl-3)	4.53[l] (<dl-20)	61.1[l] (<dl-1,190)
Tributary to Spring River	1993-1994	12	18.7[e]		2,091[e]	1.27[l]	4.53[l]	61.1[l]
Shoal Creek and tributaries	1985-1986	7	54.3[d] (nd-190)	624[d] (nd-2,600)	10,300[d] (nd-36,000)	(<dl-3)	(<dl-20)	(<dl-1,190)
	1985-1986	7	52.4[a,d] (nd-180)	646[a,d] (nd-2,600)	10,291[a,d] (nd-35,000)	1.42[a,m] (<dl-2)	12.0[a,m] (<dl-25)	61.5[a,m] (4-330)
	1993-1994	12	106.4[e]		22,278[e]	1.27[l] (<dl-3)	4.53[l] (<dl-20)	61.1[l] (<dl-1,190)
Tar Creek and tributaries	1976-1982	6	(10-40)[a,g]	(10-100)[a,g]	(1,600-12,000)[a,g]	1.42[a,m] (<dl-2)	12.0[a,m] (<dl-25)	61.5[a,m] (4-330)
	1980	1			3,300[h]	1.27[l] (<dl-3)	4.53[l] (<dl-20)	61.1[l] (<dl-1,190)
	1991	6	20[a,i] (7-40)	50[a,i] (25-80)	9,200[a,i] (700-22,000)	1.42[a,m] (<dl-2)	12.0[a,m] (<dl-25)	61.5[a,m] (4-330)
	1991	14	13.7[a,j] (0.5-40)	34.9[a,j] (1-90)	6,319[a,j] (63-22,000)			

Table 3.2. Mean metals concentrations in surface water in Cherokee County, Kansas, compared to background concentrations (cont.)

Mine-affected sampled area	Years sampled	Number of samples	Concentration (:g/L)			Mean background concentration (:g/L)		
			Cd	Pb	Zn	Cd	Pb	Zn
Short Creek Tributary	1991	9	98.4[a,j] (23-260)	8[a,j] (1-22)	10,244[a,j] (3,200-20,000)	1.42[a,m] (<dl-2)	12.0[a,m] (<dl-25)	61.5[a,m] (4-330)
Willow Creek	1991	12	1.3[a,j] (0.5-2.5)	13[a,j] (2-25)	515[a,j] (110-1,000)			
Turkey Creek	1991	1	<0.59[k]	<4.12[k]	354[k]	1.27[l] (<dl-3)	4.53[l] (<dl-20)	61.1[l] (<dl-1,190)

Mean is followed by range in parentheses. All dissolved concentrations, unless otherwise noted. Values below detection/reporting limit were entered as detection limit (dl) for calculations (including background).

a. Total recoverable.
b. Barks, 1977.
c. Kiner et al., 1997; Davis and Schumacher, 1992.
d. CH2MHill, 1987a (values listed as nondetects were calculated using 0).
e. Ferrington, undated.
f. Author unknown, 1997 (½ detection limit used for lead calculations — 2 values listed at < 50).
g. Spruill, 1984.
h. Adams, 1980.
i. Dames & Moore, 1993a.
j. Dames & Moore, 1993b.
k. Schmitt et al., 1997.
l. Background data combine data from Shawnee Creek (Spring River tributary, upstream of mining); Tar, Short, and Center creeks upstream of mining; and Spring and Neosho rivers upstream of mining. Determinations of upstream areas were based on GIS data: Barks, 1977; Adams, 1980; Oklahoma State Department of Health, 1983; CH2MHill, 1987a; Parkhurst, 1987; Dames & Moore, 1995; Author unknown, 1997.
m. Background data combine data from Shawnee Creek (Spring River tributary, upstream of mining); Tar, Short, and Center creeks upstream of mining; and Spring and Neosho rivers upstream of mining. Determinations of upstream areas were based on GIS data: CH2MHILL, 1987a; Barks, 1977; Dames & Moore, 1993b.

The data presented above show that concentrations of Cd, Pb, and Zn in groundwater at a number of locations are greatly elevated above background, confirming that groundwater is a transport medium for these hazardous substances. Mean concentrations are generally as high as one order of magnitude greater than background, and maximum concentrations exceed background by factors of up to four orders of magnitude.

Based on potentiometric contours, Dames & Moore (1995) concluded that in Jasper County, groundwater flow in the shallow aquifer generally is toward lower elevations, and the water eventually moves to the nearest spring or pond. These data suggest that contaminated groundwater will eventually surface in the various streams or other water bodies within the county. Depending on the location of contaminant infiltration to the shallow aquifer, the contaminated groundwater may also flow into one of the streams and creeks within the Kansas portion of the Tri-State Mining District (Dames & Moore, 1993b). Thus, contaminated groundwater can serve as a pathway for hazardous substances to surface waters. Contamination of surface waters in the Tri-State Mining District is addressed in the next section of this report.

3.3.2 Surface water

Figure 3.2 shows the main rivers, creeks, and tributaries in the Tri-State Mining District. Selected examples of metals concentrations in surface water samples collected in Cherokee County are presented in Table 3.2. These data include both dissolved and total recoverable concentrations from mine-affected areas, as well as respective background concentrations. Background concentrations were estimated for the Tri-State Mining District by compiling measurements from Shawnee Creek (a Spring River tributary upstream of mining); Tar, Short, and Center creeks at sites upstream of mining; and the Spring and Neosho rivers upstream of mining. Data from sites downstream of mining-affected areas were not used to identify background concentrations, even in cases where dilution appears to have mitigated the elevated metals concentrations.

The mean background concentrations used in the tables for dissolved Cd, Pb, and Zn are 1.27 µg/L, 4.53 µg/L, and 61.1 µg/L, respectively. These values are similar to but not identical to the groundwater background values identified in Chapter 2 of this report. Mean background concentrations for total Cd, Pb, and Zn are 1.42 µg/L, 12 µg/L, and 61.5 µg/L, respectively (see footnotes in Table 3.2 for sources of dissolved and total concentrations data). The Cd, Pb, and Zn concentrations in surface waters in the affected areas are clearly elevated relative to background.

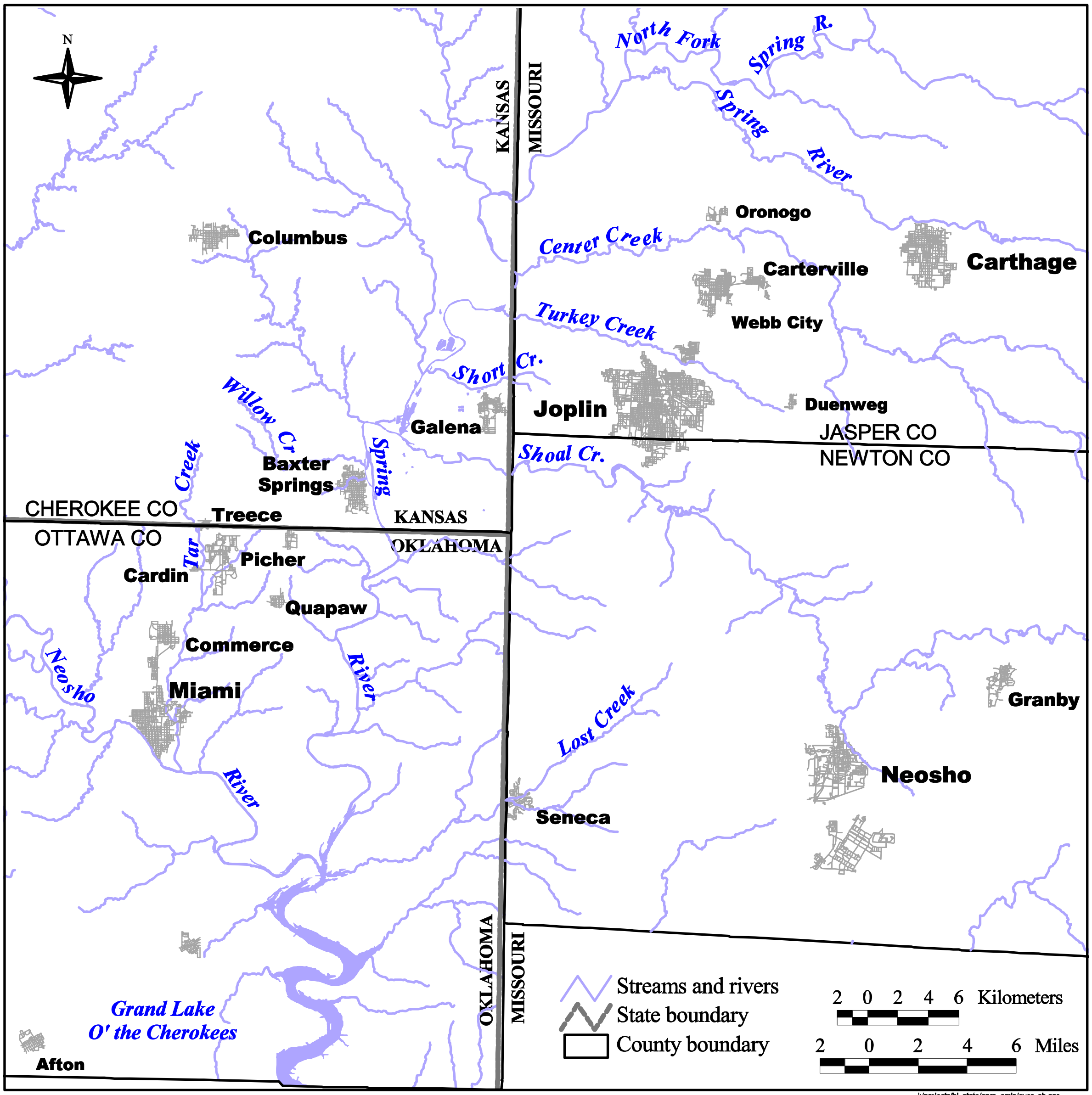

Figure 3.2. Main surface water drainages of the Tri-State Mining District.

Cherokee County, Kansas

Cherokee County data presented in Table 3.2 include measurements from Short Creek, an unnamed tributary of Spring River, Spring Branch (a tributary to Short Creek), and Shoal, Tar, Willow, and Turkey creeks as well as various tributaries of these creeks. It should be noted that, according to CH2MHill (1987a), while the creeks and their tributaries are combined in Table 3.2, Pb and Zn concentrations were considerably higher in the tributaries of Short and Shoal creeks than in the creeks themselves. In addition, Cd concentrations were also lower in Shoal Creek than in its tributaries. The mean dissolved Pb and Zn concentrations in Short Creek were 186.7 g/L and 19,226 :g/L, respectively, compared to 0.26 :g/L and 10,786 :g/L, respectively, in its tributaries. Shoal Creek tributaries had average dissolved Cd, Pb, and Zn concentrations of 126.7 :g/L, 1,456 :g/L, and 35,950 :g/L, respectively, compared with below detection limit concentrations of Cd and Pb in Shoal Creek and a mean Zn concentration of 135 :g/L. Concentrations for total metals followed a similar pattern (CH2MHill, 1987a).

With the exception of Turkey Creek, average dissolved Cd concentrations were 6-106.4 :g/L (Barks, 1977; Ferrington, undated), and most were one to two orders of magnitude above background, with maximum concentrations as high as 150 times greater than background. Average dissolved Pb concentrations were as high as 624 :g/L (CH2MHill, 1987a), almost 140 times greater than background. Maximum concentrations were as high as three orders of magnitude greater than background. Dissolved Zn concentrations were greatly elevated, with averages ranging from 354 :g/L (Schmitt et al., 1997) to 22,278 :g/L (Ferrington, undated), and maximum concentrations as high as 200,000 :g/L (Davis and Schumacher, 1992; Kiner et al., 1997), some four orders of magnitude greater than background.

Total recoverable metals concentrations in Cherokee County surface water were also elevated. Average total Cd concentrations were as high as 98.4 :g/L, almost 70 times greater than background, and maximum concentrations were as high as 260 :g/L, 130 times greater than background (Dames & Moore, 1993b). Short Creek and its tributaries had an average Pb concentration of 3,538 :g/L (Davis and Schumacher, 1992; Kiner et al., 1997), three orders of magnitude and almost 295 times greater than background. Shoal Creek and its tributaries had maximum total Pb concentrations as high as 2,600 :g/L (CH2MHill, 1987a), three orders of magnitude greater than background. Average total Zn concentrations were 354-87,000 :g/L (Davis and Schumacher, 1992; Kiner et al., 1997; Schmitt et al., 1997), with the majority of the averages two to three orders of magnitude above background. Short Creek and its tributaries had a maximum total Zn concentration of 200,000 :g/L (Davis and Schumacher, 1992; Kiner et al., 1997), some four orders of magnitude greater than background.

Summary

The above data show elevated concentrations of all three metals in surface water in Cherokee County, confirming that surface water is acting as a pathway by which hazardous substances are transported from their sources to contaminate other parts of the Tri-State Mining District.

3.3.3 Sediments

Table 3.3 shows selected examples of metals concentrations in sediments from Cherokee County. Background data were compiled in the same manner as surface water, using samples taken in the Spring and Neosho rivers upstream of mining facilities and wastes, and Center Creek upstream of Grove Creek (upstream of mining). It should be noted that for sediment background concentrations, sample sizes were not available for much of the data, so the means of the means were calculated assuming equal sample sizes. In addition to background concentrations in samples taken within the Tri-State Mining District, background concentrations in samples from selected reservoirs in the Smoky Hill catchment (outside the mining district) collected by Ferrington et al. (1989) are presented. The Tri-State background concentrations were 1.43 mg/kg, 19.4 mg/kg, and 531.1 mg/kg for Cd, Pb, and Zn, respectively; background values taken from the Smoky Hill catchment were 0.268 mg/kg, 10.33 mg/kg, and 37.63 mg/kg for Cd, Pb, and Zn, respectively.

Cherokee County, Kansas

Cherokee County sampling sites (Table 3.3) include Short Creek and its tributaries, a tributary to the Spring River, and Shoal Creek and its tributaries. Mean Cd concentrations ranged from 23.5 mg/kg (Allen and Wilson, 1992) to 244.5 mg/kg (Ferrington, undated), up to 133 times greater than site-specific background. Sediment mean Pb concentrations ranged from 230 mg/kg (Allen and Wilson, 1992) to 3,152 mg/kg (Ferrington, undated), and had a maximum concentration of 5,343 mg/kg (Ferrington, undated). The mean and average concentrations were as high as three orders of magnitude greater than site-specific background, and the maximum concentrations were as high as 275 times greater than site-specific background. Average Zn concentrations were 3,300 mg/kg (Allen and Wilson, 1992) to 22,427 mg/kg (Ferrington, undated), one to two orders of magnitude greater than site-specific background concentrations. Short Creek and its tributaries had a maximum Zn concentration of 56,533 mg/kg (Ferrington, undated), over 100 times greater than background concentrations.

Table 3.3. Mean metals concentrations in aquatic sediments in Cherokee County, Kansas, compared to background concentrations

Mine-affected sampled area	Years sampled	Number of samples	Concentration (mg/kg) Cd	Concentration (mg/kg) Pb	Concentration (mg/kg) Zn	Mean background concentration (mg/kg)[a] Cd	Mean background concentration (mg/kg)[a] Pb	Mean background concentration (mg/kg)[a] Zn
Short Creek and tributaries	1993-1994	20	189.6[b] (24.7-387.3)	3,152[b] (301.3-5,343)	22,427[b] (3,271-46,533)	Site: 1.43[e,f] (<1-3)	Site: 19.4[e,f] (14-28)	Site: 531.1[e,f] (120-1,270)
Tributary to Spring River	1993-1994	4	244.5[b]	337[b]	13,444[b]			
Shoal Creek and tributaries	1987	24	25.3[c] (17-34)	231.2[c] (147.7-297.8)	3,632[c] (2,360-5,756)	Smoky Hill Catchment: 0.268[c] (0-0.5)	Smoky Hill Catchment: 10.33[c] (2.47-21.95)	Smoky Hill Catchment: 37.63[c] (14.1-66)
	1988	2	23.5[d] (23.2-23.7)	230[d]	3,300[d] (3,310-3,290)			
	1993-1994	4	54.8[b]	3,118[b]	6,248[b]			

Mean is followed by range in parentheses.

a. Site background data were compiled from Spring River upstream of Neck/Alba (upstream of mining), Neosho River upstream of Tar Creek confluence, and Center Creek upstream of Grove Creek (east of mining); also included as background were sediment samples from the Smoky Hill Catchment, sampled by Ferrington et al. (1989) for background concentrations.
b. Ferrington, undated (ranges are ranges of means).
d. Allen and Wilson, 1992.
c. Ferrington et al., 1989.
e. Dames & Moore, 1995.
f. OWRB, 1983a.

Summary

For all three metals, sediment concentrations in affected areas of Cherokee County were greater than site background concentrations by one to two orders of magnitude. Background concentrations in the Smoky Hill catchment were lower than the site background concentrations, and the exceedences by affected area metals are even greater at two to three orders of magnitude.

These exceedences show that aquatic sediments are acting as pathways through which hazardous substances are transported from their sources, resulting in exposure to natural resources.

3.3.4 Air

Table 3.4 shows metals concentrations in total suspended particulates in air from Cherokee County. Background concentrations were estimated from measurements taken at sites distant from mining sources, in Ford and Sherman counties, Kansas. These background concentrations average 0.0001-0.0003 : g/m^3, 0.07 : g/m^3, and 0.066-0.071 : g/m^3 for Cd, Pb, and Zn, respectively [data provided by Kansas Department of Health and Environment (KDHE) in 1999].

Cherokee County, Kansas

Table 3.4 presents data for Cherokee County, mainly from the Galena subsite with some data from the Baxter Springs and Treece subsites. Air samples taken in 1970 downwind of an active smelter in Galena show average concentrations for Cd, Pb, and Zn to be 0.076 mg/m^3, 0.616 mg/m^3, and 5.91 mg/m^3, respectively. These data indicate metals concentrations one to two orders of magnitude greater than background. However, air samples taken in 1985, years after the smelter ceased operation, show Cd concentrations to be only slightly higher than background, and Pb and Zn concentrations to be comparable to background concentrations. This suggests that during smelter operations, air served as a transport medium for metals. However, in more recent years air might not have played as important a role in hazardous substance transport.

Summary

The data presented above clearly show that, at least during the time in which smelters operated in the Tri-State Mining District, air was an important pathway component by which hazardous substances were transported. It is likely that air continues to be a pathway by which hazardous substances are transported via fugitive dusts from waste piles during periods of high winds.

Table 3.4. Mean metals concentrations in air in Cherokee County, Kansas, compared to background concentrations

Sampled area	Year sampled	Number of samples	Concentration (mg/kg)			Background concentration (mg/kg)		
			Cd	Pb	Zn	Cd	Pb	Zn
Downwind of active smelter, Galena	1970	5	0.076[a] (0.16)	0.616[a] (0.95)	5.91[a] (7.9)	0.0003[d,h] (0.01)	0.07[d,h] (0.25)	0.066[d,h] (0.16)
Three farms in Galena subsite	1971	97	0.097[b] (1.86)	0.58[b] (5.65)		0.0001[d,h] (0.0001)	0.07[d,h] (0.19)	0.071[d,h] (0.17)
South of Galena (119 E. 5th St.)	1983	15	0.001[c,d] (0.007)	0.119[c,d] (0.25)	0.096[c,d] (0.311)			
West of Treece (U.S. 166, 6 miles west of K7)	1983	15	0.003[c,d] (0.012)	0.095[c,d] (0.197)	0.194[c,d] (0.76)			
Treece	1983	21	0.008[e] (0.028)	0.153[e] (0.57)	1.672[e] (4.59)			
Baxter Springs (125 W. 15th St.)	1983	23	0.003[d,e] (0.01)	0.136[d,e] (0.365)	0.442[d,e] (2.99)			
Galena (U.S. 166, 0.7 miles west of K26)	1983	20	0.001[d,e] (0.005)	0.07[d,e] (0.418)	0.118[d,e] (0.534)			
Former smelter, Galena subsite	1985	13	0.021[f] (0.048)	0.036[f] (0.068)	0.082[f] (0.224)			
North chat pile, Galena subsite	1985	10	0.014[f] (0.046)	0.037[f] (0.065)	0.035[f] (0.16)			
Bullrock, Galena subsite	1985	9	0.021[f] (0.024)	0.042[f] (0.068)	0.061[f] (0.079)			
Rural chat road, Galena subsite	1985	13	0.03[f] (0.056)	0.044[f] (0.086)	[g]			
Residential area, Galena subsite	1985	13	0.024[f] (0.044)	0.034[f] (0.046)	0.052[f] (0.095)			

Table 3.4. Mean metals concentrations in air in Cherokee County, Kansas, compared to background concentrations (cont.)

Sampled area	Year sampled	Number of samples	Concentration (mg/kg)			Background concentration (mg/kg)		
			Cd	Pb	Zn	Cd	Pb	Zn
Chat pile, Galena subsite	1985	11	0.016[f] (0.035)	0.053[f] (0.084)	[g]	0.0003[d,h] (0.01)	0.07[d,h] (0.25)	0.066[d,h] (0.16)
High school, Galena subsite	1985	12	0.012[f] (0.028)	0.03[f] (0.051)	0.039[f] (0.063)	0.0001[d,h] (0.0001)	0.07[d,h] (0.19)	0.071[d,h] (0.17)

Mean is followed by maximum in parentheses.

a. Lagerwerff and Brower, 1975.
b. Irwin 1971, as cited in Author unknown, 1985.
c. KDHE, 1984, as cited in U.S. EPA, 1986.
d. Data provided by KDHE in 1999.
e. KDHE, 1984, as cited in Author unknown, 1985.
f. U.S. EPA, 1986.
g. Original table (from U.S. EPA, 1986) presented mean concentrations that were higher than the maximum for zinc. As a result of the discrepancy, the data for zinc are not presented here.
h. Background data taken from Ford County in southwestern Kansas, and Sherman County in northwestern Kansas, respectively.

3.3.5 Soil

Large quantities of data on hazardous substances in soil were collected during the remedial investigations for Cherokee County (Dames & Moore, 1993b, 1995). It is not the intention of this section to present all of these data but only to present illustrative examples that confirm that soil is a transport pathway through which hazardous substances are transported in the environment.

Table 3.5 presents metals concentrations in soils in Cherokee County, both near mine wastes and downwind of smelters. In the various source documents, the data are presented as mine waste soil, "near soil," and "distant soils" (see Chapter 2). This section presents only the near soil data from those particular source documents to evaluate whether metals are moving from their sources via a soil transport pathway.

Selected examples of soil metals concentrations in Cherokee County are compared both to national averages and, where available, to site and state background concentrations. The mean soil concentrations for the United States for Cd, Pb, and Zn are 0.53 mg/kg, 32 mg/kg, and 64 mg/kg, respectively (Alloway, 1990; Kabata-Pendias and Pendias, 1992). The metal concentrations from Cherokee County used as background in Table 3.5 are county-specific background data collected by Dames & Moore (1993b), and are 0.4 mg/kg, 17 mg/kg, and 44 mg/kg for Cd, Pb, and Zn, respectively.

Cherokee County, Kansas

Soil data from Cherokee County presented in Table 3.5 come from samples taken from the Baxter Springs and Treece subsite near-pile soils [soil found within 300 feet from a mill waste pile but not containing any visible chat (Dames & Moore, 1993b)]. Table 3.5 also shows soil samples from the Galena subsite taken downwind of a smelter and downwind of tailings piles. Concentrations for all three metals in soils downwind of an active smelter in Galena were one to two orders of magnitude greater than both site and national background concentrations. Average Cd and Zn concentrations of 35.9 mg/kg and 4,658 mg/kg, respectively, were 90 to 100 times greater than site background (Lagerwerff and Brower, 1975). In the Baxter Springs and Treece subsites, average Cd and Zn concentrations as high as 4.5 mg/kg and 710 mg/kg were one order of magnitude greater than background, and maximum concentrations were up to two orders of magnitude greater than background (Dames & Moore, 1993b).

Table 3.5. Mean metals concentrations in near pile and downwind of smelter soils in Cherokee County, Kansas, compared to background concentrations

Mine-affected sampled area	Year sampled	Number of samples	Concentration (mg/kg)			Mean background concentration (mg/kg)		
			Cd	Pb	Zn	Cd	Pb	Zn
330-2,200 m downwind of active smelter, Galena	1971	6	35.9[a] (16.4-102)	722.7[a] (225-1,600)	4,658[a] (1,860-15,600)	0.4[d]	17[d]	44[d]
33-167 m downwind of tailings piles, Galena	1973	6	9.17[b] (4.4-18.6)	149.4[b] (39-292)	965.2[b] (425-1,760)	0.53[e] (0.005-2.4)	32[e] (10-70)	64[e] (17-125)
Baxter Springs and Treece subsites	1991	19	4.5[c] (0.8-21)	88.1[c] (25-300)	710[c] (230-2,900)			

Mean is followed by range in parentheses.

a. Lagerwerff and Brower, 1975.
b. Lagerwerff et al., 1972.
c. Dames & Moore, 1993a, 1993b.
d. County-specific averages; Dames & Moore, 1993b.
e. National averages; Alloway, 1990; Kabata-Pendias and Pendias, 1992.

Summary

The above soil data show that hazardous substances are being transported from their mine sources via soil pathways. In addition, Chapter 2 presented Cherokee County soil metal concentrations at various distances from sources of hazardous substances (see Figure 2.2). In addition to showing the mine waste to be a source of hazardous substances, these data demonstrate transport of hazardous substances through the soil. While Cd, Pb, and Zn concentrations decrease with distance from the source, even at 200 to 300 feet from the source the mean Cd and Pb concentrations are as high as one order of magnitude over background and mean Zn concentrations are as high as two orders of magnitude greater.

3.3.6 Aquatic biota

Table 3.6 presents metals concentrations in fish and benthic invertebrate tissues from Cherokee County (no aquatic vegetation or plankton tissue residue data were found in materials provided). The background concentrations presented in this table were compiled using data from the same site used in compiling surface water and sediment background concentrations.

Because of the lack of background data for many fish species in Cherokee County, Jasper County, Missouri fish background concentrations from Dames & Moore (1995) are used.

Cherokee County, Kansas

Table 3.6 presents tissue concentrations in aquatic biota in Cherokee County, and includes concentrations in fish samples from Spring Branch, Shoal, Tar, and Willow creeks, and from invertebrate samples from Shoal and Turkey creeks. Fish species include sunfish, yellow bullhead, largemouth bass, warmouth, pumpkinseed, spotted sucker, and bluegill. Invertebrates include crayfish, megalopterans, insects, and other unspecified invertebrates. Fish tissue concentration data are primarily from Dames & Moore (1993b), with some data from Allen and Wilson (1992). Invertebrate data are primarily from Allen and Wilson (1992) and Wildhaber et al. (1997), with some data from Dames & Moore (1993b).

Whole body Cd concentrations in fish were up to 0.34 mg/kg in Spring Branch and 0.31 mg/kg in Tar Creek (Dames & Moore, 1993b), one order of magnitude greater than background. With the exception of one sample, average whole body Pb concentrations ranged from 0.17 mg/kg to 2.2 mg/kg, one to two orders of magnitude greater than background. Average Zn concentrations were as high as 203 mg/kg, at least eight times greater than background.

Table 3.6. Mean metals concentrations in aquatic biota from surface waters in Cherokee County, Kansas, compared to background concentrations

Mine-affected sampled area	Years sampled	Number of samples	Species	Concentration (mg/kg)			Mean background concentration (mg/kg)		
				Cd	Pb	Zn	Cd	Pb	Zn
Fish									
Spring Branch	1991	2	Green sunfish	0.14[a,b] (0.024-0.25)	0.03[a,b] (<0.03-0.03)	6.37[a,b] (5.54-7.19)	0.017[e]	<0.05[e]	18.41[e]
		3		0.34[b] (0.13-0.51)	0.59[b] (0.53-0.66)	85.1[b] (58.3-123)	(0.01-0.03)		(15.9-22.36)
		1	Yellow bullhead	0.29[b]	0.53[b]	51.1[b]			
Shoal Creek	1988	1 (4 fish)	Largemouth bass	0.02[c]	<dl[c]	18.3[c]	0.04[f] (0.02-0.06)	0.07[f] (<0.05-0.11)	25.3[f] (17.2-25.3)
		1 (2 fish)	Sunfish	0.06[c]	1.8[c]	50[c]			
Tar Creek	1991	1	Warmouth/redear	0.31[b]	14[b]	203[b]			
Willow Creek	1991	1 (2 fish)	Pumpkinseed	0.066[b]	0.54[b]	64.6[b]			
		3	Largemouth bass	0.004[a,b] (0.004-0.005)	<0.02[a,b]	4.84[a,b] (4.51-5.06)			
		2	Spotted sucker	0.027[b] (0.025-0.029)	0.17[b] (0.066-0.27)	17.2[b] (14.6-19.7)			
Willow Creek	1991	2	Green sunfish	0.051[b] (0.042-0.059)	0.80[b] (0.69-0.9)	42.1[b] (31.2-53)	0.04[f] (0.02-0.06)	0.07[f] (<0.05-0.11)	25.3[f] (17.2-25.3)
		1	Bluegill	0.098[b]	2.2[b]	33.9[b]			
		1	Warmouth	0.026[b]	0.32[b]	34.6[b]			

Table 3.6. Mean metals concentrations in aquatic biota from surface waters in Cherokee County, Kansas, compared to background concentrations (cont.)

Mine-affected sampled area	Years sampled	Number of samples	Species	Concentration (mg/kg)			Mean background concentration (mg/kg)		
				Cd	Pb	Zn	Cd	Pb	Zn
Invertebrates									
Shoal Creek	1988	1	Insects	0.63[c]	4.5[c]	111[c]			
	1988	1	Crayfish	0.47[c]	2.6[c]	56[c]	0.11[d] (0.08-0.12)	<0.66[d] (<0.49-<1.07)	28.8[d] (19-44.9)
	1994	2		0.87[b] (<0.1-1.64)	2.22[b] (<1-3.43)	47.2[b] (20.3-74)			
	1994	2	Megaloptera	0.84[d] (0.35-1.32)	8.34[d] (2.25-14.4)	102.4[d] (76.2-128.5)	0.07[d] (0.05-0.08)	<0.49[d] (<0.45-<0.53)	24.35[d] (20.6-26.9)
	1994	1	Other invert. (probably molluscs)	0.39[d]	2.02[d]	77.9[d]			
Turkey Creek	1994	1	Megaloptera	0.97[d]	14.84[d]	137.5[d]	0.07[d] (0.05-0.08)	<0.49[d] (<0.45-<0.53)	24.35[d] (20.6-26.9)
		1	Crayfish	0.7[d]	3.54[d]	102.2[d]	0.11[d] (0.08-0.12)	<0.49[d] (<0.45-<0.53)	28.8[d] (19-44.9)

Mean is followed by range in parentheses. Wholebody unless specified.

a. Fillet.
b. Dames & Moore, 1993b.
c. Allen and Wilson, 1992.
d. Wildhaber et al., 1997.
e. Dames & Moore, 1995 (background concentrations for pelagic fish).
f. Dames & Moore, 1995 (background concentrations for benthic fish).

Invertebrate concentrations were as high as one to two orders of magnitude greater than background for all three metals. Megalopterans had average Cd concentrations as high as 14 times greater than background, average Pb concentrations as high as 30 times greater than background, and Zn concentrations as high as 6 times greater than background.

3.3.7 Terrestrial biota

Terrestrial biota metals tissue residues presented in this section include those from vegetation, invertebrates, and vertebrates from Cherokee County. With the exception of background concentrations of whole mice collected outside of the Baxter Springs area in Kansas, no background concentrations were readily available for comparison, and thus none are presented.

Cherokee County, Kansas

Tissue metals concentrations from both vegetation and small mammals in Cherokee County are presented in Table 3.7. Vegetation data presented here are from grass and sorghum plants sampled downwind of a smelter in Galena (active at the time of sample collection). Although there are no background concentrations for vegetation, background concentrations in whole mice were 0.12 mg/kg, 0.16 mg/kg, and 32.5 mg/kg for Cd, Pb, and Zn, respectively (Dames & Moore, 1993a). In comparison, tissue concentrations found in whole mice within the Baxter Springs and Treece subsites were 0.3 mg/kg, 1.2 mg/kg, and 35.1 mg/kg for the same three metals.

3.4 Conclusions

This chapter has shown the following:

- Pathways through which hazardous substances have been transported in the Tri-State Mining District include groundwater, surface water, sediment, air, soil, aquatic biota, and terrestrial biota

- Average concentrations of Cd, Pb, and Zn in the shallow aquifer of Cherokee County exceed background concentrations by up to one order of magnitude

- Mean Cd concentrations in surface water in Cherokee County were as high as one order of magnitude greater than background, and mean Pb and Zn concentrations were as high as two to three orders of magnitude above background

Table 3.7. Mean metals concentrations in terrestrial biota in near pile areas and downwind of a smelter in Cherokee County, Kansas

Mine-affected sampled area	Year sampled	Number of samples	Species	Concentration (mg/kg) Cd	Pb	Zn
Vegetation						
330-2,400 m downwind of active smelter, Galena	1971	5 Cd, 6 Pb, 6 Zn	Grass	5.12[a,b] (1.4-8.6)	48.4[a,b] (16.2-98.4)	420.2[a,b] (200-658)
1,830-2,000 m downwind of active smelter, Galena	1971	1-2	Sorghum (seeds)	1.3[a,b] (1-1.6)	30[a,b] (28-32)	22[a,b]
		2	Sorghum (stems)	3.8[a,b] (2.9-4.7)	27[a,b] (18-36)	20[a,b] (19-21)
		2	Sorghum (leaves)	5.6[a,b] (5.4-5.8)	61[a,b] (52-70)	110[a,b] (109-111)
Small mammals						
Baxter Springs/Treece	1991	10	Whole mice	0.3[c] (0.03-2.8)	1.2[c] (0.2-5.9)	35.1[c] (29.2-48.2)

Means with ranges in parentheses. Concentrations are dry weight, unless otherwise specified.

a. Wet weight.
b. Lagerwerff et al., 1972.
c. Dames & Moore, 1993a.

- Cd, Pb, and Zn concentrations in sediments of affected areas in Cherokee County were greater than site background concentrations by one to two orders of magnitude, and exceeded background concentrations from the Smoky Hill Catchment sediments by even more

- During smelter operation, air metals concentrations in Cherokee County were elevated over background, but more recent samples have a less consistent pattern

- Soil Cd, Pb, and Zn concentrations in Cherokee County were elevated over background concentrations by as much as one to two orders of magnitude

- Concentrations of all three metals are elevated in fish and invertebrate tissues in Cherokee County

- Little background data exist for metals concentrations in the tissues of terrestrial biota in the Tri-State District.

In summary, the data presented in this chapter confirm that all of the identified pathway components have been contaminated above background levels with the hazardous substances Cd, Pb, and Zn. This confirms that hazardous substances released from the sources identified in Chapter 2 are being transported through the Cherokee County Site environment via groundwater, surface water and sediments, soils, air, and aquatic and terrestrial pathways.

4. Preliminary Injury Evaluation

In this chapter we present a preliminary evaluation of whether the hazardous substances released into the environment in the Tri-State Mining District have injured natural resources. The natural resources addressed in this chapter are groundwater (Section 4.1), surface water and sediments (Section 4.2), aquatic biological resources (Section 4.3), and terrestrial biological resources (Section 4.4).

This evaluation is based on a review of data available to the Trustees in 1999. No new studies were undertaken. Injuries are evaluated based on regulatory definitions contained in federal regulations at 43 CFR Part 11. It should be noted that use of these regulations is not mandatory and that additional injury definitions could be applied.

It is emphasized that this document is not a final evaluation of natural resources injuries. Rather, it presents preliminary conclusions based on a previous review of information available in 1999, including remedial investigation (RI) reports and state agency documents. The conclusions that are expressed in this section therefore may change if and when new data are considered.

4.1 Groundwater

This section discusses potential injuries to groundwater resources in the Tri-State Mining District.

4.1.1 Description of groundwater resources

The groundwater resources in the Tri-State Mining District include a shallow and a deep aquifer. The shallow aquifer is mostly within the Boone Formation and is known as the Boone aquifer. The Boone Formation, which is principally composed of limestones and cherts, also contains the sulfide minerals that were mined. The thickness of the Boone aquifer varies widely throughout the Tri-State Mining District but may have an average thickness of 300-370 ft (OWRB, 1983b; Christenson, 1995; Dames & Moore, 1995).

The shallow and deep aquifers are separated by the Jefferson City and Cotter dolomites, which are about 400 ft thick on average (Dames & Moore, 1995). Below these dolomites is the Arbuckle Group, including the Roubidoux formation, a sandy dolomite, the Gasconade dolomite, and in Missouri, the Eminence, Potosi, and Lamotte formations. Water is generally extracted from each of the formations in the Arbuckle Group; the majority of the water coming from the Roubidoux formation, and thus the deep aquifer, is commonly known as the Roubidoux aquifer

(Christenson, 1995; Dames & Moore, 1995). A vertical cross section of both aquifers is shown in Figure 4.1. The Roubidoux aquifer is several hundred feet below the surface throughout the Tri-State Mining District. In Kansas, it ranges from 300 to 1,800 ft below the surface (Barks, 1977).

The shallow aquifer is generally near the surface in eastern Kansas, and recharge is via brecciated (fractured) carbonate rocks at the surface as well as abandoned mine shafts. The flow is generally from east to west through the Tri-State area, with a slight northwest deflection from Picher, Oklahoma, through Baxter Springs. At high flows, the shallow aquifer will discharge to surface water in Kansas via old mine shafts; however, generally the shallow aquifer does not discharge to surface water in Kansas and Oklahoma to the same extent that it does in Missouri because it dips gradually as it flows to the west. At the western edge of the mining district in Oklahoma and Kansas, the shallow aquifer is about 100 ft below the surface (Spruill, 1984; Dames & Moore, 1993b).

The deep aquifer recharges at outcroppings in the Ozarks east of the Tri-State Mining District. There is no known recharge of the deep aquifer from within the mining area, and the only known discharges are via municipal and industrial wells. In general, the water in the deep aquifer also flows from east to west through the area. However, a large cone of depression formed under Miami, Oklahoma, due to intensive groundwater extraction by the B.F. Goodrich manufacturing plant, a tire manufacturer that closed in 1986. This cone of depression deflects groundwater flow toward Miami from all directions, including from Baxter Springs and Picher to the north. Between 1986, when tire manufacturing ended, and 1993, the groundwater levels increased 30 m in the aquifer below Miami (Spruill, 1984; Christenson, 1995; Dames & Moore, 1995).

The hydraulic head of the deep aquifer is lower than that in the shallow aquifer; thus the gradient indicates a potential vertical groundwater flow from the shallow to the deep aquifer. However, the transmissivities of the Jefferson City and Cotter dolomites are more than an order of magnitude less than those of the Boone and Roubidoux formations. Therefore, the Jefferson City and Cotter formations act as a barrier to flow between the aquifers (Dames & Moore, 1995). Flow between the Boone aquifer and the Roubidoux aquifer is discussed in Section 4.1.3.

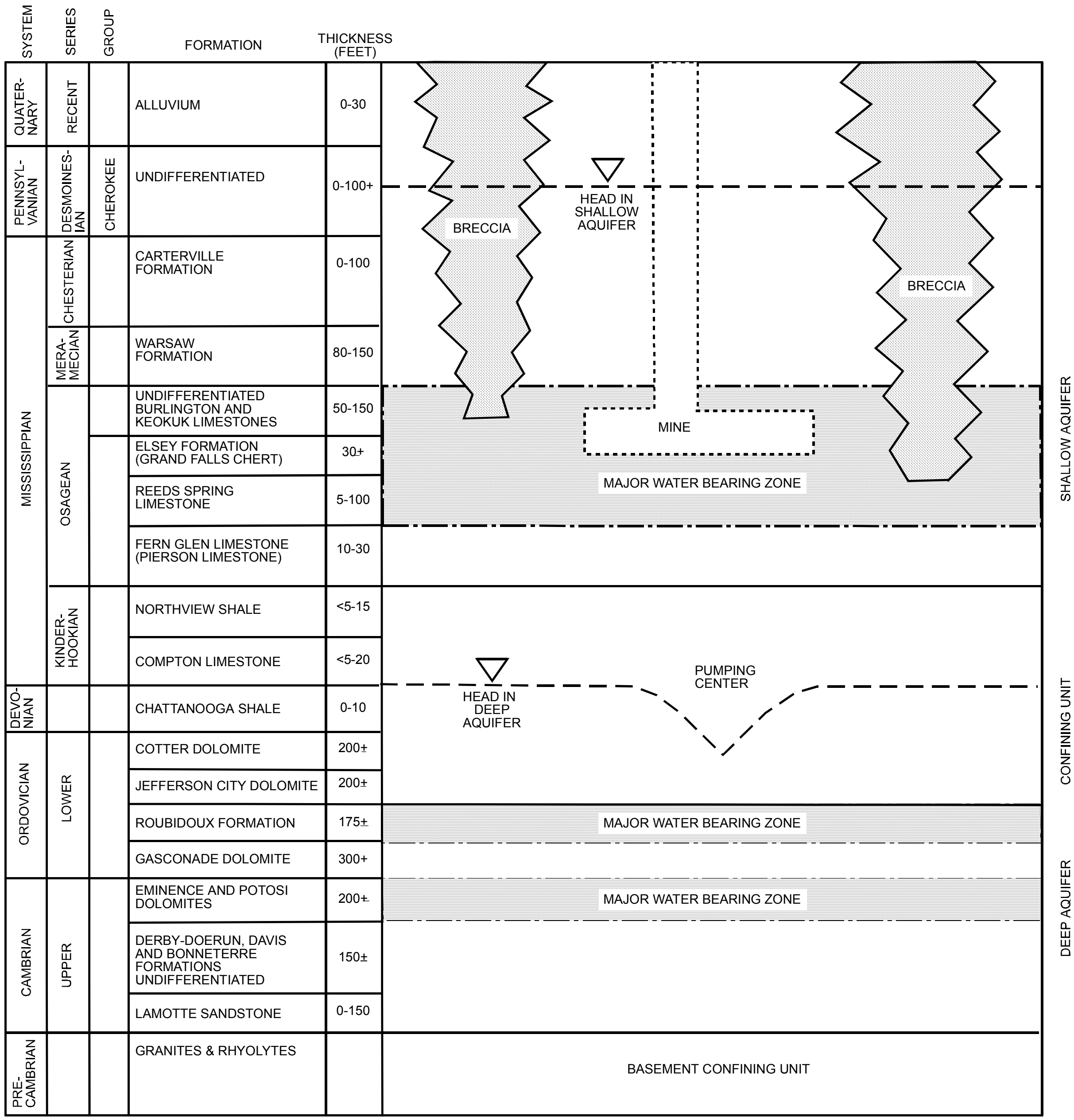

Figure 4.1. Cross-section of deep (Roubidoux) and shallow (Boone) groundwater aquifers in the Tri-State Mining District.

Source: Adapted from Dames & Moore, 1995.

4.1.2 Definitions of injury to groundwater

According to federal regulations, injuries to groundwater resulting from releases of hazardous substances occur when one or more of the following definitions are met:

- Concentrations of substances in excess of drinking water standards established by sections 1411-1416 of the Safe Drinking Water Act (SDWA), or by other Federal or State laws or regulations that establish such standards for drinking water, in groundwater that was potable before the discharge or release [43 CFR § 11.62(c)(1)(i)]

- Concentrations and duration of substances in excess of drinking water standards as established by section 1401(1)(D) of the SDWA, or by other Federal or State laws or regulations that establish such standards [43 CFR § 11.62(c)(1)(ii)]

- Concentrations of substances in excess of applicable water quality criteria established by section 304 (a)(1) of the Clean Water Act (CWA), or by other Federal or State laws or regulations that establish such criteria for domestic water supplies [43 CFR § 11.62(c)(1)(iii)]

- Concentrations of substances sufficient to have caused injury to surface water, air, geologic, or biologic resources when exposed to groundwater [43 CFR § 11.62(c)(1)(iv)].

In the Tri-State Mining District, the injuries described in the last definition of injury are most likely to occur when contaminated groundwater comes into contact with and contaminates surface waters. These injuries are evaluated in the surface water resources section of this report (Section 4.2).

The relevant standards for groundwater injury under the first definition include primary drinking water standards, maximum contaminant levels (MCLs), maximum contaminant level goals (MCLGs), and secondary maximum contaminant levels (SMCLs) established by the U.S. EPA under the SDWA, CWA drinking water criteria, and relevant state drinking water or groundwater quality standards.

The State of Kansas has promulgated water quality criteria at K.A.R. 28-16-28e, dated January 15, 1997. The U.S. EPA and State of Kansas groundwater quality standards are presented in Table 4.1. Kansas has not promulgated a drinking water criterion for Zn. However, the maximum Zn concentration for irrigation water is 2,000 μg/L, compared to the U.S. EPA groundwater criterion of 5,000 μg/L.

Table 4.1. Groundwater quality standards (µg/L)

Contaminant	MCL/MCLG	SMCL	CWA criteria	State of Kansas groundwater standards	
				Drinking water	Groundwater
Cadmium	5/5	—	—	5	5
Iron	— / —	300	—	—	—
Lead	15/ —[a]	—	—	15	15
Manganese	— / —	50	—	—	—
Nickel	[b]	—	610	100	100
Zinc	— / —	5,000	9,100	—	2,000[c]
TDS (mg/L)	— / —	500	—	—	—
Sulfate (mg/L)	— / —	250	—	250	—

— = No standard available.

a. Treatment technique in effect; action level = 15 µg/L.
b. Ni MCL/MCLG was 100 µg/L; that statute has been remanded as of June 1995 (60FR33926).
c. State of Kansas criterion for irrigation.

Sources:
MCL: 40 CFR § 141.
MCLG: 40 CFR § 141.51.
SMCL: 40 CFR § 143.

4.1.3 Injuries to the Roubidoux (deep) Aquifer

Although much of the available data in the RI/FS and U.S. Geological Survey (USGS) studies in the area focus on contamination in the Boone aquifer, there are more limited data that indicate that the Roubidoux aquifer could potentially be injured by the migration of contamination from the shallow aquifer. These data come from all three states of the District.

Feder et al. (1969) collected groundwater data from Roubidoux aquifer wells near Joplin, Missouri. They found indications that the shallow aquifer water had contaminated the Roubidoux aquifer, based on calcium/magnesium ratios and on a slight increase in Zn concentrations in the wells closest to mine sites. However, with the exception of Fe, none of the measured constituents approached concentrations sufficient to cause injury (as defined in Section 4.1.2). Several wells contained Fe in excess of the criterion of 300 µg/L, both within and outside the Tri-State Mining District, indicating that the source of the Fe may be natural.

The USGS (Spruill, 1984) looked closely at the potential for deep aquifer contamination from mine waste. They hypothesized that water could migrate from the shallow to the deep aquifer via open drill holes, abandoned wells, or “windows” such as large fractures through the confining layers. They state that, as of 1984, there were no definitive data to confirm movement of water between the aquifers. Moreover, they suggest that the aquifers are not connected, based on data showing cones of depression and changes in the water level in the shallow aquifer that have no effect on the deep aquifer. However, the USGS (Spruill, 1984) did present hypothetical models of water migration through an open well casing, and through natural pathways suggested by hydraulic head changes between aquifers. Their model suggests the potential for 3 million gallons per year to migrate from the shallow to the deep aquifer.

Data from the OWRB (1983b) show little evidence of groundwater injury in the Roubidoux aquifer in the late 1970s and early 1980s. They analyzed seven different municipal wells on multiple occasions for a total of 24 samples. Five of the seven wells had at least one sample that contained Fe in excess of 300 µg/L. One sample, from Quapaw, contained 100 µg/L Pb, which exceeds the Pb drinking water standard, and one other sample contained sulfate at 530 mg/L, which also exceeds the drinking water standard. The Quapaw sample also contained 19,000 µg/L Fe and 3,600 µg/L Zn, which is evidence of metals contamination, though the source of the contamination is not known. No other constituents from any other samples were at levels indicative of groundwater injury.

Another USGS study in 1990 (USGS, 1990, as cited in Dames & Moore, 1993b) reported deep water aquifer samples that exceeded drinking water standards for several parameters, including sulfate, cadmium, iron, manganese, and zinc. However, according to Dames & Moore, “the USGS concluded that all of the deep water aquifer contamination by mine water can be explained by faulty well seals or leaky casings and that none of the available data indicated that mine water has migrated from the shallow aquifer to the deep aquifer through the intervening geological units” (Dames & Moore, 1993b, pp. 2-36). In response to these data, the U.S. EPA cleaned and plugged at least 26 deep aquifer wells near Baxter Springs and Treece, as part of the Tar Creek NPL site remediation (Dames & Moore, 1993b, pp. 2-39).

In RI/FS studies, Dames & Moore (1993b, 1995) analyzed water samples from the deep aquifer. In Baxter Springs, two municipal wells drilled into the Roubidoux aquifer were sampled on multiple occasions, for a total of eight deep aquifer water samples. Concentrations of the hazardous substances were below injury thresholds in all samples, and were undetectable in almost all cases. In the Jasper County RI/FS, Dames & Moore (1995) collected water samples from 21 of the 25 known wells in the deep aquifer. One sample contained Cd at 5 µg/L, equaling the drinking water standard. No other injury thresholds were approached for other chemical constituents in any of the samples. These RI/FS data show little evidence of injury to the Roubidoux aquifer.

The USGS (Christenson, 1995) conducted a follow-up study on potential contamination in the Roubidoux aquifer in the early 1990s. Their summary of previously existing data includes some concentrations of contaminants from Roubidoux wells that are well in excess of injury thresholds. These data include the following maximum concentrations: 2,000 mg/L sulfate, 710 µg/L Cd, 260,000 µg/L Fe, 29 µg/L Pb, and 84,000 µg/L Zn. Christenson (1995) collected water samples from over 50 private and municipal wells drilled into the Roubidoux aquifer in northeastern Oklahoma, both near and distant from the mining district. They found that 7 of 10 municipal wells near Picher, Oklahoma contained significantly higher concentrations of various mine-related chemical constituents than did wells that were not near mining. However, relatively few of the samples exceeded injury thresholds. Iron concentrations exceeded the 300 µg/L injury threshold in several samples from Commerce and Quapaw, in most samples from Picher, and in a few samples from Miami. Several samples in Commerce and many samples in Picher contained sulfate in excess of the 250 µg/L injury threshold. One sample from Cardin contained Pb at 237 µg/L. No other samples contained Pb exceeding the 15 µg/L threshold. Similarly, two samples from Picher contained Cd at 5.1 µg/L; no other samples exceeded the 5.0 µg/L Cd injury threshold.

The USGS (Christenson, 1995) draws no conclusions regarding the source of the contamination in these wells. They report that one well in Picher was found to have a cracked casing that allowed shallow aquifer water to leak in. That well was taken off line, sealed, and abandoned. Further study would need to be conducted to determine the source contamination in the Roubidoux aquifer. Based on the available data presented above, it appears that localized injury to the Roubidoux is possible, but definite conclusions regarding the degree and extent of contamination cannot be drawn at this time.

4.1.4 Groundwater injury evaluation (shallow aquifer): Cherokee County, Kansas

The majority of available Cherokee County groundwater chemistry data comes from the RI activities at the Cherokee County NPL site, including data from Dames & Moore (1993c) and data from U.S. EPA presented by CH2M Hill (1987b, 1989). Additional data come from USGS studies from the 1980s (Spruill, 1984; Parkhurst, 1987). A small amount of data comes from USGS studies from the 1970s (Playton et al., 1978).

A summary of groundwater criteria exceedences in Kansas groundwater is presented in Table 4.2. In addition, Figures 4.2 through 4.4 show representative concentrations of Cd, Pb, and Zn that exceeded their respective criteria in the Kansas studies.

Table 4.2. Exceedences of groundwater criteria in Cherokee County, Kansas

Year sample taken	Type of sample	Number of locations	Number of samples	Number of samples exceeding groundwater criterion							
				Cd	**Fe**	**Pb**	**Mn**	**Ni**	**Zn**	**TDS**	**SO_4**
1976-1977[b]	Lucky Jew mine shaft	1	8	2	5	0	5	5	4	8	8
1981-1982[c]	Shallow aquifer at mine sites	18	33	23	9	11	24		15	10	22
1985[d]	Private wells		110	10[a]	36	0[a]	23		6		
1985[d]	Mine shafts		15	11[a]	3	5[a]	11		11		
1988[e]	Private wells and two mine shafts	16	22	5	8	3	3	2	1		
1991[f]	BS/T mine shafts and chat wells	12	76	31	63	33	66	34	32	67	63

Blank = not analyzed; samples are dissolved concentrations unless otherwise noted.
Concentrations are total recoverable rather than dissolved.

a. Cd samples exceeding 10 : g/L (rather than 5 : g/L standard); Pb samples exceeding 50 : g/L (rather than 15 : g/L action level).
b. Playton et al., 1978.
c. Spruill, 1984.
d. CH2M Hill, 1987b.
e. CH2M Hill, 1989.
f. Dames & Moore, 1993c.

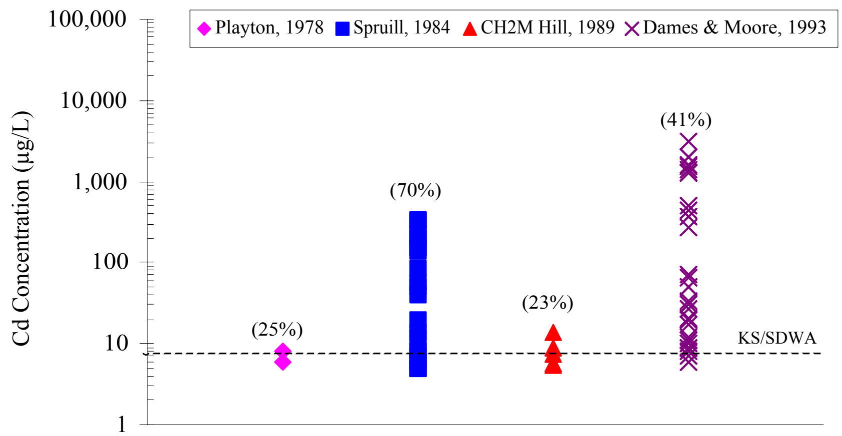

Figure 4.2. Cadmium concentrations in Kansas groundwater exceeding the 5 µg/L SDWA and State of Kansas groundwater criteria (represented by the dashed line). Note the logarithmic scale on the y-axis. The numbers in parentheses represent the percent of samples that exceeded the criteria.

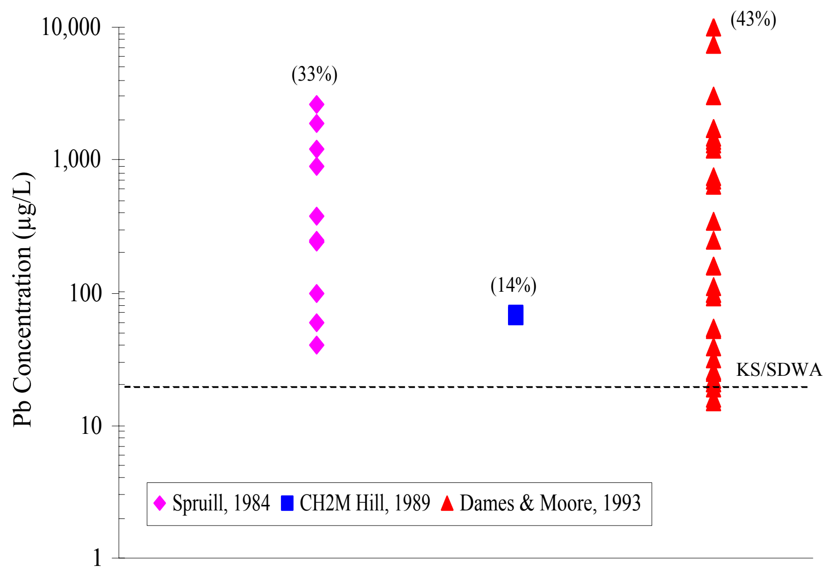

Figure 4.3. Lead concentrations in Kansas groundwater exceeding the 15 µg/L SDWA and State of Kansas groundwater criteria (represented by the dashed line). Note the logarithmic scale on the y-axis. The numbers in parentheses represent the percent of samples that exceeded the criteria.

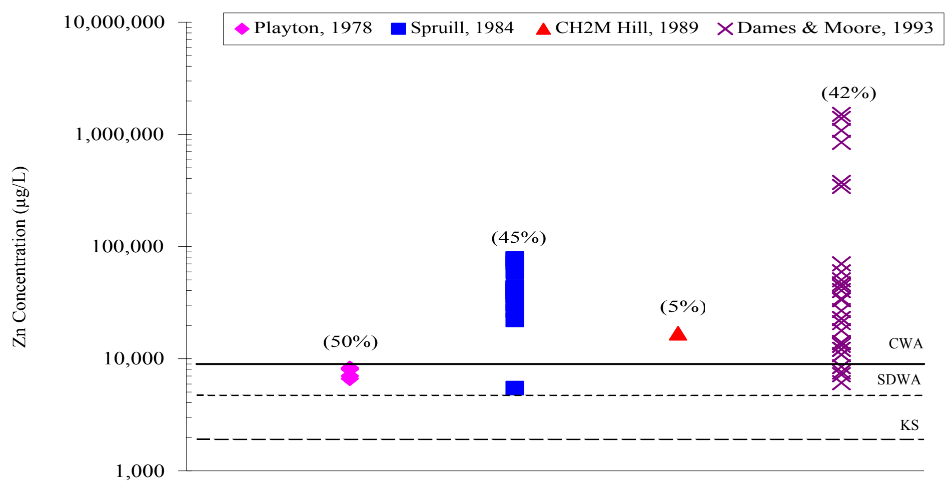

Figure 4.4. Zinc concentrations in Kansas groundwater exceeding the SDWA and State of Kansas groundwater criteria. The short dashed line represents the 5,000 µg/L SDWA criterion, the continuous line represents the 9,100 µg/L CWA criterion, and the long dashed line represents the 2,000 µg/L Kansas irrigation water criterion. Note the logarithmic scale on the y-axis. The numbers in parentheses represent the percent of samples that exceeded the criteria.

In the 1970s, the USGS (Playton et al., 1978) collected eight shallow aquifer water samples from the Lucky Jew mine near Treece, Kansas. Several groundwater criteria were exceeded in these samples (Table 4.2). Figures 4.2 and 4.4 show exceedences of Cd and Zn criteria, respectively. There were no Pb exceedences. All of the sulfate and total dissolved solids (TDS) levels exceeded groundwater criteria; many samples exceeded 1,000 mg/L, compared to the respective criteria of 250 and 500 mg/L. Several samples contained Mn in excess of 2,000 µg/L, with concentrations as high as 5,100 µg/L, over two orders of magnitude greater than the Mn criterion. In addition, several samples contained Ni concentrations greater than 200 µg/L, more than twice the Ni criterion.

USGS data from the early 1980s (Spruill, 1984) show consistent exceedences of groundwater criteria (Table 4.2) for all contaminants listed in Table 4.1. Water samples were collected from the shallow aquifer from mine shafts. Several samples contained Cd concentrations in excess of 200 µg/L, up to 340 µg/L, some 68 times greater than the Cd criterion (Figure 4.2). Three samples contained Pb concentrations greater than 1,000 µg/L (Figure 4.3), up to 2,600 µg/L, almost 175 times greater than the criterion. Finally, 14 of the samples contained Zn in excess of 20,000 µg/L, four times greater than the SDWA standard, twice as great as the CWA criterion, and an order of magnitude greater than the Kansas irrigation water standard. The maximum Zn concentration was 79,000 μg/L, almost 40 times greater than the Kansas irrigation standard.

The U.S. EPA (1988a, 1988b) collected a large number of groundwater samples from the Galena subsite in Cherokee County. CH2M Hill (1987b) presented an analysis of these data, but the analysis does not contain actual concentrations of contaminants in the samples; analysis of the raw water quality data from these studies was beyond the scope of this preliminary evaluation. However, the number of individual samples that exceeded groundwater criteria for the main hazardous substances is presented in Table 4.2 (CH2M Hill, 1987b). Note that CH2M Hill compared Cd and Pb concentrations to criteria that are higher than the current criteria for groundwater injury. Cd, Mn, and Zn concentrations from mine shaft water exceeded the CH2M Hill criteria in 11 of 15 samples collected. In addition, concentrations of Cd, Fe, Mn, and Zn exceeded drinking water criteria in 10, 36, 23, and 6 private water wells, respectively (Table 4.2).

CH2M Hill (1989) present supplemental groundwater quality data from the Galena subsite in Cherokee County, including tables of data. Groundwater quality exceedences for the hazardous substances are shown in Table 4.2. Cd concentrations were exceeded in five samples, with a maximum concentration of 14 μg/L (Figure 4.2). Similarly, Pb concentrations were exceeded in three samples, which contained Pb at 67 ± 1 μg/L (Figure 4.3), over four times greater than the Pb criterion. Only one sample contained Zn at concentrations exceeding the Zn criterion; that sample contained 17,000 μg/L Zn (Figure 4.4). Fe concentrations were exceeded in eight samples (Table 4.2), with a maximum concentration of 20,000 μg/L, some 67 times greater than the Fe groundwater criterion. Mn concentrations were as high as 410 μg/L, over eight times greater than the criterion, and the maximum Ni concentration was 310 μg/L, over three times higher than the criterion.

Dames & Moore (1993c) collected many samples from the shallow aquifer in mine shafts and from groundwater underlying chat piles. Most of the samples were analyzed for total recoverable metals instead of dissolved; therefore, the example concentrations cited below are total recoverable.

Table 4.2 summarizes the number of samples that exceeded groundwater quality criteria for the hazardous substances in Baxter Springs and Treece (Dames & Moore, 1993c). The criteria for each of the hazardous substances were exceeded in at least 30 samples, and the criteria for Fe, Mn, TDS, and sulfate were exceeded in at least 63 of 76 samples (Table 4.2). Samples that exceeded groundwater criteria for Cd, Pb, and Zn are shown in Figures 4.2 through 4.4, respectively. The highest measured concentrations of each of these contaminants in the shallow aquifer exceed groundwater criteria by close to three orders of magnitude. Several samples were reported to contain Cd and Pb concentrations in excess of 1,000 μg/L, and Zn concentrations exceeding 1,000,000 μg/L.

In Galena, CH2M Hill (1989) sampled groundwater in shallow aquifer wells at depths ranging from 12 to 450 feet. There was no consistent relationship between depth and any of the metals concentrations. This may be explained by the fact that rocks comprising the shallow aquifer are highly brecciated with a high density of solution channels (CH2M Hill, 1989). This may allow a high transmissivitity resulting in a rapid vertical mixing of the water in the aquifer.

Quantification of Groundwater Injuries in Cherokee County, Kansas

The data presented above shows that groundwater below mine waste piles and in mine shafts in Cherokee County, Kansas, is heavily contaminated with hazardous substances, particularly Cd, Pb, and Zn. However, no analyses have been published identifying the spatial extent of groundwater injury (i.e., including groundwater associated with mine sites and groundwater downgradient of those sites) in the Kansas component of the Tri-State Mining District. Nevertheless, based on published information, it is possible to arrive at an approximate estimate of the area of injury.

Based on potentiometric measurements, Spruill (1984) estimated that approximately 7 million acre-feet of shallow aquifer groundwater underlie the entire Tri-State Mining District. Using the same assumptions that Spruill used (7% porosity, a mean shallow aquifer thickness of 200 feet, and a storage coefficient of 0.0002) and by estimating the total spatial extent of the Kansas NPL sites (30.5 square miles), we estimate that approximately 300,000 acre-feet of Kansas groundwater is contaminated. This estimate is likely to be conservative since it assumes that contamination does not extend beyond the NPL sites and the average thickness of the injured aquifer may exceed 200 ft. Using the OWRB (1983b), Christenson (1995), or Dames & Moore (1995) estimates of 300-370 ft, the estimated extent of contaminated groundwater underlying Cherokee County increases to between 450,000 and 550,000 acre-feet.

4.1.5 Conclusions

The data presented in this section support the following conclusions:

- In Kansas, water samples from abandoned mine sites and from the shallow water aquifer contain concentrations of hazardous substances sufficient to cause injury to groundwater. These injuries include:
    - Exceedences of SDWA criteria
    - Exceedences of CWA criteria
    - Exceedences of State of Kansas water quality criteria.
- The above criteria were exceeded for Cd, Fe, Pb, Mn, Ni, Zn, TDS, and SO_4.

- In many locations, the groundwater quality criteria for the hazardous substances and other analytes listed above were exceeded by up to three orders of magnitude.

- Although there are few data on which to base estimates of the spatial extent of groundwater contamination, it seems likely from the data that have been published that between 300,000 and 550,000 acre-feet of groundwater in Kansas have been injured by hazardous substances in the Tri-State Mining District.

4.2 Surface Water and Sediments

This section discusses potential injuries to surface water resources and aquatic sediments in the Cherokee County Site. Federal regulations define surface water resources as including both the surface water and bed, bank, and shoreline sediments [43 CFR 11.14 § (pp)]. For purposes of our evaluation, we have separated our analysis into a discussion of surface water, first, followed by a discussion of stream and lake sediments.

It should be noted that subsequent to producing the first draft of this report, additional data were identified by the State of Kansas that indicate that injuries to surface water and biological resources may be more severe and widespread in the Spring River than determined in this document. Because of this, this evaluation may underestimate the degree and spatial extent of these injuries.

4.2.1 Definitions of injury to surface water and sediments

Relevant definitions of injury to surface waters and sediments include:

- Concentrations of released hazardous substances in excess of drinking water standards established under the SDWA, or other Federal or State laws that establish such standards, in surface water that was potable before the discharge or release, or that met the criteria prior to release and is a committed use as a public water supply [43 CFR § 11.62 (b)(1)(ii)]

- Concentrations and duration of substances in excess of applicable water quality criteria established by Section 304(a)(1) of the CWA, or by other Federal or State laws or regulations that establish such criteria . . . in surface water that before the discharge or release met the criteria and is a committed use . . . as a habitat for aquatic life, water supply, or recreation [43 CFR § 11.62 (b)(1)(iii)]

- Concentrations and duration of substances sufficient to have caused injury . . . to . . . biological resources when exposed to surface water or sediments [43 CFR § 11.62 (b)(1)(v)].

Relevant federal water quality criteria for evaluating injuries to surface water injury include ambient water quality criteria (AWQC) for protection of aquatic life and criteria for the protection of human health, established by the U.S. EPA pursuant to Section 304 of the CWA [40 CFR § 131.36 (b)(1)].

The AWQCs issued under section 303(c)(2)(B) of the CWA [62FR42160, and amended by U.S. EPA (1999 — EPA 822-Z-99-001)] provide hardness-dependent criteria for the hazardous substances released from mine wastes in the Tri-State Mining District. Table 4.3 provides the criteria maximum concentration (CMC) and criteria continuous concentration (CCC) for these contaminants, where the CMC is the short-term maximum concentration not to be exceeded more than once in a three-year period, and the CCC is a 4-day average, not to be exceeded more than once in a three-year period.

With the exception of Fe, the toxicity of each of the hazardous substances discussed in this section depends on the hardness of the water as measured in mg/L as $CaCO_3$. The federal AWQC and the State of Kansas criteria are determined by equations with hardness as the only variable.

Hardness varies widely in the Tri-State Mining District. For example, the hardness in Willow Creek, Kansas, ranged from 45 to 660 mg/L depending on time of year and flow level (Dames & Moore, 1993b). The U.S. EPA guidance for AWQCs specifies that in waters with hardness greater than 400 mg/L as $CaCO_3$, increasing hardness has little effect on the toxicity of metals.

Therefore, where hardness was reported to be less than 400 mg/L in the source documents, we calculated hardness-specific criteria. We used the calculated AWQCs at 400 mg/L hardness when actual hardness was higher than 400 mg/L. In documents that did not include hardness data, we conservatively assumed that the hardness was 200 mg/L for Kansas waters.

Water quality criteria are also dependent on filtration method: criteria are different for contaminants in the dissolved (filtered) fraction, compared to total recoverable. The federal AWQCs were originally promulgated for the total recoverable fraction, but were subsequently changed to dissolved concentrations based on hardness-dependent conversion factors (40 FR 22228). The regulations for Kansas specify that their criteria apply to the dissolved fraction. If a study reported in this preliminary evaluation described only total recoverable concentrations of contaminants, we compared those concentrations to the total recoverable AWQC (and not to either federal or state dissolved criteria).

Table 4.3. Water quality criteria as determined by hardness for hazardous substances in Cherokee County (hardness is in mg/L as $CaCO_3$; metals in μg/L; bold = lowest concentration)

Regulation	Criterion	Hardness[a]	Cd	Fe	Pb	Ni	Zn
U.S. EPA CWA AWQC, EPA 822-Z-99-001, April 1999	CMC – dissolved	200	9.0		140	840	210
	CCC – dissolved		3.7		**5.3**	**93**	**210**
	CMC – total		9.9		200	840	220
	CCC – total		4.2		7.7	94	220
State of Kansas K.A.R. 28-16-28e[b]	ALC – acute		10.3		395	3,059	253
	ALC – chronic		2.3		30.8	340	229
U.S. EPA CWA AWQC, EPA 822-Z-99-001, April 1999	CMC – dissolved	400	19		280	1,500	380
	CCC – dissolved		6.2		**11**	**170**	**380**
	CMC – total		22		480	1,500	390
	CCC – total		7.3		19	170	390
State of Kansas K.A.R. 28-16-28e	ALC – acute		22.5		954	5,499	455
	ALC – chronic		**4.0**		74.3	611	412

a. The criteria (except Fe) depend on the hardness of the water. Two sets of criteria are presented: moderately high hardness (200 mg/L) and very high hardness (400 mg/L). The AWQC and Kansas criteria are calculated from equations.
b. Criteria apply to dissolved concentrations of contaminants.

CMC = Criteria maximum concentration, average not be exceeded more than once in 3 years.
CCC = Criteria continuous concentration, 96-h average not be exceeded more than once in 3 years.
GWWF = General warm-water fishery, waters in which naturally occurring water quality and habitat conditions allow the maintenance of a wide variety of warm-water biota, including naturally reproducing populations of recreationally important fish species. LWWF = Limited warm-water fishery, waters in which natural water quality and/or habitat conditions prevent the maintenance of naturally reproducing populations of recreationally important fish species.
CWA AWQC = Clean Water Act, ambient water quality criteria.
Acute ALC = Assumed to mean the aquatic life criterion for short-term exposure, analogous to the U.S. EPA CMC.
Chronic ALC = Assumed to mean the aquatic life criterion for 96-h exposure, analogous to the U.S. EPA CCC.
Acute and chronic ALC, are not expressly defined in K.A.R. 28-16.

It should be noted that much of the data that are available for lead in surface waters refers to total concentrations. Much of the lead in these total concentrations may be bound to particulate material and, therefore, less bioavailable to aquatic life. We have, where possible, identified in the following analyses whether lead data refer to dissolved or total concentrations. Lead's affinity for binding to particulate material and reduced bioavailability should be borne in mind when interpreting total concentration data. In addition, while particulate lead is less available for uptake via the water column, it is still available to filter feeding organisms.

The U.S. EPA has concluded that waters flowing from Missouri into Kansas must meet the downstream (i.e., Kansas) standard at the state line (D. Moseby, MDNR, personal communication, 2000). Therefore, for a number of the contaminated waterbodies in Missouri, application of the lower Kansas State standards has regulatory relevance.

The State of Kansas has also issued its own set of aquatic life criteria (ALC) in the Kansas Administrative Record at K.A.R. 28-16-28e (Table 4.3). These criteria are similar to the federal AWQCs. Though not specified in the regulations, it is assumed that the acute and the chronic ALCs in Kansas have the same definition as the CMC and CCC, respectively, in the federal regulations.

4.2.2 Cherokee County, Kansas

It should be noted that the opinions expressed in this section of the report are based on data supplied to Stratus Consulting by the State of Kansas during the development of the preceding draft. Since then, additional surface water chemistry data have been provided by the State of Kansas that indicate that injuries to surface water (e.g., exceedences of federal water quality criteria) in the Kansas portion of the Spring River are likely to be more severe and widespread than reported in this document.

The majority of surface water quality data for Cherokee County that are used in this report comes from the USGS study in the 1980s (Spruill, 1984) and the Baxter Springs/Treece RI activities at the Cherokee County NPL site (Dames & Moore, 1995).

The U.S. EPA collected many water samples in the Galena subsite (U.S. EPA, 1988b). These data were summarized in various documents such as CH2M Hill (1987b) and Dames & Moore (1993a). We have included these data in this evaluation wherever we are confident about their origins.

The three creeks in the Kansas portion of the Tri-State Mining District that are perennial streams and most likely to have sustained injury from releases of hazardous substance are Short Creek, Willow Creek, and Tar Creek (Figure 4.5). The data from the USGS and RI/FS studies indicate that all three of these creeks have had concentrations of Cd, Pb, and Zn in excess of water quality criteria, with some Zn concentrations orders of magnitude greater than the AWQC CMC criterion.

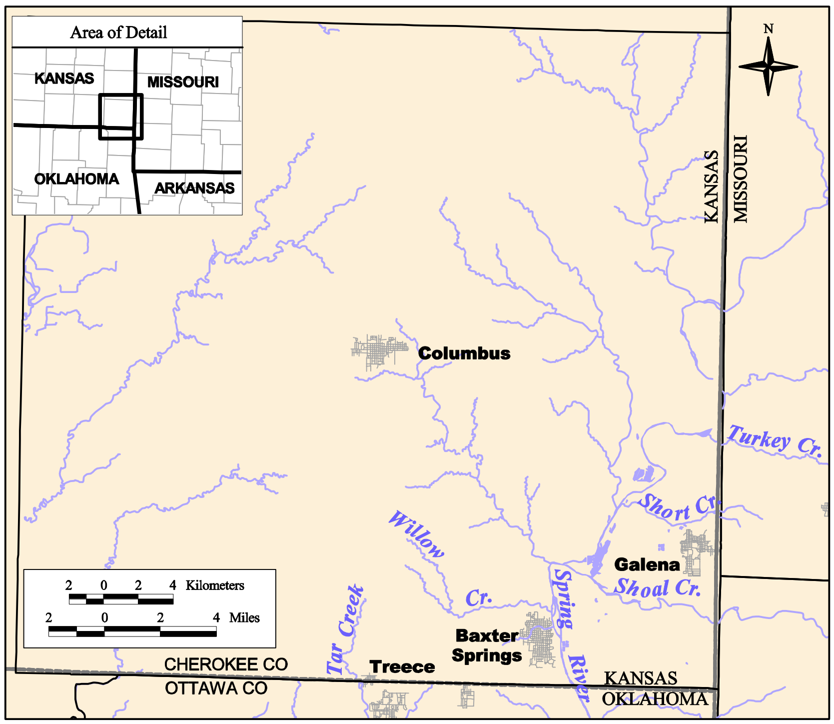

Figure 4.5. Main drainages in the Kansas portion of the Tri-State Mining District.

Short Creek passes through mined areas near Joplin, then crosses into Kansas and passes through the mined areas of the Galena subsite in Cherokee County before discharging to the Spring River. The USGS (Spruill, 1984) collected several samples from Short Creek near Galena and found Cd concentrations (Figure 4.6) and Zn concentrations (Figure 4.7) well in excess of surface water criteria. Hardness was not reported with these samples; however, even if one very conservatively assumes 400 mg/L, the maximum concentrations exceed criteria by orders of magnitude. Cd concentrations were as high as 290 µg/L, over 70 times greater than the Kansas chronic ALC, and almost 50 times greater than the AWQC CCC. The maximum Zn concentration was 28,000 µg/L, almost 75 times greater than the AWQC CMC for 400 mg/L hardness, and almost 70 times greater than the Kansas chronic ALC.

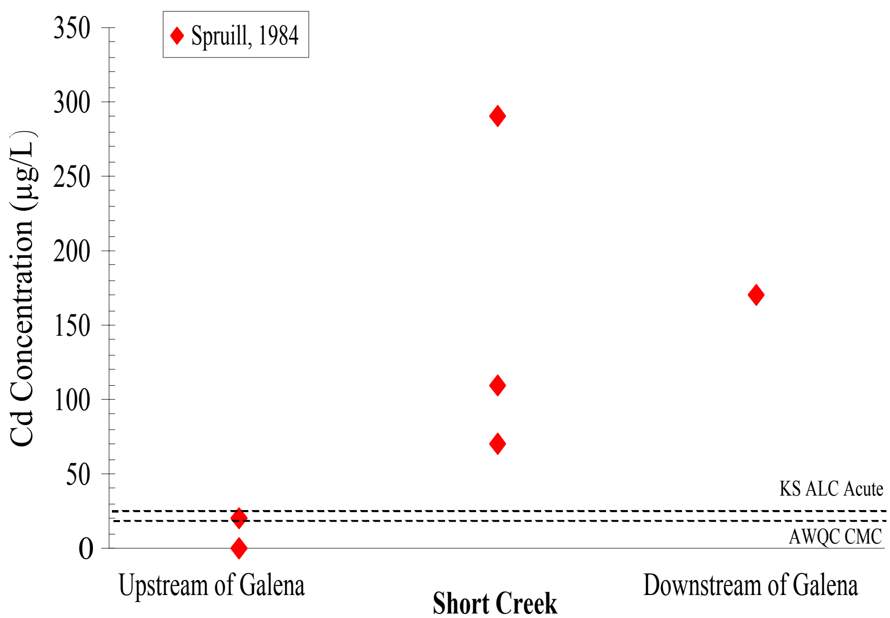

Figure 4.6. Cd concentrations from Short Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed lines represent the approximate average AWQC CMC and Kansas acute ALC; AWQC and ALC chronic criteria were exceeded by all samples. The CMC and CCC are hardness-dependent and therefore are different for each sample.

The U.S. EPA (1988b) collected several samples from Short Creek as part of the Galena subsite RI/FS. They compared their data to surface water standards from the 1980s, which do not correspond with current guidance. They also failed to distinguish the main stem of Short Creek from its tributaries. Nevertheless, the summarized data indicate that Short Creek has been injured by this injury test. The U.S. EPA (1988b) compared their Cd data to a criterion of 3.9 µg/L, which corresponds closely to the 4.0 µg/L Kansas chronic ALC for 400 mg/L hardness. Twenty of 22 samples from Short Creek and its tributaries exceeded this standard. Twenty-two of 23 samples exceeded a 180 µg/L criterion for Zn, a criterion that corresponds to the current AWQC CMC at a hardness of 165 mg/L as $CaCO_3$. These data indicate that the surface water of Short Creek in Kansas has been injured by releases of the hazardous substances Cd and Zn.

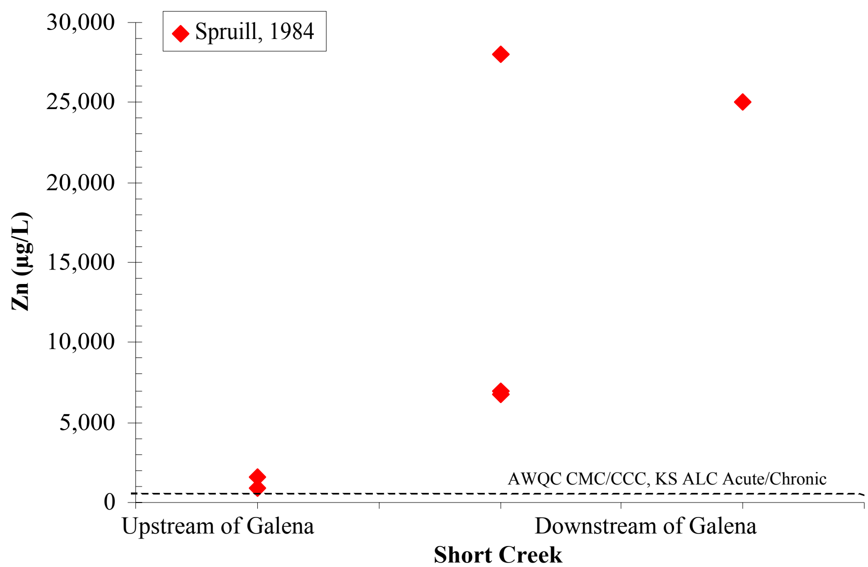

Figure 4.7. Zn concentrations from Short Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed line represents the following criteria: AWQC CMC, AWQC CCC, Kansas acute ALC, and Kansas chronic ALC. All criteria are hardness-dependent and therefore are different for each sample.

The U.S. EPA (1988b) and CH2M Hill (1987b) also present criteria exceedences in Shoal Creek south of Galena. As in Short Creek, the Shoal Creek samples and the samples from the Shoal Creek tributaries are not distinguishable in the U.S. EPA report. No hardness data are provided, making it difficult to determine if current water quality criteria have been exceeded. Of the four samples containing suitably low detection limits, all four exceeded 1.1 µg/L Cd, but none of the four exceeded 3.9 µg/L (U. S. EPA, 1988b). Three of seven samples exceeded 82 µg/L Pb. Again, it is not possible to determine if those contaminated samples came from tributaries or the main stem. Finally, five of seven samples exceeded 120 µg/L Zn.

The State of Kansas collected water samples from Shoal Creek at various times between 1967 and 1986 (CH2M Hill, 1987b). The summarized data indicate that Zn criteria were exceeded in some of the samples, and Cd and Pb concentrations may have exceeded criteria. Further investigation of these data is required to draw conclusions about surface water injury; however, it appears likely that Shoal Creek in Cherokee County has been injured by releases of hazardous substances from mine sites.

CH2M Hill (1987b) also summarized Spring River hazardous substance data. They do not report concentrations; they only summarize exceedences of water quality criteria that appear to be for inappropriately soft water. While these data, as presented, are difficult to interpret, there appear to be some samples from the Spring River that exceed water quality standards:

- Near Waco, two samples contained Pb concentrations exceeding 82 μg/L
- Near Baxter Springs, at least one sample contained Cd approaching 10 μg/L, three samples contained Pb exceeding 82 μg/L, and nine samples contained Zn exceeding 320 μg/L.

These samples were from KDHE data collected between 1967 and 1986. The concentrations listed above most likely would constitute exceedences of current water quality criteria for the Spring River. However, most other samples reported through 1987 did not contain hazardous substance concentrations that would exceed criteria. Thus, while it is possible that the Spring River in Kansas has been injured by hazardous substance releases, the data available in 1999 are inconclusive.[1]

The majority of the data from the Baxter Springs/Treece subsite come from the USGS (Spruill, 1984) and Dames & Moore (1993b). The USGS did not report hardness data for their samples. Hardness can vary greatly in these waters; for example, the hardness at one sample location on Willow Creek ranged from 71 mg/L to 660 mg/L as $CaCO_3$ during the RI/FS sampling. The hazardous substance concentrations in the USGS report are compared to criteria at 200 mg/L hardness.

The USGS (Spruill, 1984) report no detectable Cd or Pb in any of their samples. Two samples exceed the Zn CMC for 200 mg/L hardness (Figure 4.10), including one sample from Baxter Springs containing 630 μg/L Zn. In contrast, the RI/FS data (Dames & Moore, 1993b) collected in the early 1990s indicate criteria exceedences for Cd, Pb, and Zn. Two of the samples exceeded the Cd CCC (Figure 4.8), and three samples exceeded the Kansas chronic ALC, when the hardness in Willow Creek was less than 75 mg/L (Dames & Moore, 1993b). Most of the samples contained Pb in excess of the CCC (Figure 4.9). Pb concentrations in the creek were as high as 25 μg/L, over an order of magnitude greater than the Pb CCC for that sample. Similarly, most of the RI/FS samples from Willow Creek exceeded Zn criteria, some by almost an order of magnitude (Figure 4.10). The RI/FS data indicate that Willow Creek has been and most likely continues to be injured by this injury test.

1. Additional data provided to Stratus Consulting by the State of Kansas indicate that exceedences of surface water quality criteria in the Spring River for Cd, Pb, and Zn may be more frequent and widespread.

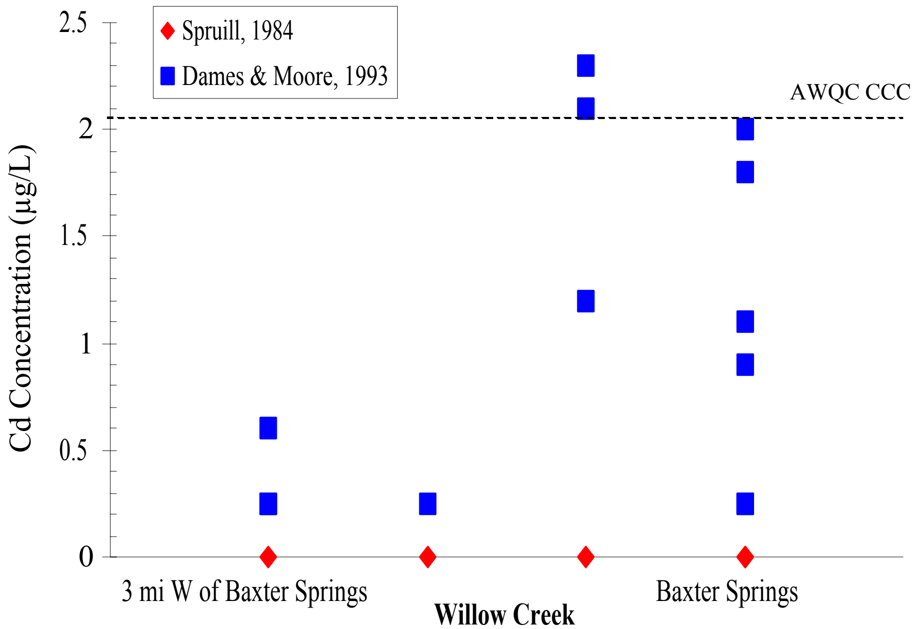

Figure 4.8. Cd concentrations from Willow Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed line represents the approximate average AWQC CCC; the criterion is hardness-dependent and therefore is different for each sample. There were no exceedences of other state or federal criteria.

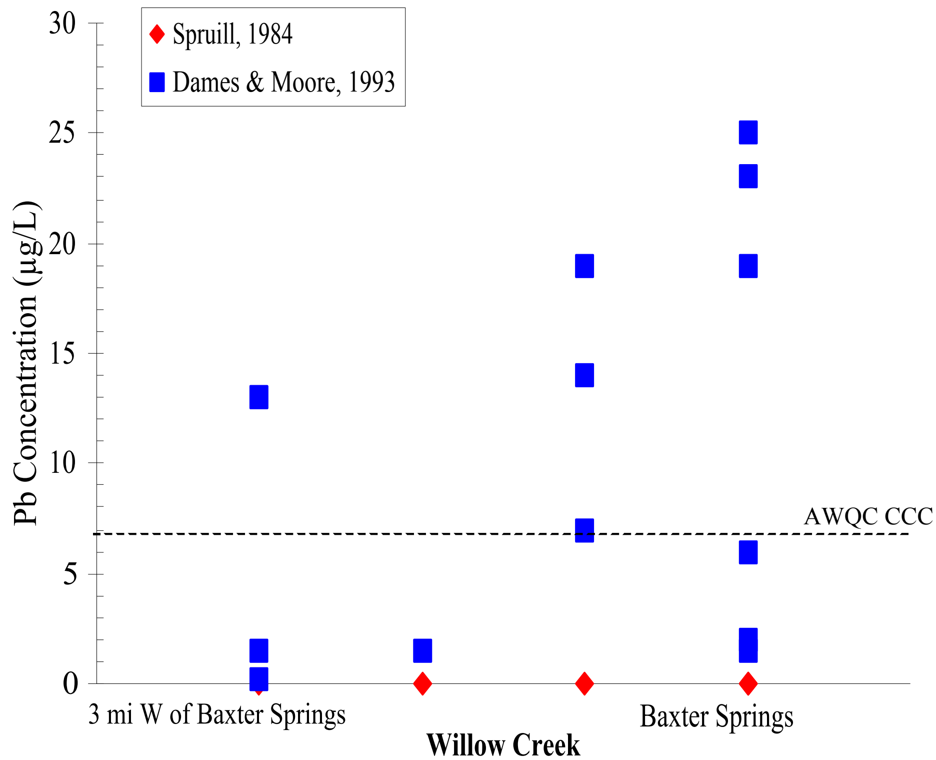

Figure 4.9. Pb concentrations from Willow Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed line represents the approximate average AWQC CCC; the CCC is hardness-dependent and therefore is different for each sample. There were no exceedences of other state or federal criteria. Concentrations in samples from Spruill are all dissolved, whereas those from Dames & Moore are predominantly total recoverable.

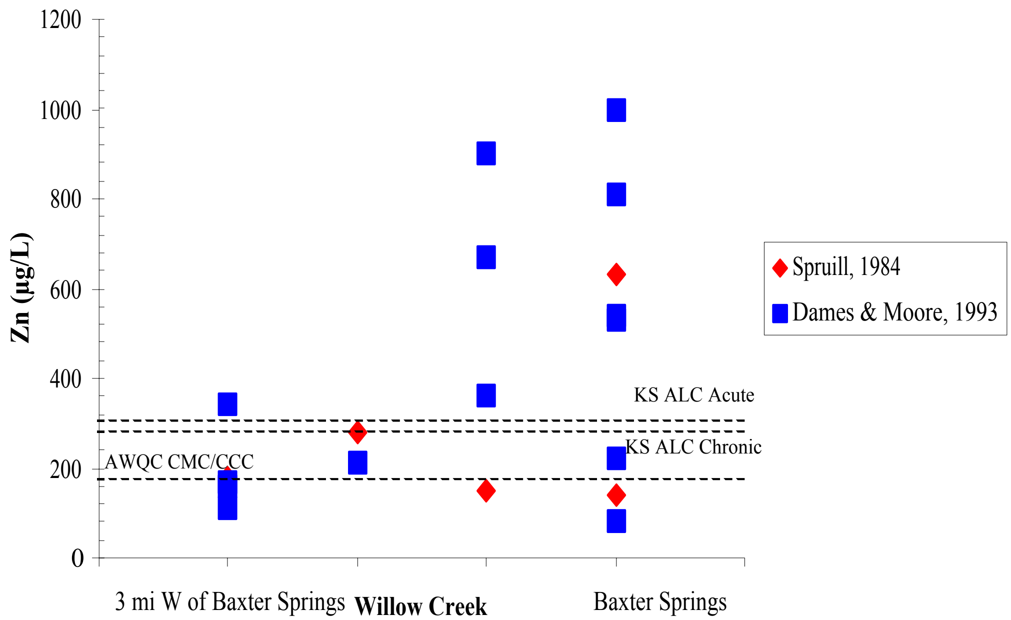

Figure 4.10. Zn concentrations from Willow Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed line represents the approximate average AWQC CMC and CCC, and Kansas acute and chronic ALC. All criteria are hardness-dependent and therefore are different for each sample.

Like Willow Creek, Tar Creek shows occasional exceedences of Cd criteria and frequent exceedences of Pb and Zn criteria, with Pb and Zn concentrations often more than an order of magnitude greater than the criteria. The USGS (Spruill, 1984) found no evidence of Cd contamination upstream of Treece, but found concentrations ranging from 10 µg/L (exceeding the CCC) to 40 µg/L (exceeding the CMC) downstream of Treece (Figure 4.11). The RI/FS data (Dames & Moore, 1993b) also show a trend of increasing Cd concentrations downstream, with concentrations also reaching a maximum of 40 µg/L.

The hardness trend in Tar Creek should be noted. The RI/FS samples taken from Tar Creek at Cravensville Rd. upstream of the Big John Mine had hardness values ranging from 40 to 55 mg/L. This contrasts with hardness ranging from 220 to 470 mg/L downstream of mining activity. Despite the very high hardness downstream, the concentrations of hazardous substances far exceed surface water criteria.

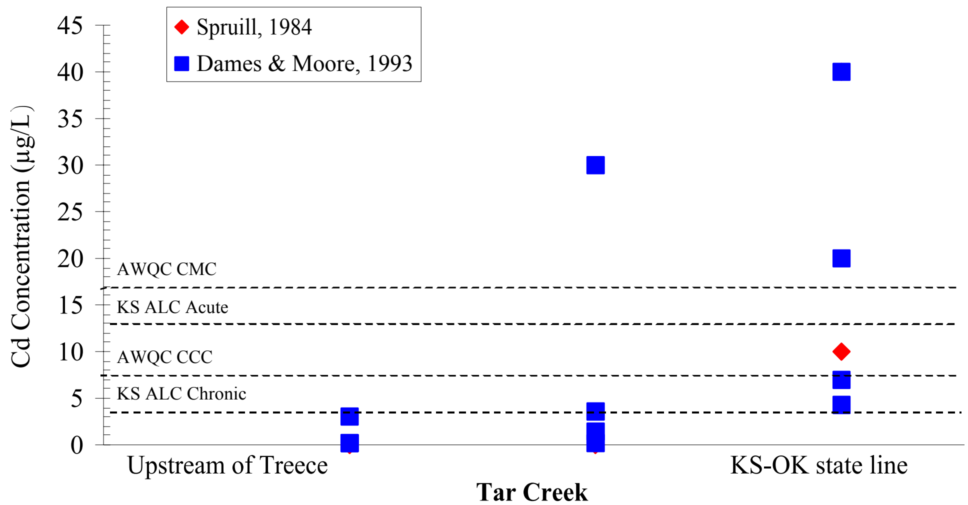

Figure 4.11. Cd concentrations from Tar Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed lines represent the approximate average AWQC CCC and CMC and Kansas acute and chronic ALC. The criteria are hardness-dependent and therefore are different for each sample.

The USGS (Spruill, 1984) found only one sample that contained detectable Pb concentrations in Tar Creek during their sampling (Figure 4.12). However, Dames & Moore (1993b) collected several water samples with elevated Pb concentrations. These include an anomalous sample from the soft water upstream reach that contained 90 µg/L Pb, exceeding the CMC (Figure 4.12).

Other samples from the same location contained 0.5 and 3 µg/L Pb. Downstream of Treece, at the state line, the Pb concentrations were consistently between 70 and 80 µg/L, which greatly exceeded the CCC but did not approach the CMC because of high hardness.

The USGS (Spruill, 1984) collected only one sample that did not exceed the Zn CMC; that sample was from upstream of most of the mining activity. All other samples from Tar Creek, including all Dames & Moore (1993b) samples, contained Zn in excess of the CMC (Figure 4.13). Some of the samples exceeded the Zn CMC by over 50 times, including two samples containing over 20,000 µg/L Zn. Based on the consistent and highly elevated concentrations of Zn alone, Tar Creek in Kansas has been and most likely continues to be injured.

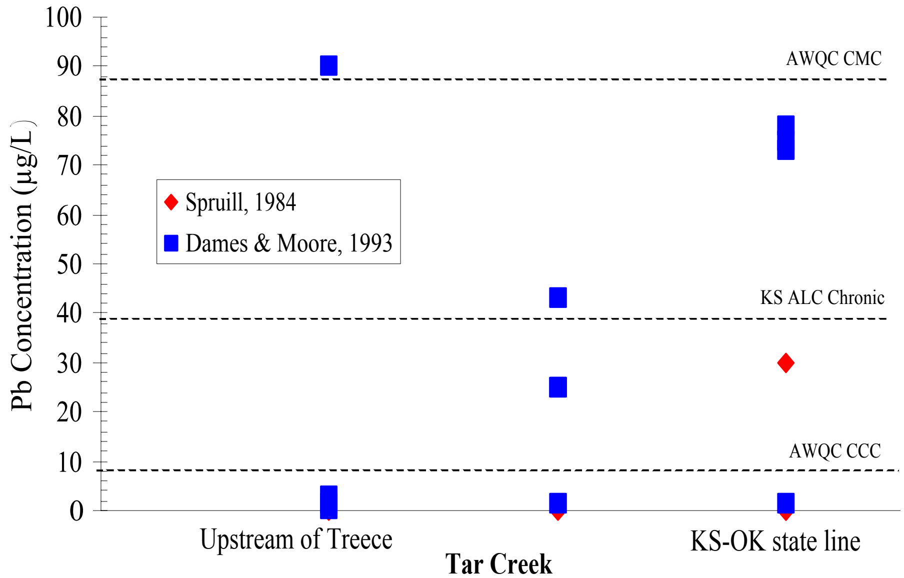

Figure 4.12. Pb concentrations from Tar Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed lines represent the approximate average AWQC CCC, and CMC, and Kansas chronic ALC. The criteria are hardness-dependent and therefore are different for each sample. There were no exceedences of Kansas acute ALC. Concentrations in samples from Spruill are all dissolved, whereas those from Dames & Moore are predominantly total recoverable.

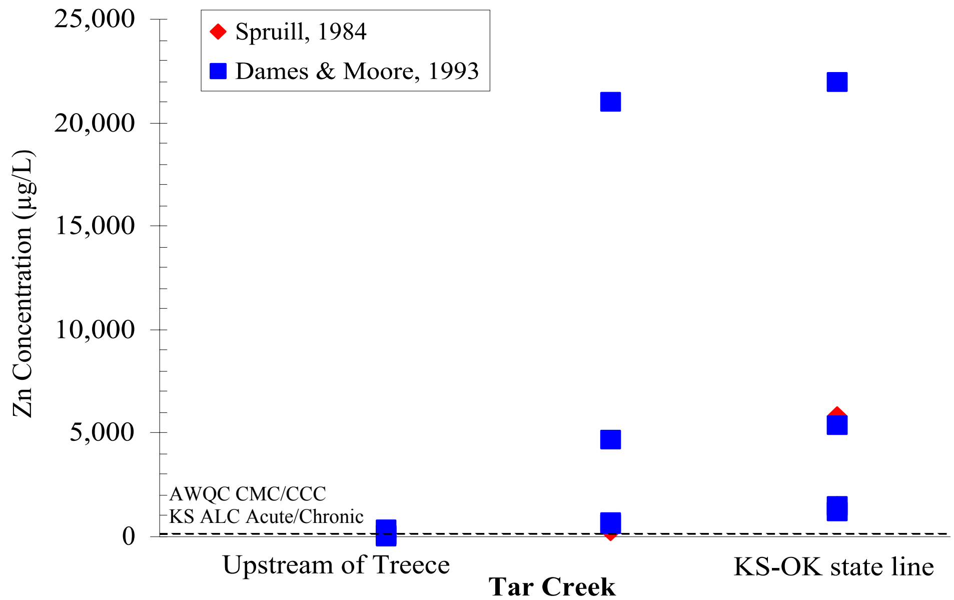

Figure 4.13. Zn concentrations from Tar Creek, Cherokee County, Kansas. The x-axis represents a general trend from upstream of mining operations to downstream. The dashed line represents the following criteria; AWQC CMC, AWQC CCC, Kansas acute ALC, and Kansas chronic ALC. The criteria are hardness-dependent and therefore are different for each sample.

4.2.3 Quantification of injuries to surface water

Figures 4.14 through 4.16 show the spatial distributions of Cd, Pb, and Zn in surface water samples relative to AWQC CCC criteria for the entire District. These data show that virtually the whole of Tar Creek between its source and its confluence with the Neosho River is injured by one or more metals. Short Creek is injured from at least Joplin to its confluence with the Spring River. Turkey Creek is injured from Joplin downstream almost to its confluence with the Spring River, and Center Creek is injured in the vicinity of Webb City.

The evidence that surface waters in the Spring and Neosho rivers have been injured by hazardous substances is much less clear.[2] Although there are a few surface water samples from these rivers that exceed or may exceed criteria, most samples are below criteria and, in the case of the Neosho River, the source of the contaminants is uncertain.

2. Additional data provided to Stratus Consulting by the State of Kansas indicate that exceedences of surface water quality criteria in the Spring River for Cd, Pb, and Zn may be more frequent and widespread.

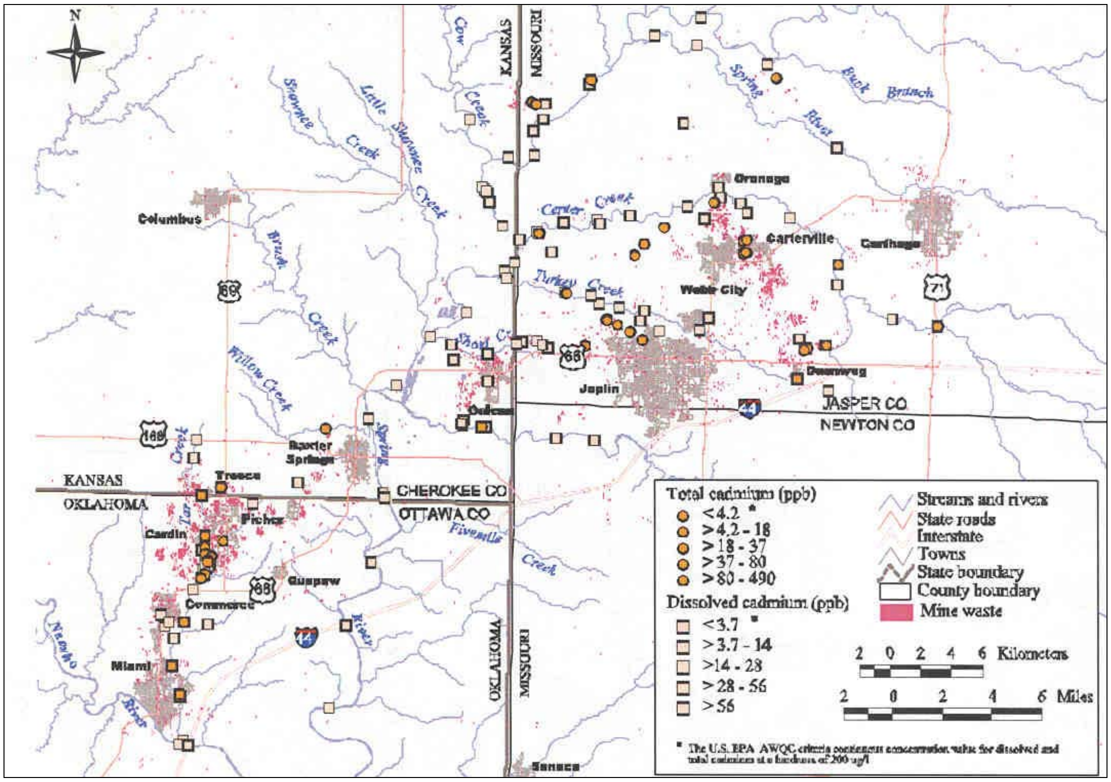

Figure 4.14. Distribution of Cd concentrations in stream surface waters of the Tri-State Mining District. The data have not been normalized to account for variation in hardness, whereas the AWQC criteria are hardness dependent.

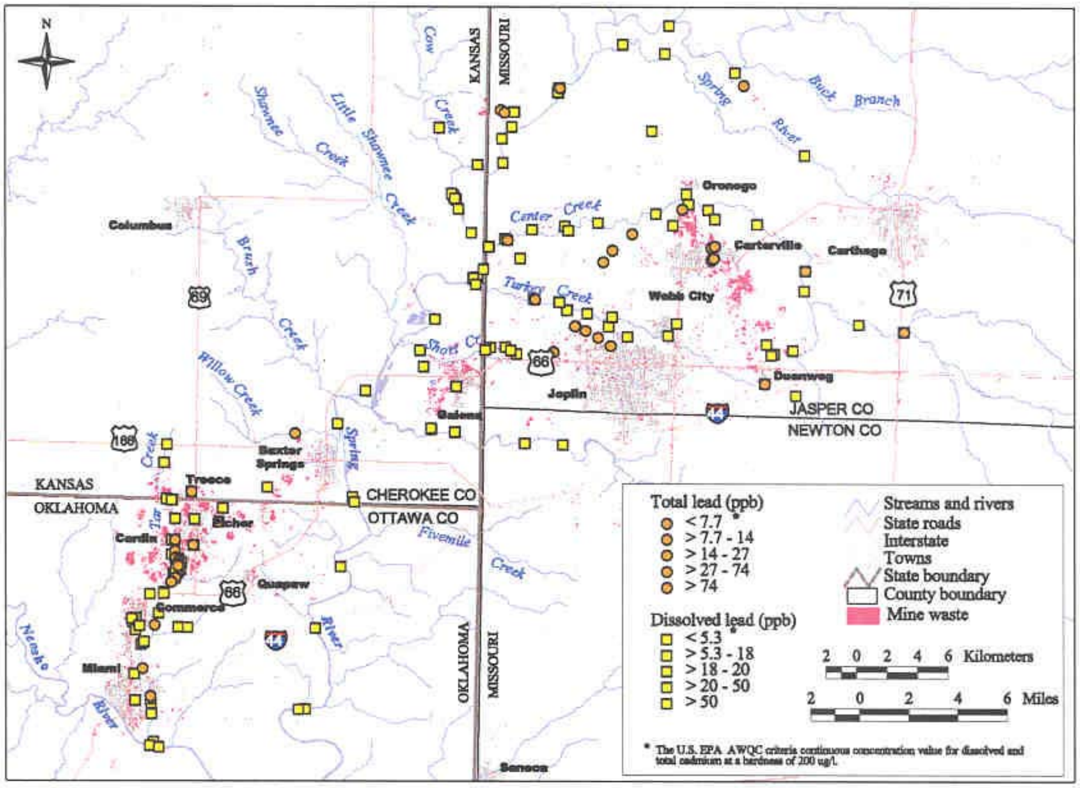

Figure 4.15. Distribution of Pb concentrations in stream surface waters of the Tri-State Mining District. The data have not been normalized to account for variation in hardness, whereas the AWQC criteria are hardness dependent.

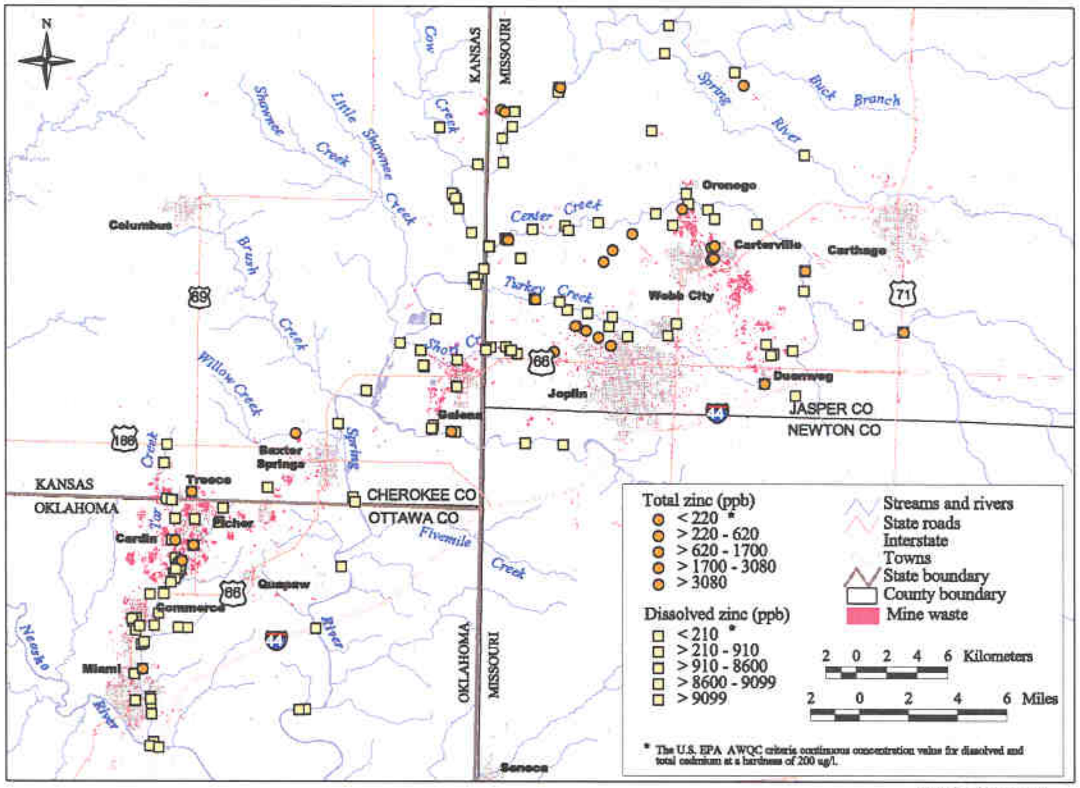

Figure 4.16. Distribution of Zn concentrations in stream surface waters of the Tri-State Mining District. The data have not been normalized to account for variation in hardness, whereas the AWQC criteria are hardness dependent.

The evidence that surface waters in the Spring and Neosho rivers have been injured by hazardous substances is much less clear.[2] Although there are a few surface water samples from these rivers that exceed or may exceed criteria, most samples are below criteria and, in the case of the Neosho River, the source of the contaminants is uncertain.

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2. Additional data provided to Stratus Consulting by the State of Kansas indicate that exceedences of surface water quality criteria in the Spring River for Cd, Pb, and Zn may be more frequent and widespread.

4.2.4 Injuries to aquatic sediments

Evaluation Criteria

A number of numerical criteria have been proposed as toxicity threshold levels or benchmarks for Cd, Pb, and Zn in freshwater aquatic sediments (e.g., Long and Morgan, 1991; Persaud et al., 1993; U.S. EPA, 1995; OSWER, 1996). These numerical values have been developed from studies in the laboratory and in the field. Jones et al. (1997) reviewed all of these studies and identified the most supportable of the benchmarks that have thus far been proposed. Jones et al. (1997) identified three different benchmarks for Cd, Pb, and Zn:

1. **The threshold effect concentration (TEC).** The concentration at which toxic effects on sediment-associated biota may begin to occur (Cd = 0.592 mg/kg, Pb = 34.2 mg/kg, Zn = 159 mg/kg).

2. **The probable effect concentration (PEC).** The concentration at which toxic effects become likely (Cd = 11.7 mg/kg, Pb = 396 mg/kg, Zn = 1,532 mg/kg).

3. **The high no effect concentration (NEC).** The concentration above which statistically significant effects have always been reported in laboratory or field studies (Cd = 41.1 mg/kg, Pb = 68.7 mg/kg, Zn = 541 mg/kg).

In this evaluation we determine whether concentrations of Cd, Pb, and Zn in sediments in Cherokee County meet the definition of injury cited in Section 4.2.1 by comparing sediment concentrations with each of the these benchmarks.

Kansas Sediments

Figures 4.17 through 4.19 show the measured Cd, Pb, and Zn concentrations in sediments from waterbodies in the Kansas portion of the Tri-State Mining District compared with toxicity benchmarks from Jones et al. (1997). These data show that Cd, Pb, and Zn concentrations in sediments from Short Creek, the Owl Branch (a tributary of Short Creek flowing through Galena), the Spring River, and Shoal Creek exceeded one or more of the toxicity benchmarks, indicating that metals concentrations in the sediments of these waterbodies may be sufficient to cause injuries to exposed aquatic biota.

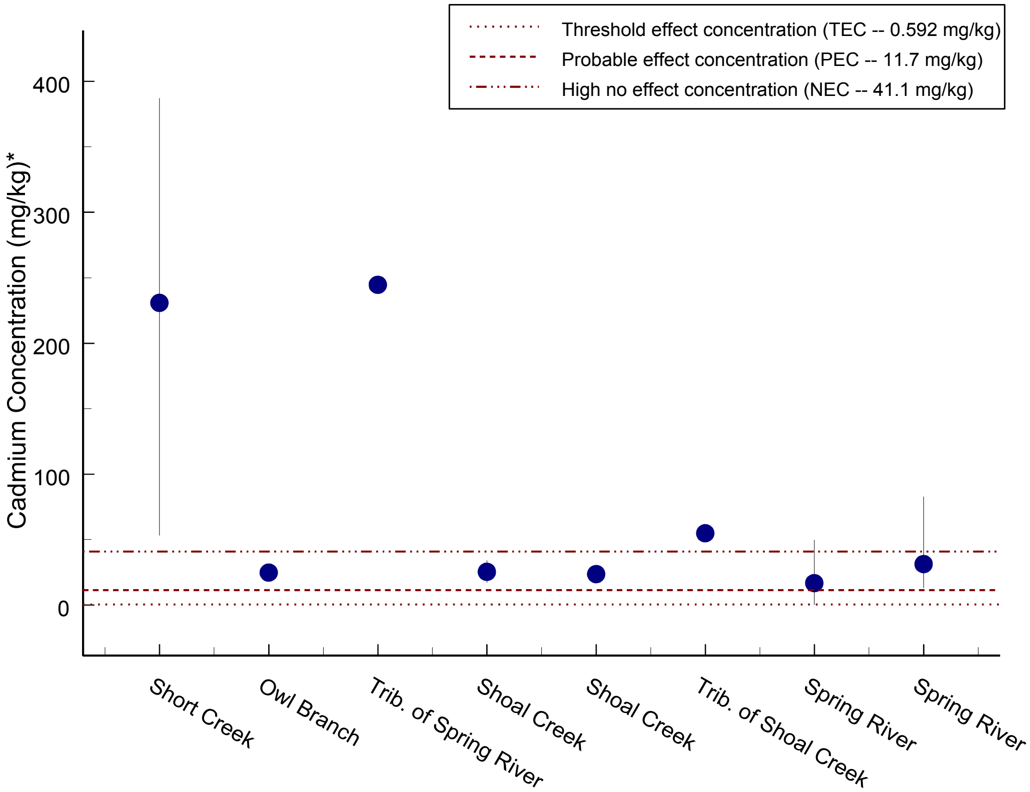

Figure 4.17. Means and ranges of cadmium concentrations in Kansas sediments.
* Wet or dry weight not specified.

Sources: Ferrington (date unknown), Allen and Wilson (1992), Ferrington et al. (1989), Jones et al. (1997).

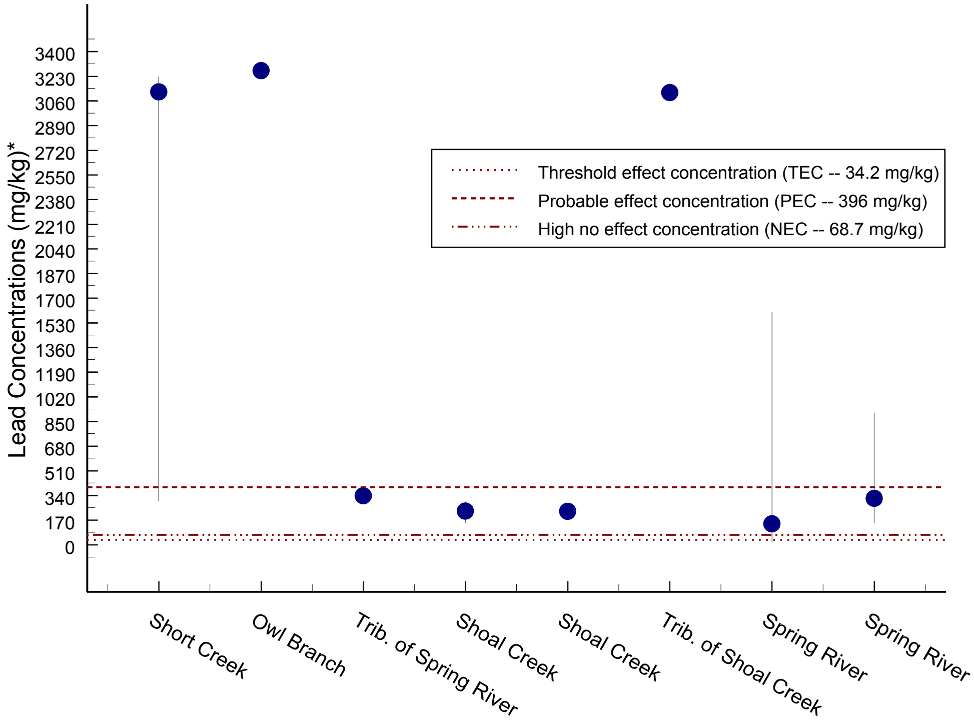

Figure 4.18. Means and ranges of lead concentrations in Kansas sediments.
* Wet or dry weight not specified.

Sources: Ferrington (date unknown), Allen and Wilson (1992), Ferrington et al. (1989), Jones et al. (1997).

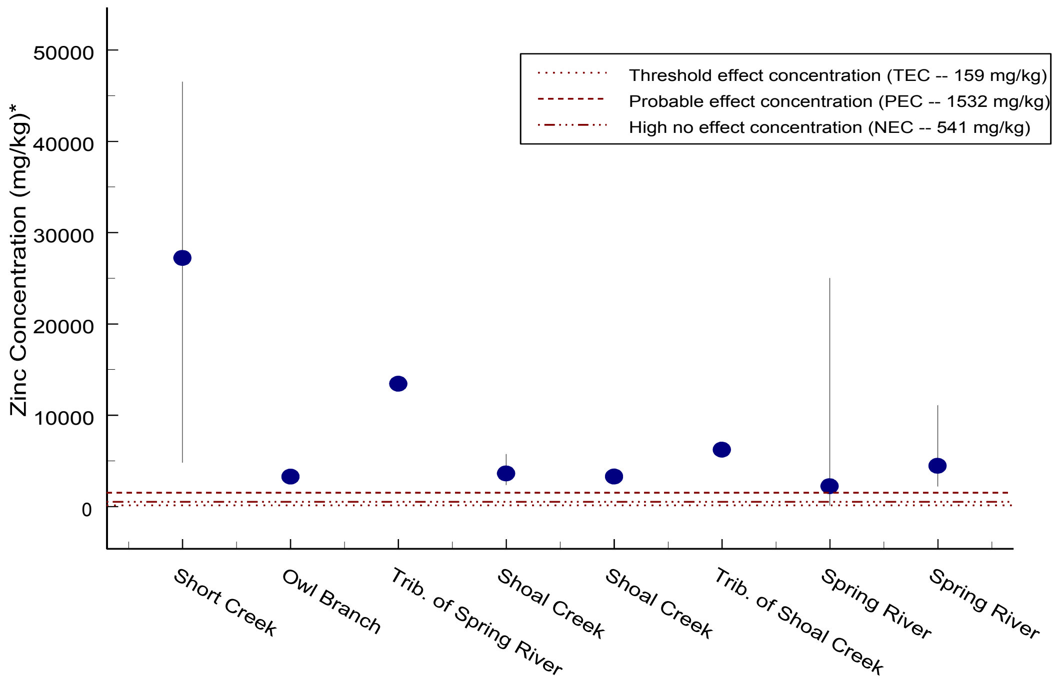

Figure 4.19. Means and ranges of zinc concentrations in Kansas sediments.
* Wet or dry weight not specified.

Sources: Ferrington (date unknown), Allen and Wilson (1992), Ferrington, et al. (1989), Jones et al. (1997).

4.2.5 Conclusions

The data presented in this section support the following conclusions regarding injuries to surface water and sediments:

- In Cherokee County, Kansas, water samples from Short Creek, Willow Creek, Lytle Creek, and Tar Creek contain or have contained concentrations of Cd, Pb, and/or Zn that exceed water quality standards set under the CWA (AWQCs), and by the State of Kansas. This constitutes injury to surface water resources under federal regulations.

- In Cherokee County, Kansas, sediments from Short Creek, Shoal Creek, Owl Branch, and Spring River contain or have contained concentrations of Cd, Pb, and/or Zn that have exceeded levels that could cause injury to resources that are exposed to those sediments. This indicates injury to sediments under the federal regulations.

4.3 Injuries to Aquatic Biological Resources

Previous sections of this chapter have reviewed injury to groundwater and to surface waters and sediments. In this section, we review the information available in 1999 that aquatic biological resources in Cherokee County have been injured by releases of hazardous substances. We focus our evaluation of injury to aquatic biological resources on Cd, Pb, and Zn exposure from surface waters and sediment and from dietary exposure (for fish only) from ingesting contaminated invertebrates.

The majority of the data that we review in this section were collected as part of RI/FS activities in Cherokee County, Kansas (Dames & Moore, 1993b). Other data sources used include peer-reviewed literature and site-specific information collected by universities and other federal and state agencies.

The organization of this section is somewhat different from other sections of this chapter. In previous sections of this chapter, we presented information on injury to groundwater, surface water, and sediments, primarily in Kansas. However, in this section, because of the types and number of injury categories that are addressed, we present information on injury to aquatic biota by injury category. Within each injury category, we present information for Kansas whenever possible. We present the conclusions of our review of existing evidence of injury to aquatic biota for Kansas.

This section is organized as follows: Section 4.3.1 provides a brief description of the aquatic resources assessed; Section 4.3.2 describes injury definitions identified in federal regulations; Section 4.3.3 discusses state consumption advisories for fish and exceedences of Food and Drug Administration (FDA) tolerance levels in shellfish, and evaluates concentrations of hazardous substances in edible fish tissue against regulatory concentration thresholds; and Section 4.3.4 discusses evidence of toxic injuries to aquatic biota, including exceedences of threshold toxicity values, evidence of acute and chronic toxicity to fish and benthic invertebrates, and evidence of change in populations indicative of injuries to aquatic biota. Section 4.3.5 summarizes the results of our evaluation.

It should be noted that the State of Kansas provided additional data to Stratus Consulting. These data, although they could not be included in this report, indicate that injuries to biological resources may have occurred in the Kansas and Oklahoma portions of the Spring River. These injuries comprise possible reductions in the densities of bivalve populations, including state listed species.

4.3.1 Description of aquatic biological resources

Aquatic biological resources in the Tri-State Mining District include fish, benthic invertebrates (e.g., ephemeropterans, trichopterans, plecopterans, megalopterans, odonates, coleopterans, and dipterans; Dames & Moore, 1995), and plankton. Fish resources consist of warmwater species such as carp (e.g., *Cyprinus carpio*), catfish (e.g., *Ictalurus punctatus*), crappie (*Pomoxis* spp.), minnows (e.g., *Notropis* spp.), darters (e.g., *Etheostoma* spp.), suckers (e.g., *Moxostoma duquesnei*), sunfish (*Lepomis* spp.), smallmouth buffalo (*Ictiobus bubalus*), smallmouth (*Micropterus punctulatus)*, and largemouth bass (*M. salmoides*) (Dames & Moore, 1993b; Pflieger, 1975 as cited in Dames & Moore, 1995).

There are several USFWS threatened and endangered (T&E) species, candidate T&E species, and state listed threatened, endangered, or rare species in Cherokee County and the Tri-State Mining District. In the Tri-State Mining District there are two USFWS listed threatened species, the Neosho madtom (*Noturus placidus*) and the Ozark cavefish (*Amblyopsus rosae*). The Arkansas darter (*Etheostoma cragini*) is a candidate species for listing as a T&E species by the USFWS.

The State of Kansas lists the Arkansas darter as a T&E fish species, as well as numerous amphibian species (Kansas Department of Wildlife and Parks, as cited in Dames & Moore, 1993b). The T&E amphibians include the cave salamander (*Eurycea lucifuga*), the central newt (*Notophthalmus viridescens louisianensis*), the dark-sided salamander (*Eurycea longicauda melanopleura*), the eastern narrowmouth toad (*Gastrophryne carolinensis*), the greybelly salamander (*Eurycea multiplicata griseogaster*), the green frog (*Rana clamitans melanota*), the grotto salamander (*Typhlotriton spelaeus*), and the northern spring peeper (*Hyla crucifer crucifer*) (Kansas Department of Wildlife and Parks as cited in Dames & Moore, 1993b). However, it is not clear if these amphibian T&E species would be expected to reside in Cherokee County.

We provide additional information on the habitat and geographical location of the Neosho madtom within the Tri-State Mining District because, as we discuss in Section 4.3.4, the influence of exposure to mine wastes on this species has received some study.

The Neosho madtom is predominantly found in the Neosho and Cottonwood rivers. A small population is also present in the Spring River in southwestern Missouri and southeastern Kansas (Wilkinson et al., 1996). The population of the Neosho madtom in the Spring River is isolated from the populations in the Neosho River by three dams, a 50 km section of river, and the upper portion of the Grand Lake of the Cherokees (Wilkinson et al., 1996). Over an intensive two year sampling survey of the Spring River in 1993 and 1994, Wilkinson et al. (1996) collected (and subsequently released) 87 Neosho madtoms from 12 of 39 sampling locations in Kansas and 7 of 53 sampling locations in Missouri. However, Neosho madtoms were not collected from

14 sampling locations in the Oklahoma section of the Spring River. The distribution of the Neosho madtom in the Spring River is limited to a small area upstream of the confluence of Willow Creek in Kansas, and a section of the Spring River ranging from the confluence with Turkey Creek upstream to the confluence with the North Fork of the Spring River (Wilkinson et al., 1996). The population upstream of the confluence of Willow Creek may be isolated from other populations by the dams on Empire Lake and by the Grand Lake of the Cherokees (Wilkinson et al., 1996). Mean densities of Neosho madtoms range from 0.9 to 4.3 fish per 100 m^2 in the Spring River. These densities appear to be lower than mean densities observed in the Neosho and Cottonwood rivers, which range from 3.3 to 32.4 fish per 100 m^2 (Wilkinson et al., 1996). To date, investigations in the major tributaries to the Spring River, including Center Creek, Turkey Creek, Short Creek, Shoal Creek, Cow Creek, and Willow Creek, have not found Neosho madtoms. Hence, the likely distribution of the Neosho madtom in the Spring River is predominately in the upper reaches of the river (above the confluence with Center Creek).

Overall, the aquatic biological resources in the Tri-State Mining District are diverse. Numerous warmwater fish species, benthic invertebrates, and plankton species are present. The area also contains several T&E species, candidate T&E species, and state listed endangered or rare species.

4.3.2 Definitions of injury to aquatic biota

We relied on categories of injury to biological resources cited in federal regulations for our preliminary injury evaluation. These include the following:

- Concentrations of a hazardous substance sufficient to exceed action or tolerance levels established under section 402 of the Food, Drug and Cosmetic Act, 21 U.S.C. 342, in edible portions of organisms [43 CFR § 11.62(f)(1)(ii)]
- Concentrations of a hazardous substance sufficient to exceed levels for which an appropriate governmental health agency has issued directives to limit or ban consumption of such organism [43 CFR § 11.62(f)(1)(iii)].

We evaluated these two tests of injury by (1) determining whether any consumption advisories or related directives have been issued, and (2) comparing concentrations of hazardous substances measured in fish in the assessment area against regulatory concentration thresholds. This evaluation is presented in Section 4.3.3.

- Concentrations of a hazardous substance sufficient to cause the biological resource or its offspring to have undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62(f)(1)(I)].

To evaluate this injury test, we compared concentrations of hazardous substances measured in surface water, sediment, and biological tissues against toxicity thresholds for death and sublethal effects (e.g., growth, reproduction). We also evaluated data on population density and community composition to determine whether available biological monitoring information is indicative of injuries to aquatic biota. This evaluation is presented in Section 4.3.4.

4.3.3 Establishment of fish consumption advisories and exceedences of FDA and/or state tolerance levels

Fish Consumption Advisories

No fish consumption advisories had been issued in 1999 for consumption of fish or shellfish (e.g., freshwater mussels) in the Tri-State Mining District. Fish consumption advisories are directives to limit or ban consumption of fish because of elevated concentrations of hazardous substances. Fish consumption advisories are typically issued based on elevated concentrations of hazardous substances in excess of a threshold concentration that has been previously determined to be associated with adverse effects. Since there have been no fish consumption advisories issued for the Tri-State Mining District at that time, we evaluated concentrations of Cd and Pb in fish tissue and compared them to tissue threshold levels that have been determined for these metals. No tissue threshold levels have been established for Zn, so we could not compare thresholds levels with Zn tissue concentrations. Below, we provide information on federal and state tissue threshold levels and then compare tissue concentrations in fish in the Tri-State Mining District to these threshold levels.

Federal and State Tissue Threshold Levels

The FDA has jurisdiction to assess the influence of environmental contaminants on the safety of consumption of fish and shellfish (e.g., molluscan bivalves and crustacea) that are intended for introduction into, or have been shipped in interstate commerce (Adams et al., 1993a). The FDA may develop guidelines or regulatory limits for fish or shellfish consumption, or may issue a formal tolerance level that limits the extent of allowable contamination (Adams et al., 1993a). The FDA has not established guidelines, regulatory limits, or tolerance levels for Cd, Pb, or Zn in freshwater fish. However, the FDA has issued guidance documents for Cd and Pb in shellfish (Adams et al., 1993a, 1993b). No guidance, regulatory limits, or tolerance levels have been established by the FDA for Zn in shellfish. For the purposes of this evaluation, we used these FDA guidance values in shellfish for comparison with Cd and Pb concentrations in freshwater fish in the Tri-State Mining District. Comparisons are based on fish fillets only; the ingestion of metals could be higher if the entire fish is consumed (including bones), as is the apparent practice in Missouri.

For Cd, the FDA suggests a maximum tolerable daily Cd intake of 55 µg/person/day. Based on an assumed consumption of 15 g/shellfish/day, the corresponding level of concern for Cd in shellfish is 3.7 µg/g (Table 4.4). For Pb, the FDA has developed provisional tolerable total intake levels for young children (up to 6 years old), older children (7 years and older), pregnant women, and adults (Adams et al., 1993b). Provisional tolerable total Pb intake levels range from 6 µg/day for a child less than 6 years old to 75 µg/day for an adult (Adams et al., 1993b). Based on the provisional tolerable total intake level established by the FDA and on an assumed consumption of 15 g/shellfish/day, the corresponding levels of concern for Pb in shellfish are 5.0 µg/g for an adult and 0.4 µg/g for children (Table 4.4). No information is provided in these source documents regarding whether the weight of fish tissue is based on wet weight or dry weight. For the purposes of this preliminary evaluation, we assumed that all tissue data are expressed as wet weight if no specific information was available from source documents.

Table 4.4. Tissue threshold concentrations for Cd and Pb in fish and shellfish used for preliminary injury evaluation

Regulatory basis	Pb	Cd
FDA guidance[a]	—	3.7
	5.0 (adults)	—
	0.4 (children < 6 years old)	—
State of Missouri	0.3	—
State of Oklahoma alert levels	2.5	0.3

Threshold concentrations are based on human consumption and expressed as µg/g (wet weight) in edible portions.

a. Adopted from guidance levels developed for consumption of shellfish.

Sources: Oklahoma State Department of Health 1983; Adams et al., 1993a, b; Fairbanks, 1999.

No advisory thresholds have been issued by the State of Kansas for Cd, Pb, or Zn levels in fish.

Metal Concentrations in the Edible Portion of Fish Tissue

To evaluate concentrations of hazardous substances measured in fish in the Tri-State Mining District relative to these regulatory threshold concentrations, we compared the FDA levels of concern for Cd (3.7 µg Cd/g) and Pb (5.0 µg Pb/g for adults; 0.4 µg Pb/g for children) in shellfish to concentrations of Cd and Pb measured in the edible portion of fish tissue in the Tri-State Mining District.

Several studies have measured metal concentrations in edible fish tissue in the Tri-State Mining District. Data sources include the Kansas Department of Wildlife and Parks and RI/FS studies conducted by Dames & Moore (1993b, 1995). When available, tissue concentration data are presented as a range of values based on concentrations measured in individual fish or composites of fish. If information on Cd and Pb levels in individual samples was not available, then tissue concentration data are presented as mean values. Information on fish Cd and Pb tissue concentrations is presented for Cherokee County, Kansas (Table 4.5). When available, tissue concentrations in fish collected from reference locations are provided to illustrate normal background concentrations of Cd and Pb in fish tissue in Cherokee County.

Table 4.5. Cadmium and lead concentrations in fish fillets collected from Baxter Springs and Treece subsites, Cherokee County, Kansas

Location	Species	Sample size	Mean metal concentration (range) (µg metal/g wet weight) Cadmium	Lead
Reference locations				
Empire Lake	Largemouth bass	2	<0.05	<0.10
Potential impacted areas				
Willow Creek near Baxter Springs	Largemouth bass[a]	3	0.004 (0.004-0.005)	<0.02 (<0.02)
Spring branch near Baxter Springs	Green sunfish	2	0.137 (0.024-0.250)	<0.03 (<0.03-0.03)
Brewster Pond near Baxter Springs	Green sunfish[b]	3	0.021 (0.003-0.054)	<0.02 (<0.02)
	White crappie	3	0.003 (<0.002-0.003)	0.03 (<0.02-0.4)
Paxson Pond near Baxter Springs	Black bullhead[c]	2	0.019 (0.016-0.022)	0.03 (<0.02-0.03)
Treece Pond near Tar Creek	Green sunfish[d]	1	0.008	0.05
Treece Pond (also referred to as Muncie Pond)	Largemouth bass	3	0.003 (<0.002-0.004)	0.03 (<0.02-0.03)
	Black bullhead	2	0.009 (0.005-0.012)	0.06 (0.05-0.06)

a. Two samples (of three) taken from the same fish.
b. All three samples taken from the same fish.
c. Both samples taken from the same fish.
d. Sample a composite of two fish.

Source: Dames & Moore, 1993b.

Cherokee County, Kansas

Dames & Moore (1993b) measured Cd and Pb concentrations in the edible tissues of fish collected from Empire Lake, Willow Creek, Spring Branch, Brewster Pond, Paxson Pond, and Treece Pond in Cherokee County, Kansas. Metal concentrations in fish fillets in areas potentially impacted by mining activity ranged from 0.003 to 0.137 µg Cd/g and <0.02 to 0.06 µg Pb/g (Table 4.5). Overall, concentrations of Cd and Pb measured in fish tissue collected from Cherokee County in areas potentially impacted by mining activity by Dames & Moore (1993b) were greater than concentrations collected from fish in reference locations (Table 4.5; see Section 3.3.6). However, concentrations of Cd and Pb in fish tissues were less than regulatory tissue threshold concentrations (see Table 4.4).

Summary

In general, concentrations of Cd, Pb, and Zn in edible portions of fish collected from Cherokee County do not exceed action or tolerance levels established by the FDA. Hence, based on the available data on Cd and Pb concentrations in fish tissue, fish in the Cherokee County Site do not appear to have been injured when evaluated against the first two categories of injury to biological resources described in Section 4.3.2.

Additional data on metal concentrations in whole fish were provided to Stratus Consulting by the State of Kansas subsequent to the drafting of this report. These data are for fish collected from the Spring River at Baxter Springs and the Neosho River at Springs and the Neosho River at Chetopa. Overall, 2 out of 26 fish had Cd concentrations in excess of the State of Oklahoma's alert level of 0.3 µg/g (data ranged from 0.06 to 0.33 µg/g) and 11 out of 26 fish had Pb concentrations in excess of the State of Missouri's level of 0.3 µg/g (data ranged from 0.17 to 2.35 µg/g). Therefore, the evaluation based on the fish tissue data used to prepare this report may underestimate the degree and spatial extent of these injuries.

In the following section, we evaluate the third category of injury to biological resources by comparing concentrations of hazardous substances measured in surface water, sediment, and biological tissues against toxicity thresholds for death and sublethal effects (e.g., growth, reproduction) and by evaluating data on population measurements and community composition to determine whether available biological monitoring information is suggestive of injuries to aquatic biota.

4.3.4 Adverse changes in viability

In this section, we review the evidence available in 1999 that adverse changes in viability (i.e., injuries related to the toxicity of metals) may have occurred or may be occurring to aquatic biota in Cherokee County. This evaluation examines three types of diagnostic information. First, we examine threshold concentrations for aqueous exposure of Cd, Pb, and Zn and dietary exposure (for fish only) by ingestion of benthic invertebrates contaminated by Cd, Pb, and Zn. Second, we examine site-specific acute and chronic toxicity data for fish and benthic invertebrates exposed to Cd, Pb, and Zn from surface water and sediment. Third, we examine population-level data to evaluate if any population patterns are indicative of injury to fish and benthic invertebrates.

However, before examining the evidence of adverse changes to viability in aquatic biota in Cherokee County, we first provide background information on the acute and chronic toxicity of Cd, Pb, and Zn to aquatic organisms.

Cadmium, lead, and zinc can affect aquatic biota in a number of ways. Exposure to elevated concentrations of Cd, Pb, and Zn can result in lethality, avoidance responses, reduced growth, immune impairment, and other physiological effects. These different toxic effects are described below. In addition, we discuss the role of modifying factors in altering the toxic effects of metals to aquatic biota.

Lethality

Cadmium, lead, and zinc have all been shown to cause death in fish (e.g., Mount, 1966; Benoit et al., 1976; Carroll et al., 1979; Chakoumakos et al., 1979; Hodson et al., 1979, 1983; Watson and Beamish, 1980; Bradley and Sprague, 1985a; Cusimano et al., 1986; Everall et al., 1989; Marr et al., 1995). The primary mechanisms of metal-induced mortality are disruption of ionoregulation and respiratory failure. The gills are the primary site of ionoregulation (Evans, 1987), a process that drives many cellular metabolic functions. Hazardous metals such as Cd and Zn can disrupt ionoregulation by injuring the gill membrane so that ions leak across the membrane, and by disrupting necessary enzymes (Lauren and McDonald, 1985; 1986). For example, Cd alters calcium balance by disrupting essential ion transport enzymes (Roch and Maly, 1979; Verbost et al., 1989). Continued disruption of ionoregulation leads to mortality. The gills are also the primary site of respiration (Evans, 1987). Exposure to hazardous metals causes physiological injury to respiratory gill tissues (Wilson and Taylor, 1993). This injury impairs the transfer of respiratory gases (e.g., oxygen) by increasing the distance that respiratory gas must diffuse across between blood and water (Hughes and Perry, 1976; Satchell, 1984; Mallatt, 1985; all as cited in Wilson and Taylor, 1993) causing asphyxiation, cardiovascular failure (Wilson and Taylor, 1993), and death.

Exposure to metals at concentrations below those that cause mortality can induce sublethal adverse effects on fish. These adverse effects can include behavioral avoidance, reduced growth, and physiological impairment.

Avoidance

The ability of fish to detect and avoid hazardous substances has been shown for a number of substances (e.g., Atchison et al., 1987). Behavioral avoidance can be of particular importance because it can occur at concentrations lower than those that cause effects on survival and growth

(Little et al., 1993). Behavioral avoidance of metals such as Cu and Zn has been suggested as a cause of reduced fish populations in natural systems (Woodward et al., 1995a), and can impair normal migratory behaviors and effectively result in habitat loss (Lipton et al., 1995). Field studies conducted by Saunders and Sprague (1967) found that the introduction of Cu and Zn (via mine runoff) into a salmon spawning tributary resulted in repulsion of ascending salmon as compared to the same tributary before mine drainage releases, causing reductions in salmonid populations.

Growth, Immune Impairment, and Other Physiological Effects

Reduced growth has been documented to be a more sensitive measure of metals toxicity than mortality during sublethal exposures to Cu and Zn mixtures (Finlayson and Verrue, 1980) and to Cd, Cu, Pb, and Zn mixtures (Marr et al., 1995). Exposure to Cd was associated with growth reductions at concentrations associated with mortality (Pickering and Gast, 1972; Eaton, 1974). Growth reduction can be caused by physiological or behavioral stress during exposure to hazardous substances. Physiological or behavioral stress can result from a reduction in food consumption or assimilation (Lorz and McPherson, 1977; Waiwood and Beamish, 1978) or from increased metabolic costs of detoxification and homeostasis during chronic, sublethal hazardous substance exposures (Dixon and Sprague, 1981; Marr et al., 1995). Consumption by fish of metals-contaminated prey can also cause sublethal injuries, including reduced growth (e.g., Woodward et al., 1994, 1995b).

Sublethal exposure has been shown to affect immune system function in fish, with resulting increases in disease, tumors, and lesions (Zelikoff, 1994). For example, Cd can cause suppressed antibody function (e.g., O'Neill, 1981), and alteration of macrophage-mediated immune function (Zelikoff et al., 1995).

Exposure to metals can cause physiological impairment of fish. Cadmium has been shown to cause both respiratory impairment (Pascoe and Mattey, 1977; McCarty et al., 1978; both as cited in Sorenson, 1991) and muscular and neural abnormalities (e.g., Bengtsson et al., 1975; Pascoe and Mattey, 1977; both as cited in Sorenson, 1991). Cadmium tends to bind to calcium binding sites on the surface of animal cells. In fish cells, Cd apparently has a high affinity for calcium-ATPase (of cell membranes). Low Cd exposure concentrations have been shown to cause depressed plasma calcium, leading to hypocalcemia of freshwater fish (Wicklund, 1990). Calcium deficiencies increase the absorption and deposition of Cd into intestinal mucosa, liver, and kidneys (U.S. EPA, 1980, as cited in SAIC and EPT, 1991).

Lead causes hematological (anemia), neuronal, and muscular impairments in fish. Signs of Pb intoxication include black tails, lordosis/scoliosis, changes in pigment patterns, and coagulation of surface mucus (Sorenson, 1991). Lead reacts with sulfhydryl groups in the enzyme delta-aminolevulinic acid dehydratase (ALAD), inactivating the enzyme. Since ALAD is a key enzyme in heme synthesis, inactivation of ALAD results in less hemoglobin production (Johansson-Sjobeck and Larsson, 1979; Tewari et al., 1987; both as cited in Sorenson, 1991). At elevated concentrations, Pb can result in fish asphyxiation as a result of a thick mucous film over the gills (Sparks et al., 1972, as cited in Sorenson, 1991; also see Varanasi et al., 1975). Lead results in muscle spasms, paralysis, hyperactivity, and loss of equilibrium (Davies et al., 1976; Holcombe et al., 1976; both as cited in Sorenson, 1991).

Zinc causes structural injury to fish gills, reducing the ability of fish to transfer oxygen across the secondary lamellae, basement membrane, and flanges of pillar cells. Zinc toxicity probably results from decreased gill oxygen permeability as a result of increased barrier thickness (due to detachment of chloride cells from underlying epithelium and curling of the secondary lamellae; Skidmore and Tovell, 1972, as cited in Sorenson, 1991) and decreased functional surface area for oxygen transfer (Skidmore, 1970; Hughes, 1973; Hughes and Perry, 1976; Hughes and Adeney, 1977; all as cited in Sorenson, 1991). Zinc has also been shown to cause histopathological lesions, inhibition of spawning (Sorenson, 1991), reduced growth (Hobson and Birge, 1989; Finlayson and Verrue, 1980), and behavioral avoidance (Saunders and Sprague, 1967).

Modifying Factors of Cd, Pb, and Zn Toxicity

The toxicity of metals to aquatic biota can be influenced by a number of chemical factors. Typically, these factors modify metal toxicity by reducing the bioavailable fraction of the metal ion or limiting the uptake of the metal ion into the organism. For Cd, Pb, and Zn, an important modifying factor is the hardness of the water. Hardness is a measure of the total calcium and magnesium ion concentrations in the water. However, depending on how it is measured, hardness can also represent other divalent cations in the water such as iron. Hardness is inversely related to Cd, Pb, and Zn toxicity; higher hardness values are associated with lower toxicity values (U.S. EPA, 1985a, 1985b, 1987a, 1999). Because of this relationship, AWQC for these metals are based on the hardness of the water (see Section 4.2).

Alkalinity and pH also modify metal toxicity. Alkalinity, primarily a measure of the carbonate and hydroxide ion concentrations in the water, is thought to reduce metal toxicity by binding to the metal ion and reducing the bioavailable fraction (Chakoumakos et al., 1979; Calamari et al., 1980, Bradley and Sprague, 1985b). The pH of the water, a measure of the hydrogen ion concentration [H+], can influence toxicity of Cd and Zn through changes in metal speciation and by competition between H+ and the metal in the water for active uptake sites on the organism (Campbell and Stokes, 1985; Cusimano et al., 1986). At low pH values (e.g., less than 5), additive toxic effects of metals and pH may occur since H+ is toxic at high concentrations. Hence, hardness equations in water quality criteria for metals may not be applicable in low pH waters (e.g., in waters receiving acid mine drainage such as Tar Creek) since toxicity may be unduly influenced by pH levels.

Preliminary Toxicity Thresholds

In the previous section, we provided data that confirm that surface waters in Cherokee County have been injured by releases of hazardous substances, as determined, in part, by exceedences of national AWQC established by Section 304(a)(1) of the CWA (see Table 4.3). These national water quality criteria are established to be protective of 95% of all aquatic species and are derived from toxicity information available for a limited number of aquatic species. Hence, exceedences of these criteria are indicative that concentrations of hazardous substances are sufficiently elevated to injure aquatic biota in the Tri-State Mining District.

National water quality criteria were determined using toxicity information from both warm water species (commonly found in the Tri-State Mining District) as well as cold water species (not commonly found in the Tri-State Mining District) and hence, are not site-specific to the Tri-State Mining District.

To provide a more detailed assessment of the potential injury to aquatic biological resources in Cherokee County, in addition to evaluating exceedences of surface water criteria (as described in Section 4.2), we further characterized and evaluated the toxicity of Cd, Pb, and Zn to site-relevant warm water organisms. This warm water toxicity evaluation was determined by evaluating the available toxicity data for warm-water organisms known to reside in Cherokee County. However, toxicity data is absent for a large number of threatened and endangered species and warm-water species in Cherokee County. As such, warm water thresholds were only generated for fish and with the exception of Cd, were based on acute exposures only (sufficient toxicity information was available to determine both acute and chronic warm-water thresholds for Cd). These thresholds are not meant to replace existing criteria or to suggest that existing criteria are inappropriate for Cherokee County. Instead these warm water thresholds provide an additional injury assessment tool based on the readily available toxicity information for warm-water species. The assessment of injury to aquatic biological resources based on exceedences of national water quality criteria in surface water is not repeated here as this assessment is already provided in Section 4.2.

In addition to exceedences of surface water criteria and warm-water thresholds, we also examined other toxicity thresholds not typically used in the generation of aquatic quality criteria (e.g., avoidance and dietary exposure).

Overall, four types of toxicity thresholds were evaluated: acute toxicity thresholds, chronic toxicity thresholds, avoidance thresholds, and dietary thresholds. Toxicity data for acute and chronic thresholds were obtained using toxicity information on warmwater fish species in metal-specific national criteria documents (U.S. EPA, 1985a, 1985b, 1987a, 1999). Toxicity data on avoidance of Cd, Pb, and Zn were obtained from studies performed with salmonids by Woodward et al. (1997). Toxicity data on dietary exposure of fish ingesting Cd, Pb, and Zn contaminated benthic invertebrates was obtained from studies performed with salmonids by Farag et al. (1999).

Acute Toxicity Thresholds

The U.S. EPA determined a mean acute toxicity value for individual species of the same genus as part of an evaluation of acute toxicity data for the development of national AWQC. This value, referred to as a genus mean acute value (GMAV), represents the average toxicity response that results in 50% mortality (e.g., LC50) determined from several toxicity experiments with a specific genus. To allow comparisons of sensitivity across different hardness values, the GMAV is calculated after toxicity data are normalized to a hardness of 50 mg/L (as $CaCO_3$).

We used GMAVs calculated by the U.S. EPA for representative warmwater fish in the Tri-State Mining District as acute toxicity thresholds for this preliminary injury evaluation. The GMAVs of warmwater fish species to acute exposure of Cd, Pb, and Zn are provided in Table 4.6. Warmwater fish species present in the Tri-State Mining District that had GMAVs are the fathead minnow, common carp, bluegill/green sunfish, white sucker, and mosquitofish (Table 4.6). We provide GMAVs for two hardness levels to reflect the range in average metal sensitivity in site-relevant species at hardness values typical of the Tri-State Mining District: hardness 50 mg/L and hardness 200 mg/L. GMAVs were normalized to different hardness values by the following equation:

$$[\text{GMAV}]_{\text{Hardness x}} = [\text{GMAV}]_{\text{Hardness 50}} \times ([\text{AWQC}]_{\text{Hardness x}}/[\text{AWQC}]_{\text{Hardness 50}})$$

As expected, the GMAV is lower for each metal at a hardness of 50 mg/L than at a hardness of 200 mg/L. Of the warmwater species listed, the fathead minnow is the species most sensitive to acute exposure of Cd, Pb, and Zn; whereas bluegill/green sunfish, a common species throughout the Tri-State Mining District, is much less sensitive to acute exposure of Cd, Pb, and Zn (Table 4.6). Limited information is available for the sensitivity of different warmwater species to Pb. Therefore, we selected fathead minnow and bluegill/green sunfish as representative warmwater fish in the Tri-State Mining District, and GMAVs for these two species were used as acute toxicity thresholds for this preliminary injury evaluation.

Since GMAVs correspond to metal concentrations associated with 50% lethality (i.e., genus mean LC50 values), we estimated the GMAV that would correspond to an LC01 value, a concentration predicted to adversely affect 1% of the exposed population by estimating a GMAV01 value. This GMAV01 value was estimated by dividing the GMAV by two, following the U.S. EPA convention to estimate LC01s for metals from LC50 data (Gary Chapman, Paladin Water Quality Consulting, personal communication, December 1997).

Table 4.6. Acute toxicity thresholds for Cd, Pb, and Zn exposure as determined by genus mean acute values for warmwater fish species

	Cadmium GMAV(µg/L)		Lead GMAV (µg/L)		Zinc GMAV (µg/L)	
Species	**Hardness 50 mg/L[a]**	**Hardness 200 mg/L[b]**	**Hardness 50 mg/L**	**Hardness 200 mg/L**	**Hardness 50 mg/L**	**Hardness 200 mg/L**
Fathead minnow	30.5	137	25,440	115,000	3,830	12,400
Common carp	2,116	972	—	—	7,230	23,500
Bluegill/green sunfish	2,400	10,800	52,310	237,000	10,600	34,300
White sucker	3,510	15,800	—	—	5,230	17,000
Mosquitofish	7,690	34,600	—	—	—	—

a. GMAV denotes the genus mean acute value (mean LC_{50} value); GMAVs are presented in U.S. EPA's water quality criteria documents at a hardness of 50 mg/L.
b. GMAV were normalized to a hardness of 200 as follows: $[GMAV]_{H200} = [GMAV]_{H50}$ H ($[AWQC]_{H200}/[AWQC]_{H50}$).
Sources: U.S. EPA, 1985a, 1985b, 1987a, 1999.

We employed a hazard quotient approach to compare concentrations of Cd, Pb, and Zn in Cherokee County to these acute toxicity thresholds, where the hazard quotient is equal to the concentration of the metal measured in a surface water sample divided by the toxicity threshold (Figures 4.20 to 4.25). We used hardness-specific GMAV01 values for fathead minnow and bluegill/green sunfish as the toxicity thresholds. Only metal concentration data for surface waters in Cherokee County that had accompanying hardness data were used in this evaluation. Because of limited data on surface water dissolved metal concentrations and hardness levels, this hazard quotient analysis was performed with total recoverable metal concentrations only. In several locations, multiple data values were available (i.e., more than one metal concentration and hardness level associated with a single location). In these cases, the mean hardness value was used to derive the hardness-specific GMAV and the maximum metal concentration was used to calculate the hazard quotient. A hazard quotient was calculated by dividing the total metal concentrations in the surface water by the GMAV01. Hazard quotients greater than 1.0 indicate that metal concentrations in the surface water are higher than acute toxicity thresholds, suggesting potential injuries. Hazard quotients for fathead minnows represent the effects of acute Cd, Pb, and Zn exposure on more metal sensitive warmwater fish species, whereas hazard quotients for bluegills/green sunfish would represent the effects on a more metal tolerant species.

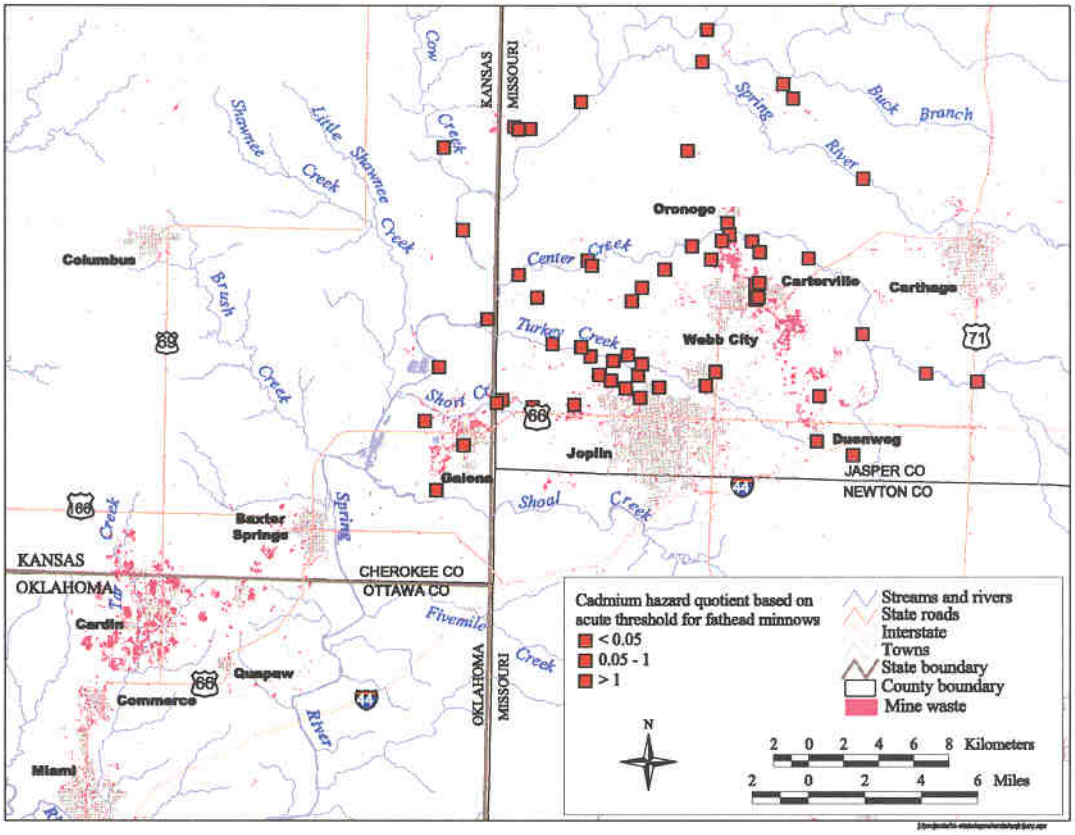

Figure 4.20. Cadmium hazard quotients for fathead minnow in the Tri-State Mining District. Hazard quotients were determined by dividing the Cd concentration measured at specific locations within the Tri-State Mining District by the fathead minnow genus mean acute value associated with adverse effects n 1% of the exposed population ($GMAC_{10}$).

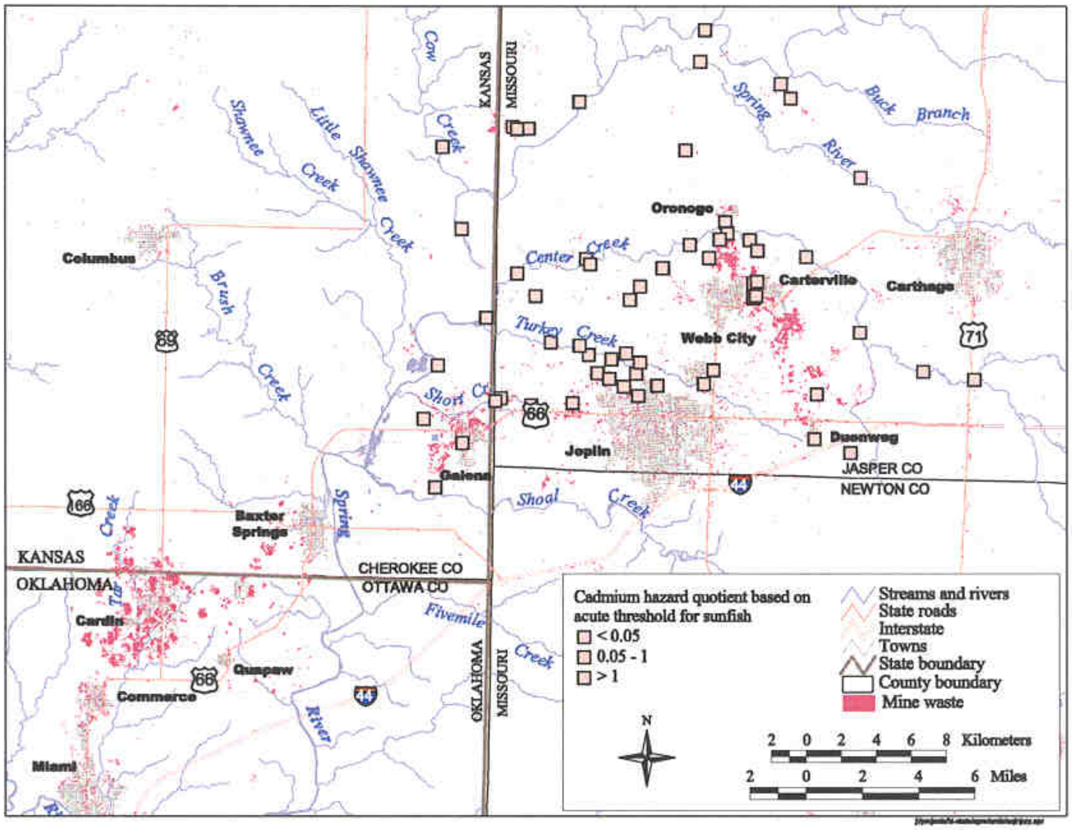

Figure 4.21. Cadmium hazard quotients for bluegill/green sunfish in the Tri-State Mining District. Hazard quotients were determined by dividing the Cd concentration measured at specific locations within the Tri-State Mining District by the bluegill/green sunfish genus mean acute value associated with adverse effects n 1% of the exposed population ($GMAC_{10}$).

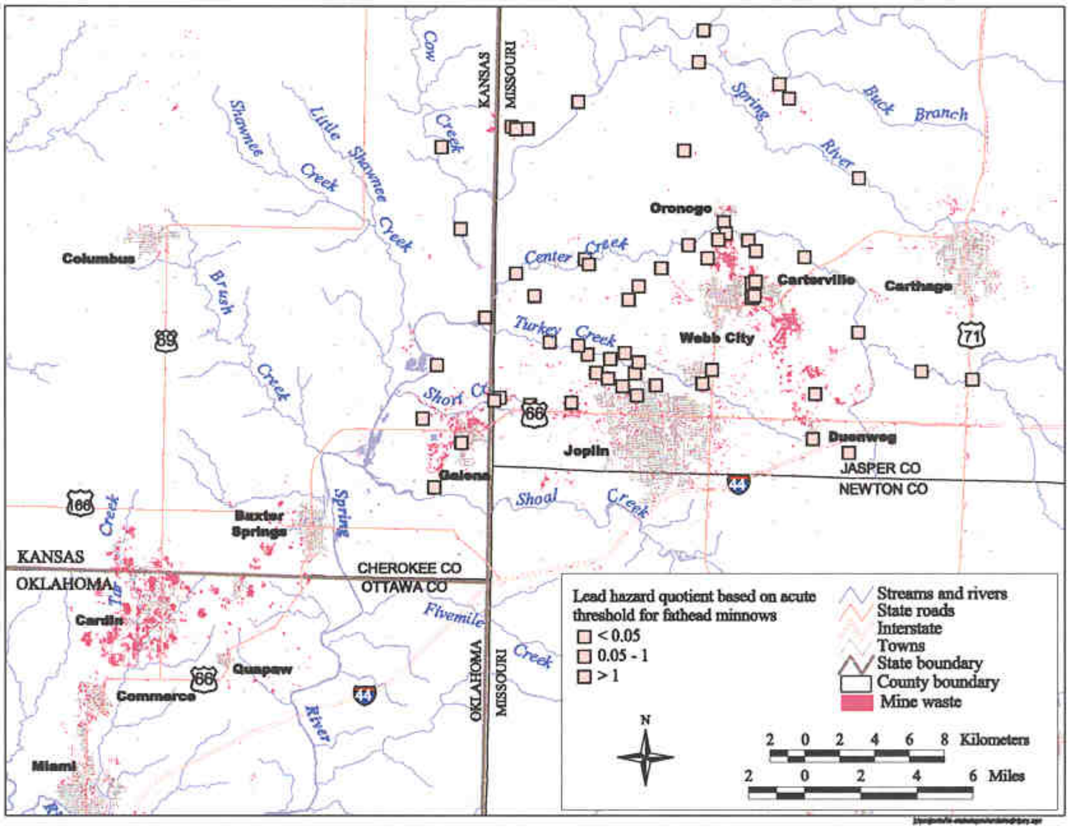

Figure 4.22. Lead hazard quotients for fathead minnow in the Tri-State Mining District. Hazard quotients were determined by dividing the Pb concentration measured at specific locations within the Tri-State Mining District by the fathead minnow genus mean acute value associated with adverse effects n 1% of the exposed population ($GMAC_{10}$).

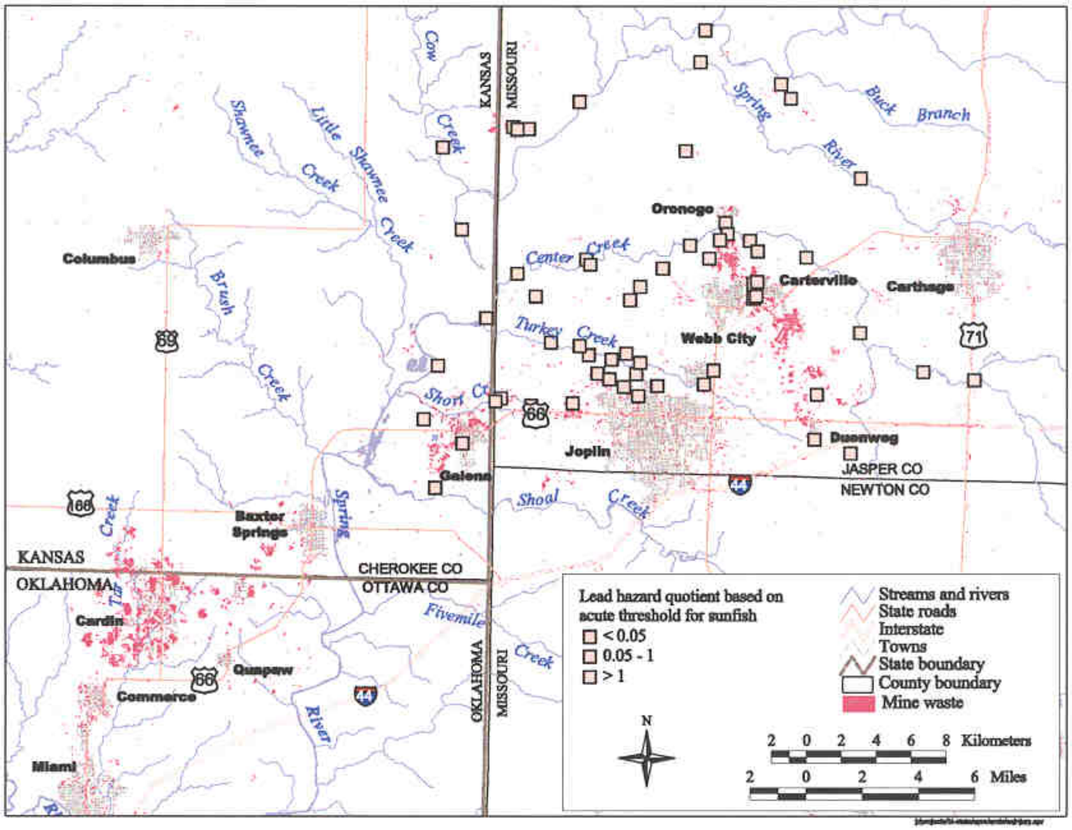

Figure 4.23. Lead hazard quotients for bluegill/green sunfish in the Tri-State Mining District. Hazard quotients were determined by dividing the Pb concentration measured at specific locations within the Tri-State Mining District by the bluegill/green sunfish genus mean acute value associated with adverse effects n 1% of the exposed population ($GMAC_{10}$).

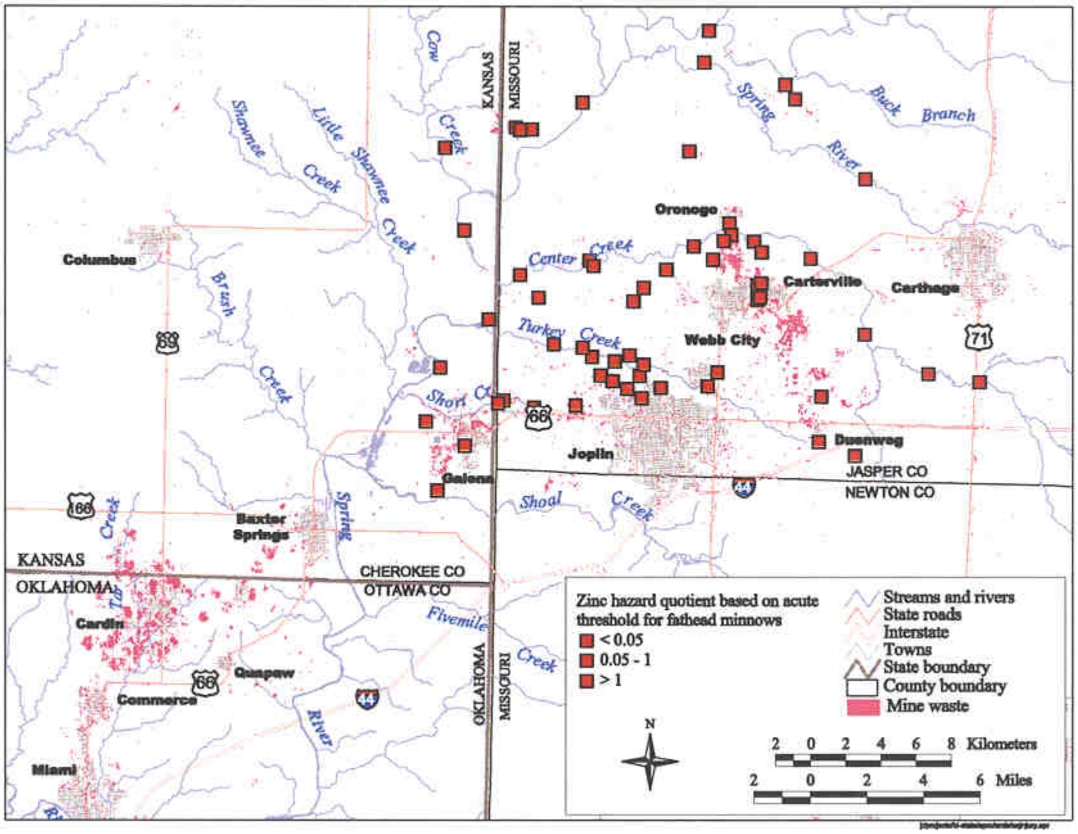

Figure 4.24. Zinc hazard quotients for fathead minnow in the Tri-State Mining District. Hazard quotients were determined by dividing the Zn concentration measured at specific locations within the Tri-State Mining District by the fathead minnow genus mean acute value associated with adverse effects n 1% of the exposed population ($GMAC_{10}$).

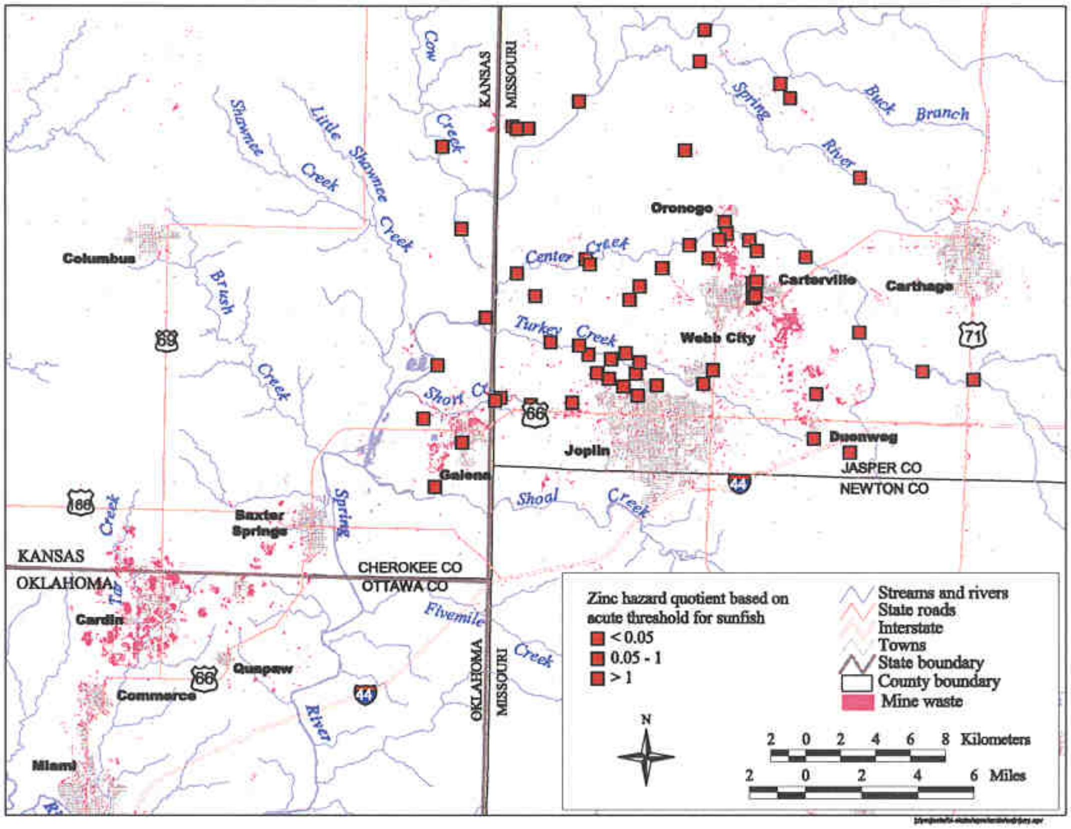

Figure 4.25. Zinc hazard quotients for bluegill/green sunfish in the Tri-State Mining District. Hazard quotients were determined by dividing the Zn concentration measured at specific locations within the Tri-State Mining District by the bluegill/green sunfish genus mean acute value associated with adverse effects n 1% of the exposed population ($GMAC_{10}$).

Data with metal concentrations and hardness values were limited for Cherokee County, Kansas. Hazard quotients for the relatively metal sensitive fathead minnow ranged from 0 to 0.57 for Cd, 0 to 0.0008 for Pb, and 0 to 1.00 for Zn. Hazard quotients for the relatively metal tolerant bluegill/green sunfish ranged from 0 to 0.007 for Cd, 0 to 0.0004 for Pb, and 0 to 0.36 for Zn. Hazard quotients greater than 1.0 were not observed for fathead minnows or green sunfish.

Overall, comparisons of Cd, Pb, and Zn concentrations in surface waters in Cherokee County to acute toxicity thresholds for warmwater fish indicate Zn concentrations may have been high enough in specific locations to exceed these acute toxicity thresholds (i.e., a hazard quotient equal to or greater than 1.0). However, exceedences of these acute toxicity thresholds were observed only for the metal sensitive fathead minnow and not for the relatively metal tolerant bluegill or green sunfish, and were limited to one mine opening. For this hazard quotient approach, we were limited to using data where both surface water metal concentrations and hardness levels were available. As a result, data were limited in Cherokee County (Kansas). Since extremely high Cd, Pb, and Zn concentrations have been measured in surface water from these areas (Figures 4.14, 4.15, and 4.16), it is likely that if hardness data were available, that hazard quotients greater than 1.0 would have been measured for the metal sensitive fathead minnow and possibly for the more metal tolerant bluegill/green sunfish.

Chronic Toxicity Thresholds

The U.S. EPA has also determined genus chronic toxicity values as part of the development of national AWQC. This genus mean chronic value (GMCV) represents the average toxicity response that results in chronic effects determined from toxicity experiments with different species with a specific genus. As with GMAVs, the GMCV is calculated after toxicity data is normalized to a hardness of 50 mg/L to facilitate comparisons of relative sensitivity across species.

We used the GMCVs calculated by the U.S. EPA for representative warmwater fish in Cherokee County as chronic toxicity thresholds for this preliminary injury evaluation. Genus mean chronic values are only available for Cd, no GMCVs have been determined for Pb or Zn, presumably because of insufficient chronic toxicity data. The GMCVs of warmwater fish species to chronic exposure of Cd are presented in Table 4.7. Warmwater fish species present in Cherokee County that have GMCVs for Cd are the fathead minnow, bluegill/green sunfish, white sucker, and smallmouth bass (Table 4.7). As before, we have provided GMAVs for hardnesses of 50 mg/L and 200 mg/L. GMCVs were normalized to different hardness values by the following equation:

$$[GMCV]_{\text{Hardness x}} = [GMCV]_{\text{Hardness 50}} \times ([AWQC]_{\text{Hardness x}}/[AWQC]_{\text{Hardness 50}})$$

Table 4.7. Chronic toxicity thresholds for Cd exposure as determined by genus mean chronic values for warmwater fish species

Species	Cadmium GMCV (µg/L) Hardness 50 mg/L[a]	Cadmium GMCV (µg/L) Hardness 200 mg/L[b]
White sucker	7.8	22.2
Smallmouth bass	8.2	23.3
Fathead minnow	15.4	43.8
Bluegill/green sunfish	16.3	46.4

a. GMCV denotes the genus mean chronic value. GMCVs are presented in U.S. EPA's water quality criteria documents at a hardness of 50 mg/L.
b. GMCV were normalized to a hardness of 200 as follows: $[GMCV]_{H200} = [GMCV]_{H50} \times ([AWQC]_{H200}/[AWQC]_{H50})$.
Source: U.S. EPA, 1996a.

As expected, the GMCV is lower for Cd at a hardness of 50 mg/L than at a hardness of 200 mg/L. Of the warmwater species listed, the white sucker is the most sensitive species to chronic exposure of Cd (Table 4.7). Consistent with their acute toxicity thresholds, bluegill/green sunfish are much less sensitive to chronic exposure of Cd (Table 4.7). We selected white sucker and bluegill/green sunfish as representative warmwater fish in Cherokee County and GMCVs for these two species were used as chronic toxicity thresholds for this preliminary injury evaluation.

As with acute toxicity thresholds, we employed a hazard quotient approach to evaluate whether concentrations of Cd in Cherokee County were greater than the chronic toxicity thresholds. Hardness-specific GMCVs for both white sucker and bluegill/green sunfish were compared to total metal concentrations measured in the surface water of the assessment area (Figures 4.26 to 4.27). Only metal concentration data for surface waters in Cherokee County that had accompanying hardness data were used in this evaluation. Because of limited data on surface water dissolved metal concentration and hardness levels, this hazard quotient analysis was performed with total recoverable metal concentrations only. In several locations, multiple data values were available (i.e., more than one metal concentration and hardness level associated with a single location). In these cases, the mean hardness value was used to derive the hardness-specific GMCV and the maximum metal concentration was used to calculate the hazard quotient. A hazard quotient was calculated by dividing the total metal concentrations in the surface water by the GMCV. Hazard quotients greater than 1.0 indicate that metal concentrations in the surface water are higher than chronic toxicity thresholds, indicating potential injuries. Hazard quotients for white sucker would represent the effects of chronic Cd exposure on more metal sensitive warmwater fish species, whereas hazard quotients for bluegills/green sunfish would represent effects on more metal tolerant species.

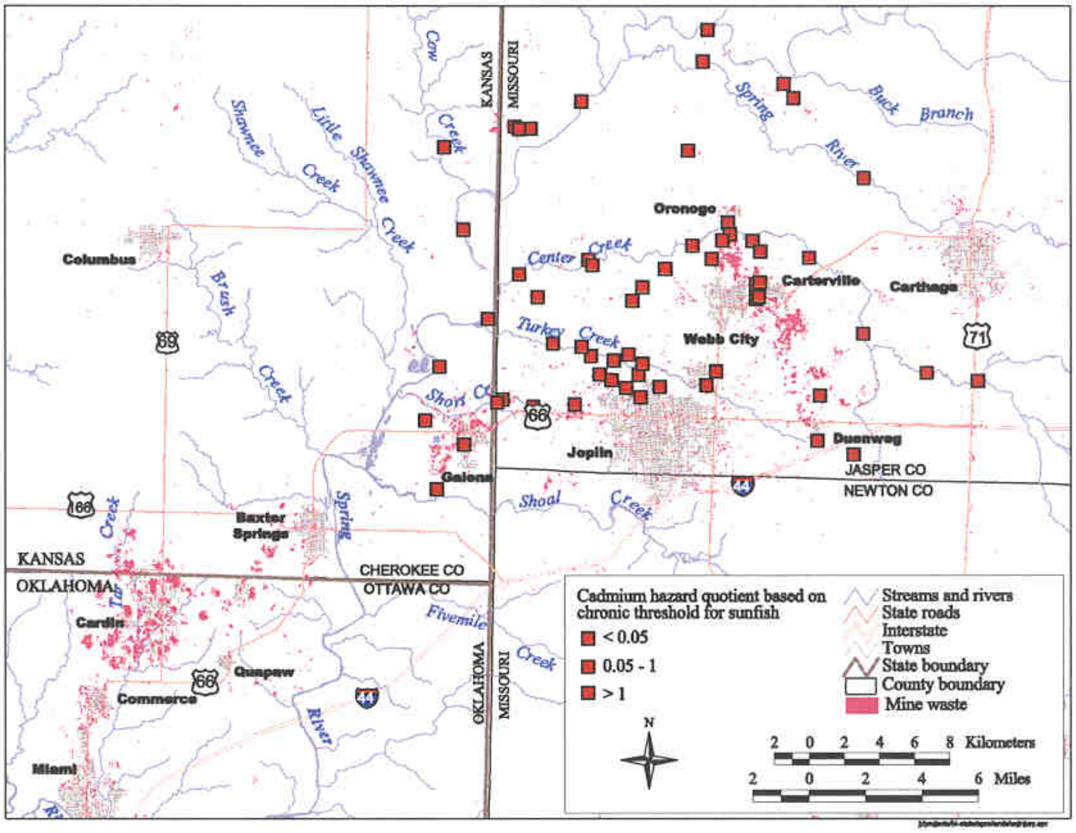

Figure 4.26. Cadmium hazard quotients for bluegill/green sunfish in the Tri-State Mining District. Hazard quotients were determined by dividing the Cd concentration measured at specific locations within the Tri-State Mining District by the bluegill/green sunfish GMCV.

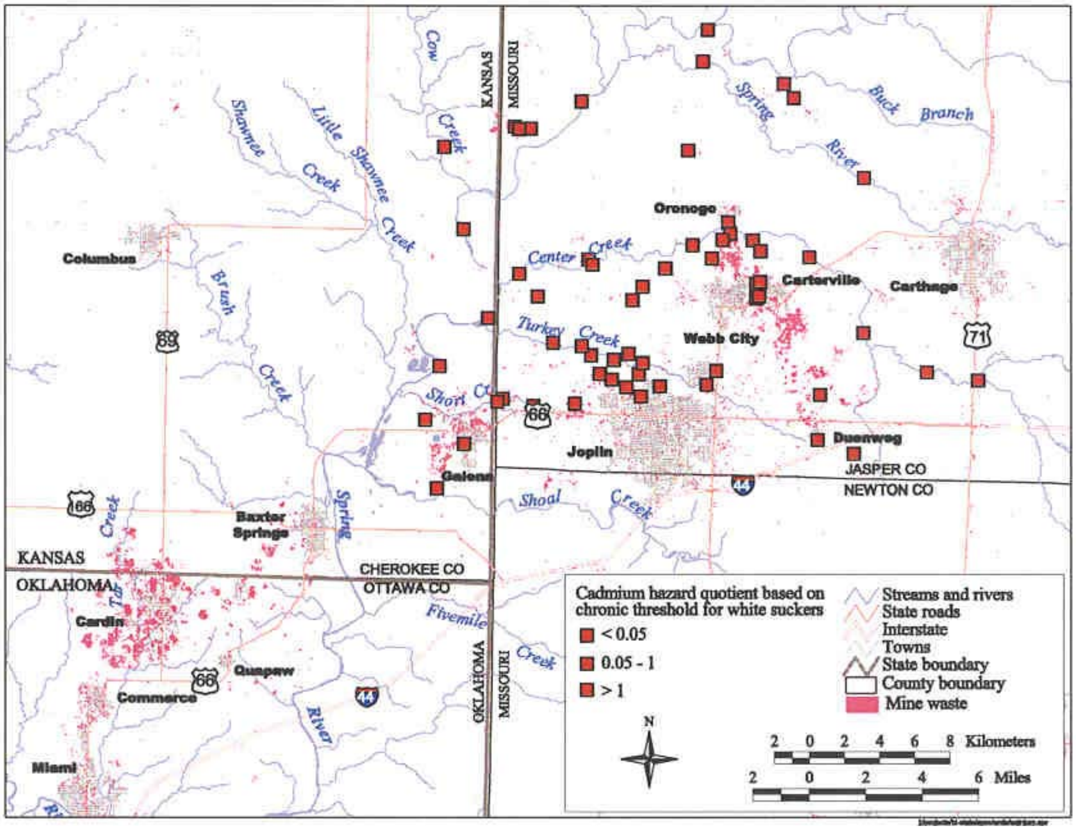

Figure 4.27. Cadmium hazard quotients for white sucker in the Tri-State Mining District. Hazard quotients were determined by dividing the Cd concentration measured at specific locations within the Tri-State Mining District by the white sucker GMCV.

As with our evaluation of acute toxicity thresholds, data with metal concentrations and hardness values were limited for Cherokee County, Kansas. Hazard quotients could only be determined for Cd as no GMCV is available for warmwater fish species for Pb or Zn. Hazard quotients for Cd ranged from 0 to 3.80 for the relatively metal-sensitive white sucker, and from 0 to 1.82 for the relatively metal-tolerant bluegill/green sunfish. As with our evaluation of acute toxicity thresholds, surface water hardness and metal concentration data were limited from Cherokee County, Kansas. Since extremely high Cd, Pb, and Zn concentrations have been measured in surface waters from these areas (Figures 4.14, 4.15, and 4.16), it is likely that if hardness data were available, that hazard quotients greater than 1.0 would have been measured for both species.

Overall, comparisons of Cd concentrations in surface waters in the Tri-State Mining District to chronic toxicity thresholds for warmwater fish indicate that Cd concentrations in surface water only exceed these chronic thresholds in mine openings. Exceedences of these chronic toxicity thresholds were observed for both the metal sensitive white sucker and the relatively metal tolerant bluegill/green sunfish.

Avoidance Thresholds

Woodward et al. (1997) evaluated behavioral avoidance of Snake River cutthroat trout exposed to Cd, Pb, and Zn singly and in mixtures in water collected from the Coeur d'Alene River, Idaho. Cutthroat trout significantly avoided 66 μg/L Zn but not 0.58 μg/L Cd or 1.3 μg/L Pb when these metals were tested singly. In multiple Cd, Pb, and Zn exposures, Coeur d'Alene River water with greater than 52 μg/L Zn was avoided by the trout. It is not known if the avoidance response is related to the hardness of water. However, no relationship was apparent from the Woodward et al. (1997) avoidance tests; avoidance was measured in water containing Cd, Pb, and Zn mixtures with hardness values ranging from 17 to 100 mg/L.

For the purposes of this preliminary injury evaluation, we used a Zn concentration of 52 μg Zn/L associated with an avoidance response in trout as an avoidance threshold for the Tri-State Mining District. However, it is uncertain if the avoidance response observed in trout is appropriate to an avoidance response that may occur in the warmwater fish species present in the Tri-State Mining District.

Surface waters in the Tri-State Mining District often contained Zn in excess of 52 μg/L Zn (e.g., Turkey Creek, Center Creek, Short Creek, Tar Creek; see Section 4.2, Figure 4.16). If warmwater fish species avoid Zn in a similar fashion to trout, then these elevated Zn concentrations could result in fish avoiding these areas in the Tri-State Mining District. This avoidance response (if present in these warmwater fish species) may result in reduced fish populations (Woodward et al., 1995a) by impairing normal migratory behaviors or by direct loss of essential habitat (Lipton et al., 1995).

Dietary Thresholds

Fish can be exposed to metals through consumption of metal-contaminated benthos (Woodward et al., 1994, 1995b; Farag et al., 1999). However, there are no tissue residue guidelines for metals to protect against adverse effects of dietary exposure. Currently there is some uncertainty in evaluating the importance of dietary exposure of metals. Tests conducted with metal-spiked formulated food (i.e., trout chow) typically have failed to show an adverse effect in fish (e.g., Spry et al., 1988). Rainbow trout fed a highly Cu-contaminated diet of brine shrimp (Artemia spp.) at 600 to 800 µg Cu/g dry weight showed about 30% mortality with no effects on growth (Mount et al., 1994). However, this mortality may have been due to waterborne Cu releases from Artemia (Mount et al., 1994). Adverse effects have been observed in fish fed metal-contaminated invertebrates that have been collected from metal-contaminated sites (Woodward et al., 1994, 1995b; Farag et al., 1999).

Adverse effects were observed in rainbow trout fed invertebrates with metal concentrations of 29.1-29.9 µg Cd/g, 15-28.4 µg Pb/g, and 650-1,070 µg Zn/g (expressed as dry weight) collected from various locations on the Coeur d'Alene River in Idaho. Adverse effects included reduced survival, reduced feeding activity, increased number of macrophage aggregates, hyperplasia of kidney cells, degeneration of mucosal epithelium in the pyloric caecae, and metallothionein induction (Farag et al., 1999).

For the purposes of this preliminary injury evaluation, we used the concentrations of Cd, Pb, and Zn in benthic invertebrates associated with adverse effects in trout via dietary exposure as a dietary threshold for fish in Cherokee County (Farag et al., 1999). We compared this dietary threshold with concentrations of Cd, Pb, and Zn measured in benthic invertebrates in the Tri-State Mining District. Because information on metal concentrations in benthic invertebrates is only available in wet weight, we converted the dietary threshold metal concentrations to wet weight by assuming a moisture content of 80% (Stephan et al., 1985). Hence, on a wet weight basis, the dietary threshold for adverse effects in trout consuming metal contaminated invertebrates is 5.8-5.98 µg Cd/g, 3.00-5.68 µg Pb/g, and 130-214 µg Zn/g.

Only limited information is available on the metal concentrations in invertebrates in Cherokee County. Elevated concentrations of Cd, Pb, and Zn in benthic invertebrates have been measured in Shoal Creek and Turkey Creek in Missouri and Cherokee County, Kansas (Table 4.8; Wildhaber et al., 1997). Concentrations of Pb in benthic invertebrates in Shoal Creek and Turkey Creek are similar to or greater than dietary threshold concentrations associated with adverse impacts in trout (Table 4.8). Concentrations of Zn in benthic invertebrates in Turkey Creek are also similar to or greater than dietary threshold concentrations associated with adverse impacts in trout (Table 4.8). Concentrations of Cd in benthic invertebrates in Shoal Creek and Turkey Creek are all below concentrations associated with adverse impacts in trout (Table 4.8).

Table 4.8. Metal concentrations in aquatic invertebrates from surface waters in Cherokee County, Kansas

				Mean metal concentration (range) (µg/g wet weight)[a]		
Location	**Species**	**Year**	**Number of samples**	**Cd**	**Pb**	**Zn**
Cherokee County, Kansas						
Shoal Creek	Insects[b]	1998	1	0.63	4.5	111
	Crayfish[b]		1	0.47	2.6	56
	Crayfish	1994	2	0.87 (<0.1-1.64)	2.22 (<1.0-3.43)	47.2 (20.3-74)
	Megaloptera		2	0.84 (0.35-1.32)	8.34 (2.25-14.4)	102.4 (76.2-128.5)
	Other invertebrates (typically molluscs)		1	0.39	2.02	77.9
Turkey Creek	Crayfish	1994	1	0.70	3.54	102.2
	Megaloptera		1	0.97	14.84	137.5
	Dietary injury thresholds for fish[d]			**5.82-5.98**	**3.00-5.68**	**130-214**

a. Background metal concentrations in invertebrate tissue provided in Table 3.6 for Cherokee County, Kansas.
b. Dietary thresholds derived from Farag et al., 1999. Thresholds converted from dry weight to wet weight by assuming 80% moisture (i.e., wet weight = dry weight H 0.2).

Source: Wildhaber et al., 1997, unless otherwise noted.

The dietary impacts discussed above were associated with trout ingesting benthic invertebrates with elevated concentrations of Cd, Pb, and Zn. It is not known if the effects observed in trout can be readily transferred to warmwater fish. Also, it is unclear what fish species (if any) could utilize the Neosho mucket as a food source. Nevertheless, the available data suggest that Pb and/or Zn concentrations in benthic invertebrates in Shoal Creek and Turkey Creek could be sufficiently elevated to result in adverse effects in fish through consumption of contaminated prey.

Site-Specific Toxicity Data

In the previous section, we evaluated threshold data related to the toxicity of Cd, Pb, and Zn to site relevant organisms as a means of evaluating potential injuries. These toxicity thresholds were acute toxicity thresholds, chronic toxicity thresholds, avoidance thresholds, and dietary thresholds. Consistent with exceedences of water quality criteria (discussed in Section 4.2), we observed exceedences of these more site-specific toxicity thresholds. These exceedences provide a further indication that concentrations of hazardous substances are sufficiently elevated to injure aquatic biota in the Tri-State Mining District. In this section, we examine evidence of acute and chronic toxicity to fish and benthic invertebrates by reviewing site-specific acute and chronic toxicity data in site water, sediments, and sediment pore waters.

Acute Toxicity in Site Waters

Acute toxicity has been investigated with site water collected from Cherokee County, Kansas. Most of these toxicity evaluations were conducted with laboratory test organisms such as the fathead minnow or the zooplankton species *Ceriodaphnia dubia*.

Acute toxicity was observed in minnows exposed to site water collected from Brush Creek, Willow Creek, and several sampling locations downstream on the Spring River (downstream of the confluence with Baxter and Willow creeks) in Cherokee County, Kansas, in the late 1930s (Baumgarter et al., undated). No information is available on test methodology or test species for these tests; however, all exposed minnows were dead after between 15 and 75 minutes of exposure to the site waters (Baumgarter et al., undated). Toxicity was attributed to iron compounds precipitating on the fish gill, resulting in suffocation (Ellis, 1937, as cited in Baumgarter et al., undated).

Acute toxicity has also been observed with *Ceriodaphnia dubia* in surface waters collected from the Spring River upstream of Baxter Springs, Cherokee County, Kansas (Table 4.9; Allert et al., 1997). Survival of Ceriodaphnia in these waters ranged from 0 to 22.2%. Survival was 100% in control test waters (Tavern Creek and well water).

Acute Toxicity in Sediments/Pore Waters

Sediments in Cherokee County have elevated concentrations of Cd, Pb, and Zn compared to background reference locations (see Sections 3.3.3 and 4.2). In this section, we review the available evidence that sediments in Cherokee County are acutely lethal to test organisms. Acute toxicity has been investigated with sediments or sediment pore water collected from Cherokee County, Kansas.

Acute lethality has been measured with *Ceriodaphnia dubia* in toxicity tests conducted with sediment pore water collected from Willow Creek in Cherokee County, Kansas (Allert, unpublished data).[1] The exact locations of where sediments were sampled were not provided in the original source document. Pore waters from these sediments were acutely toxic to *Ceriodaphnia dubia*; mortality ranged from 0 to 100% in Willow Creek (Table 4.10).

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1. This report has not been released and is confidential. Copies of the raw data were provided to us by Jim Dwyer, USFWS, for review and inclusion in this confidential preliminary evaluation of injury and damage report for the Tri-State Mining District.

Table 4.9. Acute toxicity tests (unspecified duration; renewal test) with *Ceriodaphnia dubia* in site waters in Cherokee County, Kansas

Location	Percent survival (%)	Reproduction
Control waters		
Tavern Creek	100	23.9
Well water #1	100	24.6
Well water #2	100	24.6
Site waters		
North Fork of Spring River (east of Highway 43)	90	19.5
Shoal Creek (SW of Galena)	90	29.0
Shoal Creek (upstream POTW)	90	25.6
Shoal Creek (downstream Highway P)	100	25.0
Spring River (north of Baxter, Kansas)[a]	0	0
Spring River (upstream of Highway 96)	100	28.4
Spring River (west of the Kansas/Missouri Border)	90	22.9
Spring River (NW of Galesburg)	100	27.1
Spring River (east of Waco)	80	20.4

a. Water diluted 50% (presumably with uncontaminated laboratory dilution water).

Source: Allert et al., 1997.

Table 4.10. Pore water toxicity to *Ceriodaphnia dubia* from sediments collected from Willow Creek, Kansas

Locations	Test date	Percent site water (%)	Percent mortality (%)	pH range	Hardness
Willow Creek (location not provided)	Oct. 6, 1995	50	100	6.59-8.48	—
		25	10	7.76-8.64	206
		12.5	0	7.76-8.63	—

Source: Allert, unpublished data.

Acute toxicity has been measured in laboratory toxicity tests with sediment/sediment pore water collected from Willow Creek. Acute toxicity of sediment/sediment pore water is indicative of injury to aquatic biota from exposure to elevated metal concentrations in the sediment in these locations in the Tri-State Mining District.

Chronic Toxicity — Biochemical Indicators of Injury

In this section, we review the available evidence for chronic toxicity in organisms exposed to site waters collected from the Tri-State Mining District. Exposure to metals at concentrations below those that cause acute mortality can induce sublethal adverse effects on fish. These adverse effects can include behavioral avoidance, reduced growth, and physiological impairment.

In the Tri-State Mining District, possible chronic effects have been measured only in fish collected from Center Creek, Missouri in 1989 (Schmitt et al., 1993). Schmitt et al. (1993) measured depressed ALAD levels (a key enzyme in heme synthesis) in suckers (black, golden, and shorthead redhorse) collected from two locations on Center Creek in 1989. ALAD activity was reduced 17% at an upstream site and 27% at a downstream site on Center Creek compared to reference fish species collected at various uncontaminated locations throughout Missouri (Schmitt et al., 1993).

As previously discussed, blood ALAD activity is a rapid and sensitive indicator of lead exposure in fish (Hodson et al., 1979). Reduced blood ALAD levels is considered an injury under federal regulations if the activity has been reduced more than 50% from control ALAD activity [43 CFR § 11.62 (f)(4)(v)(D)]. Thus, from the information in Schmitt et al. (1993), it appears that fish have not been exposed to Pb at concentrations sufficient to be considered a *de facto* injury under the regulations. Schmitt et al. (1993) also noted that Zn appeared to ameliorate the inactivation of ALAD by Pb. Since Zn is also elevated in the Tri-State Mining District, the interaction between Zn and Pb may be minimizing the adverse effects of Pb exposure on blood ALAD activity in these fish.

Fish and Invertebrate Population Data

So far in this section we have evaluated threshold data related to the toxicity of Cd, Pb, and Zn to site relevant organisms, and reviewed evidence of acute and chronic toxicity in organisms exposed to site waters as a means of evaluating potential injuries to aquatic biota in Cherokee County. Here, we evaluate whether information on fish and invertebrate populations supports a contention that injuries may have occurred in aquatic biota in Cherokee County. Population level information that is indicative of injuries to aquatic biota can include changes in abundance or biomass of a species, reduced diversity, or a shift in species composition toward metal tolerant organisms. For benthic invertebrates, a sensitive measure of injuries associated with metal exposure is a reduction in species richness and a reduction in the number of metal sensitive organisms (Clements, 1994).

Fish Populations

Data on fish populations and communities in the Tri-State Mining District were primarily available from RI/FS documents for Cherokee County, Kansas (Dames & Moore, 1993b). Information was also obtained on populations of the Neosho madtom for the Tri-State Mining District from USGS (Wildhaber et al., undated; Wildhaber et al., 1998).

Cherokee County, Kansas

Historically, Baxter Creek, Willow Creek, and the Spring River (downstream of the confluence with Baxter and Willow creeks) in Cherokee County, Kansas, were devoid of aquatic life as a result of mining activities. Field observations in October 1940 and February 1941 in these locations by the Oklahoma A. and M. College concluded that practically all animal and plant life had been destroyed by discharges of mine water into these waters (Baumgarter et al., undated). These researchers noted excessive iron deposits on the bottom substrate that covered the available habitat for benthic invertebrates.

Fish have been collected from Cherokee County in upper Tar Creek, Willow Creek, and the Spring Branch from the Treece and Baxter Springs subsites (Table 4.11, Dames & Moore, 1993b). Dames & Moore (1993b) concluded that the fish species diversity measured in these creeks and rivers was typical for streams in Cherokee County. However, no information is available for reference locations in the Treece and Baxter Springs subsites to determine if the fish population data are indicative of injuries to aquatic biota in these waters. Dames & Moore (1993b) noted that the bluegill and green sunfish were the most abundant fish species sampled. Since these fish species are relatively tolerant of Cd, Pb, and Zn exposure (see Tables 4.6 and 4.7), the fact that they are the most abundant fish species may suggest that more metal-sensitive species may be affected. For example, no minnows were collected from Tar Creek, Willow Creek, or Spring Branch (Dames & Moore, 1993b).

Fish species have also been observed in subsidence ponds in the Treece and Baxter Springs subsites in Cherokee County, with elevated metal concentrations in surface water in excess of the hardness-based water quality criteria (especially for Cd and Zn; see Section 4.2). These ponds have variable and typically high hardness values in excess of 400 mg/L (Dames & Moore, 1993b). Predominately the metal-tolerant green sunfish has been sampled from these pits and ponds (Table 4.12).

Overall, the available fish population data suggest that the fish community in the Treece and Baxter Springs subsites in Cherokee County is dominated by more metal-tolerant fish species (predominately bluegills and green sunfish); metal-sensitive fish species do not appear to be common in sampling studies. It is not known whether this absence is an effect of elevated metals in surface water/sediments, or is caused by other factors.

Table 4.11. Fish collections (counts and % of catch) from Upper Tar Creek, Willow Creek, and Spring River in the Treece and Baxter subsites in Cherokee County, Kansas

Location	Fish species	Count/ percent	Comments from Dames & Moore (1993b)
Tar Creek (TC-3)	Assorted sunfish	8	Mixture of green, redear, warmouth, and unidentified sunfish.
Willow Creek (WC-3)	Green sunfish	60%	Length-frequency histogram indicates three year classes for green sunfish. Other species sampled include the spotted sucker, dace, and plains topminnow.
	Longear sunfish	16%	
	Pumpkinseed	9%	
	Warmouth	3%	
Willow Creek (WC-2)	No fish	0	This section of creek was dry 60 days before sampling.
Willow Creek (WC-1a)	Bluegill	36	Bluegill ranged from 55 to 159 mm, indicating 4 year classes present. Other species collected (one of each) include the white crappie, spotted sucker, brook silverside, and shiner.
	Green sunfish	5	
	Warmouth	5	
	Redear sunfish	5	
	Largemouth bass	3	
Spring Branch (SB-2)	Assorted species	50	Species include green sunfish, yellow bullhead, plains topminnow, and chubs. Green sunfish ranged from 56 to 155 mm, indicating 4 age classes.

Source: Dames & Moore, 1993b.

Neosho Madtom

The Neosho madtom may be affected by elevated Cd, Pb, and Zn concentrations in Cherokee County. A model incorporating physical habitat, water chemistry, and nutrient concentrations from the Neosho River (data from 1991) was used to predict the distribution of Neosho madtoms in the Neosho, Cottonwood, and Spring rivers in 1994 (Wildhaber et al., 1998). Higher Neosho madtom densities were predicted in the Neosho and Cottonwood rivers than in the Spring River system. Density of the Neosho madtom was associated with smaller substrate size and lower concentrations of Cd and Pb in benthic invertebrates, suggesting that habitat and contaminant levels are important in the distribution of this species (Wildhaber et al., 1998). When the Spring River data were analyzed separately, the presence of Neosho madtoms was associated with areas with low Cd and Zn concentrations, higher fish densities and species richness, higher benthic invertebrate taxa richness, and lower benthic invertebrates concentrations of Cd and Zn (Wildhaber et al., 1998). Hence, based on population models of density of Neosho madtoms, the distribution of the Neosho madtom in the Spring River could be reduced in areas with elevated concentrations of Cd, Pb, and Zn.

Table 4.12. Numbers of fish collected in Treece and Baxter subsites in Cherokee County, Kansas

Location	Fish species	Count	Comments from Dames & Moore (1993b)
Tailings pond (TP-6)	Green sunfish	47	Majority of green sunfish were between 55 to 89 mm, indicating a strong year 1 class (1+).
	Unidentified sunfish	5	
Tailings pond (TP-7)	Bluegill	67	Large number of bluegill fish between 40 to 69 mm, indicating strong year class (0+). Estimated three year classes present.
	Largemouth bass	5	
	Black bullhead	1	
	Warmouth	4	
	Green sunfish	1	
Tailings pond (TP-5)	Green sunfish	85	Estimated that two age classes present for green sunfish.
Ballard Pond (BP-1)	No fish	0	No fish collected. However, Ballard Pond is being used as a chat-wash sedimentation pond.
Brewster Pond (BP-3)	Green sunfish	77	Green sunfish ranged from 40 to 84 mm (age classes 0+ and 1+). White crappie ranged from 350 to 370 mm (predator of green sunfish). Other fish species sampled include one black bullhead.
	White crappie	3	
Paxton Pond (BP-4)	Assorted species	NA	Fish collected include bluegills, green sunfish, and black bullheads.

NA denotes not available.

Source: Dames & Moore, 1993b.

Overall, the reduced numbers of fish species in downstream areas of Short Creek and Center Creek, the reduced numbers of total fish caught in downstream areas of Center Creek, the reduced number of minnows in downstream areas of Turkey Creek and Center Creek, the predominance of metal-tolerant fish species in the Treece and Baxter Springs subsites in Cherokee County, the reduced or nonexistent fish community in Tar Creek, and the predicted reduced density of Neosho madtoms in areas with elevated Cd, Pb, and Zn concentrations are all indicative of injuries to aquatic biota.

Benthic Invertebrate Population Data

Data on benthic invertebrate populations and communities were primarily available from RI/FS documents for Cherokee County, Kansas (Dames & Moore, 1993b).

Cherokee County, Kansas

Ferrington (undated) assessed the benthic invertebrate community in Short Creek at four sampling locations: upstream Short Creek (reference location); 0.7 miles and 1.0 miles north of Galena, and upstream from the confluence with the Spring River. Ferrington observed reduced species richness, reduced macroinvertebrate annual density, reduced average biomass, and reduced diversity (as measured by the mean Brillouin's index) in Short Creek (Table 4.13).

Table 4.13. Benthic community structure in Short Creek in Cherokee County, Kansas

Location	Total annual species richness (# species)	Mean annual density (# species/m^2)	Mean average biomass (g/ft^2)	Mean Brillouin's index (nats)[b]
Upstream Short Creek (Reference Location)[c]	87	16,806	1.171	2.194
Short Creek: 0.7 miles north of Galena	46	3,706	0.098	1.024
Short Creek: 1.0 miles north of Galena	41	3,404	0.144	1.154
Short Creek: upstream of confluence with Spring River	39	1,826	0.032	0.899

a. Macroinvertebrate community sampled four times during 1993/1994 on November 22, March 14, June 20, and September 24. Data presented based on annual means.
b. Brillouin's index is a diversity index. Index determined using natural log transformation. Values of 2.00 or greater are typically associated with excellent to good water quality in eastern Kansas.
c. This location has elevated concentrations of Cd, Pb, and Zn but lower concentrations than other areas in the mining region.

Source: Ferrington.

Spruill, 1987 (as cited in Schmitt et al., 1997) measured reduced numbers of ephemeropterans and plecopterans in the Spring River below Baxter Springs in Cherokee County, Kansas.

Overall, these benthic invertebrate data suggest injuries to aquatic biota in the Spring River below Baxter Springs and in downstream sections of Short Creek.[2]

2. Additional data supplied to Stratus Consulting by the State of Kansas indicate that mollusk (bivalve) communities and populations have been reduced or eliminated in sections of the Spring River downstream of mining activities. This is indeed the case and the effects are due to releases of hazardous substances from mining operations. Our estimates of the degree and extent of injuries to aquatic biota would be increased.

4.3.5 Summary

In this section, we summarize the existing evidence available in 1999 that aquatic biological resources in Cherokee County have been injured by releases of Cd, Pb, or Zn. Injury to these resources for this preliminary evaluation was determined based on definitions in the federal regulations. Two main types of injury were examined: injury based on issuance of fish consumption advisories and/or exceedences of federal and state regulatory concentration thresholds for Cd, Pb, and Zn in fish tissue, and injury based on adverse changes in viability. The results of our preliminary evaluation are summarized for each main injury category. We also summarize these injury results by water source to facilitate comparison of all injuries within individual waterbodies.

Fish Consumption Advisories and Exceedences of Federal and State Regulatory Consumption Thresholds

- No federal or state fish consumption advisories have been issued based on elevated concentrations of Cd, Pb, or Zn in fish tissue in the Tri-State Mining District
- Cd and Pb concentrations in fish tissue in Cherokee County generally do not exceed federal or state regulatory consumption thresholds (no federal or state regulatory consumption threshold has been established for Zn).

Adverse Changes to Viability

- Measured concentrations of Cd, Pb, and Zn in surface waters of Cherokee County do not exceed estimated acute toxicity thresholds for warmwater fish
- Measured concentrations of Cd in surface waters of Cherokee County do not exceed estimated chronic toxicity thresholds for warmwater fish
- Zn concentrations in Short Creek, Shoal Creek, Willow Creek, Turkey Creek, and other surface waters in Cherokee County exceed concentrations known to result in behavioral avoidance in trout
- Pb concentrations in Shoal and Turkey Creek benthos and Zn concentrations in Turkey Creek benthos exceed levels known to be associated with adverse dietary effects on trout
- In toxicity tests, water from Spring River, Brush Creek, and Willow Creek was acutely toxic to fathead minnows and *Ceriodaphnia dubia*
- In toxicity tests, sediment pore water collected from Willow Creek was acutely toxic to *Daphnia magna*

- The fish communities in the Treece and Baxter Springs subsites are dominated by metal-tolerant fish species
- Numbers of metal-sensitive mayflies and stoneflies are reduced in the Spring River (just below Baxter Springs) compared with nonimpacted reaches.

Summary of Evidence of Injury to Aquatic Biota by Water Source

Evidence of injury to biological resources was limited to specific locations within Cherokee County. Below, we summarize these injuries for each major water source. Typically, only information on the presence of injury is provided, as insufficient information was available to accurately quantify absence of injury. However, where appropriate, information indicating absence of injury is also noted.

- Brush Creek
  - Surface water collected in the late 1930s was acutely toxic to minnows.
- Shoal Creek
  - Zn concentrations exceed concentrations known to result in behavioral avoidance in trout
  - Pb concentrations in benthos exceed levels associated with adverse dietary effects in trout.
- Short Creek
  - Zn concentrations exceed concentrations known to result in behavioral avoidance in trout.
- Spring River
  - Surface water collected upstream of Baxter Springs was acutely toxic to *Ceriodaphnia dubia*. Surface water collected in the late 1930s downstream of the confluence of Baxter and Willows creeks was acutely toxic to minnows
  - Numbers of metal-sensitive mayflies and stoneflies are reduced just below Baxter Springs (a mining-impacted area) compared to nonimpacted reaches.

- Turkey Creek
    - Zn concentrations exceed concentrations known to result in behavioral avoidance in trout
    - Pb and Zn concentrations in benthos exceed levels associated with adverse dietary effects in trout.
- Willow Creek
    - Zn concentrations exceed concentrations known to result in behavioral avoidance in trout
    - Surface water collected in the late 1930s was acutely toxic to minnows
    - Sediment pore water collected from an unspecified location was acutely toxic to *Ceriodaphnia dubia.*

Overall, these results suggest that it is likely that aquatic biological resources in Cherokee County have been injured through their exposure to hazardous substances released from mining facilities. These injuries conform to some of the definitions of injury in the federal regulations.

4.4 Terrestrial Biological Resources

This section reviews the existing evidence available in 1999 that terrestrial biological resources in Cherokee County — vegetation communities, wildlife, and wildlife habitat — have been injured by releases of hazardous substances from mine sites in the Tri-State Mining District. We also quantify the likely spatial and temporal extent of these injuries.

4.4.1 Definitions of injury to terrestrial biological resources

Injuries to terrestrial biological resources, including vegetation, are defined in federal regulations as:

- . . . adverse changes in viability including: death, . . . physiological malfunctions (including malfunctions in reproduction), or physiological deformations [43 CFR § 11.62 (f)(1)(I)].

There are obvious vegetation community anomalies on and adjacent to mine wastes in Cherokee County. These range from the complete absence of vegetation to changes in the composition and structure of vegetation communities. These effects may be due to injuries to individual plants caused by their exposure to releases from the mine wastes of hazardous substances, primarily Cd, Pb, and Zn. Phytotoxic injuries to individual plants that conform to the above definition of injury and that could result in the observed community-level effects include death (including failure to germinate) and physiological deformations (i.e., reduced growth leading to a loss in viability).

The distribution and abundance of wildlife species are a reflection of their habitat requirements, including preferences for cover, and breeding and foraging sites. In terrestrial ecosystems, plant community structure and distribution are generally the primary determinants of whether an area provides habitat suitable for terrestrial wildlife species (Cooperrider et al., 1986). While the vegetational characteristics of an area may not capture all of the environmental parameters important to a particular animal species, vegetation normally defines the baseline quality of the habitat.

Over large parts of Cherokee County, vegetation communities have been eliminated or highly degraded by mine wastes. This has most likely resulted in major effects on the ability of these areas to provide suitable habitat for wildlife. This habitat injury may have been caused by the effects of hazardous substances on individual plants, as described in the regulatory definition of injury.

In this section we review existing data to determine the likelihood of the following:

- Injuries to individual plants in Cherokee County have been caused by their exposure to the hazardous substances Cd, Pb, and Zn
- The injuries to individual plants have resulted in the observed vegetation community anomalies
- The injuries to vegetation communities have resulted in the degradation of wildlife habitat.

We also preliminarily identify the spatial and temporal extent of the injuries caused by mine wastes to vegetation communities and wildlife habitat in Cherokee County.

4.4.2 Causes of vegetation injuries

In this section, we review the evidence for causes of vegetation injury in Cherokee County. We first compare concentrations of hazardous substances with phytotoxicity thresholds from the scientific literature. Then we review the results of previous phytotoxicity experiments. Lastly, we evaluate associations between vegetation measurements and concentrations of hazardous substances.

Comparisons with Thresholds

Cherokee County, Kansas

Table 4.14 presents the results of contaminant concentration measurements in Kansas mine wastes, together with background national concentrations and concentrations shown in controlled laboratory experiments to be toxic to plants.

Table 4.14. Mean concentrations (mg/kg) of Cd, Pb, and Zn in mine wastes in Cherokee County, Kansas, together with U.S. background concentrations and phytotoxicity thresholds

Metal	Medium	Mean concentration[a]	U.S. background[b]	Phytotoxicity threshold[c]
Cadmium	Chat	26-46	0.35	3-8
	Tailings	124		
	Mine waste	35		
Lead	Chat	63-750	19	100-400
	Tailings	1,700-3,800		
	Mine waste	1,820		
Zinc	Chat	6,033-13,688	60	70-400
	Tailings	17,000-21,600		
	Mine waste	5,710		

a. U.S. EPA, 1988b; CH2M Hill, 1989; Dames & Moore, 1993b; Veith et al., 1994.
b. Adriano, 1986.
c. Kabata-Pendias and Pendias, 1992.

The data reported in Table 4.14 indicate that Cd, Pb, and Zn concentrations in Cherokee County mine wastes greatly exceed national average soil concentrations and concentrations thought to be toxic to vegetation, indicating that the vegetation community injuries observed on Cherokee County mine wastes could be due to the phytotoxic effects of hazardous substances.

Summary

In summary, the data presented in the previous paragraph and in Table 4.14 indicate that the marked vegetation community anomalies on and adjacent to mine wastes in Cherokee County could be due to the phytotoxic effects of hazardous substances on individual plants.

4.4.3 Spatial extent of injury to vegetation

Dames & Moore (1993b) attempted to quantify the degree and spatial extent of vegetation injury in Kansas. The results are shown in Table 4.15.

Table 4.15. Acres of vegetated and devegetated mine wastes in Cherokee County, Kansas, and Ottawa County, Oklahoma

Area	Devegetated (<50% cover) wastes	Stratus Consulting estimate of devegetated (<20-30% cover) wastes	Vegetated (>50% cover) wastes
Cherokee County, Kansas[a]	621	874	448

a. Data from Baxter Springs and Treece subsites (Dames & Moore, 1993b).

Stratus Consulting also performed independent estimates of the extent of unvegetated mine wastes using an August 3, 1989 Landsat^{TM} image (obtained from USGS) of the entire Tri-State Mining District.

It should be noted that the Stratus Consulting analysis focused on areas that are largely devegetated. Additional large areas exist in all three states where the deposition of mine wastes have resulted in less marked, but still ecologically important effects. Inclusion of these areas would greatly expand the estimate of injured acres. However, this is beyond the scope of this report.

The resolution of this image was 30 meters. The satellite image was georectified to the Universal Transverse Mercator (UTM) coordinate system using USGS scanned topographic maps (digital raster graphics — DRG) for control locations. A total of 10 control points was used and the root mean squared error (RMS error) was 0.98 (pixel units). Following georectification, the image was subsetted to include only the four county study region. The resulting image was then classified using an unsupervised classification method (isodata clustering) with 35 classes. The classes were then grouped into 7 general cover type categories: unclassified, wetlands, water, barren fields, vegetated areas, urban areas, and mine wastes. These categories were assigned by identifying the classed feature using ground truthed low altitude (scale, 1:6000) color aerial photographs (provided by U.S. EPA; photograph date: 8/6/88) and USGS DRGs. Stratus Consulting then used this classified layer to remove the vegetated areas, wetlands, water, and unclassified cover types from the original satellite image, leaving barren fields, urban areas, and mine wastes.

A supervised classification technique was then employed to differentiate the mine waste from the urban and barren field features. This method uses a maximum likelihood algorithm that groups similar pixels (Lillesand and Kiefer, 1994). In supervised classification, training samples of pixels representing areas of known ground features are used to create spectral profiles and guide the classification process. Due to the variety of mine wastes present in the area, two spectral profiles were created. The first was based on a spectral definition of unvegetated mine wastes that mostly excluded any spectral overlap with nonmine waste areas. This analysis was conservative (Figure 4.28) and may have underestimated the actual acres of unvegetated mine wastes. The second approach was based on a spectral definition of mine wastes that was less restrictive and that may have included limited areas with spectral reflectances similar to mine wastes, such as residential areas, or roads surfaced with waste or waste-like materials (Figure 4.29). In both approaches, the goal was to represent the range of spectral reflectances related to that particular feature type (e.g., for mine wastes, samples included barren and dry mine wastes, partially vegetated mine wastes, damp/wet mine wastes).

In the "conservative" run, 50 sample polygons were created by delineating representative pixels of known ground cover categories (identified from photographs and DRGs), and used as inputs in the classification process. After classification was complete, this layer was compared to the photographs and DRGs to estimate the accuracy of the classifications. It was determined that this analysis might have underestimated the amount of mine waste. In the less restrictive run, the areas of mine waste that were misclassified were added as training samples. While this allowed for more areas of mine waste to be classified, it may have included limited areas with spectral reflectances similar to mine wastes, such as residential areas or roads surfaced with mine waste or waste-like materials. We believe that our less restrictive method produces acre estimates that are closest to the actual extent of mine wastes in the Tri-State Mining District. In both cases, the mine wastes generally had less than 20-30% plant cover.

Based on the data reported by Dames & Moore (1995) and CDM (1995), it appears that approximately 620 acres of mining wastes in the Baxter Springs and Treece subsites in Cherokee County, Kansas, had less than 50% vegetative cover, while 448 acres had vegetation cover of >50%.

The Stratus Consulting estimate of devegetated mine wastes in Cherokee County is 874 to 1,416 acres. It should be noted that each of the Stratus Consulting estimates are for mine wastes with less than 20-30% plant cover and are, therefore, more restrictive than the Dames & Moore and CDM estimates. However, the Stratus Consulting estimates also include areas outside of the designated areas, which were not covered by either Dames & Moore or CDM.

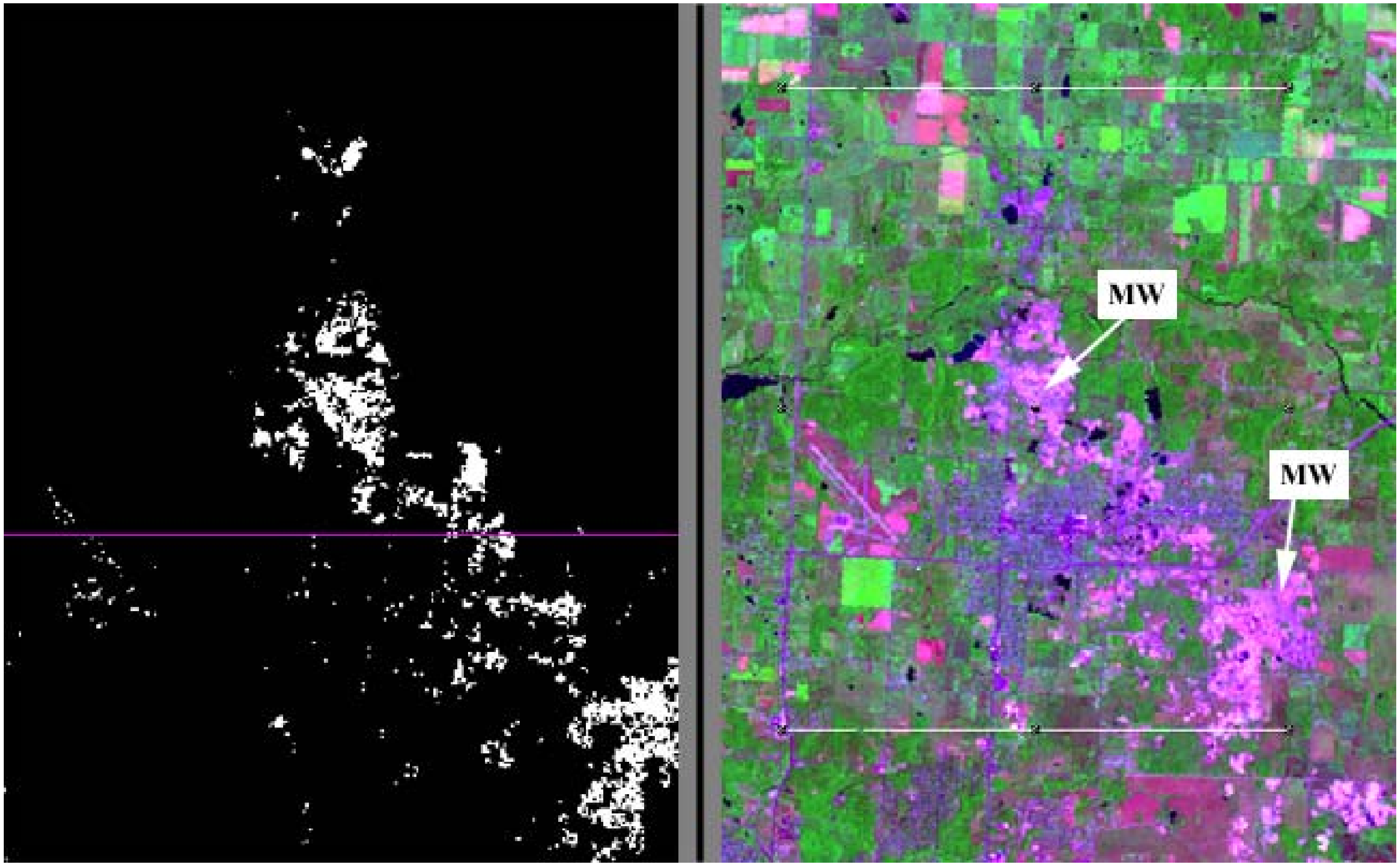

Figure 4.28. Right: distribution of mine waste sites (MW) adjacent to Webb County, Missouri, from Landsat™ satellite image (August, 1988). Left: mine waste (white) from same image identified using "conservative" approach.

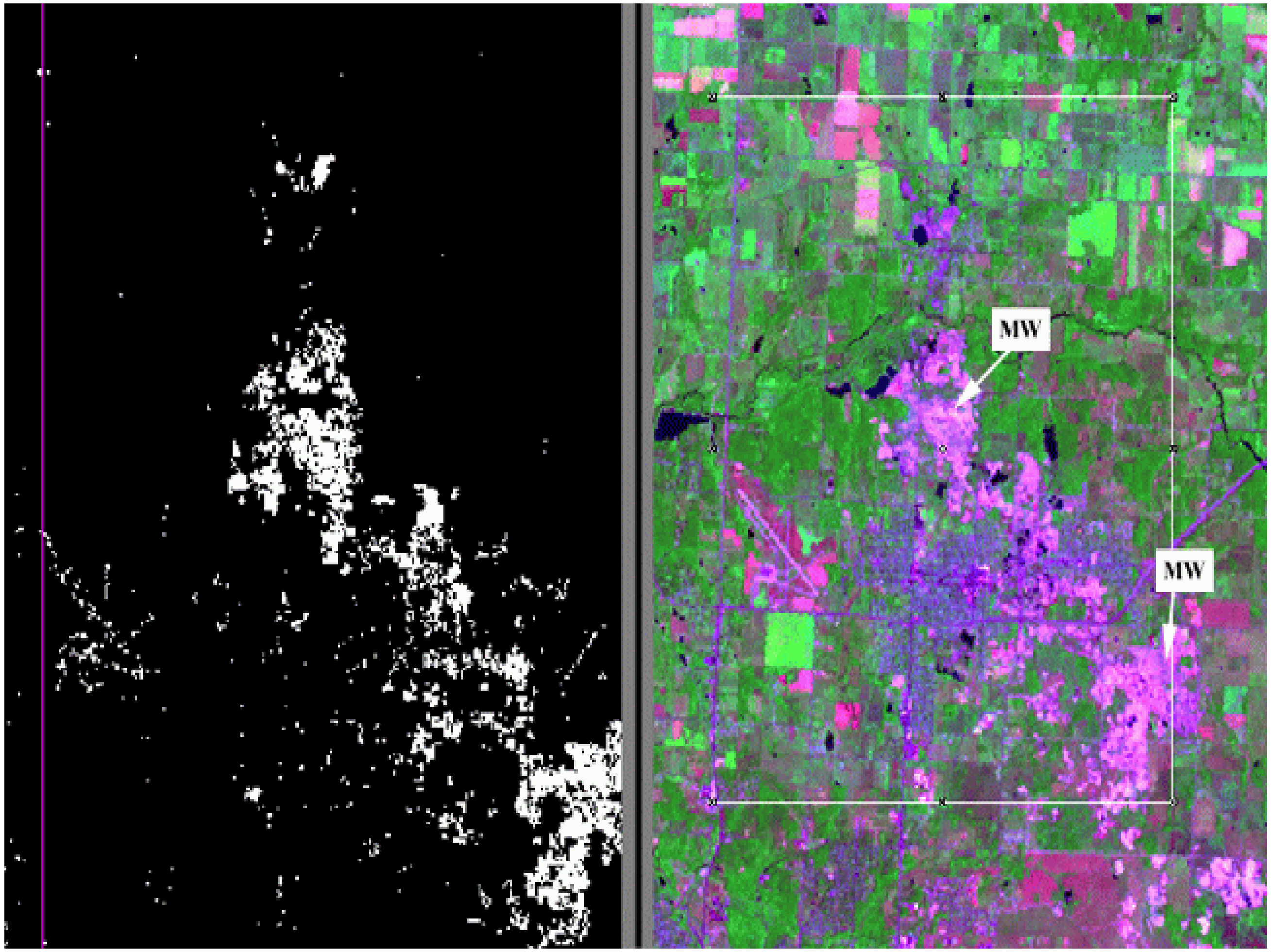

Figure 4.29. Right: distribution of mine waste sites (MW) adjacent to Webb County, Missouri, from Landsat™ satellite image (August 1998). Left: mine wastes (white) from same image identified using "less restrictive" approach.

The delineation methods used by Dames & Moore and by CDM (aerial photography and ground mapping) are likely to be more accurate than the remote sensing methods used by Stratus Consulting. If we assume that the estimates arrived at by Dames & Moore and CDM for Missouri and Kansas are the most accurate of the available estimates, and combine them with the Stratus Consulting estimate for Oklahoma, the resulting estimate of devegetated mine wastes in the entire Tri-State Mining District is between approximately 5,000 and 5,700 acres. It is important to remember that this analysis is focused on mine wastes that are more or less completely devegetated. Additional large areas of wastes with sparse vegetation exist in all three states. These areas could also be the result of the exposure of plants to hazardous substances and could provide wildlife habitat of impaired quality. However, their spatial extent is unknown. It should also be noted that there are large areas of the three states from which mine wastes have been removed. Such action could result in areas that may be devoid of obvious wastes but at which soils and other terrestrial biological resources are injured through their exposure to residual contamination.

4.4.4 Injuries to wildlife

Only one study (Cedar Creek Associates, 1999) has attempted to evaluate wildlife use of barren chat piles in the Tri-State Mining District. This study, which was performed in Jasper County, Missouri, comprised small mammal trapping, sign surveys, and direct wildlife observations at 12 barren chat piles. After 7,200 trap nights and over 360 hours of observation, the study concluded that, except close to the vegetated edges, barren chat was little used by wildlife except for a few species that hunted for aerial insects (bank swallows [*Riparia riparia*], barn swallows [*Hirundo rustica*], common nighthawks [*Chordeiles minor*], and bats), which may be more visible above the barren chat surface. Most sightings and sign of larger mammals (white-tailed deer [*Odocoileus virginianus*], red fox [*Vulpes vulpes*], coyote [*Canis latrans*]) suggested that these species used barren chat only when crossing between adjacent vegetated sites. The study concluded that "barren chat is unattractive to most wildlife because of the lack of vegetation cover and vegetation and animal food sources."

In the Baxter Springs and Treece subsites in Kansas, Dames & Moore (1993b) performed small mammal trapping, road transects to survey predatory birds, and strip transects to survey songbirds. All of these activities were carried out in "wooded habitat," and examination of Figures 3.5-3 and 3.5-4 in Dames & Moore (1993b) indicates that no sample sites were located on chat piles. Thus the data obtained cannot be used to evaluate the use of mining wastes by wildlife species. However, the data do indicate that diverse wildlife communities exist off of the chat piles: the study recorded eight different species of predatory birds and predicted that a further four species probably occur in the area. The study also recorded 43 species of songbirds on the strip surveys and postulated that a further 60 species could also occur during spring and summer (the surveys were performed in October when most summer visitors have left). Six species of small mammals were trapped. A total of 91 terrestrial wildlife species were recorded, including 61 bird species, 16 mammal species, and 14 species of herpetofauna. This contrasts markedly with the results of the Cedar Creek Associates (1999) study of wildlife use of chat piles in Missouri.

Fitzpatrick et al. (1999) sampled soil chemistry and earthworm populations on vegetated chat, soils within 200 feet of chat piles, and soils greater than 200 feet from 11 chat piles in Jasper County, Missouri. The results are shown in Table 4.16.

Table 4.16. Results of soil chemistry and earthworm sampling on vegetated chat in Jasper County, Missouri

	Vegetated chat	<200 feet of chat	>200 feet of chat
Earthworm density (earthworms/m^2)	1.2	5.1	8.4
Earthworm biomass (g/m^2)	0.4	1.2	1.4
Percent of sample with earthworms	18%	27%	24%
Soil/earthworm Cd (mg/kg)	50/145	20/157	3/57
Soil/earthworm Pb (mg/kg)	1,264/1,034	300/71	57/19
Soil/earthworm Zn (mg/kg)	5,831/4,577	2,788/1,080	266/709
PH	6.4	6.6	6.7
% soil TOC	1.5	2.0	2.0
% soil water	16.7	19.9	19.1

Source: Fitzpatrick et al., 1999.

Fitzpatrick et al. (1999) refer to a study by "Dr. Jackson" that showed that "barren substrate [is] devoid of earthworms." We have not yet been able to locate this study. However, the data in Fitzpatrick et al. (1999) show that adjacent to barren chat piles, earthworm densities and biomass increase with increasing distance from chat piles and with decreasing concentrations of Cd, Pb, and Zn. Cd, Pb, and Zn concentrations were substantially lower in soil samples that contained earthworms (22.0, 464, and 2,745 mg/kg, respectively) than in those that did not (39.9, 1,540, and 5,881 mg/kg, respectively). Soil pH, total organic carbon (TOC), and water content vary little across the three distance categories. A stepwise regression analysis with the independent variables soil TOC, pH, and % water content, and total Cd, Pb, and Zn, showed that only soil Cd contributed significantly to the density and biomass of earthworms ($P < 0.0001$ and 0.010, respectively).

Bank Swallows

Cedar Creek Associates (1994) conducted a study of bank swallows nesting in chat piles in Jasper County, Missouri, in 1994. The objective of the study was to determine if breeding success among bank swallows nesting in chat piles was reduced relative to literature values for birds nesting elsewhere. The study failed to accomplish this objective because it was begun too late in the season and most of the chicks had already fledged and left their nests.

Threatened and Endangered Species

A number of terrestrial species that have been listed by the states or by the Federal Government as threatened or endangered or of special concern have been reported to occur or potentially occur in the Tri-State Mining District. These include several amphibians (including cave salamander and dark-sided salamander), birds (including least tern), and mammals (including the federally endangered gray myotis). Some of these species could conceivably have been affected by releases of hazardous substances from mine sites. For example, some of the aquatic amphibians live in cave pools and might have been affected by acid mine drainage. However, documentation identifying adverse effects to threatened or endangered species was not available for our review in 1999. Subsequent efforts by the Trustees could identify effects to threatened and endangered species.

4.4.5 Conclusions

The available evidence indicates the following:

- Concentrations of hazardous substances, including Cd, Pb, and Zn, in and adjacent to mine wastes in all three states, greatly exceed national and state average soil concentrations.

- Concentrations of hazardous substances, including Cd, Pb, and Zn, in and adjacent to mine wastes in all three states, greatly exceed concentrations known to be toxic to individual plants.

- Vegetation communities over more than 5,000 acres of the Tri-State Mining District have been highly modified to the extent that they now provide little habitat for wildlife. The evidence also indicates that vegetation communities adjacent to mine wastes have also been affected, though to a lesser extent, and it is likely that their ability to provide wildlife habitat may also have been impaired.

- The phytotoxic effects of hazardous substances in mine wastes could be responsible for some or all of the observed injuries to vegetation communities and to wildlife habitat.

- Wildlife species have responded to this habitat degradation (and possibly to direct toxicity effects) by avoiding barren and (in the case of earthworms) vegetated chat.

5. Conclusions

The review of the evidence existing in 1999 reported in this document supports the following conclusions regarding releases of hazardous substances from mining facilities into the Tri-State Mining District environment and resulting injuries to natural resources in Cherokee County.

Sources of Hazardous Substances

- In Cherokee County, mine wastes (including chat, tailings, and waste rock), contaminated soils, mine shaft water, groundwater seeps, and subsidence ponds have historically acted, and continue to act, as sources of hazardous substances to the environment.

- In Cherokee County, the most comprehensive data regarding hazardous substance releases from mining operations are for cadmium, lead, and zinc. These data confirm that these hazardous substances have been and are being released into the environment in large quantities. Less comprehensive data sets also show that other hazardous substances, selenium, nickel, and copper, have been released from mining operations into the Tri-State Mining District environment.

- Sources of hazardous substances in the Tri-State Mining District are widespread and spatially extensive:

    - In Cherokee County, Kansas, devegetated waste piles that act as sources of cadmium, lead, and zinc cover at least 1,200 acres. Contaminated soils that also act as sources of cadmium, lead, and zinc cover at least an additional 650 acres at Baxter Springs and Treece. These sources have concentrations of cadmium, lead, and zinc up to three orders of magnitude greater than background.

    - In Cherokee County, Kansas, numerous flooded mine shafts, subsidence ponds, and tailings ponds contain highly elevated concentrations of hazardous substances, including cadmium, lead, and zinc, and act as sources of these substances to the surrounding environment.

Environmental Pathways by Which Hazardous Substances Have Been Transported

- The results of extensive sampling and analysis of the environmental media in the Tri-State Mining District confirm that once released from their sources, hazardous substances, including cadmium, lead, and zinc, are transported throughout the environment. These transport pathways include movement of hazardous substances through:
  - Groundwater
  - Surface water and aquatic sediments
  - Air (at least historically and perhaps currently, based on 1999 data)
  - Soil
  - Aquatic biota (including invertebrates and fish)
  - Terrestrial biota (including vegetation and invertebrates).

Injuries to Groundwater

- Releases of hazardous substances, particularly cadmium, lead, and zinc, have resulted in injuries that conform to the definitions of injury in federal regulations to groundwater in the shallow (Boone) aquifer in Kansas. These injuries comprise:
  - Exceedences (by up to three orders of magnitude) of SDWA water quality criteria
  - Exceedences (by up to three orders of magnitude) of CWA water quality criteria
  - Exceedences (by up to three orders of magnitude) of State of Kansas water quality criteria.
- The spatial extent of the contamination of groundwater in the Kansas portion of the Tri-State Mining District has not been rigorously determined. However, based on the spatial extent of mine waste piles and previous estimates of the volume of the entire Boone aquifer, it is likely to be at least three hundred thousand acre-feet and could be twice that.
- The existing evidence that the deep (Roubidoux) aquifer has been contaminated with hazardous substances related to mining is not conclusive, based on 1999 data.

Injuries to Surface Waters and Sediments

- In Cherokee County, Kansas, releases of the hazardous substances cadmium, lead, and zinc to stretches of Short Creek, Willow Creek, Lytle Creek, and Tar Creek have resulted in injuries that conform to the definitions of injury in federal regulations to both surface water and aquatic sediments. These injuries include:
  - Exceedences of CWA water quality standards
  - Exceedences of water quality standards set by the State of Kansas
  - Concentrations of hazardous substances that could result in injury to exposed resources.
- Surface water and sediments in the Spring River (Kansas and Oklahoma) may have been contaminated in some areas by mining-related hazardous substances to levels above background.

Injuries to Aquatic Biological Resources

- Cadmium, lead, and zinc concentrations in fish tissues from water bodies that have been affected by mining activities in the Kansas portion of the Tri-State Mining District are typically higher than concentrations in fish from unaffected water bodies.
- Cadmium, lead, and zinc concentrations in fish tissues from Cherokee County do not exceed federal or state regulatory consumption thresholds, based on 1999 data.
- Zinc concentrations in Turkey Creek, Center Creek, Short Creek, Tar Creek, and other Cherokee County waters exceed concentrations known to result in behavioral avoidance in trout.
- Lead concentrations in the Cherokee County sections of Center, Shoal, and Turkey Creek benthos exceed levels known to be associated with adverse dietary effects on trout. The same is true for zinc concentrations in benthos from Center Creek and Turkey Creek.
- Toxicity tests using water from Spring River, Brush Creek, and Willow Creek in Kansas resulted in elevated mortality in minnows and *Ceriodaphnia dubia*.
- Sediment pore water from Willow Creek, Kansas, was acutely toxic to *Daphnia magna*.

- Fish populations and communities in mining-impacted stream reaches in Kansas (Tar and Willow creeks and the Spring Branch) may have been adversely affected by metals, indicating injuries to aquatic biota. These effects include elimination or reductions in numbers of metals-sensitive species, and population reductions.[1]

- Benthos populations and communities in mining-impacted stream reaches in Kansas (Spring River) may have been affected by releases of metals, indicating injuries to aquatic biota. These effects include elimination or reductions in numbers of metals-sensitive species, and population reductions.

Injuries to Terrestrial Biological Resources

- Concentrations of cadmium, lead, and zinc in surface mine wastes in the Kansas portion of the Tri-State Mining District greatly exceed concentrations known to be toxic to individual plants.

- Vegetation communities over approximately 800 acres of mine wastes in Kansas have been highly modified (e.g., loss of cover) to the extent that they now provide little or no habitat for wildlife species.[2]

- Vegetation communities adjacent to mine wastes in Kansas are also likely to have been affected by the hazardous substances in the wastes. However, the spatial extent of this modification and its implications for wildlife habitat have not been evaluated.

1. Data subsequently supplied to Stratus Consulting by the State of Kansas also indicate that there may be widespread potential injuries to bivalve populations and communities in the Spring River.

2. In addition, large areas exist in Kansas where the loss of vegetation cover due to mine wastes may be less severe, but which likely still result in injuries to wildlife habitat.

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