Assessment Plan for
Tar Creek, Ottawa County, Oklahoma
Draft Report

Prepared for:

U.S. Department of the Interior, Fish and Wildlife Service
U.S. Department of the Interior, Bureau of Indian Affairs
State of Oklahoma, Department of Environmental Quality
State of Oklahoma, Department of Wildlife Conservation
and
Seneca-Cayuga, Miami, Wyandotte, Eastern Shawnee,
Ottawa, Peoria, and Cherokee Tribes

Prepared by:

Stratus Consulting Inc.
PO Box 4059
Boulder, CO 80306-4059

August 1, 2008
SC11112

Contents

Figures

Tables

Acronyms and Abbreviations

AOC	administrative order on consent
BUMP	Beneficial Use Monitoring Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWA	Clean Water Act
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DSAY	discounted service acre-year
EPA	U.S. Environmental Protection Agency
FS	feasibility study
FWPCA	Federal Water Pollution Control Act (a.k.a., Clean Water Act)
GWEA	groundwater equivalency analysis
HEA	habitat equivalency analysis
MCL	maximum contaminant level
MCLG	MCL goal
NCP	National Contingency Plan
NPL	National Priorities List
NRDA	natural resource damage assessment
OAC	Oklahoma Administrative Code
ODEQ	Oklahoma Department of Environmental Quality
OU	operable unit
OWRB	Oklahoma Water Resources Board
PEC	probable effect concentration
PQL	practical quantitation limit
PRP	potentially responsible party

QAPP	quality assurance project plan
RCDP	restoration and compensation determination plan
REA	resource equivalency analysis
RI	remedial investigation
ROD	record of decision
SDWA	Safe Drinking Water Act
SDWR	Secondary Drinking Water Regulations
TEC	threshold effect concentration
USGS	U.S. Geological Survey

1. Introduction

The Tri-State Mining District comprises Jasper, Newton, Lawrence, and Barry counties in southwestern Missouri; Cherokee County in southeastern Kansas; and Ottawa County in northeastern Oklahoma. This area of approximately 2,500 square miles stretches from the northwest edge of the Ozark Uplift in Missouri west and south to the eastern fringe of the Great Plains. Lead and zinc mining in the district occurred from the 1870s through the 1970s (Dames & Moore, 1995; U.S. EPA, 2007). After over 100 years of mining and milling, chat piles, tailings sites, development and waste rock piles, and subsidence ponds are prominent features of the landscape.

The Tar Creek assessment area (Figure 1.1) includes nearly 3,700 acres of upland mining waste (U.S. EPA, 2008) and approximately 73 miles of contaminated streams and rivers, extending from the Kansas border down to and including Grand Lake O' the Cherokees (Donlan, 2007). A total of 83 chat piles, comprising over 31 million cubic yards and covering 767 acres, were identified in a recent aerial survey (AATA International, 2005). Another 1.36 million cubic yards of lead-contaminated soils, covering 1,162 acres, have been identified (U.S. EPA, 2008). Figure 1.2 shows an aerial photo of the Picher Mining District in Ottawa County, Oklahoma, with chat piles clearly visible.

The widespread disposal of mining-related waste has resulted in the release of hazardous substances, particularly cadmium, lead, and zinc, to upland habitat, aquatic habitat, surface water, and groundwater resources in the Tar Creek area. As a result, the U.S. Environmental Protection Agency (EPA) included the Tar Creek Superfund Site on the National Priorities List (NPL) on September 8, 1983 to address risks to human health and the environment. Trustees of natural resources under relevant state and federal laws include U.S. Department of the Interior (DOI), the State of Oklahoma, and the Cherokee Nation, the Eastern Shawnee Tribe of Oklahoma, the Miami Tribe of Oklahoma, the Ottawa Tribe of Oklahoma, the Peoria Tribe of Indians of Oklahoma, the Seneca-Cayuga Tribe of Oklahoma, the Wyandotte Nation (collectively, the Tribes). These natural resource trustees (collectively, the Trustees) are now conducting a natural resource damage assessment (NRDA) to evaluate injuries to natural resources resulting from releases of hazardous substances. This Assessment Plan confirms exposure of natural resources to hazardous substances released by potentially responsible parties (PRPs) and describes the proposed plan for evaluating the injuries and damages to trustee natural resources.

Figure 1.1. Overview of the Tar Creek NRDA assessment area, from the Kansas border to Grand Lake O' the Cherokees.

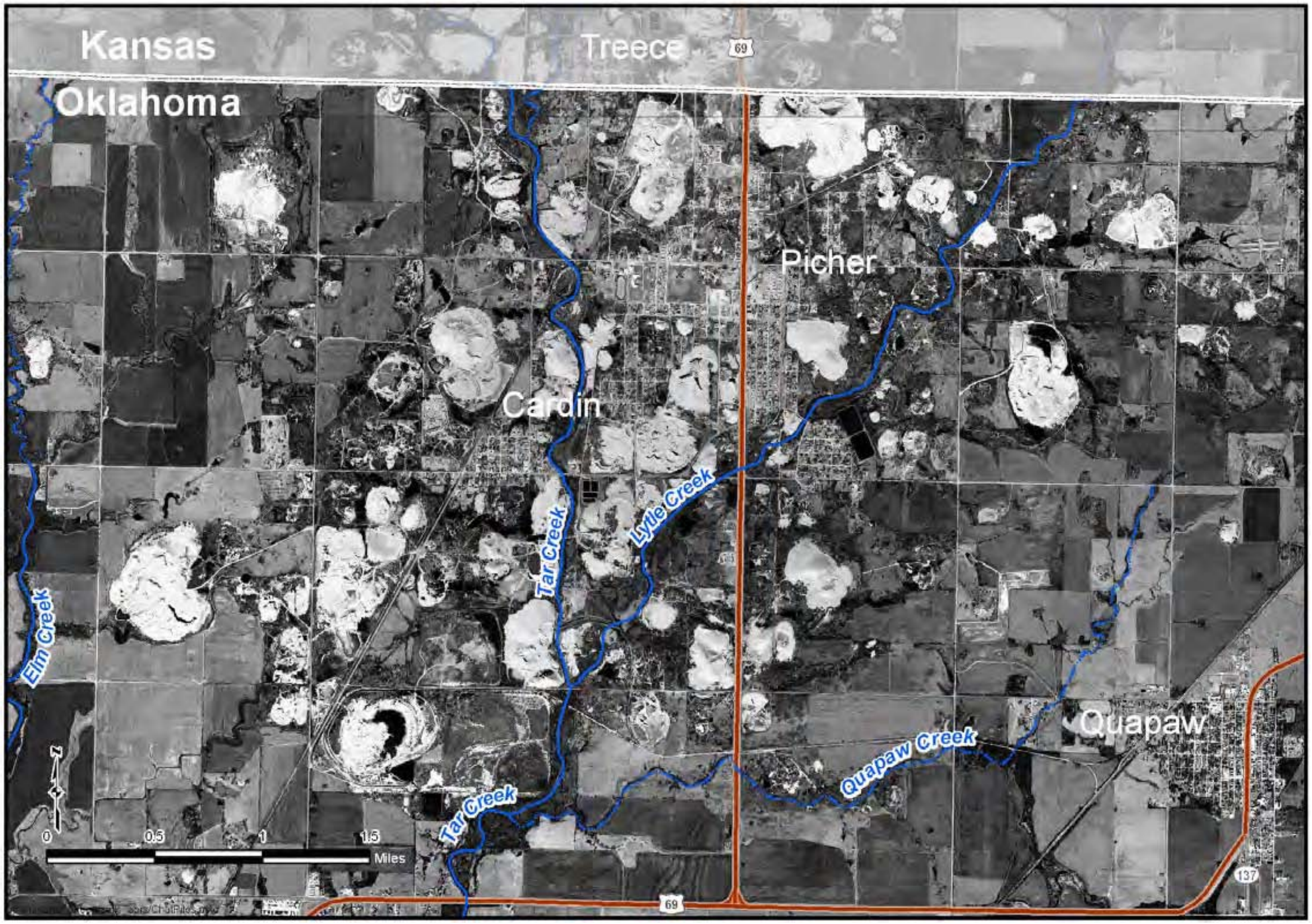

Figure 1.2. Aerial photo of Tar Creek and surrounding areas, with chat piles clearly visible.

1.1 Site Description

Ottawa County lies mainly on the Osage Plains, which are characterized by relatively flat terrain with shallow stream valleys and elevations of 800–900 ft above sea level.

The Spring River, which drains mining areas in Cherokee County, Kansas and Jasper and Newton counties in Missouri, crosses the Oklahoma State line just south of Baxter Springs, Kansas. It then flows south through Oklahoma, with inputs from Beaver and Hockerville creeks, before joining the Neosho River near the north end of Grand Lake. Tar and Elm creeks drain mining areas in Cherokee County, Kansas and Ottawa County, Oklahoma. These creeks flow south to the Neosho River, which then flows southeast to the confluence with the Spring River at Grand Lake O' the Cherokees.

The predominant land use in the area is arable agriculture (mainly wheat, sorghum, corn, soybeans, and hay). Agriculture accounts for approximately 60–70% of the land use in Cherokee County (Dames & Moore, 1995). The remaining land uses are mining-related, urban, and unimpacted natural land. The Trustees have determined that native prairie/hay would be the predominant land use in the area but for the mining. Prior to the commencement of mining activities, the Tar Creek area was known as the native hay capital of the North America (Tar Creek Task Force, 2000). Based on U.S. Government Land Office surveys, 96% of the land use within the Tar Creek Superfund Site Operable Unit (OU) 4 boundary, and 87% of the land use in northern Ottawa County between the Spring and Neosho rivers, was grassland (i.e., native prairie hay) in 1871 (Hoagland and Morris, 2007). With excellent hay cultivation and limited industry outside of mining, it is reasonable to assume that the Tar Creek area would have remained in native hay production had mining and subsequent releases of hazardous substances not occurred at the site.

1.2 Operational History

Lead and zinc mining first began at the site in the late 1800s and reached its peak in 1925. In the early years, approximately 200 mills were operating at the site (McKnight and Fischer, 1970). The ore removed from the mines was milled locally to produce ore concentrates, which were generally shipped to other locations outside of Ottawa County for smelting. One smelter in the area operated in the 1920s near Hockerville (McKnight and Fischer, 1970). Large-scale mining activities ended in the mid-1960s (U.S. EPA, 2000).

The ore-bearing strata were primarily located within a 50 to 150 foot-thick zone of the Boone Formation, approximately 90 to 400 ft below the ground surface (U.S. EPA, 1994). Mining was accomplished using room and pillar techniques. An estimated 100,000 boreholes were located in the Picher Field (mostly in Oklahoma), and 1,064 mine shafts (typically 5 ft by 7 ft or 6 ft by

6 ft) existed in the Oklahoma portion of the Tri-State Mining District (Luza, 1986; U.S. EPA, 1994). Numerous water wells, drilled for milling operations, have been abandoned (U.S. EPA, 1994).

As a result of decades of mining and milling, chat piles (mine waste from the milling process, containing a mixture of gravel and finer-grained materials), mill floatation ponds, fine-grained tailings, development and waste rock piles, and subsidence ponds are prominent features of the landscape in Ottawa County. Much of this mill waste is contaminated with hazardous substances, particularly cadmium, lead, and zinc (Datin and Cates, 2002).

In the early 1970s, when mining ceased and pumping operations were terminated, the Boone Formation began refilling with water, flooding the mine drifts and shafts and creating acid mine water with high concentrations of metals (U.S. EPA, 1994). By 1979, water levels had increased to the point that the acid mine water began discharging at the surface from several locations [Oklahoma Water Resources Board (OWRB, 1983b; U.S. EPA, 1994)]. Diverting surface water away from open mine shafts did not substantially lower the water table, and thus mine water contaminated with metals continues to discharge to surface waters in the Tar Creek watershed (U.S. EPA, 2000).

1.3 Potentially Responsible Parties

EPA and the Trustees have identified PRPs for the Tar Creek Superfund Site. Additional PRPs may be identified by either EPA or the Trustees during the course of this NRDA. Information on the Internet that may identify PRPs associated with the Site can be found in the following documents or sites:

- Tar Creek Superfund Site Preassessment Screen (http://www.fws.gov/southwest/es/oklahoma/Documents/Contaminants/Final%20Tar%20Creek%20PAS.pdf)
- U.S. EPA Superfund Information System (http://cfpub.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction = second.additional&id = 0601269)
- U.S. EPA Region 6 Superfund Decision Documents (http://www.epa.gov/earth1r6/6sf/6sf-decisiondocs.htm).

1.4 Remediation History

EPA included the Tar Creek Superfund Site on the NPL on September 8, 1983 because of elevated concentrations of metals (cadmium, lead and zinc) in the mined areas of Ottawa County. The aerial extent of the NPL site includes the approximately 40 square miles where mining took place and mine wastes remain, as well as locations where releases of hazardous substances from the mining activities have been deposited, stored, disposed of, placed, or otherwise come to be located.

The EPA and the State of Oklahoma then initiated a number of remedial investigations (RI) and identified five OUs at the NPL site. These OUs address groundwater releases to surface water (OU 1), the remediation of certain contaminated residential properties (OU 2), the removal of mining chemicals from the Eagle Picher Plant (OU 3), the remediation of chat piles and abandoned mill ponds in nonresidential areas (OU 4), and site-wide sediment and surface water (OU 5). Records of decision (RODs) were signed for OU 1 in June 1984 and for OU 2 in August 1997.

For OU 4, EPA originally signed an administrative order on consent (AOC) with three PRPs, including the DOI, Blue Tee Corp., and Gold Fields Mining Corporation, to conduct a remedial investigation and feasibility study (FS; CH2M Hill, 2005). The FS for OU 4 was completed in 2006 (CH2M Hill, 2006) and the ROD signed in February 2008 (U.S. EPA, 2008).

Remediation at the site has not been completed and remedial activities to date have not eliminated the release of hazardous substances to the surface water, groundwater, air, and soils at the site (U.S. EPA, 1994, 2000). Data collection for the OU 5 RI is ongoing.

1.5 Natural Resource Damage Assessment Activities

NRDA activities in the Tri-State Mining District have included:

- A preassessment screen (State of Kansas and DOI, 2002) and a phase 1 assessment plan (Industrial Economics, 2004) have been released addressing mining-related natural resource damages in Cherokee County, Kansas

- A preassessment screen (Missouri Department of Natural Resources and DOI, 2002) has been released addressing mining-related damages in Jasper County, Missouri; a phase I assessment plan for Jasper County is anticipated in 2008

- A preassessment screen (Tar Creek Natural Resources Trustee Council, 2004) has been released addressing mining-related damages in the Tar Creek assessment area. This document is a draft Assessment Plan for the Tar Creek area; a final Assessment Plan is anticipated by the end of 2008.

The Trustees are developing this Assessment Plan as part of the NRDA addressing releases of hazardous substances from the Tar Creek assessment area. The purpose of this Assessment Plan is to describe the Trustees' planned approach to determine and quantify injuries to natural resources and the type and amount of natural resource restoration required to make the public whole, and to determine appropriate monetary damages. By developing an Assessment Plan in accordance with federal regulations at 43 CFR Part 11, the Trustees help ensure that the NRDA will be completed at a reasonable cost relative to the magnitude of damages sought, and the results of the assessment will be given a rebuttable presumption, pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The Trustees intend for this plan to communicate assessment approaches and methodologies to the public, so that they can participate in the assessment process. See Chapter 3 for more details.

1.6 Organization of the Assessment Plan

This Assessment Plan is divided into five chapters. The remainder of the plan is organized as follows:

- Chapter 2 describes the affected natural resources, discusses the impacts that the contaminants of concern may have on Trustee resources, discusses the sources of hazardous substances in the assessment area, and confirms that Trustee resources have been exposed to these contaminants

- Chapter 3 describes the role of the Trustees in the NRDA, including a description of the NRDA process and information on how to submit comments on this Assessment Plan

- Chapter 4 presents the approaches for determining and quantifying injuries and damages to different natural resources

- Chapter 5 discusses the quality assurance project plan (QAPP).

2. Affected Natural Resources

Natural resources in the assessment area include groundwater, surface water (including sediments), geologic resources (including soils), biological resources (including terrestrial and aquatic flora and fauna), and air resources. This chapter presents data confirming that natural resources have been exposed to hazardous substances released from the Tar Creek Superfund Site.

2.1 Natural Resources in the Tar Creek Assessment Area

2.1.1 Groundwater resources

The DOI regulations define groundwater as water in a saturated zone or stratum beneath the surface of land (including land below surface water), and the rocks or sediments through which groundwater moves [43 CFR § 11.14(t)]. Potentially injured groundwater resources in the assessment area include both deep and shallow aquifers. These aquifers provide drinking water, irrigation water, and recharge to surface water. In addition, groundwater provides seeps and springs as water sources, which have cultural, ceremonial, and religious significance to many Tribes of the area.

Potentially injured groundwater resources in the Tar Creek area include the shallow Boone aquifer and the deeper Roubidoux aquifer. The Boone aquifer is within the Boone Formation (the formation targeted for most mining activities in the mining district), which is principally composed of limestones and cherts. The thickness of the Boone aquifer varies widely throughout the area but may have an average thickness of 300–370 ft (OWRB, 1983c; Christenson, 1995; Dames & Moore, 1995).

The water level of the unconfined Boone aquifer is generally near the ground surface, and recharge is via brecciated (fractured) carbonate rocks at the surface, as well as abandoned mine shafts. The regional direction of flow is west. The Neosho and Spring rivers are perennial and receive substantial base flows from the Boone aquifer via springs and direct discharge to stream channels (Osborn, 2001). In addition, numerous mineshafts discharge acid mine drainage continuously to surface water.

The Northview Shale, Compton Limestone, and Chattanooga Shale separate the shallow and deep aquifers in the assessment area. Beneath the shale is the Roubidoux aquifer, comprising the Cotter and Jefferson City Dolomites, the cherty dolomites of the Roubidoux formation, and the Gasconade Dolomite. The Roubidoux formation supplies most of the water to wells completed in the Roubidoux aquifer. The Cotter and Jefferson City Dolomites may contribute some water to wells completed in the Roubidoux aquifer in Ottawa County (Christenson, 1995). The Roubidoux aquifer is about 900–1,000 ft below ground in northeastern Oklahoma (OWRB, 1983c).

The deep aquifer recharges at outcroppings in the Ozarks east of the assessment area. 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 flows from east to west through the area. However, a large cone of depression formed under Miami, Oklahoma, due to intensive groundwater extraction by B.F. Goodrich, a tire manufacturing plant that closed in 1986. The cone of depression pulled groundwater flow toward Miami from all directions, including from the mining district north of Miami. Between 1986, when tire manufacturing ended, and 1993, the groundwater levels increased by nearly 100 ft in the aquifer below Miami (Spruill, 1984; Christenson, 1995; Dames & Moore, 1995).

Because of extractions from the municipal wells, the hydraulic head of the deep aquifer is now lower than the head in the shallow aquifer. This gradient indicates a potential for vertical groundwater flow from the shallow to the deep aquifer. However, the transmissivities of the Northview and Chattanooga shales are more than an order of magnitude less than those of the Boone and Roubidoux formations. The shale layers generally act as a barrier to flow between the aquifers (Christensen, 1995), but numerous Roubidoux water wells drilled through the shale layers within the mining district may act as conduits for groundwater to flow from the Boone to the Roubidoux formation.

2.1.2 Surface water resources

As defined in the DOI regulations, surface water resources include both surface water and sediments suspended in water or lying on the bank, bed, or shoreline [43 CFR § 11.14(pp)]. Potentially injured surface water resources in the assessment area, shown in Figure 2.1, include:

- Lytle Creek and its tributaries, from the Kansas border to the confluence with Tar Creek
- Tar Creek (Figure 2.2) and its tributaries, from the Kansas border to its mouth at the Neosho River
- Elm Creek, from approximately 1.5 miles south of the Kansas border to its mouth at the Neosho River

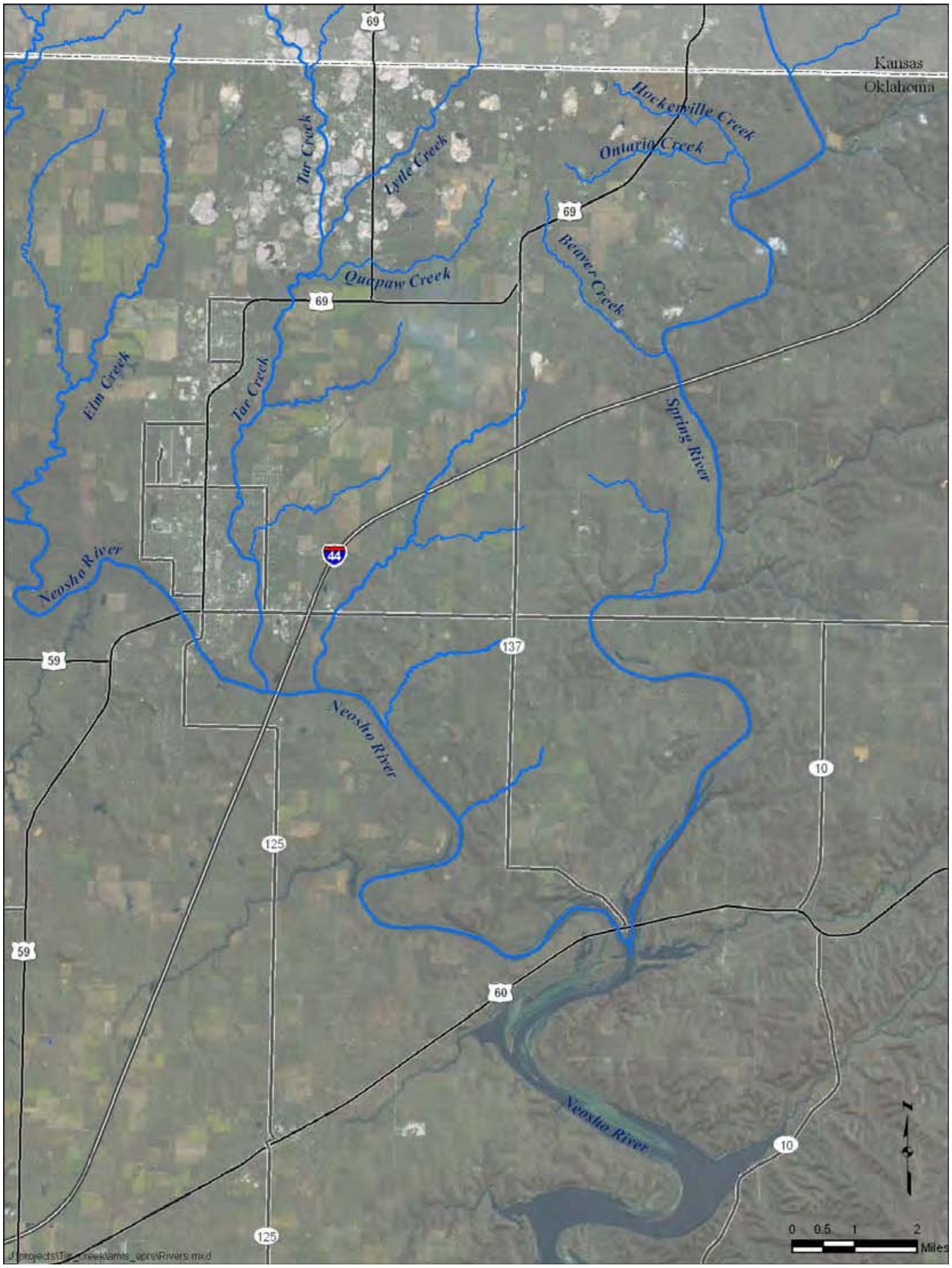

Figure 2.1. Surface water resources in the Tar Creek assessment area. Chat piles are evident in the Tar Creek and Lytle Creek drainages.

Figure 2.2. Tar Creek near the Oklahoma-Kansas state line, February 2007.

Source: Jamie Holmes, Stratus Consulting.

- Spring River and its tributaries, including Beaver, Ontario, Quapaw, and Hockerville creeks, from the Kansas border to Grand Lake O' the Cherokees
- Neosho River, from the Elm Creek confluence west of Miami to Grand Lake O' the Cherokees
- Grand Lake O' the Cherokees
- Unnamed contaminated creeks and tributaries in the assessment area.

In addition to providing recreation, water supplies, and habitat for aquatic biota, the surface water and associated biological resources (Section 2.1.4) in the assessment area have special cultural value for the Tribes. The affected Tribes each have unique cultural and traditional uses associated with surface water resources. These include use of surface water as a drinking water source, and provision of aquatic habitat for numerous plants and biota that are used for subsistence and are of great cultural significance to the Tribes.

2.1.3 Geologic resources

The DOI regulations define geologic resources as those elements of the Earth's crust such as soils, sediments, rocks, and minerals, including petroleum and natural gas, that are not included in the definitions of groundwater and surface water resources [43 CFR § 11.14(s)].

Geologic resources at the site include many square miles of devegetated tailings and chat piles, as well as injured soils downwind of mine waste, and injured soils in floodplain habitat downstream of mine waste. These soils are important for providing a medium for vegetation, invertebrates, microbes, and other biota, and they serve as a pathway to terrestrial biota. Tribal members consume and create culturally significant items from plants grown in these soils.

Under flooding conditions, contaminated floodplain soils can expose aquatic biota, floodplain vegetation, and/or surface water resources to hazardous substances. Soils also serve as a pathway to groundwater via percolation of hazardous substances from contaminated surface soils to the underlying aquifer.

2.1.4 Biological resources

Biological resources are those natural resources referred to in Section 101(16) of CERCLA as fish and wildlife and other biota. Fish and wildlife include aquatic and terrestrial species; game, nongame, and commercial species; and threatened, endangered, and state-designated sensitive species. Other biota include shellfish, terrestrial and aquatic plants, and other living organisms not otherwise listed in this definition [43 CFR § 11.14(f)]. Biological resources include biota that have cultural significance to Tribes in the area.

The riverine and floodplain forest habitats in the assessment area support a wide variety of biota that may be or have been exposed to hazardous substances. Potentially injured biological resources may include, but are not limited to:

- Mammalian resources (e.g., beaver, otter, mink, muskrat), including threatened and endangered species, species of cultural significance, game and nongame species, and the supporting habitats for these species

- Avian resources (e.g., bald eagles, red-tailed hawks, greater prairie chickens, migratory ducks and geese), including migratory birds, threatened and endangered species, species of cultural significance, game and nongame species, species targeted by birdwatchers, and the supporting habitats for these species

- Fishery resources (e.g., paddlefish, catfish, largemouth bass, crappie, sunfish, Ozark cavefish), including resident fish, threatened and endangered species, species of cultural significance, game and nongame species, species dwelling in groundwater (cave fish), and the supporting habitats for these species

- Reptile and amphibian resources (e.g., soft-shelled turtle, red eared slider, snapping turtle), including species of cultural significance, and the supporting habitats for these species

- Invertebrate resources (e.g., mussels, crayfish), including benthic invertebrates, crustaceans, bivalves, threatened and endangered species, species of cultural significance, and the supporting habitats for these species

- Aquatic and terrestrial plant resources, including threatened and endangered species, species of cultural significance, species used for Tribal subsistence, and the supporting habitats for these species.

The following threatened and endangered species (and Oklahoma species of special concern) may occur in the assessment area (Oklahoma Natural Heritage Inventory, 2003; USFWS, 2006, 2007; ODWC, 2007):

Federal endangered species

- Ozark big-eared bat (*Corynorhinus townsendii ingens*) (Figure 2.3)
- Gray bat (*Myotis grisecens*)
- American burying beetle (*Nicrophorus americanus*)
- Winged mapleleaf mussel (*Quadrula fragosa*).

Federal threatened species

- Piping plover (*Charadrius melodus*)
- Ozark cavefish (*Amblyopis rosae*) (Figure 2.4)
- Neosho madtom (*Noturus placidus*).

Federal candidate species

- Arkansas darter (*Etheostoma cragini*)
- Neosho mucket (*Lampsilis rafinesqueana).*

State endangered species

- Ozark big-eared bat
- Gray bat
- American burying beetle
- Neosho mucket
- Longnose darter (*Percina nasuta*)
- Cave crayfish (*Cambarus tartarus*).

State threatened species

- Piping plover
- Blackside darter (*Percina maculata*)
- Ozark cavefish
- Neosho madtom.

Figure 2.3. Ozark big-eared bat.

Source: USFWS, 1997.

Figure 2.4. Ozark cavefish.

Source: USFWS, 1992.

State species of special concern

- Barn owl (*Tyto alba*)
- Bells vireo (*Vireo bellii*)
- Loggerhead shrike (*Lanius ludovicianus migrans*)
- Arkansas darter
- Black buffalo (*Ictiobus niger*)
- Blue sucker (*Cycleptus elongatus*)
- Bluntfaced shiner (*Cyprinella camura*)
- Plains topminnow (*Fundulus sciadicus*)
- River darter (*Percina shumardi*)
- Shorthead redhorse (*Moxostoma macrolepidotum*)
- Southern brook lamprey (*Ichtyomyzon gagei*)
- Stonecat (*Noturus flavus*)
- Spectacle-case (a.k.a. Rabbitsfoot) mussel (*Quadrula cylindrica*)
- Oklahoma salamander (*Eurycea tynerensis*)
- Prairie mole cricket (*Gryllotalpa major*).

2.1.5 Tribal cultural resources

The Tribes historically and currently hunt and gather in the woodlands and riparian areas of the assessment area. Plant and animal resources continue to be a contributor to tribal daily life. Tribes use plants for food and cultural practices; some plants are of particular cultural significance. Certain plants, herbs, shrubs, and woody plants serve tribal cultural functions in the production of crafts, basket weaving, flutes, and hunting accessories. The Tribes use fish, mussels, crustaceans, amphibians, and turtles as food resources, and shells of mussels and turtles in tribal ceremonies. Through sustenance, cultural or religious affiliation, or as a teaching tool, tribal people depend upon a healthy, uncontaminated environment to maintain their way of life (Seneca-Cayuga Tribe of Oklahoma, 1999; personal communications from the Tribes, 2007).

2.1.6 Air resources

Air resources are defined as those naturally occurring constituents of the atmosphere, including those gases essential for human, plant, and animal life [43 CFR § 11.14(b)]. Any area downwind of a chat pile is a potentially injured air resource when the wind is sufficient to entrain fugitive dust. Air resources in most of northern Ottawa County are thus potentially injured at times and can act as a pathway to other natural resources. Concerned about the health effects of airborne contaminants, the Quapaw Tribe monitors airborne particulate matter, lead, and silica at four sites within the Tar Creek assessment area.

2.2 Contaminants of Concern

The primary hazardous substances released in the Tar Creek assessment area are cadmium, lead, and zinc. The following sections discuss the toxicity of heavy metals in general, and these three metals in particular, to terrestrial plants and aquatic biota.

2.2.1 Effects of heavy metals on terrestrial plants

Soils supply the majority of the mineral nutrients necessary for plant growth. Major nutrients derived from soils or soil processes include nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, and iron. Many trace elements in soils are essential for growth and development of organisms, including aluminum, boron, cobalt, copper, iron, manganese, molybdenum, silicon, and zinc. Zinc is one of the most abundant hazardous substances released from mining related operations in the Tar Creek assessment area, and zinc is an essential plant micronutrient. By contrast, cadmium and lead have no beneficial role in plants (Kabata-Pendias and Pendias, 1992). All micronutrients are toxic in excess concentrations (Van Assche and Clijsters, 1990), but their toxicity in soils depends on the mobility and availability of metal cations within plant biochemical systems.

The mobility and availability to plants of hazardous metals in soils are determined in part by their atomic characteristics and speciation, and by properties of the soil. The mobility of trace metals in soils depends on soil processes, including sorption, complexation, precipitation, and occlusion; diffusion into clay minerals; and binding or uptake by organic substances (Kabata-Pendias and Pendias, 1992; Brady and Weil, 1996). These processes are strongly controlled by pH and redox potential, and by the amount of clay and organic matter in the soil (Van Assche and Clijsters, 1990; Kabata-Pendias and Pendias, 1992).

Responses to heavy metals by plants include stunted shoot growth; stunted, necrotic, chlorotic, or otherwise discolored leaves; and early loss of leaves (Van Assche and Clijsters, 1990; Kabata-Pendias and Pendias, 1992; Pierzynski and Schwab, 1993). Roots can exhibit stunted growth, browning or death of the root meristem, and suppressed development of lateral roots (Krawczyk et al., 1988; Kapustka et al., 1995; Rader et al., 1997). Physiological malfunctions include inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, and transpiration (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985; Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990b; Davies, 1990; Kiekens, 1990). Metal toxicity is frequently related to inhibition of enzyme synthesis or activity (Tyler et al., 1989; Van Assche and Clijsters, 1990).

Cadmium inhibits the formation of chlorophyll and interferes with photosynthesis; reduces stomatal conductance and transpiration; inhibits enzyme formation and activity; impedes carbohydrate metabolism; and may also reduce the uptake of other metal ions by roots (Clijsters and Van Assche, 1985; Pahlsson, 1989; Sheoran et al., 1990a, 1990b; Kabata-Pendias and Pendias, 1992). In addition, cadmium has been shown to cause changes in xylem tissue and blockages in xylem tubes which transport water to above-ground tissue (Lamoreaux and Chaney, 1977; Pahlsson, 1989). Symptoms of acute cadmium toxicity include leaf discoloration, wilting, stunted growth, and premature leaf loss (Vasquez et al., 1989; Alloway, 1990a).

Plants exposed to lead may exhibit decreased photosynthetic and transpiration rates (Davies, 1990). The mechanism of photosynthetic and transpiration reduction is probably related to changes in stomatal function (Bazzaz et al., 1974). Lead interferes with the synthesis of chlorophyll and other photosynthetic pigments and inhibits root elongation (Pahlsson, 1989). Uptake of lead has also been shown to inhibit chloroplast activity and to interfere with metabolic processes (Clijsters and Van Assche, 1985; Sheoran et al., 1990a, 1990b). In addition, lead inhibits soil organic matter breakdown, litter decomposition, and nitrogen mineralization in soil, thereby reducing soil productivity (Liang and Tabatabai, 1977; Chang and Broadbent, 1982; Davies, 1990).

Plants use zinc to metabolize carbohydrates and proteins, and to synthesize DNA and RNA (Kabata-Pendias and Pendias, 1992). In excess concentrations, however, zinc interferes with chlorophyll synthesis and photosynthesis, blocks water transport in xylem and carbohydrate transport in phloem, and inhibits electron transport (Clijsters and Van Assche, 1985; Pahlsson, 1989; Kiekens, 1990; Chaney, 1993). Zinc may also increase the permeability of root membranes, causing leakage of nutrients and disruption of active transport of ions in and out of the plant (Pahlsson, 1989).

At the community level, metal toxicity in plants can shift species composition, or in cases of severe toxicity, reduce or eliminate vegetative cover (Galbraith et al., 1995; LeJeune et al., 1996; Kapustka, 2007). Reduced growth, photosynthetic efficiency, or nutrient and water uptake will preferentially inhibit sensitive plant species growing in the wild (Beyer, 1988, 2007). Species or individuals that are relatively more sensitive to metals contamination will be eliminated, if not through direct toxic effects, then through reduced viability and competitive ability. Cover of more tolerant species or species able to benefit from the reduced competition for water, nutrients, or light, may increase with the elimination of sensitive species. Since sensitivity and tolerance are governed by numerous processes internal and external to the plant (Tyler et al., 1989; Kabata-Pendias and Pendias, 1992), gradients in tolerance and in community level responses to metals contamination are common. Community level changes in vegetation cover, composition, or structure resulting from phytotoxicity are caused by death and competitive displacement of plants with reduced viability.

Table 2.1 presents examples of observed phytotoxic effects of metals at sites impacted by mining. Metals released in mine wastes, including tailings, mixed tailings, and alluvium, cause toxicity to individual plants, and reduce vegetation cover, diversity, and structural complexity of vegetation communities and habitats (Johnson and Eaton, 1980; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000; Kapustka, 2007). Loss of riparian vegetation and the functions provided by riparian vegetation degrade the ecological services provided by the riparian ecosystem (LeJeune et al., 1996).

Table 2.1. Examples of individual and community-level phytotoxic effects of metals toxicity from mine wastes on vegetation

Mine/smelter site	Examples of phytotoxic effects on vegetation
Tri-State Mining District, OK, MO, KS (tailings) (Pierzynski and Schwab, 1993; Novak et al., 2003)	Chlorosis; reduced crop productivity in contaminated floodplains; reduced plant growth; increased weedy species; decreased biomass
Coeur d'Alene, ID (Stratus Consulting, 2000)	Devegetation; reduced growth; inhibition of seedling growth; reduced species richness and diversity; reduced plant cover
Sudbury Smelter, Ontario (Freedman and Hutchinson, 1979; Lozano and Morrison, 1981)	Devegetation; reduced productivity and diversity; disruption of hardwood nutrition by SO_2, Ni, and Cu; colonization by metals tolerant grasses
Palmerton Smelter, PA (Beyer, 1988; Chaney, 1993)	Forest dieback/prevention of regrowth; inhibition of seedling root growth; stunting; changes in species composition and age structure; elimination of grasses
Anaconda Smelter, MT (Galbraith et al., 1995)	Devegetation; reduced species diversity; noxious weed invasion and dominance; reduced habitat quality; inhibition of seedling root growth
Clark Fork River, MT (tailings) (LeJeune et al., 1996; Rader et al., 1997)	Barren or sparsely vegetated floodplain deposits; reduced vegetation structural complexity; reduced habitat quality; reduced seedling root and shoot growth
McLaren Mine, MT/WY (tailings) (Stoughton and Marcus, 2000)	Reduced vegetation biomass, density, diversity in contaminated floodplains
Llanwrst Mining District, Wales (tailings) (Johnson and Eaton, 1980)	Barren or sparsely vegetated floodplains; chlorotic vegetation; reduced diversity; replacement with metals tolerant grasses

The adverse effects of metals on plant community health and abundance can impact tribal citizens and their traditional cultural practices. For example, the loss of healthy, accessible, and local populations of certain species and the loss of edible parts of certain plants adversely affect tribal citizens. In addition, accumulation of metals in plants can alter the plants' value in ceremonial practices, traditional implements, crafts, and other cultural uses.

2.2.2 Effects of heavy metals on aquatic biota

The hazardous substances cadmium, lead, and zinc are known to cause a number of toxic injuries to fish, including death, behavioral avoidance, physiological damage, and reduced growth. There is extensive scientific literature documenting these toxic effects on salmonids and other aquatic biota. This section provides a brief overview of the nature of the toxic effects of cadmium, lead, and zinc, and identifies the endpoints assessed for injury.

Mortality

Cadmium, lead, and zinc all have been shown to be lethal to 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, 1985; Cusimano et al., 1986; Everall et al., 1989; Marr et al., 1995; EVS, 1997; Hansen et al., 1999). The primary mechanisms of metal-induced mortality are disruption of ion regulation and respiratory failure. The gills are the primary site of ion regulation (Evans, 1987), the process that drives many cellular metabolic functions. Hazardous metals such as cadmium and zinc can disrupt ion regulation by injuring the gill membrane so that ions leak across the membrane, and by disrupting essential enzymes (Lauren and McDonald, 1985, 1986). For example, cadmium alters calcium balance by disrupting essential ion transport enzymes (Roch and Maly, 1979; Verbost et al., 1989).

Continued disruption of ion regulation leads to mortality. The gills are also the primary site of respiration (Evans, 1987). Exposure to hazardous metals causes physiological damage to respiratory gill tissues (Wilson and Taylor, 1993). This damage impairs the transfer of respiratory gases (e.g., oxygen) by increasing the distance that respiratory gases must diffuse between blood and water (Hughes and Perry, 1976; Satchell, 1984; Mallatt, 1985), causing asphyxiation, cardiovascular failure (Wilson and Taylor, 1993), and death.

Avoidance

Fish can detect and avoid a number of hazardous substances (e.g., Atchison et al., 1987). Behavioral avoidance can occur at concentrations lower than concentrations that cause effects on survival and growth (Little et al., 1993). Behavioral avoidance of metals such as copper, lead, and zinc has been suggested as a cause of reduced fish populations in natural systems (Woodward et al., 1995a). In addition, behavioral avoidance can impair normal migratory behaviors and result in loss of habitat availability if fish avoid stream reaches (Lipton et al., 1995).

Physiological impairment

Growth reduction in fish is an indicator of adverse effects on reproductive fitness (USFWS and University of Wyoming, 1987) and a sensitive measure of metals toxicity during sublethal exposures to copper and zinc mixtures (Finlayson and Verrue, 1980), and to copper, zinc, cadmium, and lead mixtures (Marr et al., 1995). Exposure to cadmium causes growth reductions at concentrations similar to those that cause 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 the increased metabolic stress of detoxification and homeostasis during chronic, sublethal hazardous substance exposures (Dixon and Sprague, 1981; Marr et al., 1995). Fish consumption of metal-contaminated prey can also cause sublethal injuries, including reduced growth (e.g., Woodward et al., 1994, 1995b).

Exposure to cadmium can cause physiological impairment in fish. Cadmium has been shown to cause respiratory impairment (Pascoe and Mattey, 1977, as cited in Sorenson, 1991; McCarty et al., 1978), muscular and neural abnormalities (e.g., Bengtsson et al., 1975; Pascoe and Mattey, 1977, as cited in Sorenson, 1991), and suppressed antibody function (O'Neill, 1981). Low cadmium exposure concentrations can cause depressed plasma calcium, leading to hypocalcemia of freshwater fish (Wicklund, 1990). Calcium deficiencies increase the absorption and deposition of cadmium into intestinal mucosa, the liver, and kidneys (SAIC and EP&T, 1991).

Lead causes hematological (anemia), neuronal, and muscular impairments in fish. Signs of lead exposure include black tails, lordosis/scoliosis (lordoscoliosis), changes in pigment patterns, and coagulation of surface mucus (Sorenson, 1991). At elevated concentrations, lead exposure can result in fish asphyxiation as a result of a thick mucous film over the gills (Varanasi et al., 1975). Lead results in muscle spasms, paralysis, hyperactivity, and loss of equilibrium (Davies et al., 1976; Holcombe et al., 1976).

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 and thus decreased functional surface area for oxygen transfer (Skidmore, 1970; Hughes, 1973; Hughes and Perry, 1976; Hughes and Adeney, 1977). Zinc has also been shown to cause histopathological lesions, inhibition of spawning (Sorenson, 1991), reduced growth (Finlayson and Verrue, 1980; Hobson and Birge, 1989), and behavioral avoidance (Saunders and Sprague, 1967).

2.3 Sources of Hazardous Substances

Sources of hazardous substances in the Tar Creek assessment area include underground mine workings, and surface emplacement and disposal of mine wastes. Underground mine workings have exposed mineralized areas to the environment, leading to the contamination of groundwater as it comes into contact with ore and subsurface wastes. The contaminated groundwater discharges to the surface in seeps and thus serves as a source of hazardous substances to surface resources. Other surficial sources include mixed waste piles, waste rock, tailings, and chat.

Waste rock, chat, vegetated chat, and tailings in the Tar Creek assessment area are all sources of hazardous substances. Definitions of these waste types are given below (Dames & Moore, 1993, 1995). Figures 2.5 through 2.7 show examples of some of these sources:

- **Waste rock** is 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 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 Tar Creek assessment area (Figure 1.2; Figure 2.5). Much of the gravel-sized chat has been removed, washed, and sold as fill for roadbeds, etc.

- **Vegetated chat** is 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. Areas where chat was excavated, leaving behind mixed chat and soil, are also called chat bases.

- **Tailings** are fine-grained mine wastes, the leftover rock after the final milling of the ore and the flotation of the metals from the crushed rock. Some tailings-sized wastes were also created as a byproduct of washing chat. Tailings are 35–60% silt, with the remainder generally sand. Tailings were usually sluiced into a dammed pond in a water slurry; thus many tailings piles contain ponded water (Figure 2.6).

Chat piles are a major source of heavy metals to natural resources in the Tar Creek assessment area. In the Tar Creek Superfund Site OU 4 ROD, U.S. EPA (2008) reported a total of 83 chat piles in OU 4, covering over 767 acres with a volume of over 31 million cubic yards of chat.

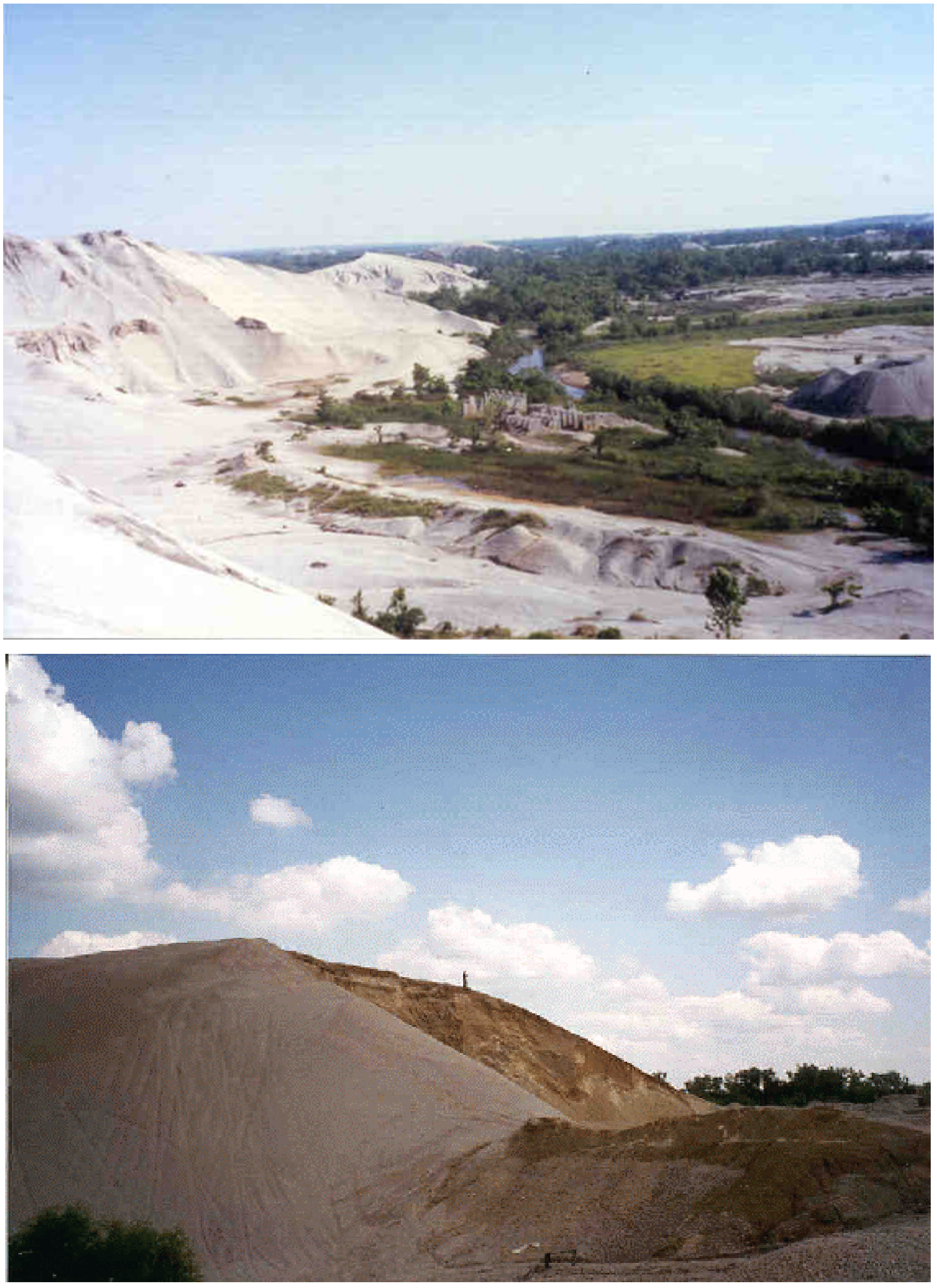

Figure 2.5. Chat piles in the Tar Creek assessment area.

Source: Stratus Consulting.

Figure 2.6. Tailings pond (top) and subsidence pond (bottom) in the Tar Creek assessment area. Subsidence ponds are created when shallow underground mine workings collapse.

Source: Stratus Consulting.

Figure 2.7. Groundwater seeps discharging to surface water in the Tar Creek assessment area.

Source: Stratus Consulting.

U.S. EPA (2008) summarized data from 168 chat samples collected at a 1-foot depth from 20 of the chat piles. Cadmium concentrations ranged from 43.1 to 199.0 mg/kg, with an average of 94.0 mg/kg. Lead ranged from 210 to 4,980 mg/kg, with an average of 1,461 mg/kg; and zinc ranged from 10,200 to 40,300 mg/kg, with an average of 23,790 mg/kg. Similarly, C.C. Johnson & Malhotra (1996) reported average lead concentrations in a chat pile near Picher of 5,300 mg/kg in the < 250-µm fraction, which is the size most likely to be mobilized. Nearly 50% of the lead in their chat samples was in the < 250-µm fraction.

U.S. EPA (2008) also identified 243 chat bases in OU 4, where chat bases are mixed soil and chat, often partially vegetated, where chat has been excavated. The average thickness of the chat bases was estimated at 2 ft. The estimated volume of chat remaining in the 243 chat bases is over 6.7 million cubic yards, spread over an area of nearly 2,080 acres.

Chat bases contain elevated concentrations of metals. U.S. EPA (2008) summarized data from 22 samples from six chat bases. Cadmium concentrations ranged from 51.0 to 151.0 mg/kg, with an average of 96.2 mg/kg; lead ranged from 650 to 3,020 mg/kg, with an average of 1,863 mg/kg; and zinc ranged from 9,520 to 40,300 mg/kg, with an average of 33,600 mg/kg.

U.S. EPA (2008) identified 63 tailings ponds in OU 4, where tailings were either flotation tailings from the metals extraction process, or fine-grained waste from chat washing operations. The tailings ponds cover over 820 acres, containing over 7.2 million cubic yards of washed fines and almost 2 million cubic yards of flotation tailings. The average metals concentrations from over 100 samples in washed fines were 79.7 mg/kg cadmium, 3,658 mg/kg lead, and 15,964 mg/kg zinc. The average concentrations in 55 flotation tailings samples were 133 mg/kg cadmium, 5,694 mg/kg lead, and 29,842 mg/kg zinc (U.S. EPA, 2008).

Groundwater in mine shafts has also been shown to be sources of hazardous substances to the Tar Creek assessment area (OWRB, 1983d, 1983f, 1983g; Tar Creek Task Force, 1983a; DeHay, 2003; DeHay et al., 2004). Mine shaft water contains highly elevated concentrations of cadmium, lead, and/or zinc, indicating that these mines are major sources of contamination to the aquifer, and contamination to surface water after groundwater seeps to the surface (Figure 2.7). Table 2.2 summarizes mine shaft water quality data from the Tar Creek site. Maximum cadmium concentrations were as high as 590 µg/L, and lead concentrations in most wells were over 100 µg/L. Six of nine wells contained maximum zinc concentrations in excess of 150,000 µg/L (Table 2.2).

Table 2.2. Average (maximum) concentrations of hazardous substances in water from mine shafts, Ottawa County, Oklahoma

Mine shaft	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)	Source
Admiralty No. 4	49 (94)	44 (80)	196,000 (331,000)	Tar Creek Task Force, 1983a
Consolidated No. 2	63 (190)	52 (207)	53,000 (274,000)	
Kenoyer	86 (250)	64 (218)	84,500 (340,000)	
Lawyer	136 (590)	34 (207)	190,300 (285,000)	
Site 4S (near Lytle Creek)	137 (310)	65 (141)	240,000 (342,000)	OWRB, 1983d
Site 13 (King Jack mine)	257 (430)	105 (282)	87,000 (130,000)	
Site 14 (S and W of Commerce, OK)	13.7 (27)	20.2 (120)	142,000 (560,000)	
Site 4t (Admiralty)	236 (250)		31,400 (34,900)	OWRB, 1983g
Site St (Swift – Commonwealth)	21 (23)		17,000 (18,300)	
Samples from 7 different shafts in Picher Mining District	8.26 [a] (111)	1.0 [a] (32.7)	2,140 [a] (11,100)	DeHay, 2003
Samples from 16 different shafts in Picher Mining District	0.34[a] (113)	0.14[a] (16.9)	2,080[a] (20,100)	DeHay et al., 2004

a. Median concentration.

2.4 Confirmation of Exposure

Federal regulations state that an Assessment Plan should confirm that:

> at least one of the natural resources identified as potentially injured in the preassessment screen has in fact been exposed to the released substance [43 CFR § 11.37(a)].

A natural resource has been exposed to hazardous substances if “all or part of [it] is, or has been, in physical contact with . . . a hazardous substance, or with media containing . . . a hazardous substance” [43 CFR § 11.14(q)]. The regulations also state that “whenever possible, exposure shall be confirmed using existing data” from previous studies of the assessment area [43 CFR § 11.37(b)(1)].

The following sections provide confirmation of exposure to hazardous substances in the assessment area, based on a review of the available data, including data for surface water resources, groundwater resources, geological resources (soils), and biological resources such as fish, birds, and floodplain forest vegetation.

2.4.1 Groundwater exposure

Roubidoux aquifer

Data from the OWRB (1983e) show little evidence of groundwater injury in the deep 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 iron in excess of 300 µg/L. One sample, from Quapaw, contained 100 µg/L lead, which exceeds the drinking water standard, and one other sample contained 530 mg/L sulfate, which also exceeds the drinking water standard. The Quapaw sample also contained 19,000 µg/L iron and 3,600 µg/L zinc, which is evidence of metals contamination, though the source of the contamination is not known.

The U.S. Geological Survey (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 cadmium, 260,000 µg/L iron, 29 µg/L lead, and 84,000 µg/L zinc. 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. Iron concentrations exceeded 300 µg/L 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 250 µg/L. One sample from Cardin contained lead at 237 µg/L (Christenson, 1995).

ODEQ (2002) conducted additional groundwater sampling in Roubidoux aquifer wells in the late 1990s. Several wells contained zinc, iron, and sulfate concentrations indicative of mine waste contamination. The likely source of the contamination was the overlying shallow aquifer, but it could not be conclusively determined whether the contamination came via leaking abandoned wells or via a natural conduit such as a fracture.

Boone aquifer

Playton et al. (1980) conducted an extensive study of the water quality in six abandoned Oklahoma mineshafts connected to the shallow Boone aquifer. Cadmium concentrations exceeded the 5 µg/L criterion in 67 of 69 samples collected; many of the samples exceeded 100 µg/L, up to a maximum of 1,200 µg/L. Lead concentrations exceeded 15 µg/L in 71% of the samples, with concentrations as high as 500 µg/L. Zinc concentrations exceeded 5,000 µg/L in almost 90% of samples, with a maximum concentration of 690,000 µg/L.

OWRB (1983f) also found elevated metals concentrations in shallow groundwater in the Tar Creek mine shafts, including cadmium concentrations as high as 230 μg/L, lead as high as 148 μg/L, and zinc concentrations in excess of 250,000 μg/L. In a study of groundwater in the shallow aquifer, OWRB (1983e) found cadmium concentrations as high as 1,233 μg/L, lead concentrations as high as 124 μg/L, and zinc concentrations up to 252,000 μg/L.

The USGS collected shallow groundwater samples from Oklahoma mine sites in the mid-1980s (Parkhurst, 1987). Cadmium concentrations were as high as 78 μg/L, lead concentrations as high as 79 μg/L, and zinc concentrations as high as 200,000 μg/L. In addition, manganese concentrations ranged up to 9,700 μg/L, and iron concentrations were found at concentrations up to 600 mg/L.

In 2002–2003, the USGS (DeHay et al., 2004) collected additional shallow groundwater samples from 16 abandoned mine sites in the assessment area (see Table 2.2). These samples contained highly elevated concentrations of hazardous substances, including cadmium concentrations as high as 113 μg/L, lead concentrations as high as 16.9 μg/L, manganese concentrations as high as 4,680 μg/L, and zinc concentrations as high as 20,100 μg/L (DeHay et al., 2004).

2.4.2 Surface water and sediment exposure

Donlan (2007) estimates that 73 stream miles in Ottawa County have been and continue to be exposed to hazardous substances from mining releases, including but not limited to Tar Creek, Lytle Creek, Elm Creek Spring River, Beaver Creek, and the Neosho River (Figure 2.1). In addition, Grand Lake O' the Cherokees and other water bodies, including wetlands, have been and continue to be exposed to hazardous substances from mining releases.

Metals concentrations in Tar Creek and Lytle Creek in the 1980s were highly elevated downstream of mine waste. The Oklahoma State Department of Health (1983) measured dissolved cadmium concentrations in Tar Creek as high as 410 μg/L, lead concentrations as high as 1,920 μg/L, and zinc concentrations as high as 151,000 μg/L. Parkhurst (1987) measured maximum concentrations in Tar Creek of 40 μg/L cadmium, 140 μg/L lead, and 67,000 μg/L zinc. Maximum concentrations of metals in Lytle Creek in the 1980s were similar, including 140 μg/L cadmium, 100 μg/L lead, and 120,000 μg/L zinc (Oklahoma State Department of Health, 1983; Parkhurst, 1987).

Recent water quality data indicate that metals concentrations are still elevated in Tar Creek, but are generally lower than the 1980s measurements described in the previous paragraph. In 2004–2005, the maximum concentrations in Tar Creek were 15 μg/L cadmium, 152 μg/L lead, and 3,100 μg/L zinc (DeHay, 2006). In a May 2006 study, U.S. EPA (2006) measured maximum metals concentrations of 12.1 μg/L cadmium, 36.5 μg/L lead, and 9,070 μg/L zinc in Tar Creek, and 16.7 μg/L cadmium, 31.0 μg/L lead, and 7,710 μg/L zinc in Lytle Creek.

Sediment in the assessment area has also been exposed to releases of hazardous substances. Pita and Hyne (1975) analyzed 11 samples from Grand Lake O' the Cherokees and found average zinc concentrations of 365 mg/kg and average lead concentrations of 55 mg/kg. They also found evidence that Tar Creek mine wastes may have been transported well beyond Grand Lake O' the Cherokees. At Fort Gibson Reservoir, downstream of both Grand Lake O' the Cherokees and Lake Hudson, average zinc concentrations were 273 mg/kg, and average lead concentrations were 36 mg/kg (Pita and Hyne, 1975).

McCormick and Burks (1987) also found highly elevated metals concentrations in sediment samples from Grand Lake O' the Cherokees, the Neosho River, and the mouth of Tar Creek. Concentrations in Tar Creek were 7.4 mg/kg cadmium, 84 mg/kg lead, and 3,500 mg/kg zinc. In the Neosho River, concentrations were 3.7 mg/kg cadmium, 64 mg/kg lead, and 2,600 mg/kg zinc, and in Grand Lake O' the Cherokees, concentrations were 9.9 mg/kg cadmium, 132 mg/kg lead, and 1,200 mg/kg zinc.

More recently, U.S. EPA (2006) found Tar Creek sediment concentrations as high as 130 mg/kg cadmium, 757 mg/kg lead, and 12,300 mg/kg zinc. Concentrations in Lytle Creek were as high as 143 mg/kg cadmium, 929 mg/kg lead, and 26,700 mg/kg zinc.

2.4.3 Geologic resources exposure

Surficial mine waste continues to be the dominant landscape feature in the Tar Creek assessment area. Figures 1.2 and 2.1 show large areas of devegetated chat clearly visible in aerial photographs. Figure 2.5 shows examples of chat piles from the ground.

U.S. EPA (2008) summarized the most recent data on exposure of geologic resources in the assessment area to hazardous substances, including cadmium, lead, and zinc. The data show that geologic resources have been exposed to hazardous substances. Specifically:

- Chat piles contain metals concentrations up to 199 mg/kg cadmium, 4,980 mg/kg lead, and 40,300 mg/kg zinc. The assessment area contains at least 83 chat piles, containing approximately 31 million cubic yards of chat over an area of 767 acres.

- Chat bases contain metals concentrations up to 151 mg/kg cadmium, 3,020 mg/kg lead, and 40,300 mg/kg zinc. The assessment area contains at least 243 chat bases, containing approximately 6.7 million cubic yards of chat-contaminated soils over an area of nearly 2,080 acres.

- Flotation tailings ponds contain metals concentrations up to 450 mg/kg cadmium, 17,800 mg/kg lead, and 103,000 mg/kg zinc. The assessment area contains 55 flotation tailings ponds containing nearly 2 million cubic yards of tailings.

- Fine-grained waste tailings from chat washing operations contain metals concentrations up to 320 mg/kg cadmium, 26,600 mg/kg lead, and 70,000 mg/kg zinc. The assessment area contains 101 washed fines tailings ponds, containing over 7.2 million cubic yards of fines. Tailings ponds (flotation and washed fines) cover over 820 acres in the assessment area.

In addition, U.S. EPA (2008) estimated that transition soils proximal to mine waste are likely to contain greater than 500 mg/kg lead. Based on that assumption, they estimated that approximately 1.36 million cubic yards of soil covering 1,160 acres contain lead concentrations exceeding 500 mg/kg.

2.4.4 Biological resources exposure

Limited data are available quantifying exposure of biota to hazardous substances in the Tar Creek assessment area. However, the data that are available indicate that biota are exposed to hazardous substances released in the assessment area, and that the hazardous substances are biologically available and likely causing adverse effects.

Terrestrial biota

Exposure data for terrestrial biological resources are scarce. As discussed in the previous section, concentrations of heavy metals in chat piles are above toxicity thresholds for plants (e.g., Kabata-Pendias and Pendias, 1992), precluding the establishment of vegetation on the piles. Bank swallows (*Riparia riparia*) frequently roost in chat piles (Figure 2.8) and thus are likely to be exposed to cadmium, lead, and zinc.

Studies of exposure of terrestrial biota to hazardous substances in the assessment area include the following:

- Erickson et al. (1988) measured concentrations of zinc up to 13,000 mg/kg in grasses along the banks of Tar Creek, indicating exposure to and likely bioavailability of hazardous substances in floodplain vegetation.

Figure 2.8. Bank swallows frequently nest in chat piles in the assessment area, evidenced by holes on steep chat pile faces.

Source: Stratus Consulting.

- Conder and Lanno (1999) compared lead concentrations in mandibles of white-tailed deer (*Odocoileus virginianus*) harvested near the Picher mining district with mandibles from deer harvested in areas south and west of the Picher mining district. Lead mandible concentrations were significantly higher in deer harvested near Picher, indicating that lead from the ubiquitous chat piles and contaminated soils may be entering the bloodstream of the deer and being deposited in bones.

- Beyer et al. (2004), Carpenter et al. (2004), Sileo et al. (2004), Beyer (2007), and Sileo (2007) found evidence of lead and zinc poisoning in free-flying wild birds in the assessment area, including American robins (*Turdus migratorius*), northern cardinals (*Cardinalis cardinalis*), a trumpeter swan (*Cygnus buccinator*), and other waterfowl. Several birds had lead tissue concentrations that have been associated with impaired biological functions and external signs of poisoning. Zinc concentrations were sufficient to cause pancreatitis in waterfowl.

Aquatic biota

Several studies have shown that aquatic biota are exposed to the hazardous substances released to rivers in the Tar Creek assessment area. These studies include the following:

- OSDH (1981) analyzed a fish from Tar Creek that had elevated tissue concentrations of cadmium and lead (0.4 µg Cd/g and 1.8 µg Pb/g, respectively). Cadmium concentrations in this fish composite sample from Tar Creek were greater than the State of Oklahoma's 1981 alert level of 0.3 µg Cd/g.

- Miller (1981) observed 100% mortality in "sensitive fish species" at five locations along Tar Creek upstream from Cardin, although no additional information was provided.

- Aggus et al. (1982) found that benthic macroinvertebrate and fish diversities were far less in Tar Creek than at a control site upstream of mining impacts. Few fish were found near the mouth of Tar Creek, and no fish were found approximately three miles upstream of the mouth.

- McCormick (1985) and McCormick and Burks (1987) extracted pore water from Tar Creek and Neosho River sediment. The extracted pore water from both rivers was toxic to the water flea *Daphnia magna*, even when highly diluted.

- Dawson et al. (1985) showed that hazardous substances in Tar Creek in the 1980s caused high rates of mortality and teratogenicity, as well as reduced growth, in frog embryos.

- Wildhaber et al. (1997) found elevated concentrations of cadmium, lead, and zinc in invertebrates downstream of mine waste in the Spring and Neosho rivers. They concluded that metals concentrations in invertebrates were inversely correlated with the presence of the threatened Neosho madtom.

- ODEQ (2003, 2007) found elevated concentrations of lead in fish collected in the Spring and Neosho rivers and Grand Lake O' the Cherokees. The elevated lead concentrations were highly correlated with elevated lead concentrations in sediment. ODEQ (2007) concluded that lead concentrations in nongame fish in all sample locations were sufficient to require consumption advisories for both residents and non-residents. Additional consumption advisories for residents were warranted for game fish and sunfish in mill ponds, and catfish and sunfish in the Spring River.

- Brumbaugh et al. (2005) found elevated concentrations of cadmium and lead in carp and catfish from the Neosho and Spring rivers.

- Schmitt et al. (2006) found elevated metals concentrations in fish and crayfish from the Tar Creek assessment area. Cadmium and lead concentrations in crayfish and bottom-dwelling fish (e.g., carp, channel catfish) from Tar Creek and the Spring River were above thresholds, indicating risk to humans and piscivorous birds that consume these organisms. Yoo and Janz (2003), Schmitt et al. (2005), and Schmitt (2007) concluded that lead released to aquatic habitats in the Tar Creek assessment area is bioavailable and biochemically active, thus causing adverse effects on aquatic fauna.

- Franssen et al. (2006) found that habitat-normalized species richness of fish was significantly lower in stream impacted by mine waste than in unimpacted streams. Almost 90% of all fish captured in Tar Creek and its impacted tributaries were metals-tolerant western mosquitofish (*Gambusia affinis*) and green sunfish (*Lepomis cyanellus*). Largemouth bass (*Micropterus salmoides*) were considerably more numerous in unimpacted streams; young-of-year largemouth bass were entirely absent in impacted streams.

2.4.5 Air resources exposure

There are few data quantifying exposure of air resources in the assessment area. The Oklahoma State Department of Health (1983) collected seven air samples in Picher in 1982 and found that the average zinc concentration of 1.48 $\mu g/m^3$ was two orders of magnitude greater than the concentrations observed at a comparison site in Kansas. The baseline human health risk assessment (Ecology and Environment, 1996) found elevated (but highly variable) lead concentrations in indoor dust in the Tar Creek area compared to reference sites. Crow (2007) reported elevated concentrations of particulates and lead at the Quapaw Tribe air monitoring sites on windy days but no violations of air quality standards.

Elevated hazardous substance concentrations in assessment area soils, including residential soils that were never directly exposed to mine waste, have been well documented (e.g., U.S. EPA, 1997, 2008). Wind likely entrained the metals in mine waste areas and subsequently deposited the metals in residential yards. Thus, air resources were exposed to the hazardous substances.

2.5 Preliminary Determination of Recovery Period

The recovery period is either the longest length of time required to return the services of the injured resource to their baseline condition, or a lesser period of time selected by the authorized official and documented in the Assessment Plan [43 CFR § 11.14(gg)]. In the Tar Creek assessment area, ubiquitous chat piles and seeps of metals-contaminated mine water provide sources of hazardous substances. The selected remedy for OU 4 (U.S. EPA, 2008) includes voluntary relocation of at least 744 properties in the assessment area, as EPA concluded that remediation was unlikely to lower human health risks to acceptable levels in a timely manner. While the selected remedy includes significant removal of mine waste at a total projected cost of over $167 million, the remedial action objectives, which will not be met for over 30 years, allow for 10 mg/kg cadmium, 500 mg/kg lead, and 1,100 mg/kg zinc to remain in the soils. In addition, EPA recognizes that institutional controls to prevent exposure to contamination will still be required (U.S. EPA, 2008). Thus, the OU 4 ROD implies that the remediation of mine waste in the assessment area is unlikely to return terrestrial habitat to baseline conditions.

As mentioned previously, the OU 1 remedy to address contaminated groundwater discharging to assessment area surface water has been ineffective. It is not known if or when EPA will re-open OU 1 and attempt a different remedy. In addition, EPA is still in the early stages of data collection for OU 5. Implementation of a selected remedy to address site-wide sediment and surface water contamination in OU 5 is many years away.

The Trustees will evaluate the recovery period as part of the assessment. Given the currently available information, it is unlikely that the Tar Creek assessment area will recover from mining related injuries in the near future.

3. Role of Trustees

This chapter discusses the role of the Trustees in the NRDA process, including trusteeship, the decision to perform a Type B assessment, and a discussion of the NRDA process that the Trustees propose to follow.

3.1 Trusteeship Authority

CERCLA, as amended [42 USC §§ 9601 et seq.], the Federal Water Pollution Control Act (FWPCA), as amended [33 USC §§ 1251 et seq.], and federal regulations at 40 CFR § 300.600(2) authorize the Secretary of the Interior to act as trustee for natural resources managed, controlled by, or appertaining to the DOI, including those resources for which the United States acts on behalf of a tribe.

CERCLA, FWPCA, and 40 CFR § 300.605 authorize state trustees to act on behalf of the public for natural resources within the boundary of a state or belonging to, managed by, controlled by, or appertaining to such state. The Oklahoma Secretary of the Environment has been designated as the Natural Resource Trustee for the State of Oklahoma [27A Okla. Stat. § 1-2-101(4)]. CERCLA, FWPCA, and 40 CFR § 300.610 authorize Indian tribes to serve as trustees for the natural resources belonging to, managed by, controlled by, or appertaining to such Indian tribe, or held in trust for the benefit of such Indian tribe, or belonging to a member of such Indian tribe, if such resources are subject to a trust restriction on alienation.

The Trustees are authorized to assess damages for injury to, destruction of, or loss of natural resources [42 USC § 9607 (f)(2)(A)-(B)]. Natural resources include land, fish, wildlife, biota, supporting habitats, air, water, groundwater, and drinking water supplies [42 USC § 9601(16), 40 CFR § 300.600(a)]. Claims may be pursued against parties that have been identified as potentially responsible for injury to, destruction of, or loss of natural resources, including the reasonable costs of assessing such injury [42 USC § 9607(a)(4)(c)].

3.2 Decision to Perform a Type B Assessment

Under federal guidance for NRDA, the Trustees can elect to perform a Type A or Type B assessment [43 CFR § 11.33]. Type A assessments are “simplified procedures that require minimal field observation” [43 CFR § 11.33(a)]. Use of the Type A assessment is generally limited to the assessment of relatively minor, short duration discharges or releases that occur in a coastal/marine or Great Lakes environment [43 CFR § 11.34(a)].

Type B assessments require "more extensive field observation than the Type A procedures" [43 CFR § 11.33(b)]. Type B assessments include three phases: injury determination, quantification, and damage determination [43 CFR § 11.60(b)] (see Section 1.4). The Trustees may incur reasonable costs in the Assessment Phase of the Type B damage assessment [43 CFR § 11.60(d)]. A Type B assessment is warranted when the simplified procedures for a Type A assessment are not applicable [43 CFR § 11.24-11.35].

Therefore, the Trustees have determined that a Type B assessment is warranted in this case because:

- The release was not of a short duration
- The release was not minor
- The release did not occur in a coastal, marine, or Great Lakes environment
- The release resulted in levels of contamination beyond the levels appropriate for a simplified Type A assessment requiring minimal field observation.

3.3 Natural Resource Damage Assessment Process

NRDA is a process by which trustees of natural resources determine compensation for natural resource injuries that have not been, or are not expected to be, addressed by response actions. The measure of such compensation is the "cost of restoration, rehabilitation, replacement, and/or acquisition of the equivalent of the injured natural resources and the services those resources provide" and may also include the "compensable value of all or a portion of the services lost to the public for the time period from the . . . release until the attainment of the restoration, rehabilitation, replacement, and/or acquisition of equivalent of the resources and their services to baseline" [43 CFR § 11.80(b)].

The DOI has promulgated guidance for conducting an NRDA related to hazardous substance releases at 43 CFR Part 11. The Trustees intend to follow the NRDA guidance to the extent practicable. The four major phases in the Type B NRDA process are the "preassessment phase," the "assessment plan phase," the "assessment phase," and the "post-assessment phase."

3.3.1 Preassessment phase

The preassessment phase of an NRDA is the first step described in the NRDA regulations. Trustees must rapidly review available data and determine whether or not to proceed with an assessment [43 CFR § 11.13(b)], and then document this decision in a preassessment screen determination [43 CFR § 11.23(c)]. The preassessment screen for this assessment area has been completed (Tar Creek Natural Resource Trustee Council, 2004). In accordance with the criteria at 43 CFR § 11.23(e), the preassessment screen demonstrates that:

- A release of hazardous substances has occurred
- Natural resources for which the Trustees may assert trusteeship under CERCLA have been or are likely to have been adversely affected
- The quantity of the release is sufficient to potentially cause injury
- Data to perform an assessment are available or obtainable at a reasonable cost
- Response actions do not or will not sufficiently remedy the injury to natural resources without further action [43 CFR § 11.23(e)].

Thus, the Trustees concluded that they should proceed with an NRDA to develop a damage claim.

3.3.2 Assessment plan phase

After deciding to perform an NRDA, the Trustees prepare an assessment plan. The purpose of the assessment plan is to ensure that the assessment is well planned and conducted systematically, and that the selected methods for assessment demonstrate reasonable cost [43 CFR § 11.13(c)]. According to 43 CFR Part 11, the assessment plan confirms exposure of natural resources to hazardous substances (Chapter 2 of this Assessment Plan), describes the objectives of any testing and sampling for injury or pathway determination (Chapter 4 of this Plan), and provides a QAPP to ensure quality control in testing and sampling (Chapter 5 of this Plan) [43 CFR § 11.31(c)(1)-(3)].

The assessment plan may also include a restoration and compensation determination plan (RCDP). However, if insufficient information is available to develop the RCDP at the time of assessment plan preparation, the RCDP may be developed at a later time before the completion of injury determination and quantification [43 CFR § 11.31(c)(4)]. This Assessment Plan contains an approach to conduct restoration planning and scaling (Chapter 4); the Trustees will develop an RCDP at a later time.

3.3.3 Assessment phase

The assessment phase is when the evaluation of injuries and damages is conducted. The parts of a Type B assessment are summarized here and described in detail in Chapter 4.

1. **Injury determination**: An assessment determines what natural resources have been injured as a result of the release of hazardous substances [43 CFR § 11.13(e)(1)]. It also involves determining the pathway, or route, through which the hazardous substances were transported from sources to the injured resource [43 CFR § 11.61(c)(3)].

2. **Quantification**: An assessment also quantifies the relationship between losses caused by determined injuries and available gains from natural resource restoration opportunities. The extent and degree of injuries, the ability of the resource to recover, and the reduction in services are included in quantification [43 CFR § 11.71(c)]. The "interdependent services" provided by natural resources are identified to "avoid double counting in the damage determination phase and to discover significant secondary services that may have been disrupted by the injury" [43 CFR § 11.71(b)(4)].

3. **Damage determination**: An assessment also determines the appropriate compensation for the injuries [43 CFR § 11.13 (e)(3)] as dollars.[1] Damages are measured as the cost or value of sufficient restoration to offset all of the public losses caused by natural resource injuries.

3.3.4 Post-assessment phase

The post-assessment phase is the final step in the NRDA process. After the assessment is complete, the Trustees produce a report of assessment containing the results of the NRDA [43 CFR § 11.90]. The Trustees may then seek recovery of damages from the PRPs [43 CFR § 11.91], and such damages may include direct and indirect costs "necessary to complete all actions identified in the selected alternative for restoration, rehabilitation, replacement, and/or acquisition of equivalent resources" [43 CFR § 11.83(b)]. If damages are received, an account is established for the damages recovered [43 CFR § 11.92], and a restoration plan is developed and implemented using the recovered damages [43 CFR § 11.93]. It is anticipated that a restoration plan will be developed after settlements or judgments.

1. Although the regulations describe a process that ends with a demand for a sum certain, Trustees may allow PRPs to resolve their liability through direct restoration activities at costs that may not be known by the Trustees. In these cases, metrics other than dollars are used to scale the amount of required restoration to losses caused by natural resource injuries.

3.4 Natural Resource Damage Coordination with Response Actions

To the extent practical, an NRDA should be conducted in coordination with investigations undertaken as part of National Contingency Plan (NCP) response actions, including, for example, an RI/FS [43 CFR § 11.31(a)(3)]. The goals of this coordination are to avoid duplication, reduce costs, and achieve dual objectives where practical. At a minimum, the Trustees intend to consider the objectives of removal actions, RI/FS activities, and remedial actions during the continued planning and implementation of the NRDA. The Trustees intend to use pre-existing data from other studies where relevant and reliable to determine injuries and quantify losses in the assessment area. Should the Trustees conduct original data collections at the site, they will explicitly coordinate damage assessment activities with other investigations. In addition, the Trustees will ensure that, whenever practicable, appropriate consideration is given to parties undertaking remediation or restoration activities that satisfy the Trustees' NRDA objectives.

3.5 Public Review and Comment

The Trustees encourage public participation in this NRDA. This Assessment Plan is available for public review and comment, including PRPs; other natural resource trustees; other affected federal, state, or Tribal agencies; and any other interested members of the general public, for a period of 30 days [43 CFR § 11.32(c)(1)]. Comments must be received within 30 days from the date the notice of availability is published in the Federal Register. Comments may be submitted in writing to:

Suzanne Dudding
U.S. Fish & Wildlife Service
9014 E. 21st Street
Tulsa, OK 74129
Or via e-mail: Suzanne_Dudding@fws.gov

Comments received during the 30-day review period and responses to those comments will be included as part of the Report of Assessment to be completed at the conclusion of the assessment.

The Trustees may amend the Assessment Plan, and any significant revisions will be made available for additional public review [43 CFR § 11.32(e)]. Significant modifications to the Assessment Plan will be made available for public review for a period of at least 30 calendar days, with reasonable extensions granted as appropriate before tasks in the Modified Plan are begun.

4. Assessment Approach

Federal regulations at 43 CFR Part 11 specify three interrelated parts of an assessment: injury determination, quantification, and damage determination. This NRDA will follow the Type B procedures for assessing damages to natural resources. In particular, the Trustees will evaluate whether existing information is sufficient to quantitatively compare losses and gains on the basis of natural resource quantity and quality, service quantity and quality, cost, or value. In addition, the Trustees will evaluate whether cost-effective data collection should be pursued as part of the assessment to determine the scale of necessary restoration and damages.

The Trustees will use the extensive body of existing data in their assessment, reviewing and compiling historical and current site-specific data. The results of any ongoing monitoring programs will also be examined.

Following this review, the Trustees may determine that additional data are required in order to assess the site. In such cases, the Trustees may issue subsequent assessment plan addenda, study plans, or standard operating procedures for public review. The Trustees could then conduct targeted assessment studies. Any assessment studies will be designed specifically to provide additional data relevant to assessing injury and losses, determining potential gains from restoration, and scaling restoration to the losses.

Natural resource services are defined as "the physical and biological functions performed by the resource including the human uses of those functions. These services are the result of the physical, chemical, or biological quality of the resource" [43 CFR § 11.14(nn)]. Natural resource injuries, resultant losses, and baseline conditions may be evaluated in terms of natural resource quantity or quality, the amount and quality of services provided by natural resources, the costs of offsetting the losses, or the value of the injury losses and/or restoration gains.

Section 4.1 describes the stages of a Type B NRDA performed under 43 CFR Part 11. How those stages will be addressed in this NRDA are in subsequent sections. Section 4.2 lists data sources, Section 4.3 describes injury determination, Section 4.4 describes pathway determination, Section 4.5 describes injury quantification, Section 4.6 describes damage determination, and Section 4.7 describes whether new studies will be considered.

4.1 Assessment Stages

The purpose of the assessment phase is to:

1. Determine whether injuries to natural resources have occurred [43 CFR § 11.62]

2. Identify the environmental pathways through which injured resources have been exposed to hazardous substances released from the site [43 CFR § 11.63]

3. Quantify the degree and extent (spatial and temporal) of injury in terms of a reduction of the quantity and quality of services from baseline conditions [43 CFR § 11.70]

4. Establish appropriate compensation as natural resource restoration for those injuries [43 CFR § 11.80].

Federal regulations at 43 CFR Part 11 list several steps for the assessment phase of a Type B NRDA. The remainder of this section describes the various assessment stages described in the regulations.

4.1.1 Injury determination

Under the regulations, injury determination includes the following two components:

1. **Determination that injury has occurred [43 CFR § 11.62]**. The regulations define injury as "a measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a . . . release of a hazardous substance, or exposure to a product of reactions resulting from the . . . release of a hazardous substance. As used in this part, injury encompasses the phrases 'injury,' 'destruction,' or 'loss'" [43 CFR § 11.14(v)]. The assessment determines whether injuries to Trustee natural resources have occurred.

2. **Pathway determination [43 CFR § 11.63]**. The assessment determines whether sufficient exposure pathways exist (or have existed) by which hazardous substances are (or were) transported in the environment, resulting in natural resource exposure to those substances [43 CFR § 11.63]. Pathways can be determined using a combination of information about the nature and transport mechanisms of the hazardous substances, potential pathways, and data documenting the presence of the hazardous substances in the pathway resource.

4.1.2 Quantification

Quantification can focus on a wide variety of metrics related to natural resource quantity and quality, service quantity and quality provided by natural resources, or the cost or value of injury losses and/or restoration gains. Quantification includes several components:

1. **Characterization of baseline conditions [43 CFR § 11.72]**. Baseline conditions are defined as "the conditions that would have existed at the assessment area had the discharge of oil or the release of the hazardous substances under investigation not occurred" [43 CFR § 11.14(e)]. The injuries determined in the injury determination phase can be quantified in terms of changes in natural resources and the services they provide from baseline conditions [43 CFR § 11.71(b)(2)]. The regulations suggest using historical data to evaluate baseline conditions, if they are available [43 CFR § 11.72(c)]. Where historical data are not available, data from control areas may be used [43 CFR § 11.72(d)].

2. **Quantification of spatial and temporal extent of injuries [43 CFR § 11.71]**. Contaminant data and historical records can help determine the spatial and temporal extent of injuries to natural resources. Tools such as geographic information systems may be used to facilitate spatial quantification.

3. **Quantification of service losses [43 CFR § 11.71]**. Natural resource services are defined as "the physical and biological functions performed by the resource including the human uses of those functions. These services are the result of the physical, chemical, or biological quality of the resource" [43 CFR § 11.14(nn)]. The natural resource services lost as a result of the hazardous substances releases are quantified by comparison to services provided under baseline conditions [43 CFR § 11.71(b)].

4. **Estimation of recovery to baseline [43 CFR § 11.73]**. An estimate is needed of the time required for the recovery of injured resources and the services they provide to baseline levels. This evaluation includes an estimate of recovery time if no actions beyond response actions are taken, and estimates of recovery time under possible alternatives for restoration, rehabilitation, replacement, and/or acquisition of equivalent resources.

4.1.3 Damage determination

Determination of damages may include the following:

1. **Selection of alternatives for restoration [43 CFR § 11.82]**. Alternatives for potential restoration options to restore, rehabilitate, replace, and/or acquire the equivalent of the injured resources are developed and selected [43 CFR § 11.82(b)(1)(iii)].

2. **Restoration costs [43 CFR § 11.80]**. If the amount of restoration necessary to offset losses has been calculated, then damages are determined as the cost of that much restoration.

3. **Valuation of natural resources [43 CFR § 11.83]**. Valuation methodologies are used to estimate the value of the losses caused by natural resource injury (or the value of sufficient restoration to offset the losses).

4. **Development of the RCDP [43 CFR § 11.81]**. The RCDP lists possible restoration alternatives and the methodologies for determining the costs of different alternatives and the compensable value of the services lost to the public. If existing data are insufficient for developing the RCDP when the Assessment Plan is published, it may be published separately after the injury assessment is completed [43 CFR § 11.81(c)].

The selection of restoration alternatives to compensate for losses caused by the injuries requires a means of ensuring that the scale of the restoration projects is commensurate with the amount of past and future injuries resulting from the hazardous substance releases. The Trustees will investigate using resource-to-resource or service-to-service scaling such as habitat equivalency analysis (HEA) and resource equivalency analysis (REA) to determine the appropriate amount and type of restoration to compensate for natural resource injuries, as described in Section 4.3. However, the Trustees will evaluate the efficacy and cost-effectiveness of other valuation methodologies as well.

4.2 Data Sources

The following documents include key data for assessing natural resource injuries and damages at the Tar Creek assessment area:

- The Preassessment Screen for this NRDA (Tar Creek Natural Resource Trustee Council, 2004)

- Documents produced as part of RI/FS activities, including the site evaluation findings reports (C.C. Johnson & Malhotra, 1996), and the OU 4 site characterization study

(AATA International, 2005), feasibility study (CH2M Hill, 2006), and ROD (U.S. EPA, 2008)

- OWRB water quality documents, including several from the early 1980s (e.g., OWRB, 1983a, 1983b, 1983c, 1983d, 1983e) and recent Beneficial Use Monitoring Program (BUMP) reports (e.g., OWRB, 2005a, 2005b)
- Oklahoma Department of Environmental Quality (ODEQ) documents summarizing fish, soils, and groundwater data (e.g., Datin and Cates, 2002; ODEQ, 2002, 2003; Cates, 2003)
- EPA documents from the site (e.g., Janik et al., 1982; U.S. EPA, 1994, 2000; Mission Research, 1996; Wildhaber et al., 1996; Brown and Root Environmental, 1997)
- Data summary documents produced by the Tar Creek Task Force and the Tar Creek Superfund Task Force (e.g., Tar Creek Task Force, 1983a, 1983b; Tar Creek Superfund Task Force, 2000a, 2000b)
- Dam re-authorization studies for the Federal Energy Regulatory Commission (e.g., Grand River Dam Authority, 2004)
- Field investigations for the U.S. Fish & Wildlife Service (e.g., Aggus et al., 1982; Allert et al., 1997; USFWS, 2000)
- Field investigations and academic papers from the USGS (e.g., Playton et al., 1980; Parkhurst, 1987, 1988; Adams, 1988; Erickson et al., 1988; Parkhurst et al., 1988; Smith et al., 1988; Christenson et al., 1990; Christenson, 1995; Schmitt et al., 1997; DeHay, 2003; DeHay et al., 2004)
- Peer-reviewed papers and presentations specific to the Tar Creek area (e.g., Schmitt et al., 1984, 2005, 2006; Dawson et al., 1985; McCormick, 1985; McCormick and Burks, 1987; Conder and Lanno, 1999; Yoo and Janz, 2003; Beyer et al., 2004; Brumbaugh et al., 2005; Franssen et al., 2006; Xiao and Ji, 2007)
- Expert reports in the Asarco, LLC bankruptcy case concerning metals releases and their effects on biological resources in the Tri-State and Southeastern Missouri mining districts (Angelo, 2007; Beyer, 2007; Galbraith, 2007; Ingersoll, 2007; Kapustka, 2007; Kindscher, 2007; Medine, 2007; Schmitt, 2007; Sileo, 2007).

4.3 Injury Determination [43 CFR § 11.62]

4.3.1 Groundwater [43 CFR § 11.62(c)]

The relevant injury definitions for groundwater resources include:

- Concentrations and duration of hazardous substances in excess of drinking water standards as 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 release [43 CFR § 11.62(c)(1)(i)]

- Concentrations and duration of hazardous substances sufficient to have caused injury to other resources when exposed to groundwater [43 CFR § 11.62(c)(1)(iv)].

The relevant injury thresholds for groundwater in the assessment area include hazardous substance concentrations in excess of the EPA drinking water standards (Sections 1411-1416 of the SDWA) and/or in excess of the numerical criteria to protect beneficial uses listed in (Oklahoma Administrative Code) OAC 785:45-7-1.

Information relevant to determining injuries to groundwater includes groundwater chemistry data, groundwater flow information, aquifer characteristics, and data from drinking water supply wells, including location, depth, and uses.

Groundwater will be determined to be injured if concentrations of hazardous substances exceed thresholds in Sections 1411-1416 of the SDWA or numerical criteria to protect beneficial uses listed in OAC 785:45-7-1. To control the level of contaminants in the nation's drinking water, EPA established three kinds of drinking water standards for public water supplies. The maximum contaminant levels (MCLs) are the highest level of a contaminant that is allowed in drinking water. The MCL goals (MCLGs) are non-enforceable health goals that are set at levels at which no known or anticipated adverse effects to human health occur and which allow an adequate margin of safety. The Secondary Drinking Water Regulations (SDWRs) are also non-enforceable federal guidelines regarding cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water.

OAC 785:45-7-2(a)(1) states: "The concentration of any synthetic substance or any substance not naturally occurring in that location shall not exceed the PQL (practical quantitation limit) in an unpolluted groundwater sample using laboratory technology. If the concentration found in the test sample exceeds the PQL, or if other substances in the groundwater are found in concentrations greater than those found in background conditions, that groundwater shall be deemed to be polluted and corrective action may be required." While the hazardous substances in the assessment area groundwater are naturally occurring, they are highly likely to occur at higher concentrations than in background samples. The establishment of suitable background samples will be part of the assessment. For the purposes of groundwater injury determination, the Trustees will first compare concentrations to SDWA MCLs and SDWRs as well as criteria to protect beneficial uses from OAC 785:45-7-1, then compare concentrations to background samples as necessary.

Injury of other resources when exposed to groundwater may also constitute an injury to groundwater [43 CFR § 11.62(c)(1)(iv)]. The Trustees may also evaluate whether groundwater is an exposure pathway to surface water, and whether concentrations of hazardous substances in groundwater are sufficient to cause water quality criteria exceedences in the exposed surface water. Chemistry data collected from seeps or springs may be used to evaluate injury to groundwater under this definition. Finally, the Trustees may investigate the specific effects of hazardous substances in groundwater on the Ozark cavefish or a surrogate species.

Injury determination will be based on existing data. If existing data are insufficient for quantifying groundwater injury, the Trustees may propose additional data collection in an addendum to this assessment plan.

4.3.2 Surface water [43 CFR § 11.62(b)]

Federal regulations define surface water resources as surface water and suspended, bed, and bank sediments [43 CFR § 11.14(pp)]. The relevant definitions of injury to surface water resources include:

- Concentrations and duration of hazardous substances in excess of drinking water standards as established by Sections 1411-1416 of the SDWA, or by other federal or state laws or regulations that establish such standards for drinking water, in surface water that was potable before the release [43 CFR § 11.62(b)(1)(i)]

- Concentrations and duration of hazardous 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, in surface water that before the release met the criteria and is a committed use as habitat for aquatic life, water supply, or recreation [43 CFR § 11.62(b)(1)(iii)]

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

The relevant injury thresholds for surface water in the assessment area include hazardous substance concentrations in excess of the EPA aquatic life criteria (pursuant to Section 304(a) of the CWA) and/or in excess of the numerical criteria to protect beneficial uses listed in OAC 785:45-5-1. Currently, no sediment criteria or standards have been promulgated that can be used as sediment injury thresholds for the hazardous substances released from the site. Section 4.3.3 describes toxicological data analysis on the hazardous substances released from the site that will be used to determine injury to sediments.

Because surface water contamination is directly affected by the dissolved or particulate concentration of contaminants in sediments, surface water and sediment quality are linked. Therefore, in evaluating injuries associated with this resource category, the Trustees will address ecological and human use services provided by both sediments and surface water.

Surface water injury determination will be evaluated by comparing concentrations of hazardous substances in surface water to EPA's water quality criteria for the protection of aquatic life (U.S. EPA, 2002) and Oklahoma's water quality criteria [OAC 785:45-3-1]. It is anticipated that injury determination and the spatial and temporal extent of surface water injuries will be evaluated using both existing data and data from future sampling events.

4.3.3 Sediments [43 CFR § 11.62(b)]

Federal regulations define suspended, bed, and bank sediments as a surface water resource [43 CFR § 11.14(pp)]. Because injury assessment in sediments differs from injury assessment in surface water, it is discussed here separately. The relevant definition of injury to sediment is:

- Concentrations and durations of hazardous substances sufficient to have caused injury to groundwater, air, geologic, or biological resources, when exposed to surface water [including suspended, bed, and bank sediment] [43 CFR § 11.62(b)(1)(v)].

EPA has not developed enforceable criteria to protect aquatic biota or wildlife from contaminants in sediments, but various federal, state, and provincial agencies in North America have developed numerical sediment quality guidelines, and sediment toxicity tests using a variety of approaches have been conducted to assess the quality of sediments. Injury to sediments may be demonstrated if concentrations in the sediments are sufficient to cause injury to other resources. In this way, guidelines can be used to evaluating potential injuries to biological resources that rely upon sediments.

MacDonald et al. (2000) assembled previously published sediment quality guidelines for 28 chemical substances and classified them into two categories according to their original narrative intent: a threshold effect concentration (TEC) and a probable effect concentration (PEC). TECs are intended to identify contaminant concentrations in sediments below which harmful effects on sediment-dwelling organisms are not expected to occur. TECs include threshold effect levels, effect range low values, lowest effect levels, minimal effect thresholds, and sediment quality advisory levels. PECs are intended to identify contaminant concentrations in sediments above which harmful effects on sediment-dwelling organisms are expected to occur frequently. PECs include probable effect levels, effect range median values, severe effect levels, and toxic effect thresholds. The published sediment quality guidelines were then used to develop consensus-based TECs and PECs (MacDonald et al., 2000). Trustees will use these and similar thresholds in evaluating injuries to sediments. As with surface water, sediment injury determination and the spatial and temporal extent of injury will be based on both existing data and future data collection.

4.3.4 Geologic resources [43 CFR § 11.62(e)]

Geologic resources include soils, sediments, rocks, and minerals that are not included in the definitions of ground and surface water resources [43 CFR § 11.14(s)]. The relevant injury definitions for geologic resources include the following:

- Concentrations of substances sufficient to cause a toxic response to soil invertebrates [43 CFR § 11.62(e)(9)]
- Concentrations of substances sufficient to cause a phytotoxic response such as retardation of plant growth [43 CFR § 11.62(e)(10)]
- Concentrations of substances sufficient to have caused injury to surface water, groundwater, air, or biological resources, when exposed to geologic resources [43 CFR § 11.62(e)(11)].

Currently, there are no promulgated criteria that can be used as soil injury thresholds for the hazardous substances released from the site. Information relevant to assessing injury to geologic resources includes soil chemistry data, vegetation community data, and literature-based toxicity thresholds for plants and soil.

To assess injury to geologic resources, the Trustees will compare concentrations of hazardous substances in soils to toxicological benchmarks indicative of injuries to soil invertebrates and plants. The U.S. Department of Energy (DOE) has developed a set of toxicological benchmarks for effects on soil invertebrates and terrestrial plants (Efroymson et al., 1997a, 1997b). These benchmark values are intended for screening level assessments, and the variations in soil properties and species sensitivity will greatly affect toxicity. However, they are useful for indicating which contaminants may be of concern in soils and worthy of further study of toxic response.

In addition to these benchmarks, the Trustees will also compare concentrations of hazardous substances to concentrations considered to be phytotoxic (Kabata-Pendias and Pendias, 1992). As with the DOE thresholds, published phytotoxic ranges are useful for screening, but actual toxicity is dependent on site-specific conditions. Laboratory or field phytotoxicity tests could be conducted to evaluate site-specific effects.

The Trustees will also evaluate injuries to geologic resources by considering injuries to riparian vegetation. If concentrations of hazardous substances in soils are sufficient to have caused injury to riparian vegetation via changes in growth rates, survival, or community composition or structure, the Trustees may conclude that geologic resources are injured as a pathway to riparian vegetation.

Injury determination and the spatial and temporal extent of injury will be based on existing data. If existing data are insufficient for quantifying injury to geologic resources, the Trustees may propose additional data collection in an addendum to this assessment plan.

4.3.5 Biological resources [43 CFR § 11.62(f)]

Biological resources include mammalian resources, avian resources, reptilian and amphibian resources, fishery resources, invertebrate resources, and plant resources.

The relevant injury definitions for biological resources include the following:

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

The applicability of these and other definitions of injury to biota will be addressed during the assessment and will be included in the Report of Assessment.

Biological resources include both terrestrial and aquatic flora and fauna in the assessment area. Injuries to biological resources may be demonstrated with both direct lines of evidence (e.g., documented fish kills) and indirect lines of evidence (e.g., contaminant concentrations in surface water known to cause adverse effects in fish in laboratory toxicity studies). Thus, information relevant to evaluating injury to biological resources may include water, sediment, and soil chemistry data; tissue contaminant data; histopathological analyses; and information on the occurrence and distribution of wildlife species (including species of special concern listed in Chapter 2).

Exceedences of aquatic life standards in surface water will be used as a screening level indication of toxicological injuries to fish and benthic invertebrates. The assessment may be supplemented with an evaluation of the likelihood of actual injuries based on the degree that toxicological thresholds derived from the literature are exceeded within the assessment area. In developing toxicological thresholds, the Trustees will consider test species and their relative sensitivity to metals toxicity and site-specific water quality conditions that may influence toxicity (e.g., hardness, calcium concentration, pH, dissolved organic carbon, alkalinity).

The Trustees will use sediment quality guidelines (described above) as a screening level indication of toxicological injuries to benthic invertebrates. Benthic macroinvertebrates themselves are used extensively to monitor the effects of contamination on aquatic systems. Benthic macroinvertebrates demonstrate individual level responses (e.g., mortality, reduced growth, reduced reproductive fitness) and community level responses (e.g., reduced density, reduced species richness, community shift to more tolerant species) to contaminants. The Trustees will evaluate benthic macroinvertebrate community data to assess injury to aquatic biota.

Fish population data can be used to evaluate whether spatial patterns of fish population density, diversity, and age structure are indicative of potential toxicological effects. The Trustees will compare fish populations in potentially affected stream reaches to fish populations in reference areas.

Laboratory toxicity testing is specified in the regulations as a method of determining injury [43 CFR § 11.62(f)(4)(i)(E)]. Depending on the results of the review and evaluation of existing data, the Trustees might conduct site-specific toxicity tests to evaluate potential acute and chronic effects of contaminants.

Field investigations of direct injuries to invertebrates, fish, amphibians, reptiles, birds, or mammals may also be conducted, based on the concentration of various hazardous substances. Any such investigations will be designed to assess injury, and to document the degree of injury over time and space.

4.3.6 Air resources [43 CFR § 11.62(d)]

Air resources include all gases essential for human, plant, and animal life [43 CFR § 11.14(b)]. The relevant definitions of injury for air resources include the following:

- Concentrations of emissions in excess of standards for hazardous air pollutants established by section 112 of the Clean Air Act, 42 USC § 7412, or by other federal or state air standards established for the protection of public welfare or natural resources [43 CFR § 11.62(d)(1)]
- Concentrations and duration of emissions sufficient to have caused injury to surface water, groundwater, geologic, or biological resources when exposed to the emissions [43 CFR § 11.62(d)(2)].

The applicability of these and other definitions of injury to air resources will be addressed during the assessment and will be included in the Report of Assessment. The Trustees will examine existing data to determine if there are measured exceedences of Clean Air Act emissions standards.

4.4 Pathway Determination

Pathways will be determined using a combination of information about the nature of transport mechanisms of the hazardous substances and data documenting the presence of the hazardous substance in the pathway resource. Figure 4.1 presents a simplified model of potential pathways for exposure of natural resources at the assessment area. The Trustees will rely on existing data to determine whether hazardous substances are present in "sufficient concentrations" in pathway resources to have served as pathways [43 CFR § 11.63 (a)(2)].

4.5 Injury Quantification

This section of the Assessment Plan describes how the Trustees will use results from the injury determination part of the assessment to quantify losses in the assessment area in order to determine what restoration is appropriate to compensate for those losses. The evaluation described in this section is intended to provide Trustees with sufficient information to design and implement the tasks necessary to, for instance, "quantify for each resource determined to be injured and for which damages will be sought, the effect of the discharge or release in terms of the reduction from the baseline condition in the quantity and quality of services" [43 CFR§ 11.70(a)(1)]. However, assessment methods may integrate analyses of different natural

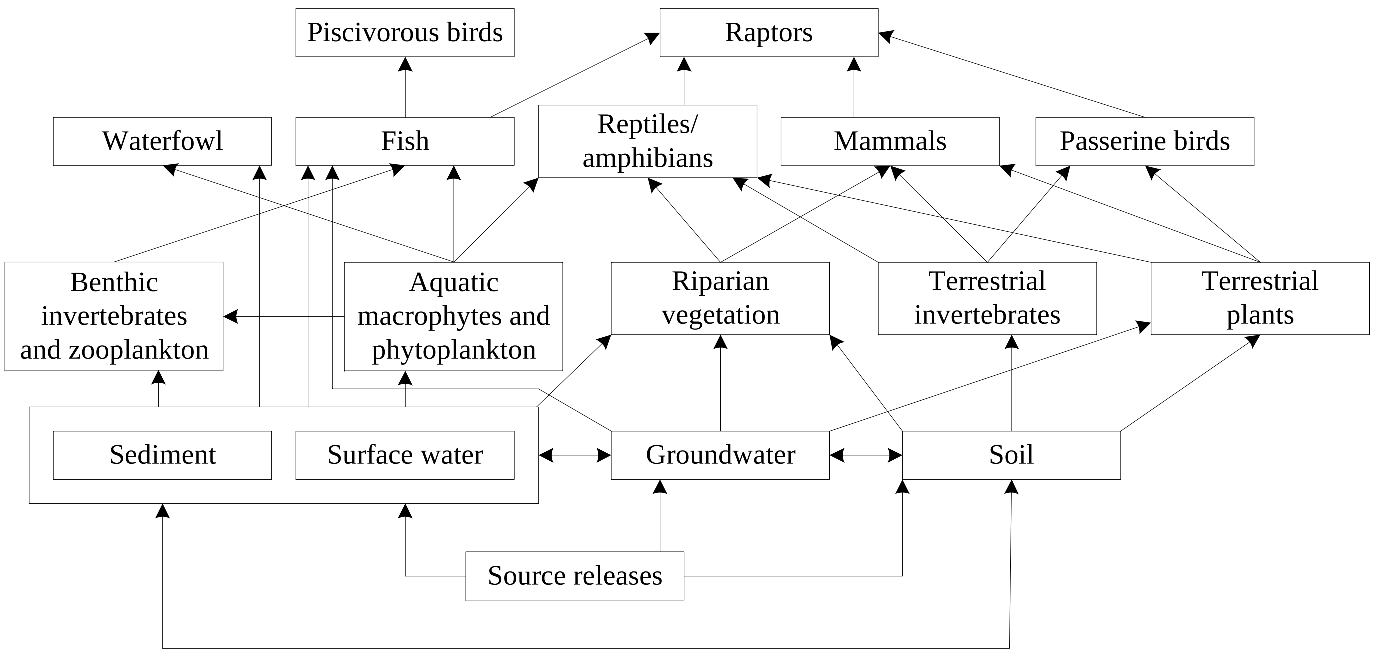

Figure 4.1. Simplified model of potential pathways for natural resource exposure at the Tar Creek assessment area.

resources, and could also look at a variety of metrics related to natural resource quantity and quality, as well as the cost or value of offsetting the losses. The process described below is an example of how the Trustees will determine the compensation to provide the "restoration, rehabilitation, replacement, and/or acquisition of the equivalent of the injured natural resource and the services those resources provide" [43 CFR § 11.80(b)].

Quantification will include evaluation of the:

- Spatial and temporal extent of injury
- Degree of injury
- Baseline conditions and services
- Service loss caused by the injury

Time required for the resources and services to recover.

4.5.1 Spatial and temporal extent and degree of injuries

The Trustees will quantify the spatial extent, the temporal extent (past, present, and expected future), and the degree of injuries in the assessment area. Approaches to estimate the extent and degree of injury may include the use of chemical, toxicological, biological, and human use and enjoyment data, historical records, geographic information and spatial analysis, and modeling.

The degree of injuries will be evaluated by considering the degree of exceedence of criteria or other thresholds that are protective of natural resources. Other indicators of injury such as changes in ecological health and viability may also be relied upon in quantifying the degree of injury.

4.5.2 Determination of baseline services

Baseline refers to the conditions that would have existed had the releases of hazardous substances not occurred [43 CFR § 11.72 (b)(1)]. The condition of the injured resources, or the services provided by the injured resources, will be compared to baseline conditions to estimate the amount of restoration, service replacement, or the value of offsets required.

The Trustees recognize that restoring natural resource services to baseline levels at the assessment area is dependent on the final remedies implemented at the site. The Trustees will evaluate the extent to which conditions have improved since the implementation of the initial response actions at the site and will attempt to estimate the trajectory of any improvements in future natural resource services. This evaluation will compare the trajectory of baseline ecological and human services provided by natural resources at the assessment area to the trajectory of services anticipated with implementation of realistic remedial alternatives.

The regulations suggest using historical data to evaluate baseline conditions, if they are available [43 CFR § 11.72 (c)]. Data from control areas may also be used [43 CFR § 11.72 (d)]. Because hazardous substance releases began in the 1800s at this site, there are no quantitative baseline data from before the beginning of releases. The Trustees propose to use data from control areas to characterize baseline conditions. Control areas will be selected based on their similarity to the assessment area and lack of exposure to the release [43 CFR § 11.72 (d)(1)]. Because baseline services can be affected by conditions and activities that are not related to the release (e.g., roads, construction, permitted land uses), reference areas will be evaluated to ensure that they are appropriate in terms of relevant physical, chemical, biological, and socioeconomic conditions.

4.5.3 Estimation of service loss

The difference between baseline services and the services provided by the injured resource is used to quantify injury to natural resources. This quantification will serve as the basis for determining the amount of damages necessary to restore natural resources on behalf of the public. The Trustees will quantify service loss by evaluating how the services that are normally provided by the natural resources under baseline conditions have been and will be disrupted by the release [43 CFR § 11.71 (b)].

Service losses are incurred when concentrations of hazardous substances exceed defined injury thresholds, and when hazardous substances prevent human use or enjoyment of natural resources. For example, in the Tar Creek assessment area, wells in the Boone aquifer are restricted [OAC 785:45-7-1] and ODEQ (2007) has issued a fish consumption advisory for fish from the Tar Creek assessment area, including Grand Lake O' the Cherokees.

When hazardous materials are deposited in floodplain soils downstream of the mining areas, natural resource service losses may occur when plants die or uptake metals, or when animals are exposed to the metals via direct contact or incidental ingestion. There may be additional service losses to tribal culture from:

- Reduced plant viability and growth. If culturally significant plants are or have been prevented from growing because of phytotoxic concentrations of hazardous substances in the floodplain soils, the tribal citizens have lost a cultural resource.

- Reduced nutritional value. If culturally significant plants or animals accumulate, or are believed to accumulate, hazardous substances, tribal members could choose not to ingest the plants or animals. The nutritional value that was provided from ingesting the plants and animals in traditional ways is lost to the tribal members.

- Reduced cultural value. If culturally significant plants or animals accumulate, or are believed to accumulate, hazardous substances, a tribal member could choose not to utilize those plants and animals for a culturally significant purpose. The cultural value that was provided from using the plants and animals in traditional ways is lost to the tribal members.

More details on these methods used to estimate service losses are provided in Section 4.6.

4.5.4 Estimation of the time required for recovery to baseline

As mentioned previously, the Trustees will estimate the time needed for recovery of injured resources and the services they provide to baseline levels. This evaluation will include an estimate of recovery time if no further actions are taken, and estimates of recovery time for possible alternatives for restoration, rehabilitation, replacement, and/or acquisition of equivalent resources [43 CFR § 11.73].

4.6 Damage Determination

Natural resource damages are directly related to the quantification of natural resource injuries. Damage determination is intended to "establish the amount of money to be sought in compensation for injuries to natural resources resulting from a . . . release of a hazardous substance" [43 CFR § 11.80(b)]. Damages are defined as ". . . the amount of money sought by the natural resource trustee as compensation for injury, destruction, or loss of natural resources as set forth in section 107(a) or 111(b) of CERCLA" [43 CFR § 11.14(l)]. Damages include:

- The cost or value of sufficient restoration to accelerate the return to baseline
- The cost or value of restoration to offset losses between the time of release and the time when baseline conditions are restored ("compensable value")
- The cost to undertake the assessment process.

Restoration costs and compensable values can be estimated by a number of techniques, separately or in combination (avoiding double-counting), that focus on the value of lost natural resources and services, or the cost of required restoration, or both.

Compensable damages accrue from the time of discharge or release until baseline conditions have been attained. Past damages accrue from the earliest point that injuries from releases can be determined, or authorization of the statute (December 1980 for CERCLA), up to the present. Future damages can include interim damages (from the present until restoration actions are completed), and residual damages (ongoing damages that accrue after restoration activities have ceased if restoration did not fully restore natural resources services to baseline levels).

Figure 4.2 illustrates temporal stages of a hypothetical release, injury, clean-up response, restoration, and recovery scenario. The area between the baseline condition line and the service curve represents a cumulative loss of services. The loss of services continues through time until the service curve reaches baseline. The sum of areas A through E make up the compensable value component of damages due to interim losses. In some instances, resources may never recover to baseline conditions and interim losses continue into the foreseeable future. At the Tar Creek assessment area, the releases of hazardous substances began at least 100 years before any response actions, and it is unlikely that future response actions will result in a return to baseline conditions in all areas.

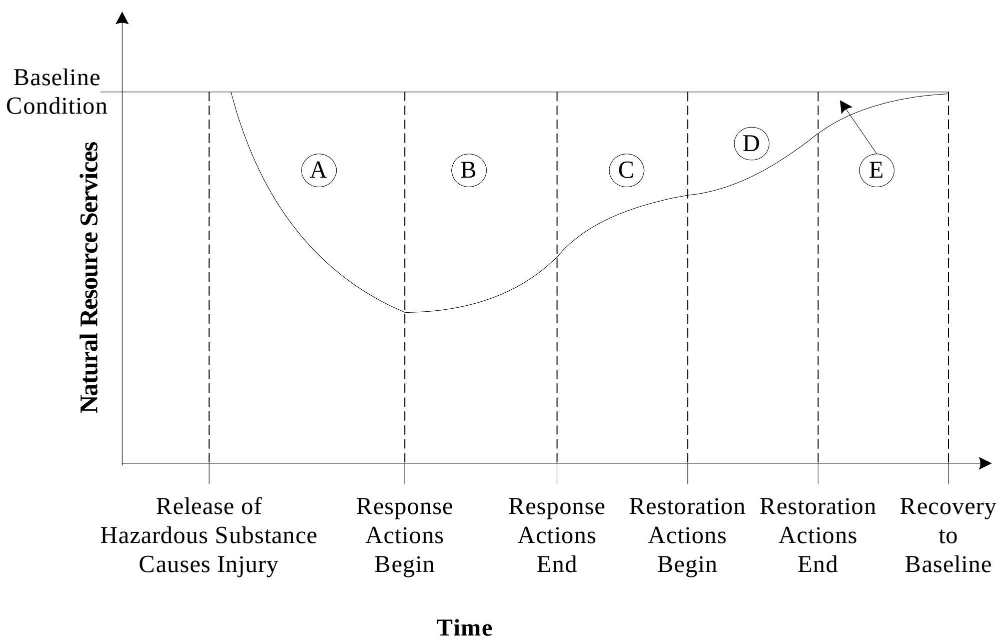

Figure 4.2. Hypothetical timeline of injuries and damages.

Compensable values can be estimated using either value-based or restoration-based approaches. For value-based damage determination, the Trustees estimate the value to the public of the natural resources and services lost or the natural resources required to make the public whole [43 CFR § 11.83(c) (l)]. For restoration-based damage determination, the Trustees estimate the amount of natural resources and services required to replace those lost, and the cost of that replacement serves as the metric for damages. Trustees may claim for that amount of restoration and allow the PRPs to implement the plan, or they may estimate the cost of implementing those restoration projects themselves and use that cost as the measure of damages. The Trustees in this assessment anticipate following this restoration-based damage determination approach, described in the following section.

4.6.1 Restoration-based estimates of compensable value

Trustees often use restoration cost approaches to estimate damages. A restoration-based damage estimate is typically developed as follows:

- Establish criteria for evaluating restoration options for each injury and service loss.
- Develop a list or database of potential restoration options.
- Apply the evaluation criteria to rank restoration options.
- Scale the preferred restoration projects such that the service or resource gain provided by the restoration actions offset the cumulative service loss caused by the injury. Scaling is the process of determining the appropriate size of a restoration project.
- Develop information about unit costs for priority restoration actions. Costs should account for the implementation and administration of the action, as well as operation, maintenance, and monitoring expenditures required to ensure that the project provides the benefits incorporated in the equivalency analysis.

Service-to-service or resource-to-resource scaling methods, including HEA, REA, and groundwater equivalency analysis (GWEA), are often used to estimate the amount of service that must be gained by restoration to offset or replace the amount of service lost because of the injury. Equivalency analyses are described in Section 4.6.2. Restoration planning, during which appropriate restoration projects are identified, evaluated, and costed, is described in Section 4.6.3. The Trustees may conduct equivalency analyses and restoration planning concurrently, to estimate restoration-based damages.

4.6.2 Equivalency analyses

The Trustees may elect to use service-to-service or resource-to-resource scaling approaches (HEA, REA, GWEA), where restoration alternatives are selected and scaled such that services or resources of the same type, quality, and value as those lost to injury are provided by the selected restoration. Natural resource services are defined as the physical, chemical, and biological processes through which ecosystems support and sustain all life, including human life (Allen et al., 2005). Example resource services include physical habitat, nutrient and energy cycling, food web interactions, flood control, groundwater recharge, and recreation [43 CFR § 11.71(e)] as well as cultural identity for Indian tribes. The injury assessment provides the degree and spatial and temporal extent of resource service losses, and the HEA, REA, and GWEA models provide a method for determining equivalent restoration to offset the injuries.

Habitat equivalency analysis

HEA was developed by the U.S. National Oceanic and Atmospheric Administration and has been applied by many natural resource trustees to determine the amount of restoration needed to compensate for losses of natural resources resulting from oil spills, hazardous substance releases, or physical injuries such as vessel groundings or construction impacts from remedial activities. Restoration is scaled so that the natural resource service gains provided at compensation sites equal the cumulative service losses at the injured site (Allen et al., 2005; Cacela et al., 2005; NOAA, 2006). Thus, HEA is used to determine the amount of restoration that is required to compensate for past, current, and future (i.e., residual to any cleanup) injuries.

A benefit of HEA is that it explicitly creates a connection between services lost because of injury and services gained through restoration. The connection provides a clear demonstration to the public that the Trustees have fulfilled their mandate of compensating the public for the interim losses of natural resources and their services. The implicit assumption of HEA is that the public can be compensated with direct service-to-service scaling, where the services provided by proposed restoration actions are of similar type, quality, and value as the services lost because of injury (Allen et al., 2005; NOAA, 2006).

HEA is based on the ecological and human use services that habitat provides, such as physical habitat, food web interactions, and recreation [43 CFR § 11.71(e)]. Injuries are quantified as the percent of services provided by natural resources that are lost as a result of the hazardous substance release. As described previously, the Trustees will evaluate various toxicological, human use, and other endpoints to determine the degree of service loss for each injured natural resource.

The information required to quantify the habitat service loss (or HEA “debits”) includes (1) time periods of injury, including evaluation of the effect of response activities and scenarios for future losses if necessary; (2) spatial extent of injury; (3) quantification of lost services over space and time compared to baseline conditions; and (4) a discount rate (typically 3%). Debits are commonly expressed in units that describe space, time, and discount rate. A typical HEA unit is discounted service acre-years (DSAYs).

HEA incorporates temporal information, including what level of service loss may have existed in the past, and how quickly the natural resources are expected to recover to baseline conditions in the future under different remediation scenarios. Should the Trustees elect to use a HEA framework, they may evaluate different potential response action scenarios to estimate the duration of injury and the recovery to baseline conditions.

Quantifying habitat service gain (or HEA “credits”) is similar to quantifying HEA debit, except that service increases resulting from resource restoration are estimated, rather than service losses resulting from injuries. The spatial extent of restoration, the time period required for natural resource services to be restored, quantification of increased services provided over time, and a discount rate would be used to calculate HEA credit. The number of DSAYs of HEA debit should be offset by an equivalent number of DSAYs of habitat restoration credit.

Resource equivalency analysis

REA is based on balancing resources lost due to injury (debit) with resources gained due to restoration (credit). In most respects, it is identical to HEA. However, the units are different, because injury debit and restoration credit are scaled to a specific resource (e.g., migratory birds) rather than to natural resource services provided in a particular habitat. Thus, REA scales restoration on a resource-to-resource basis.

The information required to quantify the resource service loss or REA debit includes (1) time periods of losses encompassing past and future losses, (2) quantification of lost services, typically the number of organisms lost over time compared to baseline conditions, and (3) a discount rate (typically 3%). Debits are commonly expressed in units that describe the amount of lost resource, a time period, and the discount rate. For example, if migratory birds have been injured, REA debits might be calculated in units of discounted service bird-use years.

Quantifying resource service gain or REA credits is similar to quantifying REA debit. The amount of the resource that is restored, the time period required for restoration, the increased services provided over time, and a discount rate are used to calculate the service gains to the resource provided by the selected restoration.

Groundwater equivalency analysis

GWEA is functionally equivalent to HEA, but with different units. Debits are commonly expressed in units that describe the amount of injured groundwater (volume, flux, or both), a time period, and the discount rate. For example, if a volume of groundwater contaminated by hazardous substance releases is estimated on an annual basis, the GWEA debits can be expressed in units of discounted acre-feet years. As with the HEA and REA models, the number of discounted acre-feet years of groundwater loss is offset by an equivalent volume of discounted acre-feet years of groundwater restoration.

Value equivalency analysis

In some cases, the losses caused by natural resource injuries are so dissimilar to the gains available from practical restoration that comparison of habitats, services, or other resources becomes impractical. Furthermore, passive values may be high for unique or rare natural resources that have been injured, or the cost of sufficient restoration may be very high. In these cases, Trustees may require information about the relative values among various injuries and restorations compared with each other, and compared with restoration costs.

4.6.3 Restoration planning

The objective of restoration planning is to develop a reasonable number of relevant and practical alternatives for the restoration, rehabilitation, replacement, and/or acquisition of the equivalent of the injured natural resources, as measured by the services those resources provide [43 CFR § 11.82(a); 15 CFR § 990.53]. The Trustees then evaluate the alternatives and select a preferred alternative. With a preferred alternative identified, the Trustees calculate the implementation costs and future operation, maintenance, and monitoring costs.

Restoration planning serves two specific purposes:

- It is a formal process during which Trustees identify, screen, select, and scale restoration actions that would be appropriate to restore resources and services and compensate the public
- It formalizes the Trustees' intentions for restoration and establishes a draft plan for restoration implementation after damages are paid.

Restoration project ideas can come from a variety of sources. The Trustees may request ideas from resource management agencies, academic experts involved in natural resource management or restoration research, the public, and the PRPs. The request will specify the types of resources that the projects should address, the preferred location (e.g., within a certain distance of the assessment area), and other information that will be critical in evaluating the relevance and feasibility of the project.

Evaluation criteria are designed to satisfy any requirements or preferences imposed by relevant state or federal statutes and regulations, as well as Trustees' natural resource management mandates. Federal regulations suggest that the following criteria be considered in evaluating restoration options [43 CFR § 11.82(d)]:

- Technical feasibility
- Relationship of the expected costs of the proposed actions to the expected benefits from the restoration, rehabilitation, replacement, and/or acquisition of equivalent resources
- Cost-effectiveness
- Results of any actual or planned response actions
- Potential for additional injury resulting from the proposed actions, including long-term and indirect impacts, to the injured resources or other resources
- Natural recovery period
- Ability of the resources to recover with or without alternative actions
- Potential effects of the action on human health and safety
- Consistency with relevant federal, state, and Tribal policies
- Compliance with applicable federal, state and Tribal laws.

In addition, natural resource trustees have the authority and opportunity to incorporate agency mandates and preferences for specific types of natural resource restoration actions and outcomes as evaluation criteria. Some examples of criteria that define or express trustee preferences might include:

- Does the proposed acquisition or restoration project have a high likelihood of successfully protecting or restoring high quality natural features, unique features, or valuable ecological services?
- Are the natural features at the site threatened by impending human activities that can be prevented by the completion of this project?
- Does the site have a completed natural area plan or restoration plan that includes inventory management and monitoring?

- Does completion of the project contribute to increased connectivity between existing natural areas or protecting interior habitats in existing designated natural areas?
- Is there broad local support for the proposed project?
- Is the proposed project a good value for the funding requested?
- Does the project build partnerships among resource managers or demonstrate collaboration?
- Is the site important for the protection or restoration of natural resources on adjacent lands?
- Does the project provide or improve opportunities for public uses for stewardship, education, or recreation compatible with resource protection and restoration goals?

As the Trustees develop and select project evaluation criteria during the assessment process, they will define how each criterion will be interpreted in evaluating proposed projects to support a transparent project selection process. Such definitions may be provided in an addendum to this Assessment Plan before they are used to rank and select restoration projects.

4.6.4 Development of the RCDP

Federal regulations [43 CFR § 11.81] instruct trustees to prepare an RCDP. The RCDP:

- Lists a reasonable number of alternatives for restoration, rehabilitation, replacement, or acquisition of equivalent resources and the related services lost to the public associated with each
- Selects one of the alternatives
- Gives the rationale for selecting that alternative
- Identifies methods to be used to determine the cost of the selected alternative and the compensable value of services lost to the public.

An RCDP contains both assessment results (trustee determinations about restoration alternatives) and assessment planning elements (identification of compensable valuation methods). Therefore, though the regulations identify the RCDP as part of the Assessment Plan, trustees often do not publish an RCDP until after the injury determination and quantification phases of the assessment are complete. The Trustees at the Tar Creek assessment area will publish, as needed, an initial

RCDP and a final RCDP, so that assessment-planning elements of the RCDP can proceed before the injury assessment is completed.

4.7 New Site-Specific Assessment Studies Being Considered by the Trustees

The Trustees intend to base this NRDA on existing data from the site unless additional data are required to determine damages reliably and can be collected at reasonable costs. If the Trustees find data gaps that prevent the determination and quantification of significant injuries and service losses, they may publish an addendum to this Assessment Plan that describes additional site-specific studies that would be conducted to fill those data gaps.

5. Quality Assurance Project Plan

After analyzing existing data, the Trustees may identify data gaps that require additional studies. If so, the Trustees would publish an amendment to this Assessment Plan [43 CFR § 11.32(e)] that describes the studies that are to be conducted and includes a QAPP [43 CFR § 11.31(c)(2)].

References

AATA International. 2005. Draft Preliminary Site Characterization Summary, Tar Creek OU4 RI/FS Program. Prepared for the Tar Creek Respondents and the U.S. Environmental Protection Agency. Fort Collins, CO. September.

Adams, G.P. 1988. Geochemical Controls on the Distribution and Mobility of Heavy Metals in the Neosho River/Grand River Lake System. U.S. Geological Survey Project Proposal OK-88E.

Aggus, L.R., L.E. Vogele, W.C. Rainwater, and D.I. Morais. 1982. Effects of Acid Mine Drainages from Tar Creek on Fishes and Benthic Macroinvertebrates in Grand Lake, Oklahoma. U.S. Fish and Wildlife Service. Prepared for Tar Creek Environmental Effects Subcommittee.

Allen II, P.D., D.J. Chapman, and D. Lane. 2005. Scaling environmental restoration to offset injury using habitat equivalency analysis. In *Economics and Ecological Risk Assessment: Applications to Watershed Management*, R.J.F. Bruins and M.T. Heberling (eds.). CRC Press, Boca Raton, FL. pp. 165-184.

Allert, A.L., M.L. Wildhaber, C.J. Schmitt, D. Chapman, and E. Callahan. 1997. Toxicity of Sediments and Pore-Waters and their Potential Impact on Neosho Madtom, *Noturus placidus*, in the Spring River System Affected by Historic Zinc-Lead Mining and Related Activities in Jasper and Newton Counties, Missouri; and Cherokee County, Kansas: Final Report to the U.S. Fish and Wildlife Service, Columbia Missouri. Prepared by U.S. Geological Survey Biological Resources Division. July.

Alloway, B.J. 1990a. Cadmium. In *Heavy Metals in Soils*, B.J. Alloway (ed.). John Wiley & Sons, New York. pp. 100-124.

Alloway, B.J. 1990b. *Heavy Metals in Soils*. John Wiley & Sons, New York.

Angelo, R.T. 2007. Injuries to Freshwater Mussel Communities Associated with Former Lead and Zinc Mining and ore Processing Operations in the Spring River Basin (Kansas, Missouri, and Oklahoma) and the Big River Basin (Missouri). July 27.

Atchison, G.J., M.G. Henry, and M.B. Sandheinrich. 1987. Effects of metals on fish behavior: A review. *Environmental Biology of Fishes* 18(1):11-25.

Bazzaz, F.A., R.W. Carlson, and G.L. Rolfe. 1974. The effect of heavy metals on plants: Part I. Inhibition of gas exchange in sunflower by Pb, Cd, Ni, and Ti. *Environmental Pollution* 7:241-246.

Bengtsson, B.E., C.H. Carlin, A. Larsson, and O. Svanberg. 1975. Vertebral damage in minnows, *Phoxinus phoxinus* L., exposed to cadmium. *Ambio* 4:166-168.

Benoit, D.A., E.N. Leonard, G.M. Christensen, and J.T. Fiandt. 1976. Toxic effects of cadmium on three generations of brook trout (*Salvelinus fontinalis*). *Transactions of the American Fish Society* 105(4):550-560.

Beyer, W.N. 1988. Damage to the forest ecosystem on Blue Mountain from zinc smelting. *Trace Substances in Environmental Health* 22:249-262.

Beyer, W.N. 2007. Injuries to Migratory Birds and Their Habitat in the Tri-State Mining District from Metal Concentration. July 27.

Beyer, W.N., J. Dalgarn, S. Dudding, J.B. French, R. Mateo, J. Meisner, L. Sileo, and J. Spann. 2004. Zinc and lead poisoning in wild birds in the Tri-State Mining District (Oklahoma, Kansas, and Missouri). *Archives of Environmental Contamination and Toxicology* 48:108-117.

Bradley, R.W. and J.B. Sprague. 1985. Accumulation of zinc by rainbow trout as influenced by pH, water hardness and fish size. *Environmental Toxicology and Chemistry* 4:685-694.

Brady, N.C. and R.R. Weil. 1996. *The Nature and Properties of Soils*. Eleventh edition. Prentice Hall, Upper Saddle River, NJ.

Brown and Root Environmental. 1997. Residential Remedial Investigation Report for Remedial Investigation/Feasibility Study, Tar Creek Superfund Site, Ottawa County, Oklahoma. Volume I & II. Prepared for United States Army Corps of Engineers – Tulsa District and U.S. EPA Region 6. January.

Brumbaugh, W.G., C.J. Schmitt, and T.W. May. 2005. Concentrations of cadmium, lead, and zinc in fish from mining-influenced water of northeastern Oklahoma: Sampling of blood, carcass, and liver for aquatic biomonitoring. *Archives of Environmental Contamination and Toxicology* 49:76-88.

Cacela, D., J. Lipton, D. Beltman, J. Hansen, and R. Wolotira. 2005. Associating ecosystem service losses with indicators of toxicity in habitat equivalency analysis. *Environmental Management* 35(3):343-351.

Carlson, R.W. and F.A. Bazzaz. 1977. Growth reduction in American sycamore (*Plantanus occidentalis L.*) caused by Pb-Cd interaction. *Environmental Pollution* 12:243-253.

Carpenter, J.W., G.A. Andrews, and W.N. Beyer. 2004. Zinc toxicosis in a free-flying trumpeter swan (*Cygnus buccinator*). *Journal of Wildlife Diseases* 40(4):769-774.

Carroll, J.J., S.J. Ellis, and W.S. Oliver. 1979. Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*). *Bulletin of Environmental Contamination and Toxicology* 22:575-581.

Cates, D. 2003. Memo re: Background Concentrations for Soils in Ottawa County. To Tar Creek File. January 10.

C.C. Johnson & Malhotra. 1996. Preliminary – Final Site Evaluation Findings Report: Tar Creek NPL Site, Oklahoma City Field Area, Oklahoma. Prepared by C.C. Johnson & Malhotra P.C. for the U.S. Department of the Interior, Bureau of Land Management. July 24.

CH2M Hill. 2005. Third Five-Year Review Report for the Tar Creek Superfund Site, Ottawa County, Oklahoma. Prepared for U.S. EPA Region 6, Dallas, TX. September.

CH2M Hill. 2006. Draft Final Feasibility Study: Tar Creek Superfund Site Operable Unit No. 4, Ottawa County, Oklahoma. Prepared for U.S. EPA. February.

Chakoumakos, C., R.C. Russo, and R.V. Thurston. 1979. Toxicity of copper to cutthroat trout (*Salmo clarki*) under different conditions of alkalinity, pH, and hardness. *Environmental Science and Technology* 13:213-219.

Chaney, R.L. 1993. Zinc phytotoxicity. In *Zinc in Soils and Plants*, A.D. Robson (ed.). Kluwer Academic Press, Boston, MA. pp. 135-150.

Chang, F.H. and F.E. Broadbent. 1982. Influence of trace metals on some soil nitrogen transformations. *Journal of Environmental Quality* 11:1-4.

Christenson, S. 1995. Contamination of Wells Completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma. U.S. Geological Survey Water-Resources Investigations Report 95-4150.

Christenson, S.C., D.L. Parkhurst, and R.W. Fairchild. 1990. Geohydrology and Water Quality of the Roubidoux Aquifer, Northeastern Oklahoma. U.S. Geological Survey Open-File Report 90-570.

Clijsters, H. and F. Van Assche. 1985. Inhibition of photosynthesis by heavy metals. *Photosynthesis Research* 7:31-40.

Conder, J.M. and R.P. Lanno. 1999. Heavy metal concentrations in mandibles of white-tailed deer living in the Picher Mining District. *Bulletin of Environmental Contamination and Toxicology* 63:80-86.

Crow, L. 2007. Quapaw Tribe of Oklahoma Air Monitoring Program (PowerPoint presentation). Available: http://www.epa.gov/earth1r6/6pd/air/pd-q/airagenda07/leon_crow.pdf. Accessed 5/22/2008.

Cusimano, R.F., D.F. Brakke, and G.A. Chapman. 1986. Effects of pH on the toxicities of cadmium, copper, and zinc to steelhead trout (*Salmo gairdneri*). *Canadian Journal of Fisheries and Aquatic Sciences* 43:1497-1503.

Dames & Moore. 1993. Final Remedial Investigation for Cherokee County, Kansas, CERCLA Site, Baxter Springs/Treece Subsites. January 27.

Dames & Moore. 1995. Volume I Final Remedial Investigation Neck/Alba, Snap, Oronogo/Duenweg, Joplin, Thoms, Carl Junction, and Waco Designated Areas, Jasper County Site, Jasper County, Missouri. Prepared for the Jasper County Respondents and the U.S. EPA, Region VII. October.

Datin, D.L. and D.A. Cates. 2002. Sampling and Metal Analysis of Chat Piles in the Tar Creek Superfund Site, Ottawa County, Oklahoma. Prepared for the Oklahoma Department of Environmental Quality. April.

Davies, B.E. 1990. Lead. In *Heavy Metals in Soils*, B.J. Alloway (ed.). John Wiley & Sons, New York. pp. 177-196.

Davies, P.H., J.P. Goetl Jr., J.R. Sinley, and N.F. Smith. 1976. Acute and chronic toxicity of lead to rainbow trout *Salmo gairdneri*, in hard and soft water. *Water Research* 10:199-206.

Dawson, D.A., C.A. McCormick, and J.A. Bantle. 1985. Detection of teratogenic substances in acidic mine water samples using the frog embryo teratogenesis assay – *Xenopus* (FETAX). *Journal of Applied Toxicology* 5(4):234-244.

DeHay, K.L. 2003. Assessment and Comparison of 1976-77 and 2002 Water Quality in Mineshafts in the Picher Mining District, Northeastern Oklahoma and Southeastern Kansas. U.S. Geological Survey Water-Resources Investigations Report 03-4248.

DeHay, K.L. 2006. Surface-Water and Sediment Quality in Tar Creek, Neosho River and Spring River, Northeast Oklahoma, 2004-05. Geological Society of America, Abstracts with Programs, Vol. 38, No. 1, p. 33. Available: http://gsa.confex.com/gsa/2006SC/finalprogram/abstract_100002.htm. Accessed 11/2/2007.

DeHay, K.L., W.J. Andrews, and M.P. Sughru. 2004. Hydrology and Ground-Water Quality in the Mine Workings within the Picher Mining District, Northeastern Oklahoma, 2002-03. U.S. Geological Survey Scientific Investigations Report 2004-5043.

Dixon, D.G. and J.B. Sprague. 1981. Copper bioaccumulation and hepatoprotein synthesis during acclimation to copper by juvenile rainbow trout. *Aquatic Toxicology* 1:69.

Donlan, M.C. 2007. Expert report concerning estimation of natural resource damages in the Tri-State Mining District in the Asarco LLC Chapter 11 Bankruptcy Matter, Case No. 05-21207. July 27.

Eaton, J.G. 1974. Chronic cadmium toxicity to the bluegill (*Lepomis macrochirus* Rafinesque). *Transactions of the American Fisheries Society* 4:729-735.

Ecology and Environment. 1996. Baseline Human Health Risk Assessment of Residential Exposures, Tar Creek Superfund Site, Ottawa County, Oklahoma. Prepared by Ecology and Environment Inc. for U.S. EPA Region 6. August.

Efroymson, R.A., M.E. Will, and G.W. Suter II. 1997a. *Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision.* ES/ER/TM-126/R2. Prepared for the U.S. Department of Energy. November.

Efroymson, R.A., M.E. Will, G.W. Suter, and A.C. Wooten. 1997b. *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Terrestrial Plants: 1997 Revision.* ES/ER/TM-85/R3. Prepared by Lockheed Martin Energy Systems, Inc. for the U.S. Department of Energy. November.

Erickson, B.M., T.F. Harms, and L.H. Filipek. 1988. Problems associated with the analysis of plant samples in the Tar Creek Study. In *U.S. Geological Survey Program on Toxic Waste – Ground-water Contamination: Proceedings of the Second Technical Meeting, Cape Cod, Massachusetts, October 21-25, 1985. Chapter D: Fate of Heavy Metals Near Abandoned Lead and Zinc Mines in Northeastern Oklahoma and Southeastern Kansas*, S.E. Ragone (ed.). U.S. Geological Survey Open-File Report 86-481. USGS, Reston, VA. pp. D17-D20.

Evans, D.H. 1987. The fish gill: Site of action and model for toxic effects of environmental pollutants. *Environmental Health Perspectives* 71:47-58.

Everall, N.C., N.A.A. MacFarlane, and R.W. Sedgwick. 1989. The interactions of water hardness and pH with the acute toxicity of zinc to the brown trout, *Salmo trutta* L. *Journal of Fish Biology* 35:27-36.

EVS. 1997. State of Idaho Technical Memorandum – Results of 1997 Acute and Chronic Toxicity Tests. Preliminary Draft. Prepared by EVS Environment Consultants for the Idaho Division of Environmental Quality.

Finlayson, B.J. and K.M. Verrue. 1980. Estimated safe zinc and copper levels for chinook salmon (*Oncorhynchus tshawytscha*) in the upper Sacramento River, California. *California Fish and Game* 66:68-82.

Franssen, C.M., M.A. Brooks, R.W. Parham, K.G. Sutherland, and W.J. Matthews. 2006. Small-bodied fishes of Tar Creek and other small streams in Ottawa County, Oklahoma. *Proceedings of the Oklahoma Academy of Science* 86:9-16.

Freedman, B. and T.C. Hutchinson. 1979. Long-term effects of smelter pollution at Sudbury, Ontario, on forest community composition. *Canadian Journal of Botany* 58:2123-2140.

Galbraith, H. 2007. Injuries to Avian Habitat and the Risk of Direct Toxicity to Birds at Mining Sites in Southeastern Missouri and Tri-State. July 27.

Galbraith, H., K. LeJeune, and J. Lipton. 1995. Metal and arsenic impacts to soils, vegetation communities, and wildlife habitat in southwest Montana uplands contaminated by smelter emissions: I. Field evaluation. *Environmental Toxicology and Chemistry* 14:1895-1903.

Grand River Dam Authority. 2004. Ecological Risk Assessment: Evaluating Concentrations of Cadmium, Chromium, Lead, and Zinc in Lake Hudson, Oklahoma. Agencies Response to FERC – Additional Information Request 2004. Contributors: Grand River Dam Authority; U.S. Fish and Wildlife Service, Oklahoma Water Resources Board.

Hansen, J.A., P.G. Welsh, and J. Lipton. 1999. Sensitivity of Bull Trout (*Salvelinus confluentus*) to Cadmium and Zinc in Water Characteristic of the Coeur d’Alene River Basin. Volume I: Acute Toxicity Report. Prepared for U.S. Environmental Protection Agency, Region X by Stratus Consulting Inc., Boulder, CO.

Hoagland, B. and D. Morris. 2007. A Landscape Reconstruction of Northeast Oklahoma using General Land Office Plats, circa 1871. Oklahoma Biological Survey.

Hobson, J.F. and W.J. Birge. 1989. Acclimation-induced changes in toxicity and induction of metallothionein-like proteins in the fathead minnow following sublethal exposure to zinc. *Environmental Toxicology and Chemistry* 8:157-169.

Hodson, P.V., B.R. Blunt, D. Jensen, and S. Morgan. 1979. Effect of fish age on predicted and observed chronic toxicity of lead to rainbow trout in Lake Ontario water. *Journal of Great Lakes Resources* 5(1):84-89.

Hodson, P.V., B.R. Blunt, U. Borgmann, C.K. Minns, and S. McGaw. 1983. Effect of fluctuating lead exposures on lead accumulation by rainbow trout (*Salmo gairdneri*). *Environmental Toxicology and Chemistry* 2:225-228.

Holcombe, G.W., D.A. Benoit, E.N. Leonard, and J.M. McKim. 1976. Long-term effects of lead exposure on three generations of brook trout (*Salvelinus fontinalis*). *Journal of Fisheries Research Board of Canada* 33:1731-1741.

Hughes, G.M. 1973. Respiratory responses to hypoxia in fish. *American Zoologist* 13:475-489.

Hughes, G.M. and R.J. Adeney. 1977. The effects of zinc on the cardiac and ventilatory rhythms of rainbow trout (*Salmo gairdneri,* Richardson*)* and their responses to environmental hypoxia. *Water Research* 11:1069-1077.

Hughes, G.M. and S.F. Perry. 1976. Morphometric study of trout gills: A light-microscopic method suitable for the evaluation of pollutant action. *Journal of Experimental Biology* 64:447-460.

Industrial Economics. 2004. Draft Phase I Damage Assessment Plan for Cherokee County, Kansas. Prepared by Industrial Economics Inc. for the Cherokee County Trustee Council. June 28.

Ingersoll, C.G. 2007. Expert Report on the Development and Application of Sediment Quality Guidelines to Assess the Toxicity of Metals in Sediment. Prepared for U.S. Department of Justice. July 24.

Janik, J.J., S.M.S. Melancon, and T.G. Miller. 1982. Site Specific Water Quality Assessment: Tar Creek, Oklahoma. U.S. EPA. June.

Johnson, M.S. and J.W. Eaton. 1980. Environmental contamination through residual trace metal dispersal from a derelict lead-zinc mine. *Journal of Environmental Quality* 9(2):175-179.

Kabata-Pendias, A. and H. Pendias. 1992. *Trace Elements in Soils and Plants*. CRC Press, Boca Raton, FL.

Kapustka, L.A. 2007. Toxicity of Metals in Soils of the Tri-State Mining District and Southeast Missouri Lead Mining District. Expert Opinion Prepared and Submitted by Lawrence A. Kapustka. U.S. Department of Justice Case #05-21207. July 26.

Kapustka, L.A., J. Lipton, H. Galbraith, D. Cacela, and K. LeJeune. 1995. Metal and arsenic impacts to soils, vegetation communities and wildlife habitat in southwest Montana uplands contaminated by smelter emissions: II. Laboratory phytotoxicity studies. *Environmental Toxicology and Chemistry* 14(11):1905-1912.

Kiekens, L. 1990. Zinc. In *Heavy Metals in Soils*, B.J. Alloway (ed.). John Wiley & Sons, New York. pp. 261-279.

Kindscher, K. 2007. Floristic Quality of Vegetation at Lead and Zinc Mined Lands in Missouri, Kansas and Oklahoma. Prepared for the U.S. Department of Justice. July 27.

Krawczyk, D.F., S.J. Fletcher, M.L. Robideaux, and C.M. Wise. 1988. Plant Growth Experiments in Bunker Hill and Zeolite-Amended Soil. U.S. EPA, Environmental Research Laboratory, Corvallis, OR.

Lamoreaux, R.J. and W.R. Chaney. 1977. Growth and water movement in silver maple seedlings affected by Cd. *Journal of Environmental Quality* 6:201-215.

Lauren, D.J. and D.G. McDonald. 1985. Effects of copper on bronchial ionoregulation in the rainbow trout, *Salmo gairdneri* Richardson. *Journal of Comparative Physiology* 155:635-644.

Lauren, D.J. and D.G. McDonald. 1986. Influence of water hardness, pH and alkalinity on the mechanisms of copper toxicity in juvenile rainbow trout, *Salmo gairdneri*. *Canadian Journal of Fisheries and Aquatic Sciences* 43:1488-1496.

LeJeune, K., H. Galbraith, J. Lipton, and L.A. Kapustka. 1996. Effects of metals and arsenic on riparian soils, vegetation communities, and wildlife habitat in southwest Montana. *Ecotoxicology* 5:297-312.

Liang, C.N. and M.A. Tabatabai. 1977. Effects of trace elements on nitrogen mineralization in soils. *Environmental Pollution* 12:141-147.

Lipton, J., H. Bergman, D. Chapman, T. Hillman, M. Kerr, J. Moore, and D. Woodward. 1995. Aquatic Resources Injury Assessment Report: Upper Clark Fork River Basin. Prepared by RCG/Hagler Bailly, Boulder, CO, for the State of Montana Natural Resource Damage Litigation Program.

Little, E.E., J.J. Fairchild, and A.J. Delonay. 1993. Behavioral methods for assessing impacts of contaminants on early life stage fishes. In *Water Quality and the Early Life Stages of Fishes*, L.A. Fuiman (ed.). American Fisheries Society Symposium 14, Bethesda, MD. pp. 67-76.

Lorz, H.W. and B.P. McPherson. 1977. *Effects of Copper and Zinc on Smoltification of Coho Salmon*. EPA-600/3-77-032. Prepared by Oregon Department of Fish and Wildlife for the U.S. Environmental Protection Agency, Office of Research and Development.

Lozano, F.C. and I.K. Morrison. 1981. Disruption of hardwood nutrition by sulfur dioxide, nickel, and copper air pollution near Sudbury, Canada. *Journal of Environmental Quality* 10(2):198-204.

Luza, K.V. 1986. *Stability Problems Associated with Abandoned Underground Mines in the Picher Field of Northeastern Oklahoma*. Oklahoma Geological Society Circular 88.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Archives of Environmental Contamination and Toxicology* 39:20-31.

Mallatt, J. 1985. Fish gill structural changes induced by toxicants and other irritants: A statistical review. *Canadian Journal of Fisheries and Aquatic Sciences* 42:630-648.

Marr, J.C.A., H.L. Bergman, J. Lipton, and C. Hogstrand. 1995. Differences in relative sensitivity of naive and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana. *Canadian Journal of Fisheries and Aquatic Sciences* 52(9):2016-2030.

McCarty, L.S., J.A.C. Henry, and A.H. Houston. 1978. Toxicity of cadmium to goldfish, *Carassius auratus,* in hard and soft water. *Journal of Fisheries Research Board of Canada* 35:35-42.

McCormick, C.A. 1985. Water Quality and Sediments of an Area Receiving Acid-Mine Drainage in Northeastern Oklahoma. Oklahoma State University.

McCormick, C.A. and S.L. Burks. 1987. Bioavailability and toxicity of extracts from acid-mine-waste-contaminated sediments. *Proceedings of the Oklahoma Academy of Science* 67:31-37.

McKnight, E.T. and R.P. Fischer. 1970. Geology and Ore Deposits of the Picher Field, Oklahoma and Kansas. U.S. Geological Survey Professional Paper 588.

Medine, A.J. 2007. Analysis of Contaminant Source, Fate and Transport in the Tri-State Mining District and Southeast Missouri Mining District; In re: ASARCO LLC, *et al.* Debtors, Case No. 05-21207. Prepared for the U.S. Department of Justice. July 27.

Miller, T.G. 1981. Toxic Waters from Publicly Owned Treatment Works (POTW). An Evaluation of the Effect of Toxic Materials on the Aquatic Biota in Receiving Streams – Interim Report and Findings. U.S. Environmental Protection Agency, Las Vegas, NV.

Mission Research. 1996. Remedial Planning Activities at Selected Uncontrolled Hazardous Substances Disposal Sites in a Zone for EPA Region VI: Interim Report for Focused Site Investigation at Tar Creek Site, Picher, Oklahoma. Prepared by Mission Research Corporation for U.S. EPA and Inter-Tribal Environmental Council. March 14.

Missouri Department of Natural Resources and DOI. 2002. Preassessment Screen and Determination, Jasper County Superfund Site, Jasper County, Missouri.

Mount, D.I. 1966. The effect of total hardness and pH on acute toxicity of zinc to fish. *Air and Water Pollution Int. Journal* 10:49-56.

NOAA. 2006. Habitat Equivalency Analysis: An Overview. Prepared by Damage Assessment and Restoration Program, National Oceanic and Atmospheric Administration, Department of Commerce. March 21, 1995 (Revised October 4, 2000 and May 23, 2006).

Novak, A.B., G.M. Pierzynski, and W.H. Fick. 2003. Zinc phytotoxicity in the Tri-State Mining Region (Abstract). In *ASA-CSSA-SSSA Annual Meeting 2003* American Society of Agronomy – Crop Science Society of America – Soil Science Society of America, Madison, WI.

ODEQ. 2002. Summary of Roubidoux Water Quality Tests for Phase II After Action Monitoring at the Tar Creek Superfund Site, Ottawa County, Oklahoma. Oklahoma Department of Environmental Quality. September.

ODEQ. 2003. Fish Tissue Metals Analysis in the Tri-State Mining Area, FY 2003 Final Report. Oklahoma Department of Environmental Quality. July 1.

ODEQ. 2007. Fish Tissue Metals Analysis in the Tri-State Mining Area, Follow-up Study, FY 2006 Final Report. Oklahoma Department of Environmental Quality. September 14.

ODWC. 2007. Endangered Species of Oklahoma. Oklahoma Department of Wildlife Conservation. Available: http://www.wildlifedepartment.com/endanger2.htm. Accessed 11/1/2007.

Oklahoma Natural Heritage Inventory. 2003. Federal and State Endangered, Threatened and Candidate Species in Oklahoma by County. May 5.

Oklahoma State Department of Health. 1983. Health Effects of the Acid Mine Discharges to Ground and Surface Waters in Ottawa County, Oklahoma. Oklahoma State Department of Health, Tar Creek Task Force. February.

O’Neill, J.G. 1981. Effects of intraperitoneal lead and cadmium on the humoral immune response of *Salmo trutta*. *Bulletin of Environmental Contamination and Toxicology* 27:42-48.

OSDH. 1981. Acute and Chronic Health Effects from the Acid Mine Drainage near Miami, Oklahoma. Tar Creek Task Force. Oklahoma State Health Department. August.

Osborn, N.I. 2001. Minor Basin Hydrogeologic Investigation Report of the Boone Groundwater Basin, Northeastern Oklahoma. Technical Report GW2001-2. Oklahoma Water Resources Board. July.

OWRB. 1983a. Effect of No Action Alternative Including the Results of Sediment Core Sampling in Upper Grand Lake. Tar Creek Feasibility Investigation: Task II.1.B.d. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. December.

OWRB. 1983b. Effects of Acid Mine Discharge on the Surface Water Resources in the Tar Creek Area, Ottawa County, Oklahoma. Tar Creek Field Investigation: Task I.1. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. March.

OWRB. 1983c. Estimation of the Quantity of Water in the Flooded Underground Lead-Zinc Mines of the Picher Field, Oklahoma and Kansas. Tar Creek Field Investigation: Task I.3.D. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. March.

OWRB. 1983d. Evaluation of Treatment Alternatives: Review of Water Quality Data to Determine Discharge Constituent Concentrations and Anticipated Flows for the Evaluation of Treatment Alternatives. Tar Creek Feasibility Investigation: Task II.4.A.a. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. December.

OWRB. 1983e. Groundwater Investigation in the Picher Field, Ottawa County, Oklahoma. Tar Creek Field Investigation: Task I.4. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. March.

OWRB. 1983f. Water Quality Assessment of the Flooded Underground Lead and Zinc Mines of the Picher Field in Ottawa County, Oklahoma. Tar Creek Field Investigation: Task I.3. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. March.

OWRB. 1983g. Water Quality Characteristics of Seepage and Runoff at Two Tailings Piles in the Picher Field, Ottawa County, Oklahoma. Tar Creek Field Investigation: Task I.2. Oklahoma Water Resources Board, Water Quality Division, Oklahoma City. March.

OWRB. 2005a. 2005 Report of the Oklahoma Beneficial Use Monitoring Program Lakes Report. Oklahoma Water Resources Board, Oklahoma City.

OWRB. 2005b. 2005 Report of the Oklahoma Beneficial Use Monitoring Program Streams Report. Oklahoma Water Resources Board, Oklahoma City.

Pahlsson, A.M. 1989. Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants: A literature review. *Water, Air, and Soil Pollution* 47:287-319.

Parkhurst, D.L. 1987. Chemical Analyses of Water Samples From the Picher Mining Area, Northeast Oklahoma and Southeast Kansas. U.S. Geological Survey Open-File Report 87-453.

Parkhurst, D.L. 1988. Mine water discharge, metal loading, and chemical reactions. In *U.S. Geological Survey Program on Toxic Waste – Ground-water Contamination: Proceedings of the Second Technical Meeting, Cape Cod, Massachusetts, October 21-25, 1985. Chapter D: Fate of Heavy Metals Near Abandoned Lead and Zinc Mines in Northeastern Oklahoma and Southeastern Kansas*, S.E. Ragone (ed.). U.S. Geological Survey Open-File Report 86-481. USGS, Reston, VA. pp. D5-D9.

Parkhurst, D.L., M. Doughten, and P.P. Hearn. 1988. Chemical Analyses of Stream Sediment in the Tar Creek Basin of the Picher Mining Area, Northeast Oklahoma. U.S. Geological Survey Open-File Report 88-469.

Pascoe, D. and D.L. Mattey. 1977. Studies on the toxicity of cadmium to the three-spined stickleback *Gasterosteus aculeatus* L. *Journal of Fish Biology* 10:467.

Pickering, Q.H. and M.H. Gast. 1972. Acute and chronic toxicity of cadmium to the fathead minnow (*Pimephales promelas*). *Journal of the Fisheries Research Board of Canada* 29:1099-1106.

Pierzynski, G.M. and A.P. Schwab. 1993. Heavy metals in the environment. *Journal of Environmental Quality* 22:247-254.

Pita, F.W. and N.J. Hyne. 1975. The depositional environment of zinc, lead and cadmium in reservoir sediments. *Water Research* 9:701-706.

Playton, S.J., R.E. Davis, and R.G. McClaflin. 1980. Chemical Quality of Water in Abandoned Zinc Mines in Northeastern Oklahoma and Southeastern Kansas. Oklahoma Geological Survey Circular 82.

Rader, B.R., D.W.R. Nimmo, and P.L. Chapman. 1997. Phytotoxicity of floodplain soils contaminated with trace metals along the Clark Fork River, Grant-Hohrs Ranch National Historic Site, Deer Lodge, Montana, USA. *Environmental Toxicology and Chemistry* 16(7):1422-1432.

Roch, M. and E.J. Maly. 1979. Relationship of cadmium-induced hypocalcemia with mortality in rainbow trout (*Salmo gairdneri* Richardson and *Salom trutta fario* L.). *Comparative Biochemistry and Physiol*ogy 62C:135.

SAIC and EP&T. 1991. Ecological Risk Assessment for the Bunker Hill Superfund Site. Prepared by Science Applications International Corporation and Ecological Planning and Toxicology for the U.S. Environmental Protection Agency, Region X.

Satchell, G.H. 1984. Respiratory toxicology of fishes. In *Aquatic Toxicology*, L.J. Weber (ed.). Raven Press, New York.

Saunders, R.L. and J.B. Sprague. 1967. Effects of copper-zinc mining pollution on a spawning migration of Atlantic salmon. *Water Resources* 1:419-432.

Schmitt, C.J. 2007. Effects of Metals from Lead-Zinc Mining on Aquatic Organisms Inhabiting Streams Draining Mining Districts in Missouri, Kansas, and Oklahoma, 1980-2007. July 26.

Schmitt, C.J., F.J. Dwyer, and S.E. Finger. 1984. Bioavailability of Pb and Zn from mine tailings as indicated by erythrocyte o-aminolevulinic acid dehydratase (ALA-D) activity in suckers (pisces: catostomidae). *Canadian Journal of Fisheries and Aquatic Sciences* 41:1030-1040.

Schmitt, C.J., W.G. Brumbaugh, G.L. Linder, and J.E. Hinck. 2006. A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from northeastern Oklahoma, USA. *Environmental Geochemistry and Health* 28(5):445-471.

Schmitt, C.J., J.J. Whyte, W.G. Brumbaugh, and D.E. Tillitt. 2005. Biochemical effects of lead, zinc, and cadmium from mining on fish in the tri-states district of northeastern Oklahoma, USA. *Environmental Toxicology and Chemistry* 24(6):1483-1495.

Schmitt, C.J., M.L. Wildhaber, A.L. Allert, and B.C. Poulton. 1997. The Effects of Historic Zinc-Lead Mining and Related Activities in the Tri-States Mining District on Aquatic Ecosystems Supporting the Neosho Madtom, *Noturus Placidus*, in Jasper County, Missouri; Ottawa County, Oklahoma; and Cherokee County, Kansas. Final Report. Prepared by U.S. Geological Survey for the U.S. EPA, Region VII. January 27.

Seneca-Cayuga Tribe of Oklahoma. 1999. Damaged Natural Resources in the Seneca-Cayuga Tribe of Oklahoma's Cultural Bio-Region.

Sheoran, I.S., N. Aggarwal, and R. Singh. 1990a. Effects of cadmium and nickel on in vivo carbon dioxide exchange rate of pigeon pea (*Cajanus cajan* L.). *Plant and Soil* 129:243-249.

Sheoran, I.S., H.R. Singal, and R. Singh. 1990b. Effects of cadmium and nickel on photosynthesis and the enzymes of the photosynthetic carbon reduction cycle in pigeon pea (*Cajanus cajan* L.). *Photosynthesis Research* 23:345-351.

Sileo, L. 2007. Diagnosis of Zinc Poisoning in Five Waterfowl in Tri-State Mining District. July 27.

Sileo, L., W.N. Beyer, and R. Mateo. 2004. Pancreatitis in wild zinc-poisoned waterfowl. *Avian Pathology* 32(6):655-660.

Skidmore, J.F. 1970. Respiration and osmoregulation in rainbow trout with gills damaged by zinc sulfate. *Journal of Experimental Biology* 52:481-494.

Smith, K.S., L.H. Filipek, and D.M. Updegraff. 1988. Distribution of microorganisms and selected metals in mine drainage, stream water, and sediment. In *U.S. Geological Survey Program on Toxic Waste – Ground-water Contamination: Proceedings of the Second Technical Meeting, Cape Cod, Massachusetts, October 21-25, 1985. Chapter D: Fate of Heavy Metals Near Abandoned Lead and Zinc Mines in Northeastern Oklahoma and Southeastern Kansas*, S.E. Ragone (ed.). U.S. Geological Survey Open-File Report 86-481. USGS, Reston, VA. pp. D11-D15.

Sorenson, E.M. 1991. *Metal Poisoning in Fish*. CRC Press, Boca Raton, FL.

Spruill, T.B. 1984. Assessment of Water Resources in Lead-Zinc Mined Areas in Cherokee County, Kansas, and Adjacent Areas. USGS Open-File Report 84-439.

State of Kansas and DOI. 2002. Preassessment Screen and Determination, Cherokee County Superfund Site, Cherokee County, Kansas. October 21.

Stoughton, J.A. and W.A. Marcus. 2000. Persistent impacts of trace metals from mining on floodplain grass communities along Soda Butte Creek, Yellowstone National Park. *Environmental Management* 25(3):305-320.

Stratus Consulting. 2000. Report of Injury Assessment and Injury Determination: Coeur d’Alene Basin Natural Resource Damage Assessment. Prepared for United States Department of the Interior, Fish and Wildlife Service, United States Department of Agriculture, Forest Service, and the Coeur d’Alene Tribe. Stratus Consulting Inc., Boulder, CO. September.

Tar Creek Natural Resource Trustee Council. 2004. Preassessment Screen for the Tar Creek Superfund Site, Ottawa County, Oklahoma. September.

Tar Creek Superfund Task Force. 2000a. Chat Usage Subcommittee. Final Report. Governor Frank Keating’s Tar Creek Superfund Task Force. September 8.

Tar Creek Superfund Task Force. 2000b. Water Quality Subcommittee Task 1 Report: Surface & Ground Water Monitoring Governor Frank Keating’s Tar Creek Superfund Task Force. July 26.

Tar Creek Task Force. 1983a. An Environmental Health Evaluation of the Tar Creek Area. Oklahoma State Department of Health. March.

Tar Creek Task Force. 1983b. Effects of Acid Mine Drainage From Tar Creek on Fishes and Benthic Macroinvertebrates in the Grand Lake System: Executive Summary. Oklahoma Department of Wildlife Conservation. April.

Tar Creek Task Force. 2000. Governor Frank Keating's Tar Creek Superfund Task Force Native American Issues Subcommittee Report.

Tyler, G., A.M.B. Pahlsson, G. Bengtsson, E. Baath, and L. Tranvik. 1989. Heavy-metal ecology of terrestrial plants, microorganisms and invertebrates. *Water, Air, and Soil Pollution* 47:189-215.

U.S. EPA. 1994. Five Year Review, Tar Creek Superfund Site, Ottawa County, Oklahoma. April. U.S. Environmental Protection Agency.

U.S. EPA. 1997. Record of Decision, Residential Areas, Operable Unit 2, Tar Creek Superfund Site, Ottawa County, Oklahoma. U.S. Environmental Protection Agency, Region 6. August.

U.S. EPA. 2000. Five Year Review, Tar Creek Superfund Site, Ottawa County, Oklahoma. April. U.S. Environmental Protection Agency, Region 6.

U.S. EPA. 2002. *National Recommended Water Quality Criteria: 2002*. EPA 822-R-02-047. U.S. Environmental Protection Agency. November.

U.S. EPA. 2006. Surface water and sediment data from Tar Creek, Neosho River, and Spring River. Raw data provided by Suzanne Dudding, U.S. Fish and Wildlife Service, Tulsa, OK.

U.S. EPA. 2007. Tar Creek Superfund Site: Tri-State Mining District – Chat Mining Waste Fact Sheet. Available: http://www.epa.gov/earth1r6/6sf/pdffiles/tar_creek_chat_rule_fact_sheet_june_2007.pdf. Accessed 5/21/2008.

U.S. EPA. 2008. Record of Decision, Operable Unit 4, Chat Piles, Other Mine and Mill Waste, and Smelter Waste, Tar Creek Superfund Site, Ottawa County, Oklahoma. U.S. Environmental Protection Agency, Region 6. Available: http://www.epa.gov/region6/6sf/pdffiles/rod_tarcreek_ou4_final022008.pdf. Accessed 5/21/2008.

USFWS. 1992. Ozark Cavefish (*Amblyopsis rosae*). Available: http://www.fws.gov/southwest/es/Oklahoma/cavefish.htm. Accessed 11/1/2007.

USFWS. 1997. Ozark Big-Eared Bat (*Corynorhinus townsendii ingens*). Available: http://www.fws.gov/southwest/es/Oklahoma/bgerbat.htm. Accessed 11/1/2007.

USFWS. 2000. Final Partial Restoration Plan and Environmental Assessment, Addressing Injuries to Migratory Birds and Threatened and Endangered Species at the Tar Creek Superfund Site, Ottawa County, Oklahoma. Tulsa Ecological Services Field Office. April 12.

USFWS. 2006. County Occurrences of Oklahoma Federally-Listed Endangered, Threatened, Proposed and Candidate Species. Oklahoma Ecological Services Field Office. August 8.

USFWS. 2007. USFWS Threatened and Endangered Species System (TESS): Listed Species for Oklahoma. Available: http://ecos.fws.gov/tess_public/StateListing.do?status = listed&state = OK. Accessed 11/1/2007.

USFWS and University of Wyoming. 1987. Type B – Technical Document: Injury to Fish and Wildlife Species. Prepared by the U.S. Fish and Wildlife Service and the University of Wyoming for the U.S. Department of the Interior, Washington, DC.

Van Assche, F. and H. Clijsters. 1990. Effects of metals on enzyme activity in plants: Commissioned review. *Plant, Cell and Environment* 13:195-206.

Varanasi, U., P.A. Robisch, and D.C. Malins. 1975. Structural alterations in fish epidermal mucus produced by water-borne lead and mercury. *Nature* 258:431.

Vasquez, M.D., C. Poschenrieder, and J. Barcelo. 1989. Pulvinus structure and leaf abscission in cadmium treated bean plants (*Phaseolus vulgaris*). *Canadian Journal of Botany* 67:2756-2764.

Verbost, P.M., J. Van Rooij, G. Flik, R.A.C. Lock, and S.E. Wendelaar Bonga. 1989. The movement of cadmium through freshwater trout branchial epithelium and its interference with calcium transport. *Journal of Experimental Biology* 145:185-197.

Waiwood, K.G. and F.W.H. Beamish. 1978. The effect of copper, hardness and pH on the growth of rainbow trout, *Salmo gairdneri*. *Journal of Fish Biology* 13:591-598.

Watson, T.A. and F.W.H. Beamish. 1980. Effects of zinc on branchial ATPase activity in vivo rainbow trout (*Salmo gairdneri*). *Comparative Biochemistry and Physiology* C66:77-82.

Wicklund, A. 1990. Metabolism of Cadmium and Zinc in Fish. Comprehensive Summaries of Uppsala University Dissertations from the Faculty of Science – 250.

Wildhaber, M.L., C.J. Schmitt, and A.L. Allert. 1996. Historic Zinc-Lead Mining and Related Activities and their Effects on Aquatic Ecosystems Supporting the Neosho Madtom, *Noturus placidus,* in Jasper County, Missouri; Ottawa County, Oklahoma; and Cherokee County, Kansas. Appendix A: Tables A1-A35. Draft Final Report to the U.S. EPA, Region VII, Kansas City, MO. July 31.

Wildhaber, M.L., C.J. Schmitt, and A.L. Allert. 1997. Elemental Concentrations in Benthic Invertebrates Collected From the Neosho, Cottonwood, and Spring Rivers. Final Report to the U.S. Fish and Wildlife Region 6. Prepared by U.S. Geological Survey Biological Resources Division. June 2.

Wilson, R.W. and E.W. Taylor. 1993. The physiological responses of freshwater rainbow trout, *Oncorhynchus mykiss*, during acutely lethal copper exposure. *Journal of Comparative Physiology B* 63:38-47.

Woodward, D.F., W.G. Brumbaugh, A.J. DeLonay, E.E. Little, and C.E. Smith. 1994. Effects on rainbow trout fry of a metals-contaminated diet of benthic invertebrates from the Clark Fork River, Montana. *Transactions of the American Fisheries Society* 123:51-62.

Woodward, D.F., J.A. Hansen, H.L. Bergman, E.E. Little, and A.J. DeLonay. 1995a. Brown trout avoidance of metals in water characteristic of the Clark Fork River, Montana. *Canadian Journal of Fisheries and Aquatic Sciences* 52:2031-2037.

Woodward, D.F., A.M. Farag, H.L. Bergman, A.J. DeLonay, E.E. Little, C.E. Smith, and F.T. Barrows. 1995b. Metals-contaminated benthic invertebrates in the Clark Fork River, Montana: Effects on age-0 brown trout and rainbow trout. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1994-2004.

Xiao, H. and W. Ji. 2007. Relating landscape characteristics to non-point source pollution in mine waste-located watersheds using geospatial techniques. *Journal of Environmental Management* 82(1):111-119.

Yoo, J.L. and D.M. Janz. 2003. Tissue-specific HSP70 levels and reproductive physiological responses in fishes inhabiting a metal-contaminated creek. *Archives of Environmental Contamination and Toxicology* 45(1):110-120.