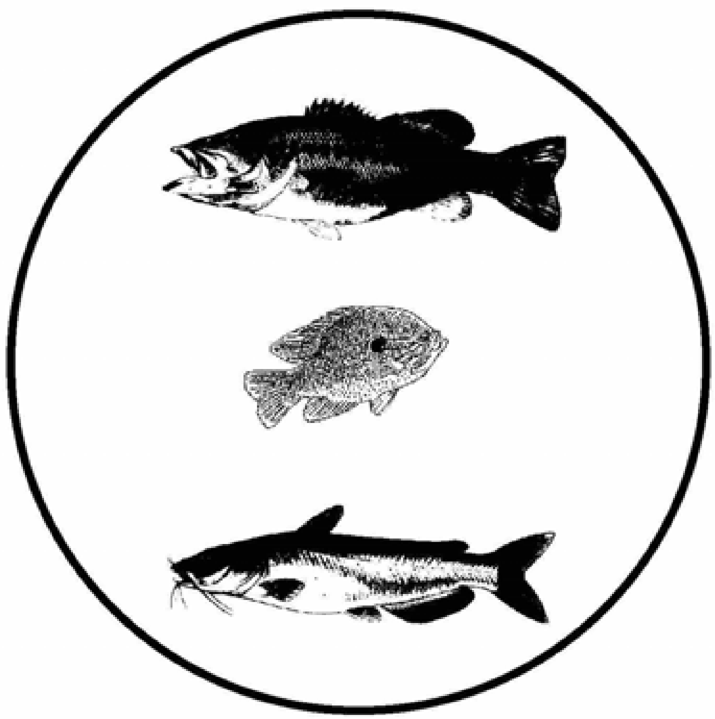
U. S. Fish and Wildlife Service
Region 2

METALS CONTAMINATION IN FISH FROM RESERVOIRS AT WICHITA MOUNTAINS WILDLIFE REFUGE COMANCHE COUNTY, OKLAHOMA 2000-2001

Project ID No. 2C37/200120005



Prepared by
Craig M. Giggleman and Jacob M. Lewis

Arlington Ecological Services Field Office
711 Stadium Drive, Suite #252
Arlington, Texas 76011

July 2003

METALS CONTAMINATION IN FISH FROM RESERVOIRS AT WICHITA MOUNTAINS WILDLIFE REFUGE COMANCHE COUNTY, OKLAHOMA 2000-2001 Project ID No. 2C37/200120005

ABSTRACT

A preliminary fisheries survey conducted in 1997 at Wichita Mountains Wildlife Refuge indicated that fish from the Refuge contained elevated levels of mercury. Prior to this survey, a contaminants investigation in 1984 indicated that mercury and other metals associated with former gold mining/processing sites at the Refuge represented potential contaminants of concern to wildlife resources inhabiting the Refuge. In response to this information, the United States Fish and Wildlife Service (USFWS), Arlington, Texas Field Office, in conjunction with USFWS personnel from Wichita Mountains Wildlife Refuge, initiated an investigation in 2000 to determine the extent of metals contamination in fishery resources at the Refuge. To accomplish this, biological samples were collected and analyzed for metallic contaminants believed to be associated with the former gold mining activities. These biological samples consisted of fillet and whole body composite fish samples collected from 12 of the Refuge's reservoirs, whole body and tissue (brain, liver, and muscle) samples from turtles collected from four of the Refuge's reservoirs, and a whole body composite frog sample collected from a closed mine site located within the boundaries of the Refuge. The fillet samples were analyzed for total mercury content, while the whole body composite fish samples, the chelonian whole body and tissue samples, and the whole body composite frog sample were analyzed for total aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, and zinc. In addition to the biological samples, 20 sediment/soil samples were collected from possible contaminant sources located within the Refuge (i.e., former ore processing sites) as well as from likely lotic contributors associated with these sites to identify potential physical pathways for migration of metallic contaminants. As with the biotic samples previously mentioned, these sediment/soil samples were analyzed for total aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, and zinc content. All analytical data resulting from this study were compared with criteria protective of wildlife and human health as well as with other comparative studies to ascertain the potential ecological and public health impacts of metals contamination at the Refuge.

Results of the metals analyses of four species of fish (bluegill, channel catfish, black bullhead, and largemouth bass) collected from 12 reservoirs at Wichita Mountains Wildlife Refuge indicate that fish inhabiting these reservoirs are contaminated with mercury. Every fish collected during the course of this study, regardless of species, contained detectable amounts of mercury. Of the species sampled, largemouth bass consistently contained elevated mercury concentrations. All whole body largemouth bass samples contained mercury concentrations exceeding the recommended avian predator protection limit of 0.1 mg Hg/kg wet weight. Every largemouth bass equal to or greater than 475 millimeters (19 inches) in length contained fillet-mercury concentrations in excess of the U.S. Food and Drug Administration (USFDA) action level of 1 mg Hg/kg wet weight. In all, 33%

of the largemouth bass fillet samples collected exceeded the USFDA level while 100% of these samples exceeded the United States Environmental Protection Agency criterion of 0.3 mg Hg/kg wet weight. Considering that the mercury levels detected in largemouth bass represented a potential health concern to fishermen, Refuge Management initiated a limited fish consumption advisory at all 12 reservoirs on March 29, 2001. Besides mercury, none of the other metals analyzed were detected in fish at levels that represent significant ecological or human health risks. Some metals were detected at elevated concentrations in comparison to cited studies in the frog and turtle samples collected from the Refuge; however, considering the limited amount of data currently available on toxicological effects to amphibians and reptiles from various contaminants including metals, more definitive toxicological information must be developed in the near future before any unambiguous conclusions can be ascertained.

All of the sediment samples collected from the Refuge contained aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, magnesium, manganese, molybdenum, nickel, selenium, and zinc concentrations below ecological screening criteria with the exception of the sample taken from Quanah Parker Creek upstream of Quanah Parker Lake, which contained elevated aluminum and iron levels. However, the aluminum and iron concentrations measured at this site were not at levels where significant adverse affects to fish and wildlife resources would be expected to occur. The reason mercury and other metals were not detected in significant amounts within the creeks may be attributed to the composition of the substrate of these streams. The majority of the sediments collected from these streams were dominated by course sands. Typically, metals do not bind as readily to course sands as they do to clays and silts. In soils, lead was detected at highly elevated levels in the samples collected from the Bonanza Mine and Blue Beaver Creek smelter sites, while mercury was detected at elevated concentrations in samples collected from the Bonanza Mine and Blue Beaver Creek tailings piles. In addition, all of the soil samples collected contained elevated manganese and zinc concentrations, while the samples taken from the Bonanza Mine smelter site and Blue Beaver Creek smelter site and tailings pile contained elevated levels of iron. The lead and mercury levels were detected at much higher concentrations than would be expected to occur naturally, whereas the high iron, manganese, and zinc concentrations may be indicative of residual contamination from earth moving activities associated with the former gold mining operations within the area or they may be the natural erosional products of the surrounding parent rock material. Considering that lead levels were detected in nominal amounts in biological data collected during the course of this study, it appears that the lead contamination detected at the smelter sites is distributed in limited, localized areas and not readily available to fish inhabiting the Refuge's reservoirs. In contrast, the supportive biological data generated from this study indicate that mercury contamination is widely distributed throughout the Refuge.

Acknowledgments: The authors wish to express their deepest gratitude to Sam Waldstein and his staff at Wichita Mountains Wildlife Refuge, especially Ralph Bryant, Mike McKenzie, Richard VanNatta, and Chip Kimball without whom this study could never have been completed. The authors also wish to thank Mike Armstrong, Barry Forsythe, Brent Bristow, and Jeff Reid for their assistance in conducting the fish sampling. The authors wish to further express appreciation to Stephen Robertson, Tom Cloud, Laila Lienesch, Joe Kimball, Bernie Freeman, Dan Martin, and Barry Forsythe for providing insightful assistance in completing this report.

METALS CONTAMINATION IN FISH FROM RESERVOIRS AT WICHITA MOUNTAINS WILDLIFE REFUGE COMANCHE COUNTY, OKLAHOMA 2000-2001
Project ID No. 2C37/200120005

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

METALS CONTAMINATION IN FISH FROM RESERVOIRS AT WICHITA MOUNTAINS WILDLIFE REFUGE COMANCHE COUNTY, OKLAHOMA 2000-2001
Project ID No. 2C37/200120005

INTRODUCTION

A preliminary survey conducted in 1997 at Wichita Mountains Wildlife Refuge indicated that fish from the Refuge contained elevated levels of mercury (Appendix A). A previous contaminants investigation conducted at the Refuge by Andreasen (1986) indicated that mercury and other metals associated with former gold mining/processing sites at the Refuge represented potential contaminants of concern to wildlife resources. In response to this information, the United States Fish and Wildlife Service (USFWS), Arlington, Texas Field Office, in conjunction with USFWS personnel from Wichita Mountains Wildlife Refuge, initiated an investigation in 2000 to determine the extent of metals contamination in fishery resources at the Refuge. To accomplish this, biological samples were collected and analyzed for metallic contaminants believed to be associated with the former gold mining activities. These biological samples consisted of fillet and whole body composite fish samples collected from 12 of the Refuge's reservoirs, whole body and tissue (brain, liver, and muscle) samples from turtles collected from four of the Refuge's reservoirs, and a whole body composite frog sample collected from a closed mine site located within the boundaries of the Refuge. The fillet samples were analyzed for total mercury content, while the whole body composite fish samples, the whole body composite frog sample, and all turtle samples were analyzed for total aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, and zinc. In addition to the biological samples, 20 sediment/soil samples were collected from possible contaminant sources located within the Refuge (i.e., former ore processing sites) as well as from likely lotic contributors associated with these sites to identify potential physical pathways for migration of metallic contaminants. As with the biotic samples previously mentioned, these sediment/soil samples were analyzed for total aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, and zinc content. All analytical data resulting from this study were compared with criteria protective of wildlife and human health as well as with other comparative studies to ascertain the potential ecological and public health impacts of metals contamination at the Refuge.

STUDY AREA & BACKGROUND INFORMATION

Wichita Mountains Wildlife Refuge is located in the Arkansas River-Red River Ecosystem, within the Red River watershed, north of the City of Lawton and Fort Sill Military Reservation, in northwest Comanche County, Oklahoma (Figure 1). The Refuge encompasses 59,019.6 acres (23,885.2 hectares) and is divided into two principal drainages: Medicine Creek in the north

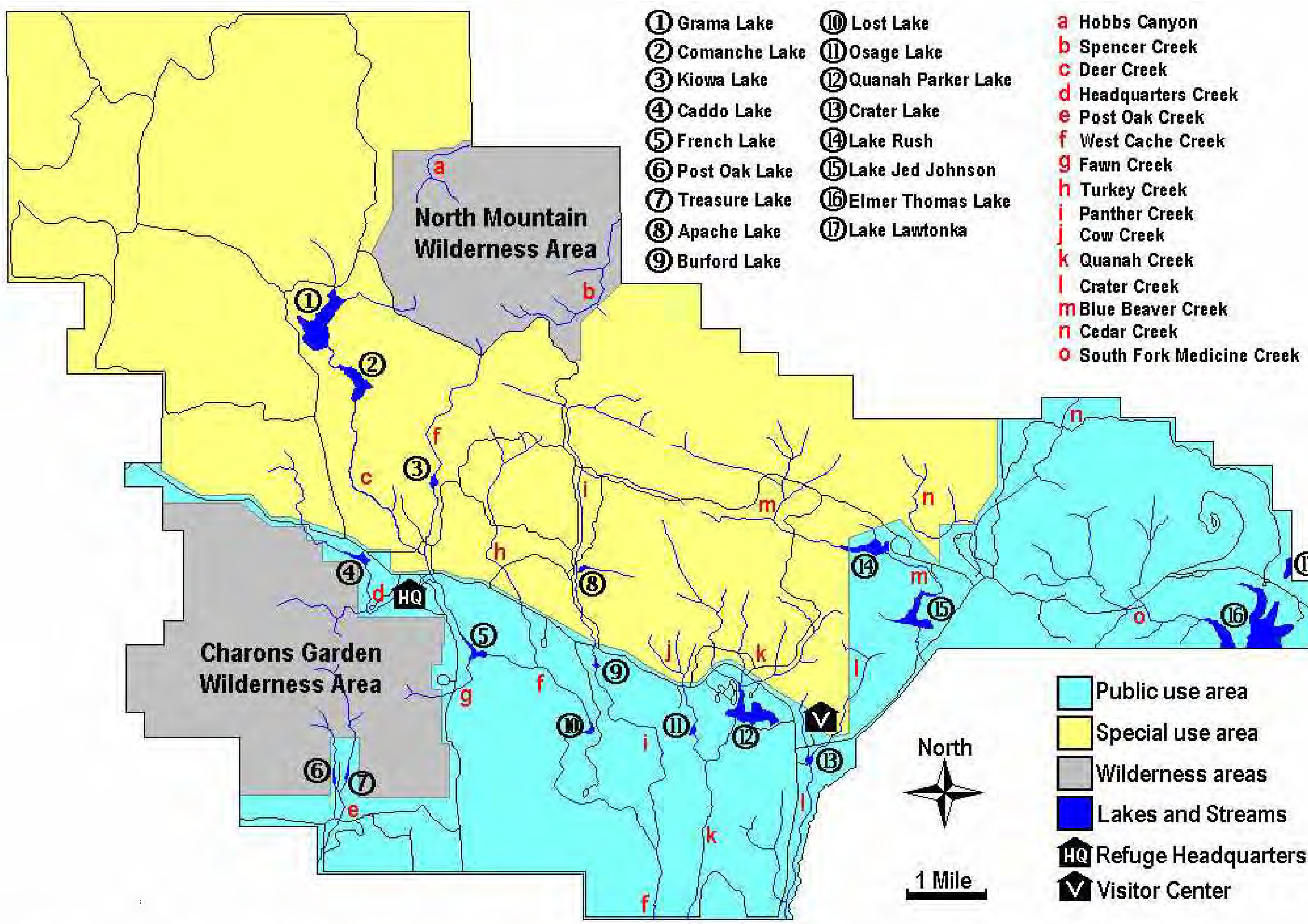


Figure 1: Wichita Mountains Wildlife Refuge, Oklahoma

-northeast and Cache Creek in the south-southwest. From the Refuge, Medicine Creek receives surface water inflow from Hobbs Canyon, Spencer Creek, Cedar Creek, South Fork Medicine Creek, and numerous draws. Tributaries of Cache Creek originating within the Refuge include Post Oak Creek, Deer Creek, Headquarters Creek, Fawn Creek, West Cache Creek, Turkey Creek, Panther Creek, Cow Creek, Quanah Creek, Crater Creek, and Blue Beaver Creek. The Refuge contains approximately 673.5 surface acres (272.6 hectares) of lentic habitat distributed principally into 16 separate reservoirs (Caddo Lake, Grama Lake, Comanche Lake, Kiowa Lake, French Lake, Lost Lake, Apache Lake, Burford Lake, Osage Lake, Quanah Parker Lake, Crater Lake, Lake Rush, Lake Jed Johnson, Elmer Thomas Lake, Post Oak Lake, and Treasure Lake). The surface acres (hectares) and stream impoundment for each of these reservoirs are presented in Table 1.

Table 1. The 16 reservoirs at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma, including surface acres and impounded streams.

Reservoir	Figure	Surface Acres (Hectares)	Impounded Stream
Caddo Lake[1]	2	11.4 (4.6)	Fork of Headquarters Creek
Grama Lake	3	114.0 (46.1)	Deer Creek
Comanche Lake	3	42.0 (17.0)	Deer Creek
Kiowa Lake	3	11.4 (4.6)	West Cache Creek
French Lake[2]	2	35.0 (14.2)	West Cache Creek
Lost Lake[3]	2	10.2 (4.1)	West Cache Creek
Apache Lake	2	4.2 (1.7)	Panther Creek
Burford Lake	2	7.1 (2.9)	Panther Creek
Osage Lake	4	5.5 (2.2)	Cow Creek
Quanah Parker Lake[4]	4	96.0 (38.9)	Quanah Creek
Crater Lake	4	9.3 (3.8)	Crater Creek
Lake Rush[5]	4	51.6 (20.9)	Blue Beaver Creek
Lake Jed Johnson[6]	4	57.6 (23.3)	Blue Beaver Creek
Elmer Thomas Lake[7]	5	360.0 (145.7)	South Fork Medicine Creek
Post Oak Lake	2	2.8 (1.1)	Post Oak Creek
Treasure Lake	2	2.9 (1.2)	Fork of Post Oak Creek

[1]Appendix D, Figures D28-D33.
[2]French Lake also receives inflow from Fawn Creek.
[3]Lost Lake was constructed in 1926 and is the oldest Reservoir at the Refuge; Appendix D, Figures D1-D6.
[4]Appendix D, Figures D7-D12.
[5]Appendix D, Figures D17-D21.
[6]Appendix D, Figures D13-D16.
[7]Appendix D, Figures D22-D27.

Figure 2. Caddo Lake, French Lake, Lost Lake, Burford Lake, Post Oak Lake, Treasure Lake, and Apache Lake in the south central portion of Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) ((MapTech, 1998).

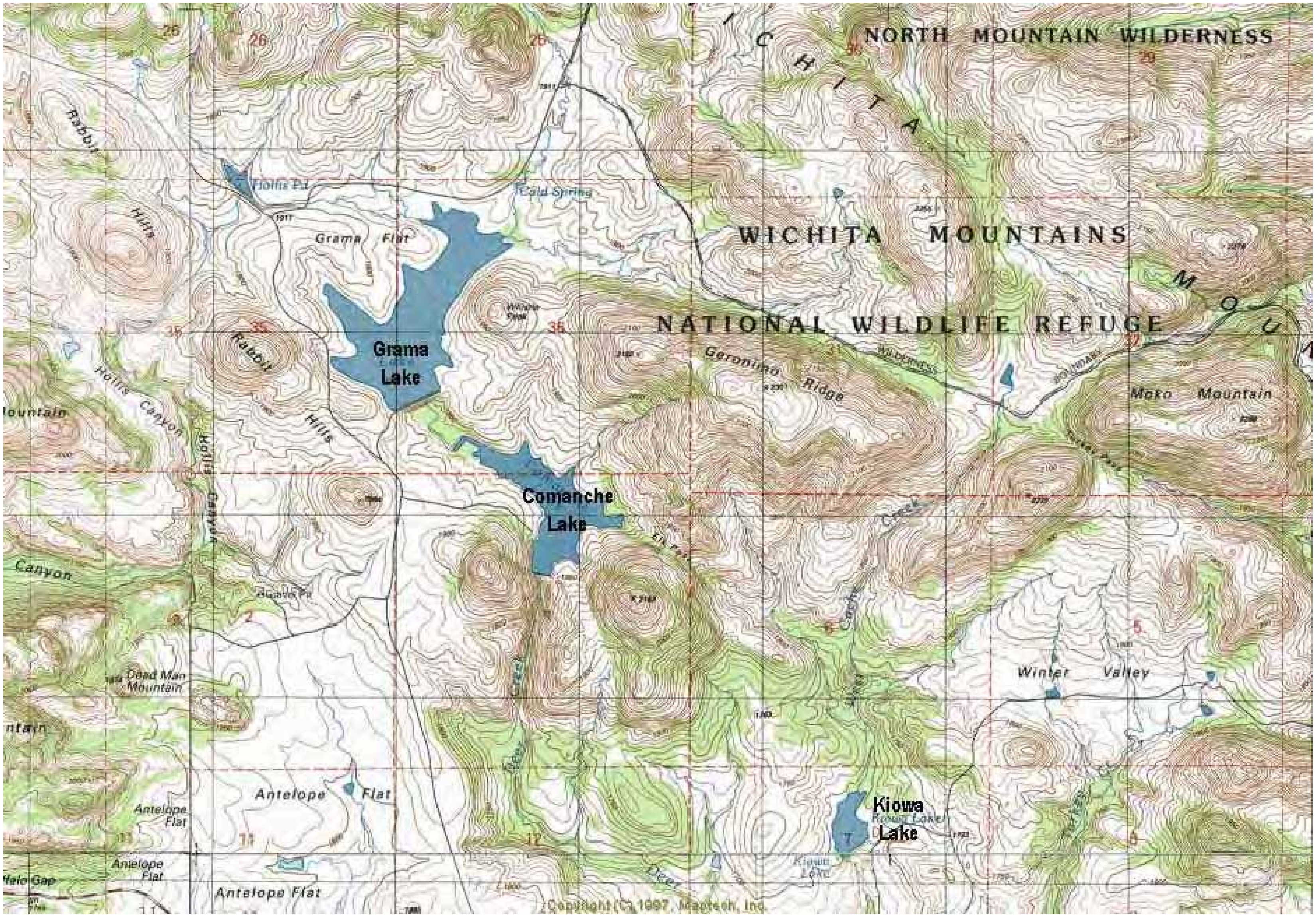


Figure 3. Grama Lake, Comanche Lake, and Kiowa Lake in north central portion of Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

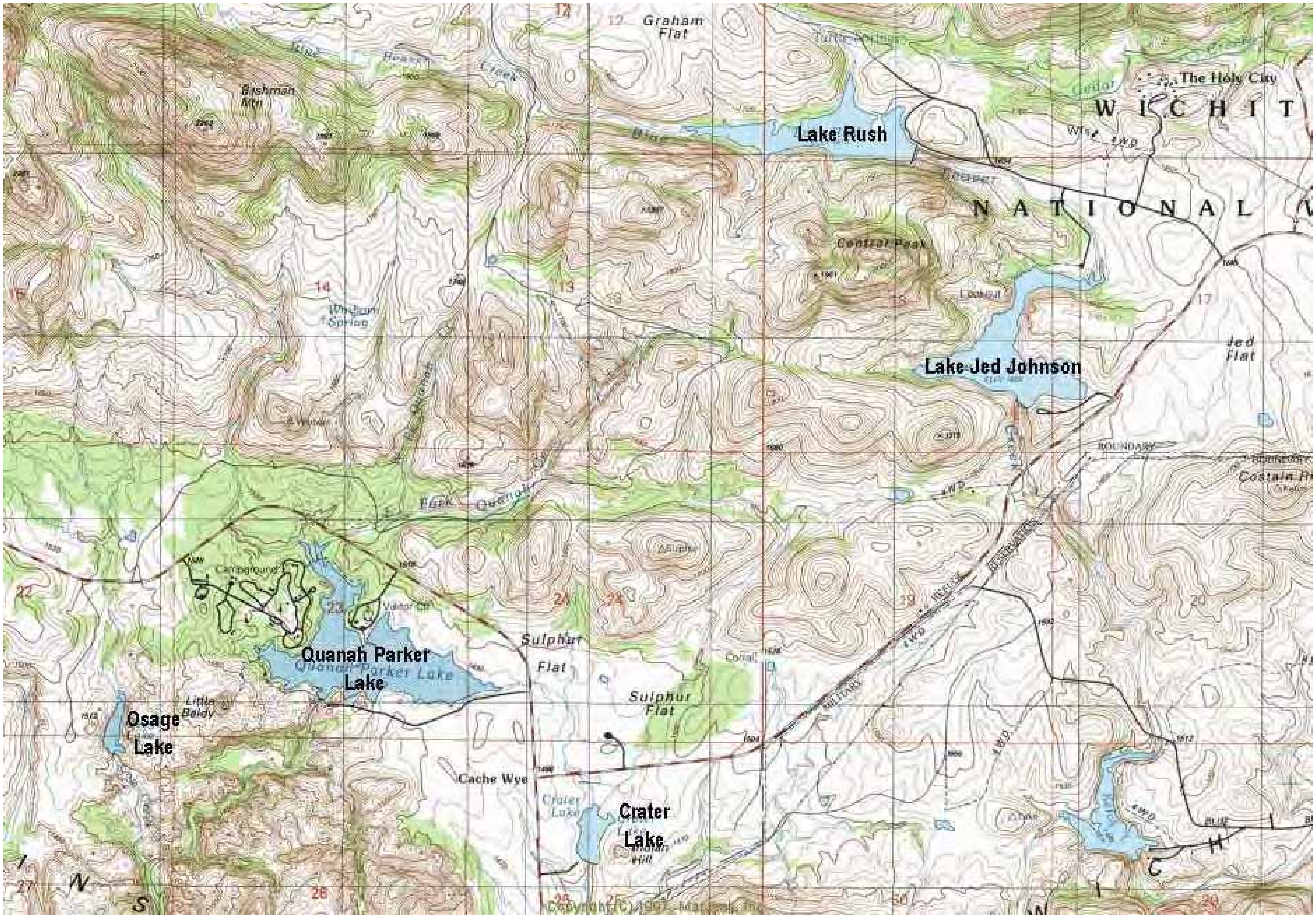


Figure 4. Osage Lake, Quanah Parker Lake, Crater Lake, Lake Rush, and Lake Jed Johnson in the eastern portion of Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

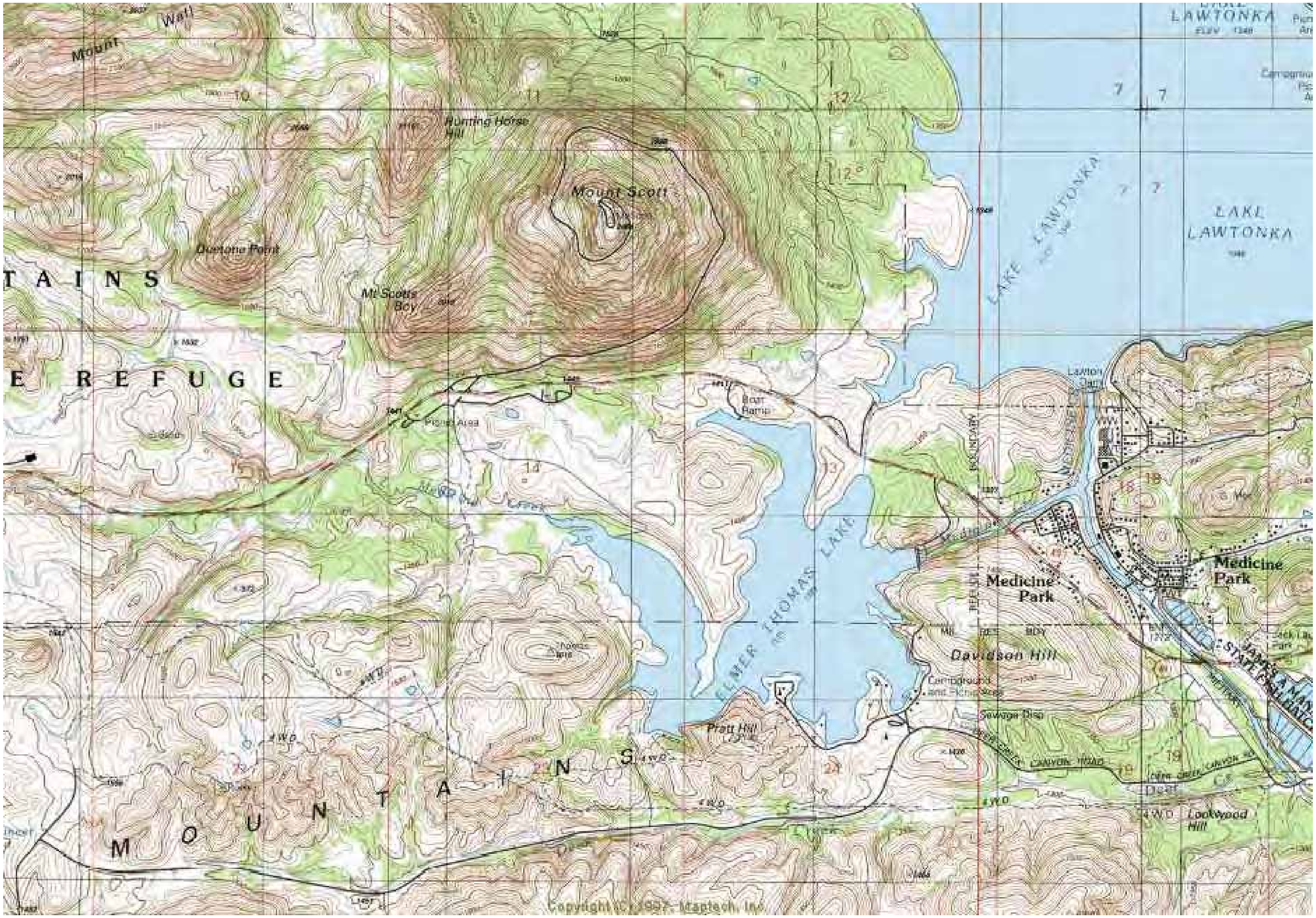


Figure 5. Elmer Thomas Lake in the far eastern portion of Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma.

Recreational fishing is allowed at Elmer Thomas Lake, Lake Rush, Lake Jed Johnson, Crater Lake, Quanah Parker Lake, Osage Lake, French Lake, Lost Lake, Burford Lake, Caddo Lake, Post Oak Lake, and Treasure Lake. The primary game fish inhabiting these reservoirs include channel catfish (*Ictalurus punctatus*), black bullhead [*Ictalurus (Ameiurus) melas*], bluegill (*Lepomis macrochirus*), and largemouth bass (*Micropterus salmoides*) (Bristow, personal communication, 1999).

Geologically, the Wichita Mountains consist of igneous rock, composed primarily of gabbro, rhyolite, and granite (UTD). In the late 19th century, prior to Oklahoma becoming a state, an estimated 3,000 miners were involved in hardrock gold mining operations within the Wichita Mountains area (Andreasen, 1986). It is believed that these miners used mercury as an additive to recover gold from the mined ore (Andreasen, 1986). Because of its density, liquid mercury was added to a slurry of water and processed ore to enhance gold recovery (Alpers and Hunerlach, 2000). The gold would combine with the mercury, form a gold-mercury amalgam, and separate out from the slurry (Alpers and Hunerlach, 2000). The amalgam would then be heated in a smelter to burn off the mercury (Andreasen, 1986). Ore from the mines at the Wichita Mountains was collected and processed into slurries at mule or horse powered grinding sites known as *arrastras* (Andreasen, 1986). The two known *arrastras* at the Refuge are located within the Cedar Creek and Panther Creek drainages (Figure 1). From the arrastras, the processed ore would have been transported to smelters for further refinement. The two known smelter sites at the Refuge are located within the Fawn Creek and Blue Beaver Creek drainages (Figure 1).

Other metals besides mercury that are possibly associated with past hardrock mining activities at the Refuge include copper, arsenic, selenium, molybdenum, zinc, cadmium, chromium, lead, nickel, magnesium, iron, aluminum, and manganese. Copper plates, coated with mercury, were thought to have been used in the Wichita Mountains area during ore processing operations to assist in recovering suspended gold particles from the crushed ore slurries (Andreasen, 1986). Arsenic can occur naturally bound with sulfides with soil-arsenic levels normally being elevated in mineralized zones containing gold and silver deposits (Eisler, 1988a). Selenium, molybdenum, and zinc are elements that are found in coal, and all can be released into the atmosphere through the smelting process (Eisler, 1985b; Eisler, 1993). Zinc may also have been used as a catalyst during part of the ore processing operations at Wichita Mountains (USFWS, 1986). Cadmium is a relatively rare metal that is usually present in small amounts as an impurity in zinc ores that can be dispersed into the environment in higher concentrations through metal smelting operations as fumes or dust (Eisler, 1985a, Wren *et al.*, 1995). Chromium, lead, and nickel can also be released into the environment as by-products of metal smelting operations (Eisler, 1986; Eisler, 1988b, Eisler, 1998b). The gabbro base rock within the Wichita Mountains area can contain naturally high levels of magnesium and iron, while aluminum, iron, and magnesium are also natural components of granite (Whitten and Brooks, 1972; Horne and Goldman, 1994; Miller and Gardiner, 1998). Elevated levels of manganese, iron, lead, and zinc may also be found in the base rock in conjunction with gold and/or silver deposits (Whitten and Brooks, 1972).

In addition to mercury and the other metals mentioned, it is possible that cyanide solutions may have also been used in the ore processing operations conducted in the Wichita Mountains to assist in gold recovery (USFWS, 1986). Gold ore extraction practices could have involved percolating cyanide solutions such as sodium cyanide through the crushed ore to dissolve the gold particles (Eisler *et al.*, 1999). The gold would then be chemically precipitated from the spent solution (Eisler *et al.*, 1999). Even though cyanide solutions may have been used in processing ore at Wichita Mountains, cyanide seldom remains biologically available in soils nor does it persist in surface waters because it is either complexed by trace metals, metabolized by various microorganisms, or lost through volatization (Eisler *et al.*, 1999). Furthermore, cyanides are neither mutagenic nor carcinogenic, and unlike mercury, cyanide does not biomagnify through trophic levels or cycle extensively in ecosystems (Eisler *et al.*, 1999). Given this information in combination with the time frame that gold mining activities ceased in the Wichita Mountains Wildlife Refuge area (over 100 years ago), cyanide was not included as a contaminant of concern during the 2000-2001 study.

MATERIALS & METHODS

In May and June, 2000, and March and June, 2001, fish were collected from the 12 recreational fishing reservoirs at Wichita Mountains Wildlife Refuge using a combination of gill nets, trot lines, hook-and-line, and a direct-current-boom electro-fishing boat. The target fish species for this study were bluegill (Appendix D, Figure D37), channel catfish (Appendix D, Figure D34), and largemouth bass (Appendix D, Figure D36).

Bluegills are a species of sunfish that are moderately tolerant to variations in water quality and thrive in warm clear water where aquatic vegetation is present (Pflieger, 1991; Jester *et al.*, 1992). This species can be found in turbid water; however, it is intolerant to continuous high turbidity and siltation (Robison and Buchanan, 1988). Bluegills are generalized sight feeders, feeding at various depths depending on food availability (Robison and Buchanan, 1988), even feeding on the surface when aquatic insects are emerging (Pflieger, 1991). Adults feed primarily on insects, but will consume crayfish, snails, and small fish (Robison and Buchanan, 1988), whereas juveniles will feed predominantly on rotifers, copepods, and cladocerans (Becker, 1983). Bluegills sexually mature at 2 to 3 years (Becker, 1983). The average life span is 5 to 6 years (Etnier and Starnes, 1993). As fingerlings, bluegill are preyed upon by a host of organisms including bullheads, largemouth bass, and herons, but as they get older and increase in size, largemouth bass are their primary predator (Becker, 1983).

Channel catfish are extremely adaptable fish that do equally well in lentic and lotic systems and are moderately tolerant to variations in water quality conditions (Robison and Buchanan, 1988; Jester *et al.*, 1992). This species feeds on a variety of prey ranging from fish, insects, molluscs, and crayfish to plant material and detritus (Robison and Buchanan, 1988). Fingerlings feed predominantly on benthic invertebrates while adults, which also usually feed on the bottom, prefer a more omnivorous to piscivorus diet (Becker, 1983; Robison and Buchanan, 1988; Pflieger, 1991; Etnier and Starnes, 1993). Channel catfish sexually mature at 3 to 5 years [305-380 millimeters (mm) in length] and can live from 10 to 24 years; however, their normal life span is usually 7 years or less (Robison and Buchanan, 1988; Pflieger, 1991; Etnier and Starnes, 1993). Adults suffer little from predation but juveniles are vulnerable to predacious insects and other fish including bluegill and bass (Becker, 1983).

Largemouth bass are highly adaptive to both lentic and lotic systems. This species is moderately tolerant to changes in water conditions (Jester *et al.*, 1992), but like bluegills, thrives in warm, moderately clear waters and is intolerant to high turbidity and extreme siltation (Robison and Buchanan, 1988; Pflieger, 1991). Fingerling largemouth bass prey principally on microcrustaceans, whereas adults are primarily piscivorus, but will eat crayfish, insects, frogs, snakes, and even mice (Becker, 1983; Robison and Buchanan, 1988; Pflieger, 1991). In large reservoirs, this species depends heavily on gizzard shad (*Dorosoma cepedianum*) and bluegill for food (Becker, 1983; Pflieger, 1991). Food is converted to a fish flesh ratio of 4 to 1 (Becker, 1983). Largemouth bass sexually mature at 2 years and may live up to 10 years or more (Robison and Buchanan, 1988). As fingerlings, this species is preyed upon by a host of organisms, but as they become adults predation by other organisms is very low (Becker, 1983).

These fish species were selected because all three species were thought to be present in the Refuge's reservoirs and all are considered game fish that are commonly consumed by fishermen (Bristow, personal communication, 1999; ODWC, 2001). Furthermore, largemouth bass were the target species in the fisheries survey conducted at the Refuge in 1997, therefore historical data was available for comparative purposes (Appendix A). Black bullheads (Appendix D, Figure D35) were collected as a surrogate species for channel catfish at six of the reservoirs (Lost Lake, French Lake, Caddo Lake, Osage Lake, Post Oak Lake, and Treasure Lake) primarily because the combination of intensive electro-shocking, gill nets, hook-and-line, and trot lines yielded a limited number of channel catfish. Black bullheads are an extremely tolerant species to changes in water quality that can be found in a variety of aquatic habitats but are typically more abundant in systems that exhibit turbid water, silty bottoms, no noticeable current, and a lack of diversity in other fish fauna (Pflieger, 1991; Jester *et al.*, 1992). Black bullheads are opportunistic bottom feeders that forage on a variety of plant and animal material including immature aquatic insects, crustaceans, molluscs, fish, aquatic vegetation and carrion (Becker, 1983; Pflieger, 1991; Etnier and Starnes, 1993). Predation by other fish, even at the fingerling stage, is low (Becker, 1983). The maximum life span of this species is 10 years, but few individuals live more then 5 years (Pflieger, 1991). Although not considered a game fish (ODWC, 2001), as with the other three species of fish already mentioned, fishermen will also occasionally consume black bullheads (Waldstein, personal communication, 2000).

Ten channel catfish, 10 bluegills, and 10 largemouth bass were collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, and Elmer Thomas Lake (Appendix C, pages C1-C4), whereas 10 bluegills, 10 largemouth bass, one channel catfish, and six black bullheads were collected from Lost Lake (Appendix C, page C5); 10 bluegills, 10 largemouth bass, two channel catfish, and five black bullheads were collected from French Lake (Appendix C, page C6); 10 bluegills, 10 largemouth bass, eight channel catfish, and two black bullheads were collected from Caddo Lake (Appendix C, page C9); 10 bluegills, 10 largemouth bass, and three channel catfish were collected from Crater Lake (Appendix C, page C7); 10 bluegills, 10 largemouth bass, and three channel catfish were collected from Burford Lake (Appendix C, page C8); 10 bluegills, three largemouth bass, and one black bullhead were collected from Osage Lake (Appendix C, page C10); 10 bluegill, three largemouth bass, three channel catfish, and one black bullhead were collected from Post Oak Lake (Appendix C, page C10); and 10 bluegill, eight largemouth bass, and one black bullhead were collected from Treasure Lake (Appendix C, page C11).

Once collected, all fish were measured and weighed. Skinless fillet samples were prepared from five of the bluegills collected from each reservoir using a Rapala stainless steel fillet knife. This knife was decontaminated after each fillet using Liqui-Nox detergent and de-ionized water. Fillet samples were prepared in the same manner for five of the largemouth bass collected from each reservoir with the exception of Osage Lake and Post Oak Lake, where due to the limited number of largemouth bass collected from these two reservoirs (only three bass were collected from each reservoir), all largemouth bass samples were prepared as fillets. Fillet samples were also prepared in the same manner for five of the channel catfish collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, and Elmer Thomas Lake (Appendix C, pages C1-C4); for one channel catfish and two black bullheads collected from Lost Lake (Appendix C, page C5); for two channel catfish and one black bullhead from French Lake (Appendix C, page C6); for three channel catfish and two black bullheads from Caddo Lake (Appendix C, page C9); for all of the channel catfish collected from Crater Lake, Burford Lake, and Post Oak Lake (Appendix C, pages C7, C8, and C10); and for all of the black bullheads collected from Osage Lake and Treasure Lake (Appendix C, pages C10-C11). After preparation, all fillet samples were vacuum sealed in plastic bags using a Food Saver VacLoc Deluxe II Vacuum Sealer (Model No. 99-21-F-01-5226) and frozen. The remaining fish collected from each reservoir (Appendix C, pages C1-C11) were composited as whole body samples by species per reservoir [with the exception of Post Oak Lake where the whole body black bullhead sample consisted of a single specimen (Appendix C, page C10)]. These samples were also vacuum sealed in plastic bags and frozen.

In addition to fish, turtles were inadvertently collected from Lost Lake [three red-eared sliders (*Trachemys scripta elegans*)], French Lake [three red-eared sliders and one pallid spiny softshell (*Apalone spinifera pallidus*)], Burford Lake (two red-eared sliders), and Osage Lake (four red-eared sliders) (Appendix C, page C12). Although turtles were not the primary focus of this study and their collection by trot lines and gill nets was unintentional, the specimens collected represented samples of opportunity to possibly determine the intake of contaminants from fish by mid-trophic level predators. Red-eared sliders are a gregarious basking chelonian species that thrive equally well in both lentic and lotic systems. This turtle will overwinter buried in the substrate of its given aquatic environment (Degenhardt *et al.*, 1996). Carapace length in adult sliders typically ranges from 7 to 12 inches (178-305 mm) with males usually being smaller than females (Bartlett & Bartlett, 1999). Males reach sexual maturity at 3 to 5 years of age, while females sexually mature at 6 to 8 years of age (Degenhardt *et al.*, 1996). Juvenile sliders feed primarily on insects, crustaceans, molluscs, and tadpoles, while adults exhibit more of an omnivorous diet, feeding on aquatic vegetation and carrion, as well as fish, molluscs, and amphibians (Behler and King, 1987). In comparison, spiny softshell turtles are highly aquatic and are powerful and agile swimmers that reside in both lentic and lotic systems (Pritchard, 1979; Behler and King, 1987; Bartlett & Bartlett, 1999). In addition to normal pulmonary respiration, gas exchange can occur through the skin and mucous membranes which allows for softshells to remain submerged and buried in the substrate for extended periods of time (Conant, 1975; Bartlett & Bartlett, 1999). Carapace length in hatchling softshells ranges from 1.25 to 1.75 inches (32-44 mm) (Conant, 1975), whereas the carapace length in adult males ranges from 5 to 8 inches (127-203 mm) and 7 to 18 inches (178-457 mm) in adult females (Conant, 1975; Garrett and Barker, 1987; Bartlett & Bartlett, 1999). This species is predominantly carnivorous, feeding on fish and frogs, but it will also eat carrion, aquatic vegetation, molluscs, crayfish and other invertebrates (Pritchard, 1979; Garrett and Barker, 1987; Sievert and Sievert, 1993). Softshells can live up to 25 years in captivity (Behler and King, 1987). According to Pritchard (1979), adult females with carapace lengths greater than 18 inches may be over 60 years of age.

After collection, all turtles were measured and weighed. These specimens were then individually vacuum sealed in plastic bags and frozen in the same manner as the fish. All biological samples collected from the Refuge were transported back to the Arlington, Texas Field Office on ice in coolers via automobile and remained frozen until shipped overnight to an analytical laboratory through the USFWS Patuxent Analytical Control Facility (PACF). All fish fillet samples were analyzed for total mercury content using cold vapor atomic absorption (Appendix B, Method Code 002). The whole body fish samples were analyzed for total aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, and zinc content using cold vapor atomic absorption, graphite furnace single element atomic absorption, and inductively coupled plasma spectroscopy (Appendix B, Method Codes 002, 006, and 007). The softshell turtle collected from French Lake was prepared as a whole body sample and analyzed for the same metals in the same manner as the whole body fish. Brain, liver, and muscle tissue samples were collected from each of the remaining turtles (as well as the French Lake softshell turtle) at the analytical laboratory. These tissues were also analyzed for the same metals as the whole body fish and samples.

In addition to the fish and turtle samples, 20 grab sediment/soil samples were collected from suspected sources of contamination and likely lotic pathways located within the confines of the Refuge (Table 2 and Figures 6A-6E). These samples were collected at a depth of 0 to12 inches [0 to 31 centimeters (cm)] using a core sampler with 2 inch (5.1 cm)-diameter polypropylene tubes and disposable plastic scoops. Once collected, these samples were transferred to pre-cleaned glass containers, placed on ice in coolers, and transported back to the Arlington, Texas Field Office via automobile and remained refrigerated until shipped to an analytical laboratory through the PACF. All sediment/soil samples were analyzed for total aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, and zinc content. Mercury concentrations were determined through the use of a cold vapor atomic absorption spectrophotometer (Appendix B). Arsenic and selenium concentrations were determined by a graphite furnace technique, while all other metal concentrations were determined by inductively coupled plasma spectroscopy (Appendix B).

Table 2. Location of sediment and/or soil sample sites within Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma.		
Site	**Designator**	**Location/Description**
1	WM1	Latitude 34.716123; Longitude -098.7187536. Soil sample from slag pile at smelter site below Bonanza Mine and above Fawn Creek (Appendix D, Figures D41-D42). Bonanza Mine is a flooded vertical mine shaft on the northern face of Mount Lincoln. The entrance to the shaft is approximately 2.0 meters x 3.0 meters (Appendix D, Figures D38-D39).
2	WM2	Latitude 34.7159158; Longitude -098.7206268. Soil sample from tailings pile at the base of Bonanza Mine (Appendix D, Figure D40).
3	WM3	Latitude 34.7149492; Longitude -098.7113855. Sediment sample from Fawn Creek, downstream of Bonanza Mine, smelter site, and mine shaft on north bank (Appendix D, Figure D43), and upstream of French Lake.
4	WM4	Latitude 34.7462949; Longitude -098.7098659. Sediment sample from West Cache Creek below Kiowa Lake.
5	WM5	Latitude 34.7208877; Longitude -098.6381701. Sediment sample from Quanah Creek upstream of Quanah Parker Lake and SH 49.
6	WM6	Latitude 34.7300056; Longitude -098.5364096. Sediment sample from South Fork Medicine Creek upstream of Elmer Thomas Lake.
7	WM7	Latitude 34.7408758; Longitude -098.6213818. Soil sample from slag pile below Blue Beaver Creek Smelter Site (Appendix D, Figures D44-D49).
8	WM8	Latitude 34.740565; Longitude -098.6177603. Sediment sample from Blue Beaver Creek downstream of smelter and upstream of Lake Rush.
9	WM9	Latitude 34.7404616; Longitude -098.6206742. Soil sample from tailings pile below vertical mine shaft adjacent to Blue Beaver Creek Smelter Site (Appendix D, Figure D50). Like the Bonanza Mine, this shaft is flooded and the entrance is approximately 2.0 meters x 3.0 meters.
10	WM10	Latitude 34.7427788; Longitude -098.6286746. Sediment sample from Blue Beaver Creek upstream of mine and smelter sites.
11	WM11	Latitude 34.7719905; Longitude -098.7020574. Sediment sample from headwaters of West Cache Creek.
12	WM12	Latitude 34.7380434; Longitude -098.6788078. Sediment sample from Panther Creek, upstream of Apache Lake.
13	WM13	Latitude 34.7253062; Longitude -098.6737199. Sediment sample from Panther Creek, upstream of SH 49 and Burford Lake.
14	WM14	Latitude 34.6842279; Longitude -098.6507497. Sediment sample from Quanah Creek at southern fence-line (Appendix D, Figure D51).
15	WM15	Latitude 34.7092189; Longitude -098.7346945. Sediment sample from Post Oak Creek, upstream of Post Oak Lake.
16	WM16	Latitude 34.7087012; Longitude -098.7315726. Sediment sample from upper portion of Treasure Lake.
17	WM17	Latitude 34.7416332; Longitude -098.7355592. Sediment sample from fork of Headquarters Creek, upstream of Caddo Lake.
18	WM18	Latitude 34.7212329; Longitude -098.6875807. Sediment sample from Chain Lake (Cache Creek), downstream of French Lake and upstream of Lost Lake (Appendix D, Figure D52).
19	WM19	Latitude 34.7154682; Longitude -098.6534064. Sediment sample from Cow Creek, upstream of Osage Lake.
20	WM20	Latitude 34.7100149; Longitude -098.6220657. Sediment sample from Crater Creek, upstream of Crater Lake and SH 49.

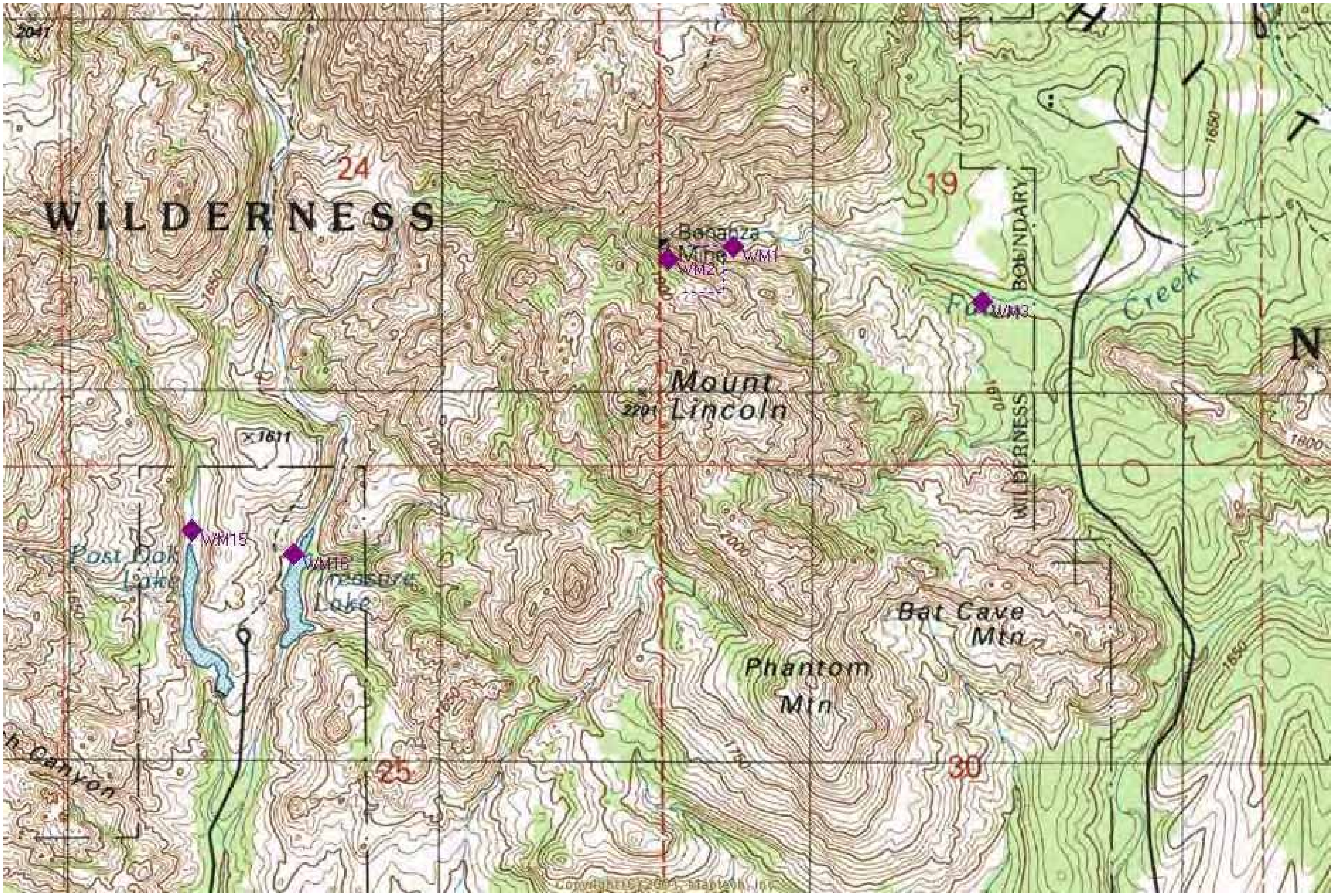


Figure 6A. Sediment/Soil sampling locations for WM1, WM2, WM3, WM15, and WM16 at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

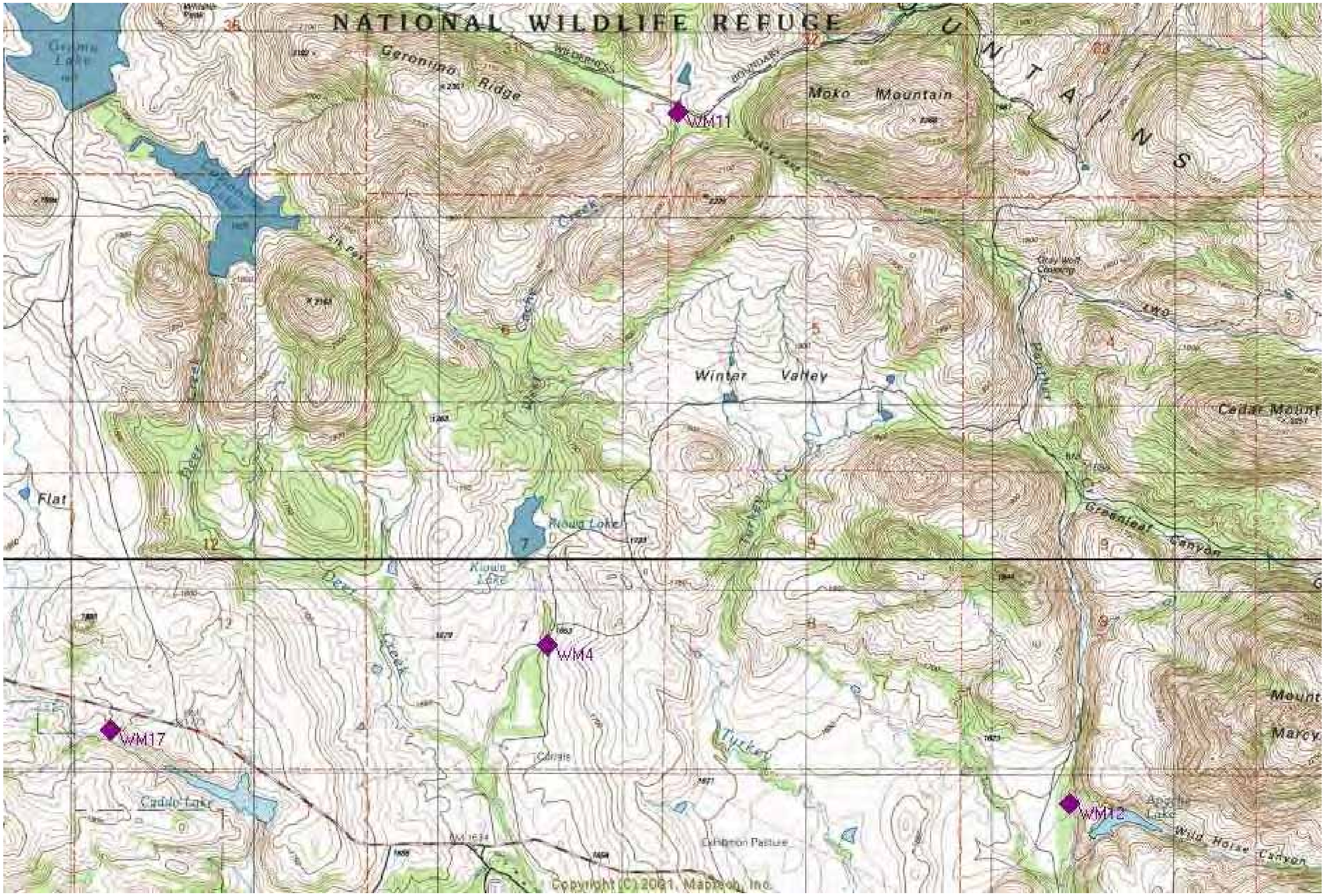


Figure 6B. Sediment/Soil sampling locations for WM4, WM11, WM12, and WM17 at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

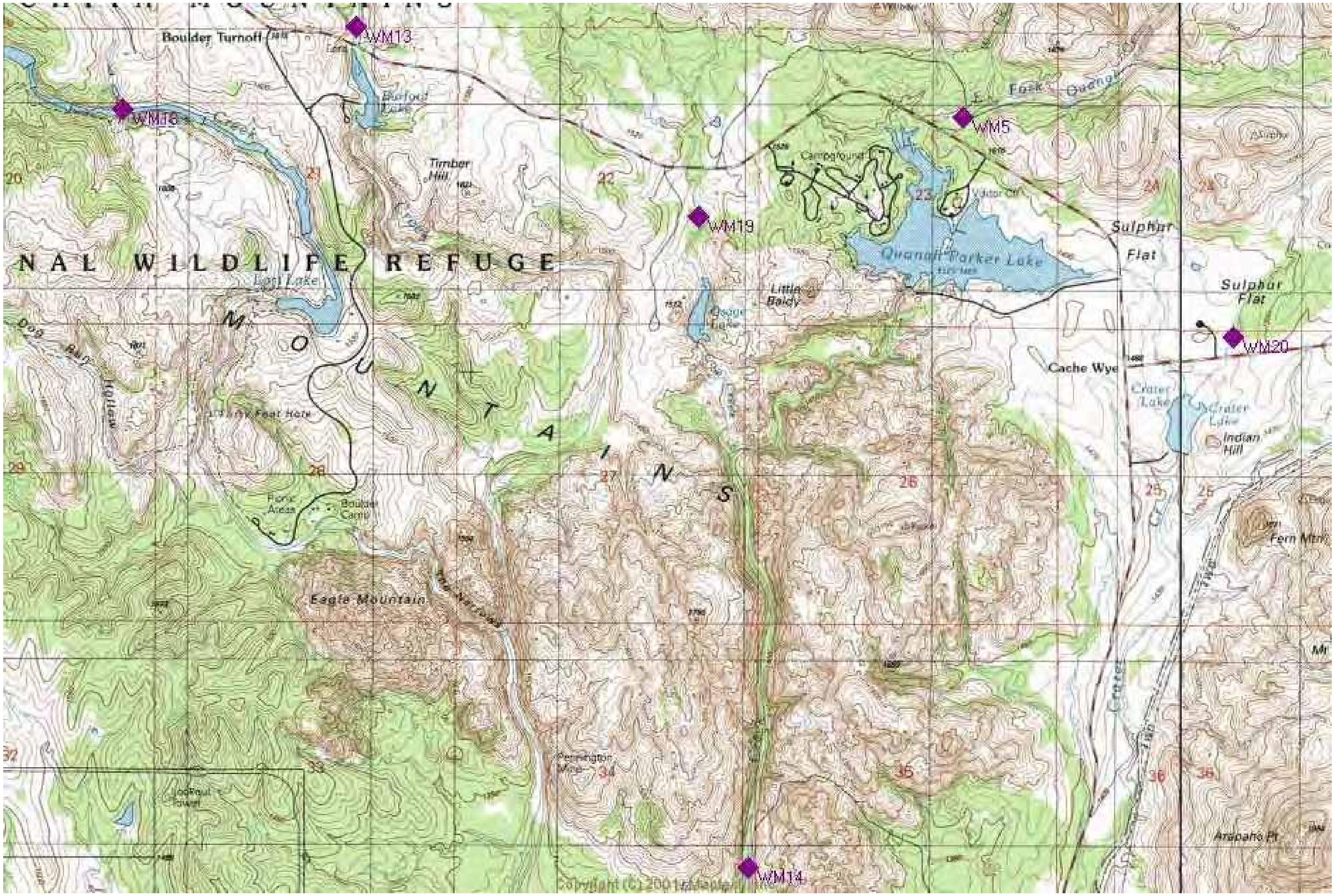


Figure 6C. Sediment/Soil sampling locations for WM5, WM13, WM14, WM18, WM19, and WM20 at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

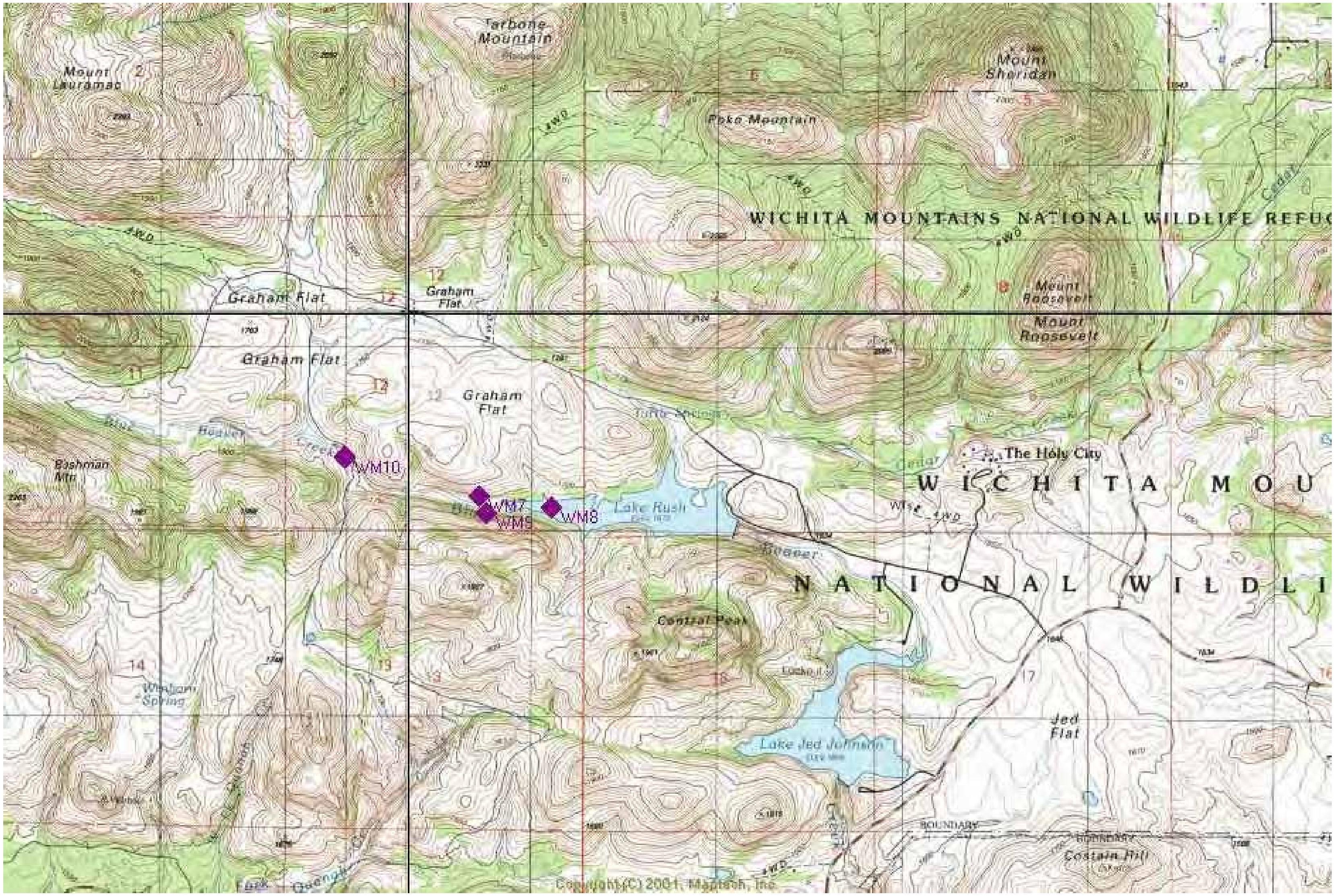


Figure 6D. Sediment/Soil sampling locations for WM7, WM8, WM9, and WM10 at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

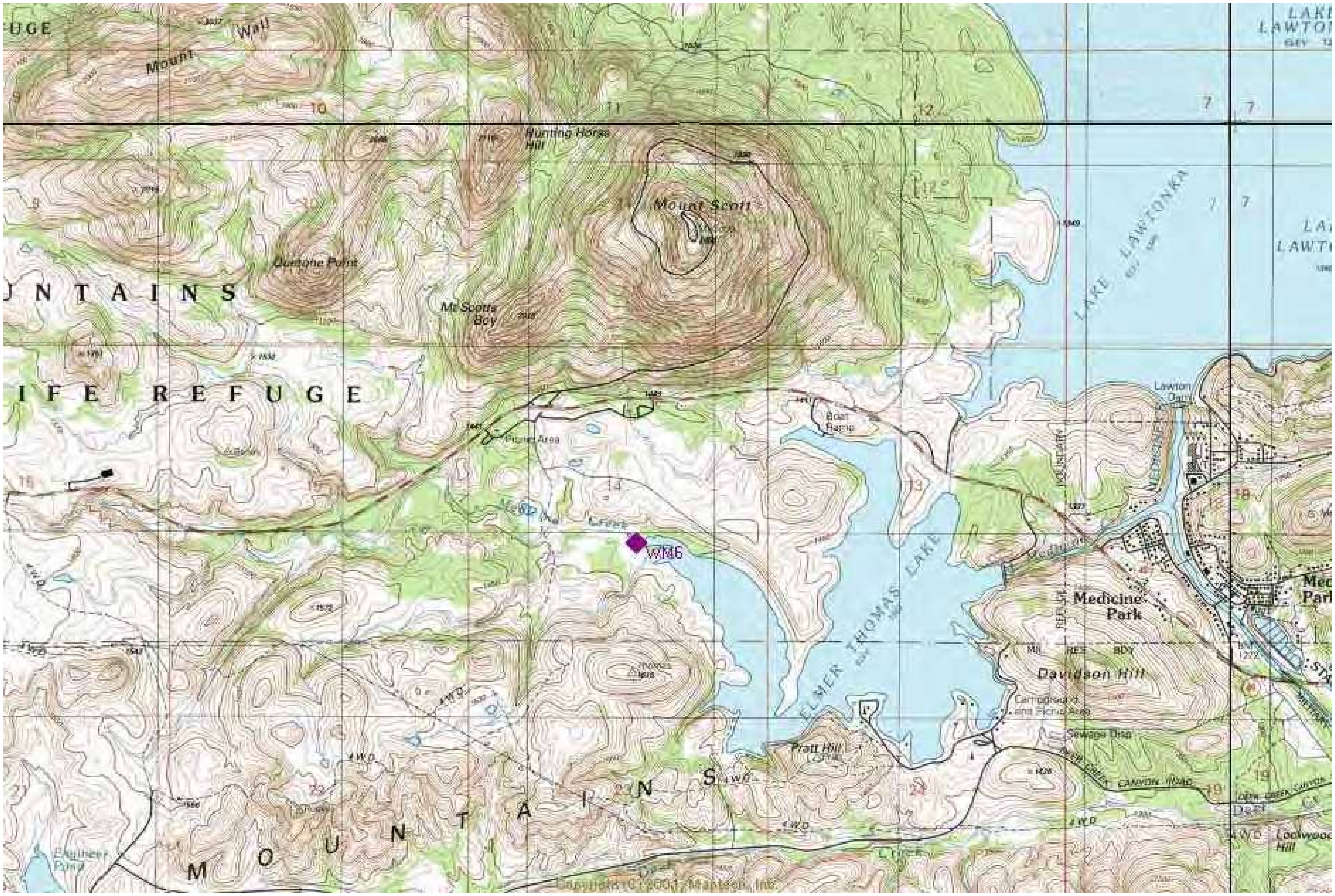


Figure 6E. Sediment/Soil sampling location for WM6 at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma. Scale: Grid line = 3,285 feet (1,000 meters) (MapTech, 1998).

While collecting soil samples in the vicinity of the Bonanza Mine (samples WM1 and WM2), two dead juvenile leopard frogs (*Rana sphenocephala*) approximately 1 inch (2.5 cm) in length were observed floating in the water at the entrance to the mine shaft. These frogs were collected in a glass container, placed on ice in a cooler, and transported back to the Arlington, Texas Field Office via automobile where they were vacuum sealed as a composite whole body sample and frozen. This sample remained frozen until submitted through the PACF to be analyzed for the same metals as the whole body fish, whole body turtle, and turtle tissue samples (Appendix B, Method Codes 002, 006, and 007).

RESULTS & DISCUSSION

Three hundred fish were collected from 12 reservoirs at Wichita Mountains Wildlife Refuge during the course of the 2000-2001 study. General data associated with these fish, including length and weight of each fish from each reservoir are presented in Appendix C. Twelve red-eared sliders and one pallid spiny softshell turtle were collected from four of the Refuge's reservoirs during this study as a byproduct of fish sampling. Individual weight and carapace length/width of each of these turtles are presented in Appendix C. The weight and length of both of the dead leopard frogs found at the entrance to Bonanza Mine are also presented in Appendix C.

Mercury (Hg) in Fish Fillets

Fillets collected from largemouth bass greater than 12 inches (300 mm) in length (with the exception of one from Osage Lake and one from Post Oak Lake, both of which were less than 12 inches in length), channel catfish greater than 12 inches (300 mm) in length, black bullheads greater than 8 inches (200 mm) in length, and bluegill greater than 6 inches (150 mm) in length were submitted for total mercury analyses. The analytical results in milligrams/kilogram (mg/kg) wet weight for total mercury concentrations in fish fillets collected from each reservoir are presented in Table 3. Arithmetic mean mercury concentrations in mg/kg wet weight for each fish species from each reservoir are summarized in Table 4.

Mercury can exist in many forms in an aquatic environment, including elemental mercury, dissolved and particulate ionic forms, and/or to a lesser extent, dissolved and particulate methylmercury (Wiener and Spry, 1996). The production of methylmercury by methylation of inorganic mercury in the sediments and the water column of an aqueous environment is dependent on microbial activity, nutrient content, pH, salinity, oxidation-reduction conditions, and alkalinity (Eisler, 1987; Wiener and Spry, 1996; Alpers and Hunerlach, 2000). In fish, 95% to 99% of the mercury present is in the form of methylmercury even though very little of the total mercury found in water and sediments may exist as methylmercury (Wiener and Spry, 1996). This is because fish tend to obtain the majority of methylmercury from their diet and to a lesser extent, from water passing over the gills (Wiener and Spry, 1996). Furthermore, methylmercury concentrations in predaceous fish are typically elevated in comparison to prey species because methylmercury content can increase by a factor of ten or less with each successive trophic level through biomagnification (Alpers and Hunerlach, 2000).

Methylmercury is toxic and has no known essential function in vertebrate organisms (Eisler, 1987). Human exposure to methylmercury is primarily due to consumption of contaminated fish (Wiener and Spry, 1996).

Table 3. Total mercury analytical results in parts per million (mg/kg) for fish fillets collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Burford Lake, Osage Lake, Post Oak Lake, and Treasure Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - mg/kg is milligram/kilogram; wwt is wet weight).

Reservoir	Species - Sample No.	Mercury (mg/kg wwt)	Detection Limit (mg/kg wwt)
Lake Rush	Channel Catfish - RR005	0.07	0.014
	Channel Catfish - RR006	0.09	0.015
	Channel Catfish - RR007	0.06	0.012
	Channel Catfish - RR018	0.39	0.018
	Channel Catfish - RR021	0.19	0.012
	Bluegill - RR008	0.09	0.017
	Bluegill - RR009	0.18	0.018
	Bluegill - RR010	0.38	0.019
	Bluegill - RR011	0.27	0.015
	Bluegill - RR012	0.30	0.018
	Largemouth Bass - RR001	1.38	0.015
	Largemouth Bass - RR002	0.69	0.015
	Largemouth Bass - RR003	1.06	0.013
	Largemouth Bass - RR004	0.66	0.015
	Largemouth Bass - RR025	1.29	0.015
Lake Jed Johnson	Channel Catfish - JJ020	0.14	0.013
	Channel Catfish - JJ021	0.65	0.015
	Channel Catfish - JJ022	0.08	0.012
	Channel Catfish - JJ029	0.08	0.015
	Channel Catfish - JJ030	0.07	0.016
	Bluegill - JJ001	0.20	0.015
	Bluegill - JJ003	0.07	0.013
	Bluegill - JJ004	0.21	0.019
	Bluegill - JJ005	0.13	0.009
	Bluegill - JJ006	0.10	0.018
	Largemouth Bass - JJ002	0.89	0.015
	Largemouth Bass - JJ007	1.51	0.027
	Largemouth Bass - JJ008	0.86	0.012
	Largemouth Bass - JJ009	0.61	0.013
	Largemouth Bass - JJ010	0.35	0.014

Table 3 (continued). Total mercury analytical results in parts per million (mg/kg) for fish fillets collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Burford Lake, Osage Lake, Post Oak Lake, and Treasure Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - mg/kg is milligram/kilogram; wwt is wet weight).

Reservoir	Species - Sample No.	Mercury (mg/kg wwt)	Detection Limit (mg/kg wwt)
Quanah Parker Lake	Channel Catfish - QP006	0.08	0.011
	Channel Catfish - QP007	0.06	0.009
	Channel Catfish - QP008	0.16	0.009
	Channel Catfish - QP009	0.10	0.011
	Channel Catfish - QP010	0.08	0.010
	Bluegill - QP026	0.14	0.013
	Bluegill - QP027	0.14	0.012
	Bluegill - QP028	0.23	0.015
	Bluegill - QP029	0.13	0.016
	Bluegill - QP030	0.21	0.012
	Largemouth Bass - QP021	1.16	0.025
	Largemouth Bass - QP022	1.13	0.018
	Largemouth Bass - QP023	0.85	0.014
	Largemouth Bass - QP024	0.52	0.014
	Largemouth Bass - QP025	0.55	0.017
Elmer Thomas Lake	Channel Catfish - ET011	0.03	0.014
	Channel Catfish - ET012	0.05	0.011
	Channel Catfish - ET013	0.13	0.013
	Channel Catfish - ET014	0.08	0.013
	Channel Catfish - ET015	0.67	0.015
	Bluegill - ET021	0.19	0.012
	Bluegill - ET022	0.23	0.016
	Bluegill - ET023	0.12	0.015
	Bluegill - ET024	0.21	0.011
	Bluegill - ET025	0.08	0.015
	Largemouth Bass - ET001	0.49	0.018
	Largemouth Bass - ET002	0.39	0.010
	Largemouth Bass - ET003	0.38	0.012
	Largemouth Bass - ET004	0.40	0.019
	Largemouth Bass - ET005	0.34	0.014

Table 3 (continued). Total mercury analytical results in parts per million (mg/kg) for fish fillets collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Burford Lake, Osage Lake, Post Oak Lake, and Tresure Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - mg/kg is milligram/kilogram; ww t is wet weight).

Reservoir	Species - Sample No.	Mercury (mg/kg ww t)	Detection Limit (mg/kg ww t)
Lost Lake	Channel Catfish - LL024	0.07	0.012
	Black Bullhead - LL025	0.32	0.013
	Black Bullhead - LL026	0.66	0.012
	Bluegill - LL007	0.14	0.014
	Bluegill - LL008	0.17	0.008
	Bluegill - LL009	0.17	0.009
	Bluegill - LL011	0.16	0.017
	Bluegill - LL014	0.09	0.012
	Largemouth Bass - LL002	0.82	0.016
	Largemouth Bass - LL003	1.26	0.017
	Largemouth Bass - LL017	1.06	0.013
	Largemouth Bass - LL018	0.41	0.011
	Largemouth Bass - LL020	1.05	0.018
French Lake	Channel Catfish - FL021	0.08	0.018
	Channel Catfish - FL026	0.30	0.002
	Black Bullhead - FL027	0.39	0.003
	Bluegill - FL001	0.21	0.016
	Bluegill - FL002	0.24	0.015
	Bluegill - FL003	0.08	0.015
	Bluegill - FL004	0.11	0.019
	Bluegill - FL005	0.29	0.018
	Largemouth Bass - FL011	0.75	0.016
	Largemouth Bass - FL012	1.72	0.017
	Largemouth Bass - FL013	0.99	0.018
	Largemouth Bass - FL014	0.51	0.018
	Largemouth Bass - FL015	0.54	0.019

Table 3 (continued). Total mercury analytical results in parts per million (mg/kg) for fish fillets collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Burford Lake, Osage Lake, Post Oak Lake, and Treasure Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - mg/kg is milligram/kilogram; wwt is wet weight).

Reservoir	Species - Sample No.	Mercury (mg/kg wwt)	Detection Limit (mg/kg wwt)
Caddo Lake	Channel Catfish - CAD028	0.09	0.001
	Channel Catfish - CAD029	0.20	0.002
	Channel Catfish - CAD030	0.28	0.002
	Black Bullhead - CAD021	0.25	0.019
	Black Bullhead - CAD022	0.10	0.018
	Bluegill - CAD011	0.22	0.019
	Bluegill - CAD012	0.20	0.023
	Bluegill - CAD013	0.15	0.022
	Bluegill - CAD014	0.14	0.023
	Bluegill - CAD015	0.28	0.021
	Largemouth Bass - CAD001	0.43	0.019
	Largemouth Bass - CAD002	0.44	0.020
	Largemouth Bass - CAD003	1.02	0.019
	Largemouth Bass - CAD004	1.34	0.021
	Largemouth Bass - CAD005	0.48	0.022
Crater Lake	Channel Catfish - CL021	0.07	0.001
	Channel Catfish - CL022	0.05	0.001
	Channel Catfish - CL023	0.12	0.001
	Bluegill - CL011	0.09	0.019
	Bluegill - CL012	0.13	0.020
	Bluegill - CL013	0.11	0.019
	Bluegill - CL014	0.15	0.019
	Bluegill - CL015	0.09	0.021
	Largemouth Bass - CL001	1.17	0.004
	Largemouth Bass - CL002	1.05	0.004
	Largemouth Bass - CL003	0.75	0.004
	Largemouth Bass - CL004	0.65	0.004
	Largemouth Bass - CL005	0.71	0.004

Table 3 (continued). Total mercury analytical results in parts per million (mg/kg) for fish fillets collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Burford Lake, Osage Lake, Post Oak Lake, and Treasure Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - mg/kg is milligram/kilogram; ww t is wet weight).

Reservoir	Species - Sample No.	Mercury (mg/kg ww t)	Detection Limit (mg/kg ww t)
Burford Lake	Channel Catfish - BL021	0.07	0.022
	Channel Catfish - BL022	0.04	0.001
	Channel Catfish - BL023	0.17	0.002
	Bluegill - BL011	0.08	0.019
	Bluegill - BL012	0.14	0.020
	Bluegill - BL013	0.12	0.021
	Bluegill - BL014	0.15	0.021
	Bluegill - BL015	0.14	0.018
	Largemouth Bass - BL001	0.69	0.020
	Largemouth Bass - BL002	0.73	0.017
	Largemouth Bass - BL003	0.77	0.020
	Largemouth Bass - BL004	0.77	0.018
	Largemouth Bass - BL005	0.85	0.022
Osage Lake	Black Bullhead - OL014	0.80	0.005
	Bluegill - OL003	0.48	0.004
	Bluegill - OL004	0.23	0.002
	Bluegill - OL005	0.18	0.001
	Bluegill - OL006	0.24	0.002
	Bluegill - OL007	0.33	0.003
	Largemouth Bass - OL001	0.67	0.005
	Largemouth Bass - OL002	1.29	0.011
	Largemouth Bass - OL013	0.44	0.003

In humans, methylmercury has a greater affinity for the brain, particularly the posterior cortex, than any other organ system (Goyer, 1991). Major human health concerns include neurotoxic effects to adults and children, and toxicity to the fetus of mothers exposed during pregnancy (Goyer, 1991). Genotoxic effects can occur during prenatal development resulting in chromosomal aberrations in the fetus due to methylmercury interacting with fetal deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) and binding with sulfhydryl groups resulting in changes of the secondary structure of DNA and RNA synthesis (Goyer, 1991). In adults, the overall acute effect is cerebral edema with the onset of paresthesia (numbness and tingling sensations around the lips, fingers, and toes), but chronic exposure can lead to the destruction of grey matter and cerebral atrophy (Goyer, 1991; USFDA, 1995). Children suffering from prenatal exposure typically demonstrate psychomotor retardation, but may also develop ataxis motor disturbances and mental symptoms similar to cerebral palsy (Goyer, 1991).

Table 3 (continued). Total mercury analytical results in parts per million (mg/kg) for fish fillets collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Burford Lake, Osage Lake, Post Oak Lake, and Tresure Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - mg/kg is milligram/kilogram; wwt is wet weight).

Reservoir	Species - Sample No.	Mercury (mg/kg wwt)	Detection Limit (mg/kg wwt)
Post Oak Lake	Channel Catfish - POL002	0.28	0.002
	Channel Catfish - POL014	0.26	0.002
	Channel Catfish - POL017	0.19	0.002
	Bluegill - POL003	0.34	0.002
	Bluegill - POL004	0.40	0.003
	Bluegill - POL005	0.29	0.002
	Bluegill - POL006	0.33	0.003
	Bluegill - POL007	0.31	0.002
	Largemouth Bass - POL001	0.90	0.010
	Largemouth Bass - POL015	1.12	0.011
	Largemouth Bass - POL016	0.67	0.005
Treasure Lake	Black Bullhead - TL019	0.10	0.001
	Bluegill - TL001	0.32	0.002
	Bluegill - TL002	0.18	0.001
	Bluegill - TL003	0.37	0.003
	Bluegill - TL004	0.23	0.002
	Bluegill - TL005	0.13	0.001
	Largemouth Bass - TL011	0.60	0.005
	Largemouth Bass - TL012	0.74	0.005
	Largemouth Bass - TL013	0.69	0.005
	Largemouth Bass - TL014	0.48	0.004
	Largemouth Bass - TL015	0.74	0.005

Table 4. Arithmetic mean mercury concentrations in mg/kg wet weight for fish fillets collected from 12 reservoirs at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - n = sample size).

Reservoir	Catfish*	Bluegill	Largemouth Bass
Rush	0.16 (n = 5)	0.24 (n = 5)	1.02 (n = 5)
Jed Johnson	0.20 (n = 5)	0.14 (n = 5)	0.84 (n = 5)
Quanah Parker	0.10 (n = 5)	0.17 (n = 5)	0.84 (n = 5)
Elmer Thomas	0.19 (n = 5)	0.17 (n = 5)	0.40 (n = 5)
Lost	0.35 (n = 3)	0.15 (n = 5)	0.92 (n = 5)
French	0.26 (n = 3)	0.19 (n = 5)	0.90 (n = 5)
Caddo	0.18 (n = 5)	0.20 (n = 5)	0.74 (n = 5)
Crater	0.08 (n = 3)	0.11 (n = 5)	0.87 (n = 5)
Burford	0.09 (n = 3)	0.13 (n = 5)	0.76 (n = 5)
Osage	0.80[1]	0.29 (n = 5)	0.80 (n = 3)
Post Oak	0.24 (n = 3)	0.33 (n = 5)	0.90 (n = 3)
Treasure	0.10[1]	0.25 (n = 5)	0.65 (n = 5)

*The arithmetic mean mercury concentrations for catfish are based on channel catfish analytical results with the exception of Lost Lake, French Lake, Caddo Lake, Osage Lake, and Treasure Lake which also includes black bullhead analytical results.
[1]Means reported for catfish from Osage Lake and Treasure Lake represent one sample from each reservoir.

The average mercury concentration in the blood and hair of non-exposed people is 8 parts per billion [micrograms per liter (µg/L)] and 2 mg Hg/kg, respectively, whereas toxic effects are expected in people who have mercury-blood concentrations of 200 µg Hg/L and mercury-hair levels of 50 mg Hg/kg (USFDA, 1995). According to Goyer (1991), the estimated average long-term daily intake associated with adverse health effects in an adult is 4.3 µg Hg/day/kg of body weight while adverse prenatal effects are expected at maternal intake concentrations of 0.8 to 1.7 µg Hg/day/kg of body weight. The United States Food and Drug Administration (USFDA) has established an action level of 1 mg Hg/kg wet weight for total mercury in fish tissues for initiating fish consumption advisories to protect public health (USEPA, 1989). In comparison, the United States Environmental Protection Agency (USEPA) recommends a tissue residue criterion of 0.3 mg Hg/kg wet weight to be protective of human health (USEPA, 2001a). None of the mean detected mercury concentrations in bluegill fillets and catfish (including black bullheads in the case of Lost Lake, French Lake, Caddo Lake, Osage Lake, and Treasure Lake) fillets collected from the reservoirs at Wichita Mountains Wildlife

Refuge (Table 4) exceeded the USFDA human health action level. In addition, none of the individual bluegill, channel catfish, or black bullhead samples contained mercury levels (Table 3) that exceeded the USFDA limit. Individually, one channel catfish and two bluegill collected from Lake Rush, one channel catfish collected from Lake Jed Johnson, one channel catfish collected from Elmer Thomas Lake, both black bullheads collected from Lost Lake, one channel catfish and one black bullhead from French Lake, one black bullhead and two bluegills collected from Osage Lake, four bluegills from Post Oak Lake, and two bluegills collected from Treasure Lake contained mercury concentrations (Table 3) that equaled or exceeded the USEPA criterion. In total, 16% of the bluegill collected during the course of this study, 11% of the channel catfish, and 57% of the bullheads collected contained fillet-mercury concentrations that were elevated in comparison to the USEPA criterion.

In contrast to the bluegill and catfish, 100% of the individual largemouth bass collected from the Refuge exceeded the USEPA criterion. In addition, mean largemouth bass fillet samples collected from Lake Rush ($\bar{x}$ = 1.02 mg Hg/kg wet weight) exceeded both the USFDA and USEPA criteria, whereas mean largemouth bass fillets collected from the remaining 11 reservoirs exceeded only the USEPA criterion. Individual bass samples collected from Lake Jed Johnson, Quanah Parker Lake, Lost Lake, French Lake, Caddo Lake, Crater Lake, Osage Lake, and Post Oak Lake exceeded the USFDA limit. Furthermore, all individual largemouth bass samples were elevated in comparison to the detected concentration in a largemouth bass fillet (0.13 mg Hg/kg wet weight) collected for a national study in 1986 from Fort Cobb Reservoir (USEPA, 1992), which is located within the Arkansas River-Red River Ecosystem in Caddo County, Oklahoma, north of the Wichita Mountains. Although eight of the twelve reservoirs sampled contained individual largemouth bass with mercury concentrations exceeding the USFDA action level, the mean detected concentrations in largemouth bass from these reservoirs (Table 4) were less than the detected mean concentration in largemouth bass ($\bar{x}$ = 1.44 mg Hg/kg wet weight) collected from gold/silver mine contaminated sites within the Pena Blanca watershed in Arizona, an area where a human fish consumption advisory has been established due to the elevated fish tissue-mercury concentrations (Tetra Tech, 1997).

A typical human-fish consumption advisory based on elevated mercury content consists of establishing consumption limits for particular sectors of the population over a given period of time. For example, the advisory established by the State of Texas at Caddo Lake in the Cypress Creek watershed in East Texas which is a component of the Arkansas River-Red River Ecosystem, states that adults should consume no more than two meals, not to exceed 8 ounces (226.8 grams) of fish per serving, per month, whereas children should consume no more than two meals per month, not to exceed 4 ounces (113.4 grams) of fish per serving (TDH, 1997). In comparison, advisories established at D'Arbonne and Upper Ouachita National Wildlife Refuges in northern Louisiana, recommend that pregnant women and children less than 7-years of age consume no bass and limit the consumption of other species of fish to two meals (8 ounces or 226.8 grams) per month, while non-pregnant women, men, and children 7-years of age or older, should limit the consumption of bass to two meals per month with no limit being placed on the consumption of other species of fish (Conzelmann, personal communication, 2001). For an additional comparison, the USFDA (1995) recommends that persons other than pregnant women and women of child bearing age who may become pregnant consume no more than 7 ounces (198.5 grams) of fish per week when mercury levels in fish are detected at 1 mg Hg/kg. For fish with mercury levels averaging 0.5 mg Hg/kg, the USFDA (1995) recommends that regular consumption should be limited to no more than 14 ounces (396.9 grams) per week. According to the USEPA (2001b), some states (for example, Georgia, Michigan, Minnesota, New York, and Oregon) have even issued non-consumption advisories, regardless of fish species, for pregnant women, nursing mothers, and young children.

Risk-based monthly consumption limits developed by the USEPA (2001b) for methylmercury levels detected in fish tissues, regardless of the species, are presented in Table 5. These limits were

Table 5. Monthly consumption limits recommended by the USEPA (2001b) for methylmercury in fish tissues (Note > is greater than).

Fish tissue concentration	Fish meals per month
>0.03 to 0.06 mg Hg/kg wet weight	16
>0.06 to 0.08 mg Hg/kg wet weight	12
>0.08 to 0.12 mg Hg/kg wet weight	8
>0.12 to 0.24 mg Hg/kg wet weight	4
>0.24 to 0.32 mg Hg/kg wet weight	3
>0.32 to 0.48 mg Hg/kg wet weight	2
>0.48 to 0.97 mg Hg/kg wet weight	1
>0.97 to 1.90 mg Hg/kg wet weight	0.5
>1.90 mg Hg/kg wet weight	No consumption

calculated using the following assumptions: average adult consumer body weight is 70 kg (154.4 pounds); average fish meal size equals 0.227 kg (8 oz); time-averaging period is one month (30.4 days); and USEPA methylmercury reference dose (RfD) equals 1×10^{-4} mg Hg/kg/day (USEPA, 2001b).

Table 5. Results of metals analyses in mg/kg wet weight for whole body composite channel catfish (CCC), bluegill (BGSC), and largemouth bass (LMBC) samples collected from Lake Rush (RR), Lake Jed Johnson (JJ), and Quanah Parker Lake (QP), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	RRCCC	RRBGSC	RRLMBC	JJCCC	JJBGSC	JJLMBC	QPCCC	QPBGSC	QPLMBC
Aluminum	124.00	14.70	2.48	26.20	3.69	2.19	22.90	27.90	4.46
dl	0.30	0.31	0.32	0.35	0.34	0.32	0.37	0.33	0.35
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.06
Cadmium	0.008	bdl	bdl	0.021	0.006	0.015	0.008	0.009	bdl
dl	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Chromium	0.57	0.44	0.43	0.62	0.26	0.33	0.73	0.15	0.15
dl	0.05	0.05	0.05	0.06	0.06	0.05	0.06	0.05	0.06
Copper	0.35	0.32	0.24	0.79	0.38	0.36	0.43	0.32	0.41
dl	0.02	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03
Iron	160.00	38.60	22.30	77.70	15.50	42.20	62.40	25.60	16.20
dl	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.06
Lead	0.18	0.05	0.05	0.25	0.04	0.14	0.10	0.06	0.06
dl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Magnesium	408.00	388.00	472.00	367.00	508.00	474.00	431.00	539.00	619.00
dl	0.62	0.60	0.64	0.70	0.67	0.63	0.73	0.65	0.69
Manganese	31.20	14.60	1.80	12.00	13.00	4.48	7.31	9.79	2.37
dl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mercury	0.04	0.15	1.02	0.05	0.08	0.59	0.08	0.09	0.39
dl	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01
Molybdenum	bdl	bdl	bdl	bdl	0.11	bdl	bdl	bdl	bdl
dl	0.08	0.08	0.08	0.09	0.09	0.08	0.09	0.08	0.09
Nickel	0.52	0.35	0.64	0.35	0.62	0.45	0.48	0.57	0.70
dl	0.13	0.12	0.13	0.14	0.14	0.13	0.15	0.13	0.14
Selenium	0.04	0.34	0.26	0.18	0.36	0.41	0.28	0.33	bdl
dl	0.03	0.03	0.07	0.08	0.08	0.07	0.04	0.07	0.07
Zinc	14.90	21.70	13.40	16.90	22.40	17.40	21.00	23.50	20.20
dl	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.04

Table 5 (continued). Results of metals analyses in mg/kg wet weight for whole body composite channel catfish (CCC), black bullhead (BHC or WBBH), bluegill (BGSC), largemouth bass (LMBC), and softshell turtle (WBSS) samples collected from Elmer Thomas Lake (ET), Lost Lake (LL), and French Lake (FL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	ETCCC	ETBGSC	ETLMBC	LLBHC	LLBGSC	LLLMBC	FLWBBH	FLBGSC	FLLMBC	FLWBSS
Aluminum	52.40	11.70	2.46	3.19	18.80	3.49	5.42	4.33	1.88	66.80
dl	0.38	0.36	0.33	0.29	0.35	0.31	1.14	0.32	0.30	1.07
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.07	0.06	0.06	0.05	0.06	0.06	0.11	0.06	0.05	0.11
Cadmium	0.008	0.006	bdl	0.009	0.008	0.005	0.004	bdl	bdl	0.007
dl	0.005	0.005	0.005	0.004	0.005	0.004	0.001	0.005	0.004	0.002
Chromium	0.70	0.58	0.51	0.45	0.40	0.33	0.14	0.33	0.34	0.41
dl	0.06	0.06	0.05	0.05	0.06	0.05	0.11	0.05	0.05	0.11
Copper	0.46	0.47	0.44	0.53	0.35	0.47	0.67	0.26	0.23	1.06
dl	0.03	0.03	0.03	0.02	0.03	0.02	0.11	0.03	0.02	0.11
Iron	163.00	31.40	22.50	24.90	39.90	38.30	18.20	19.80	14.20	120.00
dl	0.07	0.06	0.06	0.05	0.06	0.06	0.23	0.06	0.05	0.21
Lead	0.11	0.12	0.05	0.18	0.11	0.05	bdl	bdl	bdl	0.17
dl	0.02	0.02	0.02	0.02	0.02	0.02	0.08	0.02	0.02	0.08
Magnesium	379.00	428.00	434.00	387.00	484.00	473.00	359.00	481.00	464.00	265.00
dl	0.76	0.71	0.66	0.58	0.70	0.62	0.23	0.64	0.59	0.22
Manganese	17.10	14.80	2.71	4.48	11.90	3.15	3.98	11.30	2.34	3.26
dl	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.04
Mercury	0.08	0.04	0.23	0.14	0.08	0.59	0.28	0.12	0.35	0.25
dl	0.02	0.02	0.02	0.02	0.02	0.01	0.006	0.02	0.02	0.005
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.10	bdl	bdl
dl	0.10	0.09	0.09	0.08	0.09	0.08	0.23	0.08	0.08	0.21
Nickel	0.65	0.36	0.47	0.34	0.59	0.51	bdl	0.48	0.44	2.65
dl	0.15	0.15	0.14	0.12	0.14	0.13	0.11	0.13	0.12	0.11
Selenium	0.40	0.50	0.44	0.22	0.11	0.34	0.19	0.16	0.22	0.24
dl	0.08	0.08	0.07	0.03	0.08	0.03	0.005	0.03	0.06	0.004
Zinc	17.20	19.90	16.20	17.90	24.80	15.50	13.80	23.80	15.50	24.50
dl	0.04	0.04	0.03	0.03	0.04	0.03	0.11	0.03	0.03	0.11

Table 5 (continued). Results of metals analyses in mg/kg wet weight for whole body composite channel catfish (WBCC), bluegill (WBBG), and largemouth bass (WBLMB) samples collected from Crater Lake (CL), Burford Lake (BL), and Caddo Lake (CAD), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	CLWBBG	CLWBLMB	BLWBBG	BLWBLMB	CADWBCC	CADWBBG	CADWBLMB
Aluminum	71.80	5.96	58.80	13.00	13.00	22.00	7.58
dl	1.23	1.28	1.22	1.28	1.32	1.20	1.36
Arsenic	0.62	0.74	0.74	0.78	bdl	0.94	0.74
dl	0.12	0.13	0.12	0.14	0.13	0.12	0.14
Cadmium	bdl	bdl	bdl	bdl	0.012	bdl	bdl
dl	0.03	0.03	0.03	0.03	0.001	0.02	0.03
Chromium	0.75	0.90	1.92	0.66	0.14	1.45	0.50
dl	0.12	0.13	0.12	0.13	0.13	0.12	0.14
Copper	0.36	0.25	0.37	0.42	0.83	0.27	0.24
dl	0.12	0.13	0.12	0.13	0.13	0.12	0.14
Iron	66.10	13.70	66.40	22.10	32.60	34.30	13.20
dl	2.50	2.60	2.50	2.60	0.26	2.40	2.72
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.25	0.26	0.25	0.26	0.09	0.24	0.27
Magnesium	474.00	565.00	514.00	541.00	315.00	703.00	542.00
dl	2.50	2.60	2.50	2.60	0.26	2.40	2.72
Manganese	17.30	2.90	6.49	2.92	15.80	16.10	2.13
dl	0.10	0.10	0.10	0.10	0.05	0.10	0.11
Mercury	0.10	0.32	0.16	0.37	0.13	0.10	0.34
dl	0.03	0.03	0.03	0.03	0.006	0.02	0.03
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.12	0.13	0.12	0.13	0.26	0.12	0.14
Nickel	bdl	bdl	0.29	bdl	bdl	bdl	bdl
dl	0.12	0.13	0.12	0.13	0.13	0.12	0.14
Selenium	0.50	0.50	0.65	0.54	0.20	0.67	0.62
dl	0.12	0.13	0.12	0.13	0.005	0.12	0.14
Zinc	27.80	14.80	30.20	17.20	15.50	28.90	16.00
dl	0.25	0.26	0.25	0.26	0.13	0.24	0.27

Table 5 (continued). Results of metals analyses in mg/kg wet weight for whole body black bullhead (WBBH), bluegill (WBBG), and largemouth bass (WBLMB) samples collected from Osage Lake (OL), Post Oak Lake (POL), Treasure Lake (TL), and a whole body leopard frog (WM21) sample collected from the Bonanza Mine, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	OLWBBG	POLWBBH	POLWBBG	TLWBBG	TLWBLMB	WM21
Aluminum	59.10	7.08	26.70	59.10	9.64	338.00
dl	1.34	1.21	1.44	1.32	1.33	1.00
Arsenic	bdl	bdl	bdl	bdl	bdl	0.20
dl	0.13	0.12	0.14	0.13	0.13	0.10
Cadmium	0.005	0.016	0.029	0.034	0.034	bdl
dl	0.001	0.001	0.001	0.001	0.001	0.09
Chromium	0.21	bdl	0.20	0.23	0.18	bdl
dl	0.13	0.12	0.14	0.13	0.13	0.60
Copper	0.92	0.84	0.93	0.79	1.41	2.40
dl	0.13	0.12	0.14	0.13	0.13	0.30
Iron	53.50	96.60	37.10	73.80	22.40	2,360.00
dl	0.27	0.24	0.29	0.26	0.27	2.00
Lead	bdl	bdl	bdl	0.11	bdl	1.80
dl	0.09	0.09	0.10	0.09	0.09	0.10
Magnesium	497.00	344.00	374.00	369.00	442.00	325.00
dl	0.27	0.24	0.29	0.26	0.27	2.00
Manganese	11.60	9.05	5.00	7.28	3.54	74.40
dl	0.05	0.05	0.06	0.05	0.05	0.30
Mercury	0.31	0.21	0.36	0.27	0.59	0.20
dl	0.007	0.006	0.007	0.007	0.007	0.08
Molybdenum	1.19	bdl	bdl	bdl	bdl	bdl
dl	0.27	0.24	0.29	0.26	0.27	1.00
Nickel	bdl	bdl	bdl	bdl	bdl	2.60
dl	0.13	0.12	0.14	0.13	0.13	0.40
Selenium	0.23	0.16	0.30	0.36	0.32	0.55
dl	0.005	0.005	0.006	0.005	0.005	0.07
Zinc	24.10	16.60	21.80	22.30	18.70	99.40
dl	0.13	0.12	0.14	0.13	0.13	0.40

Table 6A. Results of metals analyses in mg/kg wet weight for brain tissues from red-eared slider (RE) and pallid spiny softshell (SS) samples collected from Lost Lake (LL), French Lake (FL), Burford Lake (BL), and Osage Lake (OL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	LLRE01	LLRE02	LLRE03	FLRE01	FLRE02	FLRE03	FLSS	BLRE01	BLRE02	OLRE01	OLRE02	OLRE03	OLRE04
Aluminum	1.09	bdl	1.54	bdl	bdl	bdl	bdl	1.20	bdl	3.17	bdl	8.25	bdl
dl	0.92	1.28	1.21	5.63	3.23	1.76	0.60	1.15	2.04	1.74	2.49	2.62	1.42
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.10	0.13	0.12	0.56	0.32	0.18	0.06	0.12	0.20	0.17	0.25	0.26	0.14
Cadmium	0.0031	0.0018	0.0015	0.0079	0.0039	0.0028	0.0022	0.0018	0.0025	0.0024	bdl	0.0039	0.0025
dl	0.0009	0.0013	0.0012	0.0056	0.0032	0.0018	0.0006	0.0012	0.0020	0.0017	0.0025	0.0026	0.0014
Chromium	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.40	0.93	bdl
dl	0.09	0.13	0.12	0.56	0.32	0.18	0.06	0.12	0.20	0.17	0.25	0.26	0.14
Copper	1.67	1.52	1.14	1.27	0.98	1.62	1.18	2.18	1.04	0.79	1.62	2.30	1.74
dl	0.09	0.13	0.12	0.56	0.32	0.18	0.06	0.12	0.20	0.17	0.25	0.26	0.14
Iron	10.90	9.46	11.10	33.60	18.00	9.50	16.20	12.20	12.50	10.90	11.60	18.30	15.90
dl	0.35	0.26	0.24	1.13	0.65	0.35	0.12	0.23	0.41	0.35	0.50	0.53	0.28
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.06	0.09	0.08	0.39	0.23	0.12	0.04	0.08	0.14	0.12	0.18	0.19	0.10
Magnesium	90.50	106.00	115.00	164.00	192.00	105.00	98.70	124.00	147.00	126.00	129.00	117.00	111.00
dl	0.18	0.26	0.24	1.13	0.65	0.35	0.12	0.23	0.41	0.35	0.50	0.53	0.28
Manganese	0.77	0.43	0.42	bdl	0.85	0.30	0.24	0.46	0.39	0.31	0.28	0.36	0.57
dl	0.04	0.05	0.05	0.23	0.13	0.07	0.02	0.05	0.08	0.07	0.10	0.11	0.06
Mercury	0.046	0.044	0.031	0.019	0.031	0.023	0.194	0.085	0.033	0.049	0.044	0.081	0.026
dl	0.002	0.003	0.002	0.011	0.007	0.004	0.001	0.002	0.004	0.004	0.005	0.005	0.003
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.18	0.26	0.24	1.13	0.65	0.35	0.12	0.23	0.41	0.35	0.50	0.53	0.28
Nickel	bdl	bdl	bdl	1.24	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.10	0.13	0.12	0.56	0.32	0.18	0.06	0.12	0.20	0.17	0.25	0.26	0.14
Selenium	0.111	0.184	0.101	0.095	0.135	0.071	0.181	0.115	0.099	0.107	0.127	0.106	0.094
dl	0.012	0.017	0.016	0.076	0.043	0.023	0.009	0.015	0.027	0.023	0.032	0.053	0.019
Zinc	6.40	7.15	6.33	8.78	8.56	6.42	6.90	7.38	6.85	7.07	7.74	6.61	6.52
dl	0.09	0.13	0.12	0.56	0.32	0.18	0.06	0.12	0.20	0.17	0.25	0.26	0.14

Table 6B. Results of metals analyses in mg/kg wet weight for livers from red-eared slider (RE) and pallid spiny softshell (SS) samples collected from Lost Lake (LL), French Lake (FL), Burford Lake (BL), and Osage Lake (OL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	LLRE01	LLRE02	LLRE03	FLRE01	FLRE02	FLRE03	FLSS	BLRE01	BLRE02	OLRE01	OLRE02	OLRE03	OLRE04
Aluminum	16.80	5.99	8.69	1.56	1.75	1.65	66.20	8.75	4.37	6.40	1.32	bdl	16.20
dl	0.91	1.05	1.09	1.26	1.69	0.94	1.10	0.90	1.20	1.32	1.20	1.63	1.09
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.09	0.11	0.11	0.13	0.17	0.09	0.11	0.09	0.12	0.13	0.12	0.16	0.11
Cadmium	0.0252	0.0054	0.0107	0.0131	0.0061	0.0122	0.0213	0.0276	0.0103	0.0108	0.0086	0.0104	0.0350
dl	0.0009	0.0011	0.0011	0.0013	0.0017	0.0009	0.0011	0.0009	0.0012	0.0013	0.0012	0.0016	0.0011
Chromium	0.18	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.09	0.11	0.11	0.13	0.17	0.09	0.11	0.09	0.12	0.13	0.12	0.16	0.11
Copper	14.10	3.14	4.10	4.98	1.13	2.94	1.57	1.28	1.12	1.26	2.51	2.04	7.72
dl	0.09	0.11	0.11	0.13	0.17	0.09	0.11	0.09	0.12	0.13	0.12	0.16	0.11
Iron	483.00	265.00	980.00	238.00	411.00	427.00	950.00	922.00	891.00	2,130.00	292.00	460.00	1,870.00
dl	0.18	0.21	0.22	0.25	0.34	0.19	0.22	0.18	0.24	0.27	0.24	0.33	0.22
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.11	bdl	0.23	bdl	0.09
dl	0.06	0.07	0.08	0.09	0.12	0.07	0.08	0.06	0.08	0.09	0.08	0.11	0.08
Magnesium	114.00	134.00	149.00	187.00	117.00	144.00	132.00	171.00	148.00	159.00	171.00	125.00	180.00
dl	0.18	0.21	0.22	0.25	0.34	0.19	0.22	0.18	0.24	0.27	0.24	0.33	0.22
Manganese	9.80	3.86	4.85	5.26	8.48	2.34	3.85	6.94	11.20	12.40	7.41	8.30	21.90
dl	0.04	0.04	0.04	0.05	0.07	0.04	0.04	0.04	0.05	0.05	0.05	0.07	0.04
Mercury	0.311	0.176	0.190	0.075	0.063	0.074	1.220	0.237	0.094	0.227	0.173	0.187	0.348
dl	0.005	0.005	0.006	0.001	0.002	0.001	0.012	0.005	0.001	0.001	0.001	0.002	0.005
Molybdenum	0.32	bdl	0.29	bdl	bdl	bdl	0.30	0.34	bdl	bdl	bdl	bdl	1.05
dl	0.18	0.21	0.22	0.25	0.34	0.19	0.22	0.18	0.24	0.27	0.24	0.33	0.22
Nickel	0.19	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.09	0.11	0.11	0.13	0.17	0.09	0.11	0.09	0.12	0.13	0.12	0.16	0.11
Selenium	0.549	0.426	0.414	0.271	0.220	0.217	0.959	0.427	0.223	0.342	0.355	0.317	0.429
dl	0.004	0.004	0.004	0.005	0.007	0.004	0.004	0.004	0.005	0.005	0.005	0.007	0.004
Zinc	23.20	17.60	17.00	19.10	12.30	14.80	14.10	16.30	12.30	16.00	15.90	12.70	17.00
dl	0.09	0.11	0.11	0.13	0.17	0.09	0.11	0.09	0.12	0.13	0.12	0.16	0.11

Table 6C. Results of metals analyses in mg/kg wet weight for muscle tissues from red-eared slider (RE) and pallid spiny softshell (SS) samples collected from Lost Lake (LL), French Lake (FL), Burford Lake (BL), and Osage Lake (OL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	LLRE01	LLRE02	LLRE03	FLRE01	FLRE02	FLRE03	FLSS	BLRE01	BLRE02	OLRE01	OLRE02	OLRE03	OLRE04
Aluminum	bdl	2.05	1.20	bdl	3.52	bdl	bdl	3.13	bdl	bdl	5.04	2.67	5.87
dl	0.91	1.00	0.95	1.00	0.97	0.98	0.89	0.93	0.95	1.01	2.58	0.99	1.01
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.26	0.10	0.10
Cadmium	bdl	0.0052	0.0015	0.0014	0.0010	0.0012	bdl	0.0015	0.0023	0.0012	0.0041	0.0016	0.0022
dl	0.0009	0.0010	0.0010	0.0010	0.0010	0.0010	0.0009	0.0009	0.0010	0.0010	0.0026	0.0010	0.0010
Chromium	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	1.06	0.10	bdl
dl	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.26	0.10	0.10
Copper	0.59	0.64	0.64	0.84	0.56	0.56	0.31	0.74	0.73	0.45	1.02	0.66	0.70
dl	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.26	0.10	0.10
Iron	15.40	20.50	17.40	20.70	15.90	13.30	14.40	24.90	22.00	14.20	37.60	13.40	20.30
dl	0.18	0.20	0.19	0.20	0.19	0.20	0.18	0.19	0.19	0.20	0.52	0.20	0.20
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.18	0.07	0.07
Magnesium	135.00	176.00	153.00	190.00	174.00	204.00	133.00	160.00	161.00	159.00	211.00	171.00	170.00
dl	0.18	0.20	0.19	0.20	0.19	0.20	0.18	0.19	0.19	0.20	0.52	0.20	0.20
Manganese	0.36	1.88	0.58	0.35	0.51	0.46	0.19	0.36	0.78	0.48	0.86	0.32	2.22
dl	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.10	0.04	0.04
Mercury	0.040	0.038	0.033	0.018	0.027	0.025	0.422	0.078	0.032	0.069	0.054	0.101	0.037
dl	0.001	0.001	0.001	0.001	0.001	0.001	0.010	0.001	0.001	0.001	0.003	0.001	0.001
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.18	0.20	0.19	0.20	0.19	0.20	0.18	0.19	0.19	0.20	0.52	0.20	0.20
Nickel	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.26	0.10	0.10
Selenium	0.16	0.13	0.15	0.14	0.18	0.13	0.18	0.14	0.17	0.15	0.22	0.16	0.15
dl	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.010	0.004	0.004
Zinc	17.40	19.70	23.00	25.20	23.30	22.00	20.00	29.50	25.60	26.00	19.60	17.50	21.30
dl	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.26	0.10	0.10

Metals in Whole Body Fish, Turtles, & Frogs

The results of the metals analyses in mg/kg wet weight for the composite whole body fish samples collected from the 12 reservoirs, the whole body softshell turtle sample collected from French Lake, and the composite whole body leopard frog sample collected from the Bonanza Mine are presented in Table 6. The results of the metals analyses in mg/kg wet weight for brain, liver, and muscle tissue samples from red-eared sliders collected from Lost Lake, French Lake, Burford Lake, and Osage Lake, and the softshell turtle collected from French Lake are presented in Tables 7A-7C. The fish, turtle, and frog results were compared with screening criteria, predator protection limits, and comparative studies to evaluate the ecological significance of metals contamination within the Refuge as well as address potential human health concerns. As with the fillet samples, channel catfish and largemouth bass greater than 300 mm (12 inches) in length, black bullhead greater than 200 mm (8 inches) in length, and bluegill greater than 150 mm (6 inches) in length were targeted for the analyses. However, due to the limited number of fish collected from Treasure Lake, largemouth bass less than 300 mm (12 inches) and bluegill less than 150 mm (6 inches) were submitted from this reservoir for analyses. In addition, no whole body catfish or bullhead samples were collected from Crater Lake, Burford Lake, Osage Lake, and Treasure Lake, while no whole body largemouth bass samples were collected from Osage Lake and Post Oak Lake.

[Aluminum (Al)] Bioavailability of aluminum in an aqueous environment is driven by pH (Sparling and Lowe, 1996). Aluminum is relatively innocuous when the pH ranges from 5.5 to 7.5 but becomes soluble and biologically available when the pH is less than 5.5 (Sparling and Lowe, 1996). For many species of fish exposed to elevated levels of aluminum, toxic effects appear to correlate with decreasing pH, resulting in adverse effects that shift from asphyxiation to impaired ion regulation (Sparling and Lowe, 1996). In birds, elevated levels of aluminum in the diet can result in adverse effects in calcium and phosphorus metabolism (Sparling and Lowe, 1996). In humans, the daily average intake of aluminum is estimated to be 20 mg Al/day (Goyer, 1991). Typically, the human body maintains a balance between aluminum exposure and content within body tissues so that very little aluminum is absorbed; however, with intakes greater than 1000 mg Al/day, retention within the tissues (primarily bone and lung) usually occurs (Goyer, 1991). In turn, excess aluminum can affect absorption of other necessary elements in the gastrointestinal tract and eventually impair intestinal function (Goyer, 1991).

In a study conducted in the Arkansas River-Red River Ecosystem by the USFWS in 1993, whole body largemouth bass collected from Caddo Lake in East Texas contained a mean of 1.3 mg Al/kg wet weight while whole body bluegill taken from the same lake contained a mean of 10.4 mg Al/kg wet weight (Giggleman *et al.*, 1998). A whole body channel catfish sample collected from the Guadalupe River for a baseline study conducted in 1992 by the USFWS in South Central Texas contained 56.1 mg Al/kg wet weight (Lee and Schultz, 1994), while whole body channel catfish samples collected in Arizona from the Gila River, a lotic system that receives drainage from agriculture and mining areas, contained up to 67 mg Al/kg wet weight (Baker and King, 1994). In a 1991 study conducted by USFWS at Buffalo Lake National Wildlife Refuge in the Texas

Panhandle, which is also located in the Arkansas River-Red River Ecosystem, a whole body black bullhead sample collected from Tierra Blanca Creek contained 28 mg Al/kg dry weight (Irwin and Dodson, 1991). Tierra Blanca Creek is a lotic system that has been adversely impacted from animal feedlot discharges (Irwin and Dodson, 1991; Baker *et al.*, 1998). By comparison, largemouth bass and bluegill collected from the reservoirs at Wichita Mountains Wildlife Refuge in 2000-2001 contained higher aluminum levels than those reported by Giggleman *et al.* (1998). Collectively, largemouth bass from the Refuge contained a mean of 5.3 mg Al/kg wet weight [sample size (n) = 10], while bluegill contained a mean of 31.6 mg Al/kg wet weight (n = 12). As a feeding group and as separate species, catfish and bullheads collected from the Refuge contained lower aluminum concentrations [collective mean ($\bar{x}$) = 31.7 mg Al/kg wet weight (n = 8); channel catfish $\bar{x}$ = 47.7 mg Al/kg wet weight (n = 5); and black bullhead $\bar{x}$ = 7.2 mg Al/kg wet weight (23.1 mg Al/kg dry weight) (n = 3)] than the levels reported by Irwin and Dodson (1991), Baker and King (1994), and Lee and Schultz (1994). Even though some of the detected concentrations in whole body fish collected from the Refuge were elevated in comparison to other studies, the highest aluminum concentration measured (124 mg Al/kg wet weight in channel catfish collected from Lake Rush) was below 200 mg Al/kg wet weight, which is the predator-prey limit recommended by the National Research Council (1980) for protection of piscivorus feeders.

The whole body softshell turtle sample collected from French Lake in 2000-2001 contained 66.8 mg Al/kg wet weight (252 mg Al/kg dry weight) which exceeded the highest concentration detected in whole body softshell turtles (150.4 mg Al/kg dry weight) collected by the USFWS between 1994-1995 from the Lower Gila River in Arizona (King *et al.*, 1997) and the concentration detected in whole body softshell turtles (38.8 mg Al/kg wet weight) collected in 1985-1986 by the USFWS from the Lower Rio Grande in South Texas (Gamble *et al.*, 1988). Aluminum levels above the analytical detection limits were not detected in the brain and muscle tissues sampled from the French Lake softshell turtle (Tables 7A and 7C); however, the detected liver-aluminum concentration (66.2 mg Al/kg wet weight) in this turtle exceeded the geometric mean concentration (17.8 mg Al/kg) measured in snapping turtle (*Chelydra serpentina*) livers collected in 1992 by the USFWS at Wertheim National Wildlife Refuge in New York (Mann-Klager, 1997). Brain, liver, and muscle samples from the red-eared sliders collected from Lost, French, Burford, and Osage Lakes contained aluminum levels ranging from less than 0.6 to 8.3 mg Al/kg wet weight, 1.3 to 16.8 mg Al/kg wet weight, and less than 0.9 to 5.9 mg Al/kg wet weight (Tables 7A-7C), respectively. Unlike the softshell liver-aluminum concentration, slider liver-aluminum concentrations were below the geometric mean liver-aluminum concentration reported by Mann-Klager (1997) for snapping turtles. The detected muscle-aluminum concentrations in one red-eared slider collected from Lost Lake (2.1 mg Al/kg wet weight), one red-eared slider from French Lake (3.5 mg Al/kg wet weight), one red-eared slider from Burford Lake (3.1 mg Al/kg wet weight), and three red-eared sliders from Osage Lake (range 2.7 to 5.9 mg Al/kg wet weight) exceeded the muscle-aluminum concentration (1.3 mg Al/kg wet weight) detected in a snapping turtle collected by the USFWS in 1988 from the upper Trinity River in North Central Texas which receives influent from numerous urban sources (Irwin, 1988), but were below the concentration (36.5 mg Al/kg) detected in muscular tissue samples from snapping turtles collected at the Aberdeen Proving Ground in Maryland in 1994 (U.S. Army Environmental Hygiene Agency, 1994). The composite whole body frog sample collected at the entrance to Bonanza Mine at Wichita Mountains contained the highest aluminum concentration [338 mg Al/kg wet weight (1,080 mg Al/kg dry weight)] of any of the organisms tested. This concentration exceeded the highest aluminum concentration (771 mg Al/kg dry weight) detected in whole body tiger salamanders (*Ambystoma tigrinum*) collected by the USFWS in 1991 from a cattle stock tank-playa in the Texas Panhandle (Irwin and Dodson, 1991).

[Arsenic (As)] Toxic effects of arsenic to aquatic life are significantly dependent on numerous biological and abiotic factors, including water temperature, pH, organic content, phosphate concentrations, suspended solids, and arsenic speciation (Eisler, 1988a). Birds and freshwater biota usually contain arsenic concentrations less than1 mg As/kg wet weight (USDOI, 1998). In humans and other mammalian species, arsenic can be carcinogenic and teratogenic (NOAA, 1990; USDOI, 1998). The ingestion of large doses of arsenic (70 to180 mg) can be acutely fatal, while chronic exposure to smaller amounts can lead to neurotoxicity of both the peripheral and central nervous systems (Goyer, 1991). Arsenic levels of 0.05 mg/L in the blood and greater than 0.1 mg/L in urine are indicative of excessive exposure (Goyer, 1991). Normal daily intake by humans of arsenic as residue in food is estimated at 0.012-0.025 mg As/day (Law, 1996). In Canada, the action level for initiating human-fish consumption advisories is triggered by a fish tissue-arsenic concentration of greater than or equal to 3.5 mg As/kg wet weight (USEPA, 1989), whereas in the United States, the recommended screening criterion protective of human health for fish consumption is a tissue concentration of 3 mg As/kg wet weight (USEPA, 1995).

According to Schmitt and Brumbaugh (1990), the national 85th percentile for arsenic in whole body fish in the United States is 0.27 mg As/kg wet weight. A largemouth bass collected from Texoma Reservoir, which is an impoundment of the Red River in North Texas and Southern Oklahoma, and a component of the Arkansas River-Red River Ecosystem, contained a whole body arsenic concentration of 0.13 mg As/kg wet weight (Schmitt and Brumbaugh, 1990). Whole body channel catfish collected from the Red River outside of Alexandria (Rapides Parish), Louisiana, which is also located within the Arkansas River-Red River Ecosystem, contained between 0.05-0.08 mg As/kg wet weight (Schmitt and Brumbaugh, 1990). No detectable amounts of arsenic were measured in channel catfish collected from the Guadalupe River in 1992 by the USFWS in South Central Texas (Lee and Schultz, 1994), whereas whole body catfish collected from the Upper Gila River in 1990 by the USFWS in Arizona, contained up to 0.2 mg As/kg wet weight (Baker and King, 1994). Arsenic tissue residues of 1.35 mg As/kg wet weight in juvenile bluegills and 5 mg As/kg wet weight in adult bluegills are considered elevated and potentially hazardous (Eisler, 1988a). Eisler (1988 a) recommends a predator protection limit of 30 mg As/kg wet weight for protection of avian species and other piscivorus wildlife.

Of the 12 reservoirs sampled at Wichita Mountains Wildlife Refuge during 2000-2001, only bluegill and largemouth bass collected from Crater Lake, Burford Lake, and Caddo Lake contained detectable amounts of arsenic (Table 6). The detected arsenic concentrations in bluegill from these three reservoirs ranged from 0.62 mg As/kg wet weight in Crater Lake to 0.94 mg As/kg wet weight in Caddo Lake, while the detected arsenic concentrations in largemouth bass from the same three reservoirs ranged from 0.74 mg As/kg wet weight in Crater and Caddo Lakes to 0.78 mg As/kg wet weight in Burford Lake (Table 6). Although elevated in comparison to other studies, all of the measured arsenic concentrations were well below the predator limit proposed by Eisler (1988a). In addition, none of the channel catfish or black bullhead samples nor any of the turtle samples collected contained arsenic concentrations above the analytical detection limits (Tables 6, and 7A-7C). The composite frog sample collected at the entrance to Bonanza Mine contained 0.2 mg As/kg wet weight (0.6 mg As/kg dry weight). This value was below the arsenic concentration (0.32 mg As/kg wet weight) reported by Clark *et al.* (1998) for a newly-transformed leopard frog collected in 1994 downstream of a closed arsenic-based defoliant production facility in Central Texas, and well below the reported arsenic concentration (11.11 mg As/kg) for a whole body leopard frog collected in 1995 from the Aberdeen Proving Ground in Maryland (U.S. Army, 1995).

[Cadmium (Cd)] Biologically, cadmium is neither essential nor beneficial (Hodges, 1977). Fish typically contain from 0.001 to 0.05 mg/kg of cadmium (Goyer, 1991). Although cadmium accumulates in aquatic organisms, it does not biomagnify in succeeding trophic levels, but it is the only metal that clearly accumulates in increasing concentrations with the increasing age of the exposed animal (Wren *et al.*, 1995). The tolerable limit for cadmium consumed by humans is 0.055 mg Cd/person/day (USEPA, 1994). This metal tends to concentrate in the liver, kidneys, pancreas, and thyroid gland of exposed humans with chronic exposure resulting in renal damage and neurological birth defects (Schneider, 1971; USEPA, 1994). According to Goyer (1991), daily intake in food of 0.14 to 0.16 mg Cd/day for 50 years produced renal dysfunction in adult humans. The USEPA recommended screening criterion for cadmium in fish tissues to address human health concerns is 10 mg Cd/kg wet weight (USEPA, 1995).

The national 85th percentile in the U.S. for cadmium in whole body fish is 0.05 mg Cd/kg wet weight (Schmitt and Brumbaugh, 1990). Largemouth bass collected from Texoma Reservoir in North Texas and bluegill collected from Caddo Lake in East Texas contained no detectable cadmium concentrations (Schmitt and Brumbaugh, 1990; Giggleman *et al.*, 1998). Channel catfish collected from the Red River outside of Alexandria, Louisiana, contained a whole body cadmium concentration of 0.01 mg Cd/kg wet weight (Schmitt and Brumbaugh, 1990), while whole body channel catfish collected from the Guadalupe River in 1992 by the USFWS in South Central Texas, and whole body catfish collected from the Upper Gila River in 1990 by the USFWS in Arizona, contained no detectable amounts of cadmium (Baker and King, 1994; Lee and Schultz, 1994). A whole body black bullhead sample collected from Tierra Blanca Creek in West Texas by the USFWS in 1991 contained 0.58 mg Cd/kg dry weight. A recommended predator protection limit for cadmium in potential prey items of piscivorus wildlife is 0.5 mg Cd/kg wet weight (Irwin, 1988). No detectable amounts of cadmium were measured in whole body softshell turtle samples collected by the USFWS in 1994-1995 from the Lower Gila River in Arizona, whereas whole body softshells collected in the Lower Rio Grande in South Texas by the USFWS in 1985-1986 contained 0.012 mg Cd/kg wet weight (Gamble *et al.*, 1988; King *et al.*, 1997). Six snapping turtles collected from the Hudson River in New York between 1976-1977 contained liver-cadmium concentrations ranging from less than 0.06 to 26.2 mg Cd/kg wet weight and muscle-cadmium concentrations ranging from less than 0.06 to 1.41 mg Cd/kg wet weight (Stone *et al.*, 1980). Snapping turtles collected from contaminated wetlands in New Jersey between 1981-1982, contained liver-cadmium concentrations ranging from 0.08 to 0.1 mg Cd/kg wet weight (Albers *et al.*, 1986). Mann-Klager (1997), reported a geometric mean liver-cadmium concentration of 0.45 mg Cd/kg for snapping turtles collected in 1992 from Wertheim National Refuge in New York.

In comparison, fish collected from the 12 reservoirs at Wichita Mountains Wildlife Refuge in 2000-2001, contained whole body cadmium concentrations ranging from less than 0.004 to 0.034 mg Cd/kg wet weight (Table 6). The whole body softshell turtle sample from French Lake contained 0.007 mg Cd/kg wet weight, while chelonian brain-cadmium concentrations ranged from 0.0015 to 0.0079 mg Cd/kg wet weight (Table 7A); liver-cadmium concentrations ranged from 0.0054 to 0.035 mg Cd/kg wet weight (Table 7B); and muscle concentrations ranged from less than 0.0009 to 0.0052 mg Cd/kg wet weight (Table 7C). The composite frog sample collected at the entrance to Bonanza Mine contained no detectable amount of cadmium (Table 6). Although elevated in comparison to other studies, cadmium levels measured in fish collected from the Refuge were below the 85^{th} percentile value reported by Schmitt and Brumbaugh (1990) and below the predator protection limit recommended by Irwin (1988). The detected whole body concentration in the French Lake softshell was less than the value reported by Gamble *et al.* (1988), while all turtles collected from the Refuge contained liver-cadmium concentrations and muscle-cadmium concentrations less than the values reported by Stone *et al.* (1980), Albers *et al.* (1986), and Mann-Klager (1997).

[Chromium (Cr)] Excessive chromium can be mutagenic, carcinogenic, and teratogenic to a wide variety of organisms (Eisler, 1986). It occurs in aqueous environments in various ionic forms, including the chromous, chromic, chromite, chromate, and/or dichromate ions (Becker and Thatcher, 1973). In the chromic or chromite forms, the ions are trivalent, whereas in the chromate and dichromate forms, the ions are hexavalent (Becker and Thatcher, 1973). Overall toxicity of chromium to aquatic biota is dependent on water hardness, temperature, pH, chemical speciation, and salinity, but in general, hexavalent chromium is more toxic than trivalent chromium (Becker and Thatcher, 1973; Eisler, 1986). Chromium is essential for normal metabolism of insulin and glucose in humans and other animals (Eisler, 1986). Toxicologically, the major immediate effect from ingested chromium in humans is acute renal tubular necrosis (Goyer, 1991). The typical chromium-blood concentration in persons who have not experienced excessive exposure is 0.02-0.03 mg/L (Goyer, 1991). The human health screening level for chromium in fish tissues is 100 mg Cr/kg wet weight (TNRCC, 2000).

In 1993, whole body largemouth bass collected by the USFWS from Caddo Lake in East Texas contained a mean of 0.5 mg Cr/kg wet weight, while whole body bluegill from the same lake contained a mean of 0.6 mg Cr/kg wet weight (Giggleman *et al.*, 1998). King *et al.* (1997) reported a geometric mean of 1.06 mg Cr/kg dry weight for channel catfish collected by the USFWS in 1994-1995 from the Lower Gila River in Arizona, whereas a whole body channel catfish sample collected from the Guadalupe River in 1992 by the USFWS in South Central Texas contained no detectable amounts of chromium (Lee and Schultz, 1994). A whole body black bullhead sample collected by the USFWS in 1991 from Tierra Blanca Creek in West Texas contained 1.1 mg Cr/kg dry weight (Irwin and Dodson, 1991). Collectively, detected chromium levels in both largemouth bass [$\bar{x}$ = 0.43 mg Cr/kg wet weight (n = 10)] and bluegill [$\bar{x}$ = 0.58 mg Cr/kg wet weight (n = 12)] sampled at Wichita Mountains Wildlife Refuge in 2000-2001 contained lower chromium concentrations in comparison to the 1993 East Texas study. The mean detected chromium concentration in channel catfish [$\bar{x}$ = 0.55 mg Cr/kg wet weight ($\bar{x}$ = 2.1 mg Cr/kg dry weight) (n = 5)] collected from the Refuge exceeded the value reported by King *et al.* (1997), while the mean concentration measured in bullheads [$\bar{x}$ = 0.23 mg Cr/kg wet weight ($\bar{x}$ = 1.02 mg Cr/kg dry weight) (n = 3)] was below the value reported by Irwin and Dodson (1991). With the exception of bluegill collected from Burford Lake (7.2 mg Cr/kg dry weight) and Caddo Lake (5.6 mg Cr/kg dry weight), all individual whole body fish samples collected from the 12 reservoirs at the Refuge contained chromium levels (Appendix E) below 4 mg Cr/kg dry weight, which is the recommended piscivorus wildlife predator protection limit proposed by Eisler (1986). The composite frog sample collected at the entrance to Bonanza Mine did not contain detectable amounts of chromium (Table 6). The whole body softshell turtle sample collected from French Lake contained 0.41 mg Cr/kg wet weight (1.54 mg Cr/kg dry weight) which exceeded chromium concentrations (range 0.1 to 0.3 mg Cr/kg wet weight) detected in softshell turtles collected by the USFWS in 1988 from the upper Trinity River in North Central Texas (Irwin, 1989) and the chromium concentration (0.37 mg Cr/kg wet weight) measured by Gamble *et al.* (1988) in a whole body softshell collected from the Lower Rio Grande in South Texas in 1985-1986; however, the detected concentration in the French Lake softshell was below the chromium concentration (0.96 mg Cr/kg wet weight) detected in a whole body composite softshell turtle sample collected by the USFWS in 1986 from the Upper Rio Grande in South West Texas (Irwin, 1989) and below the geometric mean value (1.68 mg Cr/kg dry weight) reported by King *et al.* (1997) for whole body softshells taken from the Lower Gila River in Arizona. Only one of the 13 turtles collected from the Refuge (a red-eared slider from Lost Lake) contained liver-chromium levels above the analytical detection limits (Table 7B), while only two of the turtles collected (red-eared sliders from Osage Lake) contained brain-chromium and muscle-chromium concentrations above the analytical detection limits (Tables 7A and 7C). The measured liver-chromium concentration (0.18 mg Cr/kg wet weight) in the turtle collected from Lost Lake was less than the value (0.36 mg Cr/kg wet weight) reported by Albers *et al.* (1986) for a snapping turtle collected from a contaminated freshwater wetland in New Jersey; less than the geometric mean liver-chromium value (0.94 mg Cr/kg) reported by Mann-Klager (1997) for snapping turtles collected from Wertheim National Wildlife Refuge in New York; and well less than the reported liver-chromium values (range 1 to 1.97 mg Cr/kg wet weight) for snapping turtles collected from a reference wetland in Maryland (Albers *et al.*, 1986). The measured muscle-chromium concentrations (1.1 and 0.1 mg Cr/kg wet weight) in red-eared sliders collected from Osage Lake were less than the value (2.87 mg Cr/kg) reported by the U.S. Army Environmental Hygiene Agency (1994) for a snapping turtle collected in 1994 from the Aberdeen Proving Ground in Maryland.

[Copper (Cu)] Copper is an essential micro-nutrient that interacts in animals with essential trace elements such as iron, zinc, molybdenum, manganese, nickel, and selenium and also with nonessential elements including silver, cadmium, mercury, and lead (Goyer, 1991; Eisler, 1998a). Enzymes concerned with nitrate transformations in algae require copper (Horne and Goldman, 1994). The type and amount of various copper compounds present in freshwater depends on water pH, temperature, alkalinity, and on the concentrations of bicarbonate, sulfide, and organic ligands (Eisler, 1998a). In general, elevated copper concentrations can be more toxic to aquatic organisms than to birds or mammals (USDOI, 1998). Bio-availability and toxicity of copper to aquatic organisms depends primarily on the total concentration of copper present and its speciation (Eisler, 1998a). Copper toxicity appears to exert its major effect on algae by interfering with the activity of enzymes situated on cell membranes (Horne and Goldman, 1994). In humans, acute poisoning from the ingestion of excessive amounts of copper salts may produce death (Goyer, 1991). Normal copper-blood serum levels in humans range from 120-145 μg/deciliter (dl) (Goyer, 1991). Severe hepatic disorders have been documented in children in the U.S. resulting from the ingestion of 10 mg Cu/10 kg child/day through contaminated milk (Goyer, 1991).

The national 85th percentile in the U.S. as reported by Schmitt and Brumbaugh (1990), for copper in whole body fish is 1 mg Cu/kg wet weight. A largemouth bass collected from Texoma Reservoir in North Texas contained a whole body copper concentration of 0.36 mg Cu/kg wet weight (Schmitt and Brumbaugh, 1990). Channel catfish collected from the Red River outside of Alexandria, Louisiana, contained a whole body copper concentration of 0.34 mg Cu/kg wet weight (Schmitt and Brumbaugh, 1990), while a whole body channel catfish sample collected from the Guadalupe River in South Central Texas contained 0.37 mg Cu/kg wet weight (Lee and Schultz, 1994), and a whole body channel catfish sample collected from the Upper Gila River in Arizona contained 1.5 mg Cu/kg wet weight (Baker and King, 1990). Bluegill collected from Caddo Lake in East Texas contained a mean of 0.76 mg Cu/kg wet weight (Giggleman *et al.*, 1998). A whole body black bullhead sample collected from Tierra Blanca Creek in West Texas contained 3.1 mg Cu/kg dry weight (Irwin and Dodson, 1991). A recommended predator protection limit for copper in prey items for avian species and other piscivorus wildlife is 300 mg Cu/kg wet weight (NRC, 1980). Whole body softshell turtles collected from the Lower Gila River in Arizona contained a geometric mean value of 118.9 mg Cu/kg dry weight, whereas whole body softshell turtles collected in the Lower Rio Grande in South Texas contained 1.63 mg Cu/kg wet weight (Gamble *et al.*, 1988; King *et al.*, 1997). Snapping turtles collected from contaminated wetlands in New Jersey contained liver-copper concentrations ranging from 2.08 to 9.72 mg Cu/kg wet weight (Albers *et al.*, 1986). Mann-Klager (1997), reported a geometric mean liver-copper concentration of 11.98 mg Cu/kg for snapping turtles collected from the Wertheim National Refuge in New York. The U.S. Army Environmental Hygiene Agency (1994) reported a muscle-copper concentration of 33.3 mg Cu/kg for a snapping turtle collected from the Aberdeen Proving Ground in Maryland. Whole body tiger salamanders collected from a cattle stock tank-playa in the Texas Panhandle contained up to 4.6 mg Cu/kg dry weight (Irwin and Dodson, 1991).

By comparison, largemouth bass collected from Wichita Mountains Wildlife Refuge in 2000-2001 collectively contained a mean of 0.45 mg Cu/kg wet weight (n = 10), while bluegill contained a mean of 0.48 mg Cu/kg wet weight (n = 12), and catfish/bullheads as a feeding group contained a mean of 0.61 mg Cu/kg wet weight (2.49 mg Cu/kg dry weight) (n = 8). The highest copper level detected in any individual fish sampled from the Refuge was the concentration measured in the whole body composite largemouth bass sample from Treasure Lake (1.41 mg Cu/kg wet weight). All other individual composite fish samples contained copper levels (Table 6) below the national 85th percentile value reported by Schmitt and Brumbaugh (1990). Though high in comparison to other studies, the copper concentration detected in the Treasure Lake largemouth bass was well below the predator protection limit recommended by the National Research Council (1980). The whole body softshell turtle sample collected from French Lake contained 1.06 mg Cu/kg wet weight (4 mg Cu/kg dry weight), while brain, liver, and muscle samples from turtles collected at Lost Lake, French Lake, Burford Lake, and Osage Lake contained copper levels ranging from 0.79 to 2.3 mg Cu/kg wet weight, 1.12 to 14.1 mg Cu/kg wet weight, and 0.31 to 1.02 mg Cu/kg wet weight (Tables 7A-7C), respectively. The detected whole body copper concentration in the French Lake softshell was less than the values reported by Gamble *et al.* (1988) and King *et al.* (1997). With the exception of the liver-copper concentration (14.1 mg Cu/kg wet weight) measured in a red-eared slider collected from Lost Lake, all other chelonian liver-copper concentrations were less than the values reported by Albers *et al.* (1986) and Mann-Klager (1997). All measured muscle-copper concentrations were less than the level detected in snapping turtle samples collected by the U.S. Army Environmental Hygiene Agency (1994). The composite frog sample collected at the entrance to Bonanza Mine contained 2.4 mg Cu/kg wet weight (7.8 mg Cu/kg dry weight), which is greater than the value reported for salamanders by Irwin and Dodson (1991).

[Iron (Fe)] Iron is a necessary nutrient that is a constituent of many enzymatic and other cellular processes (Horne and Goldman, 1994). It is absolutely essential both for the transport of oxygen to the tissues and for maintenance of oxidative systems within the tissue cells (Guyton, 1981). The human body contains approximately 3 to 5 grams of iron of which about 33% is bound to hemoglobin, 10 % is bound to myoglobin and iron containing enzymes, and the remainder is bound to the iron storage proteins ferritin and hemosiderin (Goyer, 1991). The required daily intake to maintain homeostasis in the average human body is 18 mg Fe/day (Guyton, 1981). According to Goyer (1991), acute iron toxicity in humans is nearly always due to accidental ingestion of iron containing medicines, and most often occurs in children. Chronic iron toxicity can occur in humans due to excess dietary iron and can result in hepatic and renal disorders, endocrine disturbances, and negative cardiovascular effects (Goyer, 1991).

Most animals acquire iron directly from their diet (Horne and Goldman, 1994). A recommended predator protection limit in prey items for wildlife is 1000 mg Fe/kg wet weight (NRC, 1980). In 1993, whole body largemouth bass collected by the USFWS from Caddo Lake in East Texas contained a mean of 18.1 mg Fe/kg wet weight while whole body bluegill from the same lake contained a mean of 47.1 mg Fe/kg wet weight (Giggleman *et al.*, 1998). Channel catfish collected from the Guadalupe River in 1992 by the USFWS in South Central Texas contained 52.5 mg Fe/kg wet weight (Lee and Schultz, 1994), while channel catfish collected by the USFWS in 1990 from the Upper Gila River in Arizona contained up to 70 mg Fe/kg wet weight (Baker and King, 1994). A whole body black bullhead sample collected by the USFWS in 1991 from Tierra Blanca Creek in West Texas contained 71 mg Fe/kg dry weight (Irwin and Dodson, 1991). Whole body softshell turtles collected in the Lower Rio Grande in South Texas by the USFWS between 1985-1986 contained 84.3 mg Fe/kg wet weight (Gamble *et al.*, 1988). Mann-Klager (1997), reported a geometric mean liver-iron concentration of 4,839.7 mg Fe/kg in snapping turtles collected in 1992 from the Wertheim National Refuge in New York. The U.S. Army Environmental Hygiene Agency (1994) detected muscle-iron concentrations ranging from 8.8 to 22 mg Fe/kg in snapping turtles collected from the Aberdeen Proving Ground in Maryland in 1994. Whole body tiger salamanders collected by the USFWS in 1991 from a cattle stock tank-playa in the Texas Panhandle contained up to 554 mg Fe/kg dry weight (Irwin and Dodson, 1991).

In comparison, whole body largemouth bass samples collected at Wichita Mountains Wildlife Refuge in 2000-2001 contained slightly higher iron levels [$\bar{x}$ = 22.7 mg Fe/kg wet weight (n = 10)] than the detected concentration in bass collected from Caddo Lake in East Texas, while bluegill from the Refuge contained iron concentrations [$\bar{x}$ = 41.8 mg Fe/kg wet weight (n = 12)] less than the measured level in bluegill from East Texas. As a feeding guild, whole body catfish collected from the Refuge contained iron levels ranging from 18.2 mg Fe/kg wet weight (84.8 mg Fe/kg dry weight) in black bullheads taken from French Lake to 163 mg Fe/kg wet weight (558 mg Fe/kg dry weight) in channel catfish sampled at Elmer Thomas Lake (Table 6 and Appendix E). All of the channel catfish collected from Wichita Mountains contained iron concentrations exceeding the level reported by Lee and Schultz (1994), while the channel catfish sampled from Lake Rush, Lake Jed Johnson, and Elmer Thomas Lake contained iron levels that also exceeded the value reported by Baker and King (1994). All of the whole body black bullheads collected from the Refuge contained iron concentrations that were elevated in comparison to the level reported by Irwin and Dodson (1991). Even though some of the fish collected from Wichita Mountains contained elevated iron levels in comparison to other studies, all of the individual whole body fish samples contained iron concentrations well below the predator protection limit recommended by the National Research Council (1980). The iron concentration measured in the whole body softshell turtle collected from French Lake (120 mg Fe/kg wet weight) exceeded the value reported by Gamble *et al.* (1988). Chelonian brain-iron concentrations ranged from 9.46 mg Fe/kg wet weight measured in a red-eared slider collected from Lost Lake to 33.6 mg Fe/kg wet weight in a red-eared slider from French Lake (Table 7A). Liver-iron concentrations ranged from 238 mg Fe/kg wet weight measured in a red-eared slider taken from French Lake to 2,130 mg Fe/kg wet weight in a red-eared slider sampled in Osage Lake (Table 7B), while muscle-iron concentrations ranged from 13.3 mg Fe/kg wet weight measured in a red-eared slider collected from French Lake to 37.6 mg Fe/kg wet weight in a red-eared slider collected from Osage Lake (Table 7C). The detected turtle liver-iron concentrations were well below the mean value reported by Mann-Klager (1997), whereas two of the 13 turtles collected from the Refuge, contained muscle-iron levels (24.9 mg Fe/kg wet weight in a red-eared slider collected from Burford Lake and 37.6 mg Fe/kg wet weight in a red-eared slider collected from Osage Lake) exceeding the values reported by the U.S. Army Environmental Hygiene Agency (1994). The composite frog sample collected at the entrance to Bonanza Mine contained 2,360 mg Fe/kg wet weight (7,550 mg Fe/kg dry weight), which was well above the value reported for salamanders by Irwin and Dodson (1991).

[Lead (Pb)] Lead is neither essential nor beneficial to living organisms, and unlike mercury, it does not exhibit biomagnification through progressive trophic levels (Eisler, 1988b; Pain 1995). In water, lead is more soluble and bioavailable under conditions of low pH, low organic content, low concentrations of suspended sediments, and low concentrations of calcium, iron, manganese, zinc, and cadmium salts (Eisler, 1988b). Depending on the concentration, lead can adversely affect survival, growth, and/or reproduction in all fish species (Eisler, 1988b). In humans, food is the principal route of exposure to lead (Goyer, 1991). The average dietary intake of adult humans in the

U.S. is 0.1 mg Pb/day (Goyer, 1991). Adults absorb from 5% to 15% of ingested lead but usually retain less than 5% of what is absorbed; however, children demonstrate a greater affinity for the absorption of lead than adults (Goyer, 1991). In adults, the toxic effects of lead can involve several organ systems, whereas in children the critical effects typically involve the central nervous system (Goyer, 1991). *In utero* neurological effects occur at maternal lead-blood serum levels of less than 15 μg/dl (Goyer, 1991). Peripheral neuropathy occurs in both adults and children at lead-blood serum concentrations of 40 μg/dl, while academic performance [i.e., intelligence quotient (I.Q.)] deficits occur in children with lead-blood serum levels of less than 30 μg/dl (Goyer, 1991). The action level for establishing fish consumption advisories in the U.S. for lead in fish tissues is 1.3 mg Pb/kg, while the Canadian action level for human consumption advisories is initiated when lead concentrations are greater than or equal to 0.5 mg Pb/kg wet weight in fish tissues (USEPA, 1989; USEPA, 1997).

Measured lead concentrations in whole body fish collected from Wichita Mountains Wildlife Refuge (Table 6) exceeded the national 85th percentile concentration of 0.22 mg Pb/kg wet weight (Schmitt and Brumbaugh, 1990) in only one sample (0.25 mg Pb/kg wet weight in the whole body composite channel catfish sample from Lake Jed Johnson). Lead was detected above the analytical limits in all three fish groups only in Rush Lake, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, and Lost Lake (Table 6). Collectively, largemouth bass collected from these five reservoirs contained a mean of 0.07 mg Pb/kg wet weight, which exceeded the concentration (0.05 mg Pb/kg wet weight) reported by Schmitt and Brumbaugh (1990) for a largemouth bass collected from Texoma Reservoir in North Texas. The mean detected lead concentration in catfish/bullheads collected from these five reservoirs ($\bar{x}$ = 0.16 mg Pb/kg wet weight) exceeded the lead concentration (0.08 mg Pb/kg wet weight) reported by Schmitt and Brumbaugh (1990) in channel catfish collected from the Red River outside of Alexandria, Louisiana, and the concentration (less than 0.12 mg Pb/kg wet weight) reported by Lee and Schultz (1994) for channel catfish collected from the Guadalupe River in South Central Texas. In addition to the bluegill collected from these five reservoirs, the bluegill sampled from Treasure Lake also contained lead levels above the analytical detection limits. The mean detected lead concentration ($\bar{x}$ = 0.08 mg Pb/kg wet weight) measured in whole body bluegill collected from these six reservoirs was elevated in comparison to bluegill collected from Caddo Lake in East Texas which contained no detectable amount of lead (Giggleman *et al*., 1998). However, none of the detected lead concentrations in any of the individual whole body fish samples collected from the Refuge approached 50 mg Pb/kg wet weight, which is the limit for lead in prey items recommended by the National Research Council (1980) to be protective of avian predators and other piscivorus wildlife. The lead concentration measured in the whole body softshell turtle collected from French Lake (0.17 mg Pb/kg wet weight) exceeded the lead concentration (0.06 mg Pb/kg wet weight) reported by Gamble *et al.* (1988) in softshell turtles collected from the Lower Rio Grande in South Texas. None of the brain and muscle tissues sampled from the 13 turtles collected at the Refuge contained lead levels above the analytical detection limits (Tables 7A and 7C). Only one red-eared slider from Burford Lake and two sliders collected from Osage Lake exhibited liver-lead levels above the analytical detection limits (Table 7B). The measured liver-lead concentrations of these three turtles ranged from 0.09 to 0.23 mg Pb/kg wet weight (Table 7B). Only the highest of these lead concentrations exceeded the mean liver-lead concentration (0.18 mg Pb/kg wet weight) measured in snapping turtles collected during a study conducted on the Big River in Missouri upstream of lead mining sites (Overmann and Krajicek, 1995). However, all three of these sliders contained liver-lead levels below the liver-lead concentrations (range 0.3 to 0.49 mg Pb/kg wet weight) reported by Overmann and Krajicek (1995) for snapping turtles collected on the Big River, downstream of lead mining sites (Overmann and Krajicek, 1995). The composite frog sample collected at the entrance to Bonanza Mine contained 1.8 mg Pb/kg wet weight (5.6 mg Pb/kg dry weight). This value exceeded the highest concentration (0.6 mg Pb/kg dry weight) reported by Irwin and Dodson (1991) for whole body tiger salamanders collected from a cattle stock tank-playa in the Texas Panhandle, but was below all concentrations (range 2.1 to 86.1 mg Pb/kg) reported by the U.S. Army (1995) for whole body leopard frogs collected from the Aberdeen Proving Ground in Maryland.

[Magnesium (Mg)] Magnesium is an essential nutrient that is required for energy transfer in all living cells because it catalyzes the change from adenosine triphosphate (ATP) to adenosine diphosphate (ADP) (Horne and Goldman, 1994). In freshwater systems, magnesium is typically second only to calcium as the most abundant cation present (Cole, 1983). Fish are capable of extracting magnesium from the water, although the majority of it is taken in through dietary sources (Chow and Schell, 2002). The bulk of magnesium in fish is stored in the skeleton with the remainder being distributed throughout the organs, muscle tissues, and in extracellular fluids (Chow and Schell, 2002). The required daily intake of magnesium to maintain homeostasis in the human body is 400 mg Mg/day (Guyton, 1981). Intoxication in humans due to the oral intake of excessive amounts of magnesium salts is rare, but may occur in the face of renal impairment (Goyer, 1991).

In 1993, whole body largemouth bass collected by the USFWS from Caddo Lake in East Texas contained a mean of 456 mg Mg/kg wet weight while whole body bluegill from the same lake contained a mean of 513 mg Mg/kg wet weight (Giggleman *et al*., 1998). Channel catfish collected in the Upper Gila River in Arizona by the USFWS in 1990 contained up to 432 mg Mg/kg wet weight (Baker and King, 1994). A recommended predator protection limit for piscivorus avian species is 3,000 mg Mg/kg wet weight (NRC, 1980). In comparison, largemouth bass collected from Wichita Mountains Wildlife Refuge between 2000-2001 collectively contained a mean of 502.6 mg Mg/kg wet weight (n = 10), while bluegill contained a mean of 479.9 mg Mg/kg wet weight (n = 12) and catfish as a group contained a mean of 373.8 mg Mg/kg wet weight (n = 8). Of the individual whole body fish samples, the largemouth bass collected from Quanah Parker Lake contained the highest magnesium concentration (619 mg Mg/kg wet weight) measured which was well below the predator protection limit recommended by the National Research Council (1980). The whole body magnesium concentration (265 mg Mg/kg wet weight) measured in the softshell turtle collected from French Lake was below the magnesium concentration (417.8 mg Mg/kg wet weight) reported by Gamble *et al.* (1988) for softshell turtles collected in 1985-1986 by the USFWS from the Lower Rio Grande in South Texas. Brain, liver, and muscle tissues from turtles collected at Lost Lake, French Lake, Burford Lake, and Osage Lake contained magnesium levels ranging from 90.5 to 192 mg Mg/kg wet weight, 117 to 187 mg Mg/kg wet weight, and 133 to 211 mg Mg/kg wet weight (Tables 7A-7C), respectively. Measured liver-magnesium concentrations were below the geometric mean value (565.6 mg Mg/kg) reported by Mann-Klager (1997) for liver-magnesium concentrations detected in snapping turtles collected in 1990 from the Wertheim National Wildlife Refuge in New York. In contrast, the muscle-magnesium concentrations measured in turtles collected from the Refuge exceeded the value (1.11 mg Mg/kg) reported in muscular tissue samples from snapping turtles collected in 1994 at the Aberdeen Proving Ground in Maryland (U.S. Army Environmental Hygiene Agency, 1994). The composite leopard frog sample collected at Wichita Mountains from the entrance to Bonanza Mine contained 325 mg Mg/kg wet weight. This value was not compared to data from other studies because comparative data associated with amphibian magnesium levels could not be located.

[Manganese (Mn)] Manganese is a necessary nutrient for plants and animals that is relatively nontoxic to aquatic biota (Wiener and Giesy, 1979; Cole 1983). It stimulates planktonic growth in freshwater conditions by activating enzymatic systems (Cole, 1983). In humans, manganese is an essential element that is a cofactor for a number of enzymatic reactions, but excessive exposure can produce disorders of the pulmonary, hepatic, gastrointestinal, genitourinary, and central nervous systems (Shukla and Singhal, 1984; Goyer, 1991). Normal daily intake for humans ranges from 2 to 9 mg Mn (Goyer, 1991). Once in the body, manganese concentrates in the mitochondria of cells, so that tissues rich in these organelles, such as the pancreas, liver, kidneys, and intestines, tend to contain the highest manganese concentrations (Goyer, 1991). Acute systemic toxicity in humans due to oral intake of manganese salts is rare (Goyer, 1991). This is because the administration of large doses of these salts causes extreme gastrointestinal irritation which results in the vast majority of the manganese being rapidly passed out of the digestive system by means of the feces with very little absorption occurring in the digestive tract (Goyer, 1991). Although, continuous chronic exposure to large amounts of manganese in drinking water has produced symptoms resembling Parkinson's Disease in humans (Shukla and Singhal, 1984).

Whole body largemouth bass collected by the USFWS from Caddo Lake in East Texas in 1993 contained a mean of 7.2 mg Mn/kg wet weight while whole body bluegill from the same lake contained a mean of 65.8 mg Mn/kg wet weight (Giggleman *et al*., 1998). Channel catfish collected in the Upper Gila River in Arizona by the USFWS in 1990 contained up to 6.2 mg Mn/kg wet weight (Baker and King, 1994), whereas a whole body channel catfish sample collected from the Guadalupe River in 1992 by the USFWS in South Central Texas contained 4.4 mg Mn/kg wet weight (Lee and Schultz, 1994). A recommended predator protection limit for piscivorus avian species is 2,000 mg Mn/kg wet weight, while a recommended predator protection limit for mammalian species is 400 mg Mn/kg wet weight (NRC, 1980). Whole body softshell turtles collected in the Lower Rio Grande in South Texas by the USFWS in 1985-1986 contained 3 mg Mn/kg wet weight (Gamble *et al*., 1988). Mann-Klager (1997) reported geometric mean liver-manganese concentrations ranging from 5.4 to 39.3 mg Mn/kg for snapping turtles collected from the Wertheim National Wildlife Refuge in New York between 1990-1992. In comparison, largemouth bass and bluegill collected from the reservoirs at Wichita Mountains Wildlife Refuge in 2000-2001 contained mean manganese concentrations [bass $\bar{x}$ = 2.8 mg Mn/kg wet weight (n = 10) and bluegill $\bar{x}$ = 11.6 mg Mn/kg wet weight (n = 12), respectively] less than the measured concentrations at Caddo Lake in East Texas. As a trophic group, catfish collected from the Refuge contained elevated manganese levels [$\bar{x}$ = 12.6 mg Mn/kg wet weight (n = 8)] in comparison to other studies. However, the highest manganese concentration measured in any of the individual whole body catfish/bullhead samples (31.2 mg Mn/kg wet weight in channel catfish taken from Lake Rush) was below both the avian and mammalian predator protection limits recommended by the National Research Council (1980). The whole body softshell turtle sample collected from French Lake contained 3.3 mg Mn/kg wet weight, which is slightly above the value reported by Gamble *et al.* (1988). Chelonian brain tissue samples collected from the Refuge contained manganese concentrations that ranged from less than 0.23 to 0.85 mg Mn/kg wet weight (Table 7A), while liver-manganese concentrations ranged from 2.34 to 21.9 mg Mn/kg wet weight (Table 7B) and muscle-manganese levels ranged from 0.19 to 2.22 mg Mn/kg wet weight (Table 7C). One red-eared slider collected from Lost Lake, one red-eared slider taken from French Lake, and all the sliders collected from both Burford and Osage Lakes contained liver-manganese concentrations that exceeded the lower geometric mean value reported for snapping turtles by Mann-Klager (1997); however, none of the turtles collected from the Refuge contained liver-manganese levels exceeding the higher manganese concentration stated by Mann-Klager (1997). The composite frog sample collected at the entrance to Bonanza Mine contained 74.4 mg Mn/kg wet weight. This value was not compared to data from other studies because comparative data associated with amphibian manganese levels could not be located.

[Mercury (Hg)] Schmitt and Brumbaugh (1990) report the national 85th percentile for mercury in whole body fish in the U.S. as being 0.17 mg Hg/kg wet weight. A whole body bass sample collected from Texoma Reservoir in North Texas contained 0.03 mg Hg/kg wet weight (Schmitt and Brumbaugh, 1990). Bluegill collected by the USFWS from Caddo Lake in East Texas in 1993 contained a mean whole body mercury concentration of 0.13 mg Hg/kg wet weight (Giggleman *et al.*, 1998). A whole body channel catfish sample collected in 1992 from Fort Gibson Reservoir, which is located in the Arkansas River drainage in Wagoner County, Oklahoma, within the Arkansas River-Red River Ecosystem, contained no detectable mercury (USEPA, 1992). Channel catfish collected in the Upper Gila River in Arizona by the USFWS in 1990 contained up to 0.19 mg Hg/kg wet weight (Baker and King, 1994), while whole body channel catfish collected from the Guadalupe River in 1992 by the USFWS in South Central Texas contained 0.037 mg Hg/kg wet weight (Lee and Schultz, 1994). Whole body black bullhead samples collected in 1991 by the USFWS from Maxwell National Wildlife Refuge in New Mexico contained mercury levels ranging from less than 0.1 to 0.14 mg Hg/kg dry weight (Custer *et al.*, 1993).

In comparison, all of the whole body composite fish samples collected from Wichita Mountains Wildlife Refuge during 2000-2001 contained detectable amounts of mercury (Table 6). Whole body black bullhead samples collected from French Lake [0.28 mg Hg/kg wet weight (1.29 mg Hg/kg dry weight)] and Post Oak Lake [0.21 mg Hg/kg wet weight (0.93 mg Hg/kg dry weight)], bluegill collected from Osage Lake (0.31 mg Hg/kg wet weight), Post Oak Lake (0.36 mg Hg/kg wet weight) and Treasure Lake (0.27 mg Hg/kg wet weight), and all of the composite largemouth bass samples collected from the Refuge (Table 6) exceeded the national 85th percentile value reported by Schmitt and Brumbaugh (1990). Although all of the channel catfish samples collected from the Refuge contained whole body mercury concentrations (Table 5) elevated in comparison to the value reported by Lee and Schultz (1994), none of these catfish samples contained mercury levels exceeding the national 85th percentile criterion (Schmitt and Brumbaugh, 1990). In addition to the measured mercury concentrations in bluegill collected from the three reservoirs mentioned above, the whole body mercury levels detected in bluegill taken from Lake Rush (0.15 mg Hg/kg wet weight) and Burford Lake (0.16 mg Hg/kg wet weight) also exceeded the value reported by Giggleman *et al.* (1998) for bluegill collected in East Texas. For further comparative purposes among largemouth bass, the analytical results of the mercury analysis for whole body bass collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, and Crater Lake during the 1997 fisheries survey conducted at Wichita Mountains Wildlife Refuge (Appendix A) are presented in Table 8 in conjunction with the analytical results for the same six reservoirs from the 2000-2001 study. When comparing the results from both of these studies, it is evident that all of the detected mercury concentrations from 2000-2001 exceeded the 1997 measured concentrations. This may be attributed to the 2000-2001 study consistently targeting larger fish. It should be noted though, that in regards to Elmer Thomas Lake, the detected increase in mercury in 2000-2001 is almost negligible in comparison to the 1997 value, even though larger fish were collected for the 2000-2001 analysis.

In addressing the affects of whole body mercury concentrations in fish to potential predators, Eisler (1987), recommends an avian predator protection limit of 0.1 mg Hg/kg wet weight and a mammalian predator protection limit of 1.1 mg Hg/kg wet weight. None of the whole body composite fish samples collected from the Refuge's reservoirs contained mercury concentrations exceeding the recommended mammalian predator protection limit (Eisler, 1987). Bluegill collected from eight reservoirs (Lake Rush, French Lake, Crater Lake, Burford Lake, Caddo Lake, Osage

Table 8. Comparison between 1997 and 2000-2001 of mercury concentrations detected in whole body largemouth bass collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, and Crater Lake, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - Hg is mercury; mg/kg is milligram/kilogram; and wwt is wet weight).

Reservoir	1997*	2000-2001
Lake Rush	0.41 mg Hg/kg wwt	1.02 mg Hg/kg wwt
Lake Jed Johnson	0.14 mg Hg/kg wwt	0.59 mg Hg/kg wwt
Quanah Parker Lake	0.21 mg Hg/kg wwt	0.39 mg Hg/kg wwt
Elmer Thomas Lake	0.21 mg Hg/kg wwt	0.23 mg Hg/kg wwt
Lost Lake	0.22 mg Hg/kg wwt	0.59 mg Hg/kg wwt
Crater Lake	0.20 mg Hg/kg wwt	0.32 mg Hg/kg wwt

*mean results from Appendix A.

Lake, Post Oak Lake, and Treasure Lake) contained mercury concentrations (Table 6) that equaled or exceeded the avian predator protection limit (Eisler, 1987). Channel catfish collected from one reservoir (Caddo Lake) and black bullhead taken from Lost Lake, French Lake, and Post Oak Lake all contained mercury levels (Table 6) that exceeded the avian protection limit (Eisler, 1987). All of the whole body largemouth bass collected from the Refuge contained mercury levels (Table 6) exceeding the recommended avian predator protection limit (Eisler, 1987), while the bass from Lake

Rush contained a mercury concentration (1.02 mg Hg/kg wet weight) that approached the mammalian predator protection limit (Eisler, 1987).

The mercury concentration measured in the whole body softshell turtle sample collected from French Lake was 0.25 mg Hg/kg wet weight (0.92 mg Hg/kg dry weight). This concentration was elevated in comparison to the concentration (0.003 mg Hg/kg wet weight) detected in whole body softshell turtles collected by the USFWS in 1985-1986 from the Lower Rio Grande in South Texas (Gamble *et al.*, 1988), higher than the mean concentration (0.073 mg Hg/kg wet weight) detected in whole body softshell turtles collected by the USFWS in 1986 from the Upper Rio Grande in South West Texas (Irwin, 1989), above the concentrations measured in two softshell turtles (0.05 and 0.06 mg Hg/kg wet weight, respectively) collected by the USFWS in 1988 from the upper Trinity River in North Central Texas (Irwin, 1989), and exceeded the mean level (0.36 mg Hg/kg dry weight) detected in softshell turtles collected by the USFWS from the Lower Gila River in Arizona between 1993-1994 (King *et al.*, 1997). Mercury was also detected in all of the chelonian brain, liver, and muscle tissue samples collected from the Refuge. The detected brain-mercury concentration in the softshell turtle sample from French Lake was 0.19 mg Hg/kg wet weight, while red-eared sliders contained brain-mercury levels ranging from 0.019 to 0.085 mg Hg/kg wet weight (Table 7A). Measured liver-mercury concentrations in red-eared sliders ranged from 0.063 to 0.35 mg Hg/kg wet weight (Table 7B), while the French Lake softshell turtle liver contained 1.22 mg Hg/kg wet weight. In comparison, the measured red-eared liver-mercury concentrations were less than the concentration (0.6 mg Hg/kg wet weight) reported by Albers *et al.* (1986) for snapping turtles collected from a contaminated freshwater wetland in New Jersey and below the levels (range 0.46 to 0.9 mg Hg/kg wet weight) detected in snapping turtles collected from a reference wetland in Maryland (Albers *et al.*, 1986). In contrast, the measured liver-mercury concentration in the French Lake softshell exceeded all of the values reported by Albers *et al.* (1986). However, this concentration was less than the geometric mean liver-mercury concentration (1.78 mg Hg/kg) reported by Mann-Klager (1997) for snapping turtles collected in 1992 from the Wertheim National Refuge in New York. Detected muscle-mercury concentrations in red-eared sliders collected from Wichita Mountains ranged from 0.018 to 0.1 mg Hg/kg wet weight (Table 7C), with three of the 12 sliders containing muscle-mercury concentrations exceeding the muscle tissue concentration (0.06 mg Hg/kg wet weight) reported by Meyers-Schone and Walton (1994) for snapping turtles collected from a reference wetland in Tennessee. However, none of the red-eared sliders collected from the Refuge contained muscle-mercury concentrations exceeding the muscle-mercury concentration (0.17 mg Hg/kg wet weight) reported by Meyers-Schone (1994) for snapping turtles collected from a contaminated wetland in Tennessee, nor the lowest level detected (0.1 mg Hg/kg) in muscular tissue samples from snapping turtles collected at the Aberdeen Proving Ground in Maryland (U.S. Army Environmental Hygiene Agency, 1994). Contrasting the levels measured in the sliders, the French Lake softshell contained a muscle-mercury concentration (0.42 mg Hg/kg wet weight) that exceeded all of the previously mentioned comparative values, as well as the highest level (0.24 mg Hg/kg wet weight) reported by Helwig and Hora (1983) for snapping turtles collected from lentic and lotic systems in Minnesota. However, the detected concentration in this softshell was less than the highest value (0.5 mg Hg/kg wet weight) reported by Golet and Haines (2001) for snapping turtles collected from five small lakes in southeastern Connecticut. The composite frog sample collected from Wichita Mountains at the entrance to the Bonanza Mine contained 0.2 mg Hg/kg wet weight. This concentration exceeded the concentrations (0.15 mg Hg/kg wet weight and 0.17 mg Hg/kg wet weight) reported by Beyer (1994) for two whole body pig frogs (*Rana grylio*) collected in 1993 from an area with suspected mercury contamination at Florida Panther National Wildlife Refuge in Florida, but was below the level detected in a pig frog (0.53 mg Hg/kg wet weight) collected in 1993 from Wilson Lake at the same refuge in Florida (Beyer, 1994).

[Molybdenum (Mo)] Molybdenum is an essential micronutrient for most life forms; however, excessive exposure can result in toxicity to both animals and humans (Goyer, 1991; USDOI, 1998). This metal is necessary for fixing atmospheric nitrogen by bacteria in plants (Goyer, 1991). In water at a pH greater than 7, molybdenum exists primarily as the molybdate ion, whereas at a pH less than 7, various polymeric compounds are formed, including the paramolybdate ion (Eisler, 1989). Aquatic organisms are relatively resistant to molybdenum toxicity (USDOI, 1998). A recommended predator protection limit for molybdenum in prey items for mammals is 10 mg Mo/kg wet weight and 100 mg Mo/kg wet weight for predaceous avian species (NRC, 1980). In terrestrial systems, pastures containing between 20-100 mg Mo/kg may produce a disease in grazing animals known as teart (molybdenosis) which can prove fatal (Goyer, 1991). In humans, the average daily intake in food is approximately 0.35 mg (Goyer, 1991). Normal molybdenum-blood concentrations in people averages approximately 14.7 µg Mo/L (Eisler, 1989). The recommended dietary intake for humans is less than 7 µg Mo/kg food, based on a 70 kg adult (Eisler, 1989). Of the fish sampled at Wichita Mountains Wildlife Refuge between 2000-2001, only bluegill collected from Lake Jed Johnson, French Lake, and Osage Lake contained molybdenum levels above the analytical detection limits (Table 6). The detected concentrations ranged from 0.1 mg Mo/kg wet weight in French Lake to 1.19 mg Mo/kg wet weight at Osage Lake (Table 6), all well below the predator protection limits proposed by the National Research Council (1980). Neither the whole body softshell turtle collected from French Lake (Table 6), nor any of the chelonian brain and muscle tissues collected from the Refuge contained molybdenum concentrations above the analytical detection limits (Tables 7A and 7C). Molybdenum concentrations were detected above the analytical detection limits in livers from five of the 13 turtles sampled (Table 7B). These detected concentrations ranged from 0.29 mg Mo/kg wet weight in a red-eared slider collected from Lost Lake to 1.05 mg Mo/kg wet weight in a slider collected from Osage Lake (Table 7B). No detectable amounts of molybdenum were measured in the composite whole body leopard frog sample collected from Bonanza Mine (Table 6).

[Nickel (Ni)] The physical and chemical forms of nickel and its salts strongly influence its bio-availability and toxicity in aqueous environments (Eisler, 1998b). In mammals, dietary nickel is poorly absorbed and relatively non-toxic (Law, 1996). A recommended predator protection limit for nickel in prey items is 100 mg Ni/kg wet weight (NRC, 1980). In humans, some forms of nickel can be carcinogenic, however, carcinogenesis is primarily attributed to inhalation of nickel compounds typically associated with the nickel refining industry (Goyer, 1991; Eisler, 1998). Usually, nickel entering the digestive tract in humans is likely to be noncarcinogenic (Eisler, 1998). Dietary nickel intake by adults in the U.S. is estimated to be 0.3-0.6 mg/day (Goyer, 1991). The action level recommended by the USFDA for nickel residues in fish tissues is 70 mg Ni/kg (USEPA, 1997).

In 1993, whole body largemouth bass collected by the USFWS from Caddo Lake in East Texas contained a mean of 0.23 mg Ni/kg wet weight, while whole body bluegill from the same lake contained a mean of 0.12 mg Ni/kg wet weight (Giggleman *et al.*, 1998). Whole body channel catfish collected from the Guadalupe River in 1992 by the USFWS in South Central Texas contained no detectable amounts of nickel (Lee and Schultz, 1994), whereas a whole body channel catfish sample collected in Arizona from the Lower Gila River contained 1.19 mg Ni/kg wet weight (King *et al.*, 1997). Irwin and Dodson (1991) reported a whole body concentration of 0.47 mg Ni/kg dry weight in a black bullhead sample collected from Tierra Blanca Creek in West Texas. Gamble *et al.* (1988) reported a nickel concentration of 0.28 mg Ni/kg wet weight for whole body softshell turtles collected in 1985-1986 by the USFWS from the Lower Rio Grande in South Texas, whereas the highest nickel concentration detected by King *et al.* (1997) in whole body softshell samples collected by the USFWS in 1994-1995 from the Lower Gila River in Arizona, was 8.11 mg Ni/kg dry weight. According to Albers *et al.* (1986) snapping turtles collected from a reference wetland site in Maryland contained liver-nickel concentrations up to 0.99 mg Ni/kg wet weight, while snapping turtles collected from a contaminated freshwater wetland in New Jersey contained 0.13 mg Ni/kg wet weight. Mann-Klager (1997) reported a mean liver-nickel concentration of 2.55 mg Ni/kg for snapping turtles collected in 1992 from the Wertheim National Wildlife Refuge in New York. A snapping turtle collected from the Aberdeen Proving Ground in Maryland contained a muscle-nickel concentration of 6.82 mg Ni/kg (U.S. Army Environmental Hygiene Agency, 1994). In amphibians, Irwin and Dodson (1991) reported a whole body nickel concentration of 0.87 mg Ni/kg dry weight as the highest nickel concentration detected in whole body tiger salamanders collected by the USFWS in 1991 from a cattle stock tank-playa in the Texas Panhandle.

By comparison, none of the fish sampled from Crater Lake, Caddo Lake, Osage Lake, Post Oak Lake, or Treasure Lake contained detectable amounts of nickel (Table 6). In addition, neither the whole body largemouth bass sample collected from Burford Lake, nor the whole body black bullhead sample collected from Post Oak Lake contained any detectable nickel (Table 6). The detected nickel concentrations in largemouth bass collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, and French Lake ranged from 0.44 to 0.7 mg Ni/kg wet weight (Table 6), all above the mean nickel concentration reported for bass from East Texas (Giggleman *et al.*, 1998). Bluegill collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, Elmer Thomas Lake, Lost Lake, French Lake, and Burford Lake contained nickel concentrations ranging from 0.29 to 0.62 mg Ni/kg wet weight (Table 6), all elevated in comparison to the mean nickel concentration reported for Caddo Lake in East Texas (Giggleman *et al.*, 1998). Detected nickel concentrations in channel catfish collected from Lake Rush, Lake Jed Johnson, Quanah Parker Lake, and Elmer Thomas Lake ranged from 0.35 to 0.65 mg Ni/kg wet weight, all below the level reported by King *et al.* (1997). The whole body composite black bullhead sample collected from Lost Lake contained 0.35 mg Ni/kg wet weight (1.43 mg Ni/kg dry weight) which exceeded the value reported by Irwin and Dodson (1991). Even though some of the fish collected from the Refuge contained elevated nickel levels in comparison to other studies, none of the fish sampled contained whole body nickel concentrations (Table 6) exceeding the recommended predator protection limit for nickel in prey items (NRC, 1980). The French Lake whole body softshell turtle sample contained 2.6 mg Ni/kg wet weight (10 mg/ Ni/kg dry weight). This concentration exceeded the values reported by Gamble *et al.* (1988) and King *et al.* (1997). One red-eared slider taken from French Lake contained a brain-nickel concentration of 1.24 mg Ni/kg wet weight (Table 7A), while one red-eared slider collected from Lost Lake contained a liver-nickel concentration of 0.19 mg Ni/kg wet weight (Table 7B). None of the remaining turtles contained brain, liver, or muscle tissues with nickel concentrations above the analytical detection limits (Tables 7A-7C). The measured liver-nickel concentration in the Lost Lake slider was below the reference value reported by Albers *et al.* (1986) and the mean concentration reported by Mann-Klager (1997). The composite frog sample collected at the entrance to Bonanza Mine contained 2.6 mg Ni/kg wet weight (10 mg Ni/kg dry weight) which greatly exceeded the value reported for salamanders by Irwin and Dodson (1991).

[Selenium (Se)] Selenium is an essential micronutrient but like other necessary dietary minerals, elevated levels can have detrimental effects on exposed organisms. It typically exists in nature and biological systems as either selenate, selenite, elemental selenium, and/or selenide (Eisler, 1985b; Goyer, 1991). In an aqueous environment, selenium concentrations in the water column are a function of selenium levels contained within the drainage system and water pH (Eisler, 1985b). In humans, selenium is probably not carcinogenic, however it can be considered embryo-toxic and teratogenic (Goyer, 1991). Normal human dietary levels range from 0.04 to 0.1 mg/kg of selenium, with 0.2 mg Se/day being the recommended maximum safe intake for adults (Eisler, 1985b; Goyer, 1991). Toxicological effects are expected to occur when food-selenium concentrations approach 4 mg Se/kg (Eisler, 1985b).

According to Schmitt and Brumbaugh (1990), the national 85th percentile criterion for selenium in whole body fish in the U.S. is 0.73 mg Se/kg wet weight. All of the whole body fish collected from Wichita Mountains Wildlife Refuge in 2000-2001 contained selenium levels below this value. In comparing measured selenium concentrations in fish collected from the Refuge with other studies, channel catfish contained slightly higher selenium levels [$\bar{x}$ = 0.22 mg Se/kg wet weight (n = 5)] than channel catfish (whole body selenium concentration = 0.18 mg Se/kg wet weight) collected from the Red River outside of Alexandria, Louisiana (Schmitt and Brumbaugh, 1990), but less than the measured selenium concentrations (up to 0.31 mg Se/kg wet weight) in channel catfish collected from the Guadalupe River in South Central Texas (Lee and Schultz, 1994), and less than the lowest concentration (0.29 mg Se/kg wet weight) detected in whole body channel catfish samples collected from the Upper Gila River in Arizona (Baker and King, 1994). Black bullhead collected from the Refuge contained lower selenium levels [$\bar{x}$ = 0.19 mg Se/kg wet weight (0.83 mg Se/kg dry weight) (n = 3)] than the mean concentration (1.88 mg Se/kg dry weight) measured in black bullheads collected from Maxwell National Wildlife Refuge (Custer *et al.*, 1993). Largemouth bass collected from the Refuge contained lower selenium levels [$\bar{x}$ = 0.37 mg Se/kg wet weight (n = 10)] than largemouth bass collected from Texoma Reservoir which contained a whole body selenium concentration of 0.4 mg Se/kg wet weight (Schmitt and Brumbaugh, 1990). Bluegill collected from the Refuge contained selenium concentrations [$\bar{x}$ = 0.38 mg Se/kg wet weight (n = 12)] slightly higher than the selenium concentration ($\bar{x}$ = 0.34 mg Se/kg wet weight) measured in bluegill collected from Caddo Lake in East Texas (Giggleman *et al.*, 1998). Reproductive failure has been observed in bluegill with whole body selenium concentrations greater than16 mg Se/kg dry weight, while teratogenic effects have been observed in bluegill with whole body selenium concentrations of 15 mg Se/kg dry weight (Lemly, 1996). These adverse effects would not be expected to occur in bluegill inhabiting the Refuge's reservoirs because on a dry weight basis, the detected selenium concentrations ranged from 0.45 mg Se/kg dry weight to 2.44 mg Se/kg dry weight (Appendix E), well less than the thresholds reported by Lemly (1996).

The detected selenium concentration in the whole body softshell turtle collected from French Lake was 0.24 mg Se/kg wet weight (0.91 mg Se/kg dry weight). This concentration was less than the concentration (0.31 mg Se/kg wet weight) detected in whole body softshell turtles collected in 1985-1986 by the USFWS from the Lower Rio Grande in South Texas (Gamble *et al.*, 1988), less than the concentration (0.64 mg Se/kg wet weight) measured in whole body softshell turtles collected by the USFWS in 1986 from the Upper Rio Grande in South West Texas (Irwin, 1989), less than the concentrations (0.26 and 0.43 mg Se/kg wet weight, respectively) detected in two softshell turtles collected by the USFWS in 1988 from the upper Trinity River in North Central Texas (Irwin, 1989), and less than the mean concentration (1.08 mg Se/kg dry weight) detected in whole body softshell turtles collected by the USFWS in 1994-1995 from the Lower Gila River in Arizona (King *et al.*, 1997). Detected brain tissue-selenium levels in turtles collected from the Refuge ranged from 0.07 to 0.18 mg Se/kg wet weight (Table 7A), while liver-selenium concentrations ranged from 0.22 to 0.96 mg Se/kg wet weight (Table 7B) and muscle-selenium concentrations ranged from 0.13 to 0.22 mg Se/kg wet weight (Table 7C). The measured liver-selenium concentrations were less than the geometric mean concentration (4.94 mg Se/kg) reported by Mann-Klager (1997) for snapping turtles collected in 1992 from the Wertheim National Wildlife Refuge in New York. The composite leopard frog sample collected from Wichita Mountains at the entrance to Bonanza Mine contained 0.55 mg Se/kg wet weight (1.8 mg Se/kg dry weight). This value was not compared to data from other studies because comparative data associated with amphibian selenium levels could not be located.

[Zinc (Zn)] Zinc is also a nutritionally essential metal that can be harmful to exposed organisms at elevated levels (Goyer, 1991; USDOI, 1998). It serves as an activator in enzymatic reactions in freshwater algae (Horne and Goldman, 1994). It is more toxic in aqueous environments to fish under conditions of low dissolved oxygen, high sodium concentrations, decreased loading of organic complexing agents, and low pH (Eisler, 1993). Zinc toxicosis in humans is not a common medical problem with most poisonings being attributed to the consumption of foods or beverages which were stored for lengthy periods in galvanized (zinc coated) containers or from use of galvanized eating utensils (Goyer, 1991; Eisler, 1993). In the U.S. the average daily intake of zinc by adults is estimated at 12-15 mg Zn (Goyer, 1991).

The national 85th percentile concentration for zinc in whole body fish in the U.S. reported by Schmitt and Brumbaugh (1990) is 34.2 mg Zn/kg wet weight. All of the fish sampled at Wichita Mountains Wildlife Refuge in 2000-2001 contained zinc levels below this value. In further comparisons, catfish collected from the Refuge contained lower zinc levels [$\bar{x}$ = 17.1 mg Zn/kg wet weight (n = 5)] than concentrations (18.6 mg Zn/kg wet weight) measured in channel catfish collected from the Red River outside of Alexandria, Louisiana (Schmitt and Brumbaugh, 1990), levels (up to 20.3 mg Zn/kg wet weight) detected in channel catfish collected from the Guadalupe River (Lee and Schultz, 1994), and concentrations measured in channel catfish (range 22.8 to 26.1 mg Zn/kg wet weight) collected from the Gila River (Baker and King, 1994). Black bullhead from the Refuge contained less zinc [$\bar{x}$ = 16.1 mg Zn/kg wet weight (70.6 mg Zn/kg dry weight) (n = 3)] than black bullhead (87 mg Zn/kg dry weight) collected from Tierra Blanca Creek in West Texas (Irwin and Dodson, 1991). Largemouth bass collected from the Refuge contained slightly higher zinc levels [$\bar{x}$ = 16.5 mg Zn/kg wet weight (n = 10)] than largemouth bass collected from Texoma Reservoir which contained a zinc level of 15.9 mg Zn/kg wet weight (Schmitt and Brumbaugh, 1990). Bluegill collected from the Refuge contained zinc concentrations [$\bar{x}$ = 24.2 mg Zn/kg wet weight (n = 12)] lower than the measured zinc concentrations ($\bar{x}$ = 27.2 mg Zn/kg wet weight) in bluegill collected from Caddo Lake in East Texas (Giggleman *et al*., 1998). According to Eisler (1993), an adequate diet for avian species should contain a zinc concentration between 93-120 mg Zn/kg dry weight, whereas a zinc concentration greater than 178 mg Zn/kg dry weight is excessive and could produce detrimental effects. On a dry weight basis, whole body fish collected at the Refuge contained zinc concentrations ranging from 53.1 to 113 mg Zn/kg dry weight (Appendix E), well below the level where adverse effects to piscivorus birds would be expected to occur.

The whole body softshell turtle collected from French Lake contained 24.5 mg Zn/kg wet weight (92.3 mg Zn/kg dry weight), which exceeded the level (23.1 mg Zn/kg wet weight) reported by Gamble *et al.* (1988) for whole body softshell turtles collected from the Lower Rio Grande in South Texas, and the geometric mean concentration (70.85 mg Zn/kg dry weight) reported by King *et al.* (1997) for softshell turtles collected from the Gila River. Detected brain tissue-zinc levels in turtles collected from the Refuge ranged from 6.33 to 8.78 mg Zn/kg wet weight (Table 7A), while liver-zinc concentrations ranged from 12.3 to 23.2 mg Zn/kg wet weight (Table 7B) and muscle-zinc concentrations ranged from 17.4 to 29.5 mg Zn/kg wet weight (Table 7C). The measured chelonian liver-zinc concentrations were less than the concentration (30.7 mg Zn/kg wet weight) reported by Albers *et al.* (1986) for snapping turtles collected from a contaminated freshwater wetland in New Jersey and less than the values (range 27.7 to 29.3 mg Zn/kg wet weight) reported for snapping turtles collected from a reference wetland in Maryland. These detected liver concentrations were also less than the geometric mean concentration (177.6 mg Zn/kg) reported by Mann-Klager (1997) for snapping turtles collected from the Wertheim National Wildlife Refuge in New York. The detected muscle-zinc concentrations in the Wichita Mountains turtles were less than the concentration (39 mg Zn/kg) detected in muscular tissue samples taken from snapping turtles collected from the Aberdeen Proving Ground in Maryland (U.S. Army Environmental Hygiene Agency, 1994). The composite leopard frog sample collected at the entrance to Bonanza Mine contained 99.4 mg Zn/kg wet weight (318 mg Zn/kg dry weight) which greatly exceeded the highest zinc concentration (85 mg Zn/kg dry weight) in tiger salamanders reported by Irwin and Dodson (1991), but was below the concentration (118 mg Zn/kg wet weight) reported by Clark *et al.* (1998) for a newly-transformed leopard frog collected downstream of a closed arsenic-based defoliant production facility in Central Texas.

Metals in Sediments/Soils

Physical characteristics (moisture, sand, silt, and clay content as percentages) for each of the 20 soil/sediment samples collected at Wichita Mountains Wildlife Refuge are presented in Table 9, while the analytical results from the metals analyses for these samples are presented in Table 10.

The samples collected from sites WM1, WM2, WM7, and WM9 are considered soils, whereas the samples collected from the remaining 16 sites are classified as sediments based on sample location (Table 2). All of these samples were dominated by course sands, with the exception of the sediment sample collected at Site WM5 which contained a high silt content (Table 9).

Where applicable, the analytical results were compared with benchmark values protective of wildlife including criteria recommended by the USEPA, Efroymson *et al.* (1997), the Texas Natural Resource Conservation Commission (TNRCC), the Ontario Ministry of the Environment (OME) (Persaud *et al.*, 1993), Long *et al.* (1995), MacDonald *et al.* (2000), additional screening criteria, and data from comparative studies to determine the extent and possible effects of metals contamination in sediments and soils collected from the Refuge. In defining specific criteria, benchmarks are values derived from toxicity data resulting from multiple studies. Soil benchmarks are typically based on the degree of toxicity of a given contaminant to plants, earthworms, heterotrophic microbes, and other invertebrates (Efroymson *et al.*, 1997). In sediments, the OME considers the lowest effects level (LEL) indicative of a level of contamination that is non-toxic to the majority of benthic organisms, whereas the severe effect level (SEL) is indicative of contaminated sediments that would be detrimental to a majority of benthic organisms (Persaud *et al.*, 1993). In comparison, according to Long *et al.* (1995), the effects range-low (ER-L) of a detected chemical represents the lower 10th percentile of toxicological effects data for that specific chemical, whereas the effects range-median (ER-M) represents the toxicological effects data for the

Table 9. Percent (%) Moisture, Sand, Silt, and Clay content for 4 soil samples* and 16 sediment samples collected from Wichita Mountains Wildlife Refuge, 2000-2001.

Site	%Moisture	%Sand	%Silt	%Clay
WM1*	15.9	67	30	3
WM2*	7.6	88	12	0
WM3	21.7	82	15	3
WM4	22.3	90	7	3
WM5	32.6	45	52	23
WM6	27.6	98	2	0
WM7*	3.0	82	15	3
WM8	58.0	63	32	5
WM9*	5.8	75	17	8
WM10	23.9	95	5	0
WM11	26.5	78	17	5
WM12	22.0	98	2	0
WM13	22.8	100	0	0
WM14	21.0	87	10	3
WM15	25.2	88	12	0
WM16	45.8	85	15	0
WM17	23.2	85	12	3
WM18	28.6	95	2	3
WM19	1.3	95	2	3
WM20	1.9	93	2	5

Table 10. Results of metals analyses in mg/kg dry weight for sediment/soil samples collected from 20 sites at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - WM is site designator; dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	WM1	WM2	WM3	WM4	WM5	WM6	WM7	WM8	WM9	WM10
Aluminum	11,600.0	2,900.0	8,670.0	11,500.0	32,800.0	5,200.0	15,800.0	16,700.0	42,300.0	4,650.0
dl	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Arsenic	34.0	1.5	1.4	0.8	2.4	1.0	17.0	2.1	1.7	1.0
dl	2.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Cadmium	1.5	0.2	bdl	bdl	bdl	bdl	0.4	bdl	bdl	bdl
dl	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Chromium	24.0	bdl	3.7	15.0	14.0	2.0	33.0	11.0	53.0	2.0
dl	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	24.0	50.0	2.0	3.3	8.0	3.0	48.0	6.9	29.0	2.0
dl	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Iron	104,000.0	18,700.0	6,400.0	11,300.0	21,200.0	9,650.0	48,400.0	13,700.0	67,200.0	9,250.0
dl	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Lead	1,180.0	35.0	7.0	6.0	10.0	7.0	6,120.0	10.0	33.0	6.0
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Magnesium	2,010.0	280.0	576.0	1,370.0	4,280.0	380.0	5,540.0	1,510.0	19,100.0	340.0
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Manganese	1,020.0	120.0	34.0	100.0	275.0	62.0	660.0	190.0	1,430.0	93.0
dl	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Mercury	bdl	1.1	bdl	bdl	bdl	bdl	bdl	bdl	1.0	bdl
dl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Molybdenum	bdl	8.0	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Nickel	10.0	bdl	bdl	7.0	10.0	bdl	59.0	6.0	41.0	bdl
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Selenium	0.8	0.2	0.3	bdl	bdl	bdl	0.6	0.7	2.4	0.2
dl	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Zinc	597.0	150.0	30.0	24.0	48.0	61.0	400.0	45.0	170.0	22.0
dl	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Table 10 (continued). Results of metals analyses in mg/kg dry weight for sediment/soil samples collected from 20 sites at Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - WM is site designator; dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	WM11	WM12	WM13	WM14	WM15	WM16	WM17	WM18	WM19	WM20
Aluminum	11,300.0	4,650.0	9,040.0	10,400.0	7,150.0	8,570.0	4,800.0	6,160.0	11,900.0	6,810.0
dl	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Arsenic	1.8	1.0	0.6	1.0	1.0	1.2	0.7	0.7	0.7	1.3
dl	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Cadmium	bdl	bdl	bdl	bdl	0.2	bdl	bdl	bdl	bdl	bdl
dl	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Chromium	5.6	2.0	8.5	4.8	3.0	5.0	3.0	5.1	7.0	3.2
dl	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	4.2	1.0	5.6	2.0	3.2	15.0	2.0	bdl	3.0	2.0
dl	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Iron	12,900.0	8,190.0	10,400.0	7,480.0	4,630.0	7,300.0	4,950.0	4,930.0	7,430.0	8,380.0
dl	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Lead	10.0	bdl	5.0	bdl	10.0	10.0	bdl	bdl	bdl	bdl
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Magnesium	1,060.0	400.0	1,280.0	808.0	577.0	910.0	440.0	360.0	922.0	440.0
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Manganese	257.0	130.0	75.0	140.0	48.0	120.0	38.0	28.0	78.0	110.0
dl	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Mercury	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Nickel	bdl	bdl	6.0	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Selenium	0.3	bdl	0.2	0.2	bdl	0.2	bdl	0.3	0.2	0.2
dl	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Zinc	34.0	23.0	24.0	24.0	31.0	41.0	14.0	15.0	23.0	20.0
dl	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

chemical at the 50th percentile. Concentrations detected below the ER-L represent a value where minimal effects would be expected, whereas concentrations detected at or above the ER-L but below the ER-M, represent a possible effects range (Long *et al.*, 1995). Concentrations detected at or above the ER-M represent a probable effects range where adverse toxicological effects would frequently occur (Long *et al.*, 1995). In a consensus based approach towards evaluating sediment screening criteria, Macdonald *et al.*(2000), state that the threshold effect concentration (TEC) for a contaminant is the concentration below which adverse effects are not expected, whereas the probable effect concentration (PEC) is the level above which adverse effects would likely occur. As with the OME LEL and SEL values, ER-L, ER-M, TEC, and PEC values, as well as other benchmark criteria, are all non-regulatory screening guidelines developed to assist in assessing the degree of sediment and soil contamination in a given area.

[Aluminum (Al)] Approximately 8.1% of the Earth's crust is composed of aluminum (Miller and Gardiner, 1998). Background surface soil concentrations in the western U.S. range up to 74,000 mg Al/kg (Shacklette and Boerngen, 1984). According to the TNRCC (2001), a soil-aluminum concentration of 30,000 mg Al/kg is considered background in the State of Texas. Efroymson *et al.* (1997) proposed 600 mg Al/kg dry weight as a screening benchmark value for aluminum toxicity to soil microorganisms. King *et al.* (2001) reported an aluminum concentration of 1,421 mg Al/kg dry weight in soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge, Arizona. In freshwater sediments, the National Oceanic and Atmospheric Administration (NOAA) considers 25,500 mg Al/kg dry weight as the threshold effects level (TEL) for aluminum toxicity (Buchman, 1999). Aluminum levels in sediments/soils collected from Wichita Mountains Wildlife Refuge in 2000-2001, ranged from 2,900 mg Al/kg dry weight at Site WM2 to 42,300 mg Al/kg dry weight at Site WM9 (Table 10). All of the detected aluminum concentrations in soil samples collected from Sites WM1, WM2, WM7, and WM9 (Table 10) were elevated in comparison to the soils screening criterion proposed by Efroymson *et al.* (1997) and the concentration reported by King *et al.* (2001). However, none of the samples from these four sites contained aluminum concentrations above the soils background value reported by Shacklette and Boerngen (1984), while only one of the sites, Site WM9, contained a soil-aluminum concentration exceeding the soil background criterion recommended by the TNRCC (2001). Of the 16 sites sampled for sediments, only Site WM5 contained an aluminum concentration (32,800 mg Al/kg dry weight) that exceeded the sediment TEL recommended by NOAA (Buchman, 1999).

[Arsenic (As)] According to Shacklette and Boerngen (1984), the estimated arithmetic mean for background elemental arsenic concentrations in surface soils in the western U.S. is 7 mg As/kg. Pennington (1991) reported soil-arsenic concentrations ranging up to 13.36 mg As/kg in the Texas Panhandle. Efroymson *et al.* (1997) proposed an earthworm soils toxicity screening benchmark value of 60 mg As/kg dry weight, while the USEPA (2000) considers a soil-arsenic concentration of 37 mg As/kg dry weight as a benchmark value for terrestrial plants. According to King *et al.* (2001), soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge in 1998 contained an arsenic concentration of 1,468 mg As/kg dry weight. In aquatic environments, elemental arsenic is insoluble in water, but many arsenic species are highly soluble in freshwater (Schneider, 1971). Common arsenic species include arsenate, arsenite, methanearsonic acid, and dimethyl arsenic acid (USEPA, 1980). In aerobic waters, reduced forms of arsenic tend to be oxidized into arsenates (USEPA, 1980). In turn, the adsorption of arsenate by metal oxides and the formation of arsenic sulfide appears to remove arsenic from the water column, binding it to the sediments, and preventing high concentrations of arsenic being present in solution (USEPA, 1980). The estimated residence time for arsenic in lentic systems is 45 years (Eisler, 1988b). The OME suggest a sediment LEL of 6 mg As/kg dry weight and a SEL of 33 mg As/kg dry weight (Persaud *et al.*, 1993), while Long *et al.* (1995), consider 8.2 mg As/kg dry weight as the ER-L for arsenic in sediments. MacDonald *et al.* (2000), recommend a sediment TEC of 9.79 mg As/kg dry weight and a PEC of 33 mg As/kg dry weight. With the exception of arsenic levels detected at Site WM1 (34 mg As/kg dry weight) and Site WM7 (17 mg As/kg dry weight), all of the remaining sites sampled contained arsenic concentrations (Table 10) well below the cited ecological benchmarks and comparative values. The soils at Sites WM1 and WM7 contained arsenic levels that exceeded background values, but were below the benchmark values recommended by Efroymson *et al.* (1997) and the USEPA (2000) and did not approach the concentration reported by King *et al.* (2001).

[Cadmium (Cd)] Ryan *et al.* (1980) reported that the normal range for elemental cadmium in surface soils in the U.S. is 0.06 to 0.5 mg Cd/kg. According to Efroymson *et al.* (1997), a proposed screening benchmark value for cadmium toxicity to soil microorganisms is 20 mg Cd/kg dry weight. In sampling conducted in 1985 at Wichita Mountains Wildlife Refuge, Andreasen (1986) reported cadmium concentrations of 0.6 mg Cd/kg dry weight in soils collected from the Fawn Creek (Bonanza Mine) Smelter site and 0.2 mg Cd/kg dry weight in soils taken from the Blue Beaver Creek Smelter site. King *et al.* (2001) reported a cadmium concentration of 6.75 mg Cd/kg dry weight measured in soils collected in 1998 from the Sheep Tank Mine at Kofa National Wildlife Refuge in Arizona. In aquatic systems, elemental cadmium is insoluble in water, whereas cadmium chloride, nitrate, and sulfate compounds are highly soluble in freshwater (Schneider, 1971). Cadmium toxicity in freshwater is moderated by increasing water hardness through either complexation with carbonate or competition with calcium ions (Wren *et al.*, 1995). In sediments, the OME recommends a LEL of 0.6 mg Cd/kg dry weight and a SEL of 10 mg Cd/kg dry weight (Persaud *et al.*, 1993), whereas Long *et al.* (1995), consider 1.2 mg Cd/kg dry weight as the ER-L for cadmium. MacDonald *et al.* (2000), suggest a sediment TEC of 0.99 mg Cd/kg dry weight and a PEC of 4.98 mg Cd/kg dry weight. Of the 20 sites sampled at Wichita Mountains Wildlife Refuge between 2000-2001, cadmium levels were detected above the analytical detection limits at only four sites (Table 10). Sediments/soils from three of these sites, WM2, WM7, and WM15, contained cadmium levels (Table 10) well below any of the ecological screening criteria cited. In addition, the cadmium concentration measured at Site WM7 (0.4 mg Cd/kg dry weight) was only slightly elevated in comparison to the cadmium concentration reported by Andreasen (1986) for samples collected in 1985 from the same area (Blue Beaver Creek Smelter site). In contrast, the detected concentration at Site WM1 (1.5 mg Cd/kg dry weight) exceeded the cadmium concentration detected at the Bonanza Mine in 1985 (Andreasen, 1986) and the soil background criterion (Ryan *et al.*, 1980), but was below the soil benchmark value recommended by Efroymson *et al.* (1997) and the value reported by King *et al.* (2001).

[Chromium (Cr)] Shacklette and Boerngen (1984) reported an estimated arithmetic mean of 56 mg Cr/kg as background for soils in the western U.S. According to the TNRCC (2001), a soil-chromium concentration of 30 mg Cr/kg dry weight can be considered background in the State of Texas.

Efroymson *et al.* (1997) proposed soils toxicity screening benchmark values ranging from 0.4 mg Cr/kg dry weight for earthworms to 10 mg Cr/kg dry weight for soil microorganisms. The USEPA (2000) considers a soil-chromium concentration of 5 mg Cr/kg dry weight as a benchmark value for terrestrial plants. King *et al.* (2001) reported a chromium concentration of 42.6 mg Cr/kg dry weight in soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge. In freshwater systems, hydrolysis and precipitation are more important physical processes in determining the fate of chromium in comparison to adsorption and bio-accumulation (Eisler, 1986). According to Eisler (1986), the majority of chromium bound in sediments is unavailable for living organisms. Molluscs accumulate chromium from contaminated sediments at comparatively low concentrations (Eisler, 1986a). The OME suggest a LEL of 26 mg Cr/kg dry weight and a SEL of 110 mg Cr/kg dry weight for chromium in sediments (Persaud *et al.*, 1993), whereas MacDonald *et al.* (2000), recommend a sediment TEC of 43.4 mg Cr/kg dry weight and a PEC of 111 mg Cr/kg dry weight. Detected chromium levels in sediments/soils collected from Wichita Mountains Wildlife Refuge in 2000-2001, ranged from 2.0 mg Cr/kg dry weight at Sites WM6, WM10, and WM12 to 53 mg Cr/kg dry weight at Site WM9 (Table 10). None of the sediment samples collected from the Refuge contained chromium concentrations (Table 10) exceeding any of the lower ecological threshold values or sediment screening criteria. Soils collected from Site WM2 did not contain detectable amounts of chromium (Table 10). None of the soil samples collected from Sites WM1, WM7, and WM9 contained chromium concentrations (Table 10) above the soils background value reported by Shacklette and Boerngen (1984), whereas soils from Sites WM7 and WM9 (Table 10) exceeded the Texas background level (TNRCC, 2001). In addition, the detected soil-chromium concentrations at all three sites (Table 10) exceeded the ecological screening criteria recommended by Efroymson *et al.* (1997) and the USEPA (2000), while only the sample from WM9 exceeded the value reported by King *et al.* (2001). The chromium concentration measured at Site WM1 (24 mg Cr/kg dry weight) also exceeded the value (8.7 mg Cr/kg dry weight) reported by Andreasen (1986) for soils collected in 1985 from the Bonanza Mine Smelter site. Although elevated in comparison to ecological benchmarks, the chromium concentrations detected at Sites WM7 and WM9 (Table 10) were similar to the chromium concentrations (range 26 to 56 mg Cr/kg dry weight) reported by Andreasen (1986) for samples collected from the same area (Blue Beaver Creek Smelter site) by the USFWS in 1985.

[Copper (Cu)] According to Shacklette and Boerngen (1984), the estimated arithmetic mean for background copper concentrations in surface soils in the western U.S. is 27 mg Cu/kg, while a soil-copper concentration of 15 mg Cu/kg dry weight is considered background in the State of Texas (TNRCC, 2001). Efroymson *et al.* (1997), proposed a soils toxicity screening benchmark value of 100 mg Cu/kg dry weight. The TNRCC (2001) reports 61 mg Cu/kg dry weight as the soils benchmark value for earthworms. King *et al.* (2001) reported a copper concentration of 53.6 mg Cu/kg dry weight in soils collected from the Sheep Tank Mine at the Kofa National Wildlife Refuge. In surface water, the solubility of copper and copper salts is decreased under reducing conditions and is further modified by pH, temperature, and hardness; size and density of suspended materials; rates of coagulation and sedimentation of particulates; and concentration of dissolved organics (Eisler, 1998a). Copper concentrations in sediment interstitial pore waters correlate positively with concentrations of dissolved copper in the overlying water column (Eisler, 1998a). Typically, sediment bound copper is available to benthic organisms under anoxic and low pH conditions (Eisler, 1998a). The OME recommends a sediment LEL of 16 mg Cu/kg dry weight and a SEL of 110 mg Cu/kg dry weight (Persaud *et al.*, 1993), whereas Long *et al.* (1995), consider 34 mg Cu/kg dry weight as the ER-L for copper in sediments. MacDonald *et al.* (2000), suggest a sediment TEC of 31.6 mg Cu/kg dry weight and a PEC of 149 mg Cu/kg dry weight. Detected copper levels in sediments/soils collected from Wichita Mountains Wildlife Refuge in 2000-2001, ranged from 1 mg Cu/kg dry weight at Site WM12 to 50 mg Cr/kg dry weight at Site WM2 (Table 10). Sediments collected from Site WM18 did not contain detectable amounts of copper (Table 10). None of the remaining sediment samples collected from the Refuge contained copper concentrations (Table 10) above any of the lower ecological screening values. The soil sample collected at WM1 contained a copper concentration (24 mg Cu/kg dry weight) less than the background value reported by Shacklette and Boerngen (1984), whereas the copper levels detected in soils taken from WM2, WM7, and WM9 (Table 10) exceeded this criterion. Soils collected at all four sites contained copper concentrations above the background value recommended by the TNRCC (2001), but were below ecological screening criteria proposed by Efroymson *et al.* (1997) and the TNRCC (2001), and less than the value reported by King *et al.* (2001). The copper concentrations detected at Sites WM7, WM8, and WM9 (Table 10) were also similar to the copper concentrations (range 8.6 to 28 mg Cu/kg dry weight) reported by Andreasen (1986) for samples collected in 1985 from the same area (Blue Beaver Creek Smelter site), while the levels detected at Sites WM1 and WM2 (Table 10) exceeded the values (range 4.7 to 5.5 mg Cu/kg dry weight) measured in soils collected in 1985 from the Bonanza Mine area (Andreasen, 1986).

[Iron (Fe)] Iron composes approximately 5% of the Earth's crust (Miller and Gardiner, 1998). Background iron concentrations in surface soils in the western U.S. range up to 26,000 mg Fe/kg (Shacklette and Boerngen, 1984). In Texas, median background soil-iron concentrations are reported as 15,000 mg Fe/kg (TNRCC, 2001). According to Efroymson *et al.* (1997), a proposed screening benchmark value for iron toxicity to soil microorganisms is 200 mg Fe/kg. Soil samples collected by the USFWS in 1998 from the Sheep Tank Mine located within Kofa National Wildlife Refuge contained 71,857 mg Fe/kg dry weight (King *et al.*, 2001). Under normal oxidizing conditions in freshwater systems, ferric iron predominates over ferrous iron, and in turn, ferric iron forms insoluble compounds that rapidly disassociate from the water column and drop to the sediments (Horne and Goldman, 1994). The OME recommends a LEL of 20,000 mg Fe/kg dry weight and a SEL of 40,000 mg Fe/kg dry weight for iron in sediments (Persaud *et al.*, 1993). According to Beyer (1990), sediments from the Great Lakes containing less than 17,000 mg Fe/kg dry weight are considered non-polluted, whereas sediments containing iron concentrations greater than 25,000 mg Fe/kg dry weight are considered extremely polluted. Iron levels were detected above the analytical detection limits in all of the sediment/soil samples collected from Wichita Mountains Wildlife Refuge in 2000-2001. These levels ranged from 4,630 mg Fe/kg dry weight at Site WM15 to 104,000 at Site WM1 (Table 10). All sediment-iron concentrations were below the OME lower screening criterion with the exception of the concentration detected at Site WM5 (21,200 mg Fe/kg dry weight). The soil samples collected from Sites WM1, WM7 (48,400 mg Fe/kg dry weight), and WM9 (67,200 mg Fe/kg dry weight) contained elevated levels of iron in comparison to expected background concentrations (Shacklette and Boerngen, 1984; TNRCC, 2001).

[Lead (Pb)] According to Shacklette and Boerngen (1984), the estimated arithmetic mean for background lead concentrations in surface soils in the western U.S. is 20 mg Pb/kg. The TNRCC (2001), considers a soil-lead concentration of 15 mg Pb/kg dry weight as background in the State of Texas. Soil benchmark values can range from 50 mg Pb/kg dry weight for terrestrial plants to 500 mg Pb/kg dry weight for earthworms (TNRCC, 2001). Efroymson *et al.* (1997), proposed a soils toxicity screening criterion of 900 mg Pb/kg. King *et al.* (2001), reported a lead level of 843 mg Pb/kg dry weight for soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge. In aqueous environments, the deposition of lead to sediments is attributed primarily to the strong binding capacities of many sediment components for metals (Pain, 1995). In turn, lead concentrations in aquatic plants have been directly correlated with sediment lead concentrations (Pain, 1995). The OME suggests a sediment LEL of 31 mg Pb/kg dry weight and a SEL of 250 mg Pb/kg dry weight (Persaud *et al.*, 1993), while Long *et al.* (1995), consider 47 mg Pb/kg dry weight as the ER-L for lead in sediments. MacDonald *et al.* (2000), suggest a sediment TEC of 35.8 mg Pb/kg dry weight and a PEC of 128 mg Pb/kg dry weight. Detected sediment-lead levels measured in samples collected from Wichita Mountains Wildlife Refuge in 2000-2001 ranged from 5 mg Pb/kg dry weight at Site WM13 to 10 mg Pb/kg dry weight at Sites WM5, WM8, WM11, WM15, and WM18 (Table 10). No detectable amounts of lead were measured in the sediment samples collected from Sites WM12, WM14, and WM17 through WM20 (Table 10). All of the detected sediment-lead concentrations (Table 10) were well below the lower threshold sediment screening criteria (Persaud *et al.*, 1993; Long *et al.*, 1995; MacDonald *et al.*, 2000). Although slightly elevated in comparison to soil background values (Shacklette and Boerngen, 1984; TNRCC, 2001), the measured lead concentrations in soils collected from Sites WM2 (35 mg Pb/kg dry weight) and WM9 (33 mg Pb/kg dry weight) were below ecological benchmark values (Efroymson *et al.*, 1997). The detected concentrations in soils taken from Sites WM1 (1,180 mg Pb/kg dry weight) and WM7 (6,120 mg Pb/kg dry weight) not only exceeded expected background concentrations (Shacklette and Boerngen, 1984; TNRCC, 2001), but were highly elevated in comparison to benchmark values (Efroymson *et al.*, 1997) and the lead concentration reported by King *et al.* (2001). In addition, the soil-lead concentration at Site WM1 exceeded the lead concentration (260 mg Pb/kg dry weight) reported by Andreasen (1986) for soils collected in 1985 from the Bonanza Mine Smelter site, while the lead level measured at WM7 exceeded the highest lead concentration (290 mg Pb/kg dry weight) reported by Andreasen (1986) for soils collected from the Blue Beaver Creek Smelter site in 1985.

[Magnesium (Mg)] The Earth's crust is composed of approximately 2.1% magnesium (Miller and Gardiner, 1998). Shacklette and Boerngen (1984), estimated the arithmetic mean for background magnesium concentrations in surface soils in the western U.S. as 10,000 mg Mg/kg, whereas soil samples collected in Arizona by the USFWS from the Sheep Tank Mine contained 596 mg Mg/kg dry weight (King *et al.*, 2001). Along with calcium, magnesium is one of the two most common polyvalent metallic ions found in freshwater (Irwin and Dodson, 1991). Sediment samples collected by the USFWS in 1993 from Cypress Springs Reservoir, Lake O'The Pines, and Caddo Lake in East Texas contained mean sediment concentrations of $\bar{x}$ = 928.8 mg Mg/kg dry weight, $\bar{x}$ = 475.6 mg Mg/kg dry weight, and $\bar{x}$ = 1,148.1 mg Mg/kg dry weight, respectively (Giggleman *et al.*, 1998). Sediment-magnesium concentrations detected in samples collected from Wichita Mountains Wildlife Refuge in 2000-2001 ranged from 340 mg Mg/kg dry weight at Site WM10 to 4,280 mg Mg/kg dry weight at Site WM5, while soil-magnesium concentrations ranged from 280 mg Mg/kg dry weight at Site WM2 to 19,100 mg Mg/kg dry weight at Site WM9 (Table 10). Magnesium levels in sediment samples collected from Sites WM4, WM5, WM8, and WM13 (Table 10) were elevated in comparison to data reported by Giggleman *et al.* (1998) for Caddo Lake in East Texas. In soils, the magnesium levels detected in samples collected from Sites WM1, MW7, and WM9 (Table 10) were elevated in comparison to the value reported by King *et al.* (2001), whereas only the sample collected from Site WM9 exceeded the background concentration reported by Shacklette and Boerngen (1984).

[Manganese (Mn)] Manganese is a widely distributed, abundant element that constitutes approximately 0.085% of the earth's crust (Irwin and Dodson, 1991). Approximately 0.5% of igneous rock is composed of manganese (Cole, 1983). According to Shacklette and Boerngen (1984), the estimated arithmetic mean for background manganese concentrations in surface soils in the western U.S. is 480 mg Mn/kg. The TNRCC (2001), considers a soil-manganese concentration of 300 mg Mn/kg dry weight as background in the State of Texas. According to Efroymson *et al.* (1997), a proposed screening benchmark value for manganese toxicity to soil microorganisms is 100 mg Mn/kg dry weight, while the TNRCC (2001) reports a soil-manganese concentration of 500 mg Mn/kg dry weight as a benchmark value for terrestrial plants. The ecological screening benchmark recommended by the USEPA for manganese in soils is 100 mg Mn/kg (RAIS, 2002). King *et al.* (2001), reported manganese levels as high as 180,505 mg Mn/kg dry weight for soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge. In sediments, the OME recommends a LEL of 460 mg Mn/kg dry weight and a SEL of 1,100 mg Mn/kg dry weight (Persaud *et al.*, 1993). The 85th percentile screening criterion recommended by the TNRCC (1996) to be protective of aquatic wildlife for manganese concentrations in sediments from lentic systems within the Red River watershed in Texas is 1,210 mg/kg dry weight. Sediments from the Great Lakes containing less than 300 mg Mn/kg dry weight are considered non-polluted, whereas sediments containing manganese concentrations greater than 500 mg Mn/kg dry weight are considered heavily polluted (Beyer, 1990). Manganese levels in sediment samples collected from Wichita Mountains Wildlife Refuge in 2000-2001 ranged from 28 mg Mn/kg dry weight at Site WM18 to 275 mg Mn/kg dry weight at Site WM5 (Table 10), all below suggested sediment screening criteria (Beyer, 1990; Persaud *et al.*, 1993; TNRCC, 1996). The soil-manganese concentrations detected at Sites WM1 (1,020 mg Mn/kg dry weight), WM7 (660 mg Mn/kg dry weight), and WM9 (1,430 mg Mn/kg dry weight) exceeded expected background concentrations and all ecological screening criteria cited (Shacklette and Boerngen, 1984; Efroymson *et al.*, 1997; TNRCC, 2001; RAIS, 2002), however, these concentrations were well less than the value reported by King *et al.* (2001).

[Mercury (Hg)] Background surface soil-mercury concentrations in the western U.S. are typically less than or equal to 0.065 mg Hg/kg (Shacklette and Boerngen, 1984). In the State of Texas, a soil-mercury concentration of 0.04 is considered background (TNRCC, 2001). The TNRCC (2001) recommends soil-mercury concentrations of 0.1 mg Hg/kg dry weight as a benchmark value for earthworms and 0.3 mg Hg/kg dry weight as a benchmark value for terrestrial plants. According to Andreasen (1986), no detectable amounts of mercury were measured in soils collected in 1985 from the Bonanza Mine site and the Blue Beaver Creek Smelter site at Wichita Mountains. King *et al.*

(2001) reported an elevated value of 5.63 mg Hg/kg dry weight for soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge. In surface water systems exposed to mercury influxes, methylmercury is generally found in sediments that, although subject to anoxic or sub-oxic conditions, have limited sulfate availability (Jaffe *et al.*, 1997). Typical concentrations of mercury in benthic invertebrates from uncontaminated sediments are generally less than 0.1 mg Hg/kg wet weight (Wren *et al.*, 1995). The OME suggest a sediment LEL of 0.2 mg Hg/kg dry weight and a SEL of 2.0 mg Hg/kg dry weight (Persaud *et al.*, 1993), while Long *et al.* (1995), recommend 0.15 mg Hg/kg dry weight as the ER-L for mercury in sediments. MacDonald *et al.* (2000), suggest a sediment TEC of 0.18 mg Hg/kg dry weight and a PEC of 1.06 mg Hg/kg dry weight. None of the sediment samples collected from Wichita Mountains Wildlife Refuge in 2000-2001 contained detectable amounts of mercury (Table 10). No detectable amounts of mercury were measured in soil samples collected from Sites WM1 and WM7 (Table 10), either. The mercury concentrations detected in soil samples collected from WM2 (1.1 mg Hg/kg dry weight) and WM9 (1 mg Hg/kg dry weight) were less than the value reported by King *et al.* (2001), but exceeded suggested background levels and all reported ecological benchmark criteria (Shacklette and Boerngen, 1984; TNRCC, 2001), as well as the results reported by Andreasen (1986).

[Molybdenum (Mo)] Molybdenum is a comparatively rare element that does not occur free in nature and is usually found in conjunction with sulfur, oxygen, tungsten, lead, uranium, iron, magnesium, cobalt, vanadium, bismuth, or calcium (Eisler, 1989). According to Shacklette and Boerngen (1984), the estimated arithmetic mean for background molybdenum concentrations in surface soils in the western U.S. is 1.1 mg Mo/kg. Efroymson *et al.* (1997), proposed a soils toxicity screening benchmark value of 200 mg Mo/kg dry weight for soil microorganisms, while the TNRCC (2001) considers a soils concentration of 2 mg Mo/kg as the benchmark value for terrestrial plants. Soil samples collected in Arizona by the USFWS in 1998 from the Sheep Tank Mine contained 21 mg Mo/kg dry weight (King *et al.*, 2001). The largest soil-molybdenum concentrations are usually found within the top 30 cm of surface soils (USDOI, 1998). Ionic forms of molybdenum such as molybdate, tend to be sorbed most readily in alkaline soils which are high in calcium and chlorides, whereas retention is limited in low pH and low sulfate soils (Eisler, 1989). Background concentrations in lotic sediments in the U.S. range from 5 to 57 mg Mo/kg dry weight (USDOI, 1998). Sediment samples collected by the USFWS in 1993 from Cypress Springs Reservoir, Lake O'The Pines, and Caddo Lake in East Texas contained no detectable molybdenum concentrations (Giggleman *et al.*, 1998). None of the sediment samples collected from Wichita Mountains Wildlife Refuge in 2000-2001 contained detectable amounts of molybdenum (Table 10). Of the four sites where soil samples were collected at the Refuge, only Site WM2, contained soils that had detectable amounts of molybdenum (Table 10). The detected concentration at this site (8 mg Mo/kg dry weight) exceeded the expected background value and the lower ecological threshold criterion (Shacklette and Boerngen, 1984; TNRCC, 2001), but was below the concentration reported for the Sheep Tank Mine as well as the higher ecological benchmark value (Efroymson *et al.*, 1997; King *et al.*, 2001).

[Nickel (Ni)] Background surface soil-nickel concentrations range up to 19 mg Ni/kg in the western U.S. and up to 10 mg Ni/kg in the State of Texas (Shacklette and Boerngen, 1984; TNRCC, 2001).

Efroymson *et al.* (1997), proposed a screening benchmark value for nickel toxicity to soil microorganisms of 90 mg Ni/kg dry weight, while the TNRCC (2001) reports a soil-nickel concentration of 30 mg Ni/kg dry weight as a benchmark value for terrestrial plants. From sampling conducted at Wichita Mountains Wildlife Refuge in 1985, Andreasen (1986) reported nickel concentrations of 3 mg Ni/kg dry weight and 4 mg Ni/kg dry weight in soils collected from the Bonanza Mine and the Bonanza Mine Smelter sites, respectively. Andreasen (1986) also reported nickel concentrations ranging up to 44 mg Ni/kg dry weight in soils collected from the Blue Beaver Creek Smelter site. Soil samples collected in Arizona by the USFWS in 1998 from the Sheep Tank Mine contained 3.53 mg Ni/kg dry weight (King *et al.*, 2001). In aqueous systems, nickel occurs as soluble salts adsorbed onto clay particles and organic matter (Eisler, 1998b). Nickel distribution in an aquatic environment can be affected by pH, ionic strength, and availability of solid surfaces for adsorption (Eisler, 1998b). Sediment samples collected adjacent to a nickel smelter in Canada contained nickel concentrations as high as 5,000 mg Ni/kg dry weight, whereas sediments collected from lakes in the Rocky Mountains in the U.S. with no known sources other than background, contained nickel concentrations ranging from 10 to 18 mg Ni/kg dry weight (Eisler, 1998b). The OME recommends a sediment LEL of 16 mg Ni/kg dry weight and a SEL of 75 mg Ni/kg dry weight (Persaud *et al.*, 1993), whereas Long *et al.* (1995), recommend 21 mg Ni/kg dry weight as the ER-L for nickel in sediments. MacDonald *et al.* (2000), suggest a sediment TEC of 22.7 mg Ni/kg dry weight and a PEC of 48.6 mg Ni/kg dry weight. Nickel concentrations were detected above the analytical detection limits at Wichita Mountains Wildlife Refuge in 2000-2001 in sediment samples collected from Sites WM4, WM5, WM8, and WM13, and in soil samples collected from Sites WM1, WM7 and WM9 (Table 10). The detected sediment-nickel concentrations ranged from 6 mg Ni/kg dry weight at Sites WM8 and WM13 to 10 mg Ni/kg dry weight at Site WM5 (Table 10), all below the reported sediment screening criteria (Persaud *et al.*, 1993; Long *et al.*, 1995; MacDonald *et al.*, 2000) The detected nickel concentration in soil collected from Site WM1 (10 mg Ni/kg dry weight) exceeded the concentration reported by Andreasen (1986) for the Bonanza Mine Smelter site and the value reported by King *et al.* (2001) for the Sheep tank Mine, but was less than or equal to recommended background concentrations (Shacklette and Boerngen, 1984; TNRCC, 2001) and below all reported ecological benchmark values (Efroymson *et al.*, 1997; TNRCC, 2001). The detected soil-nickel concentrations at Sites WM7 (59 mg Ni/kg dry weight) and WM9 (41 mg Ni/kg dry weight) exceeded cited background values and the lower ecological threshold criterion (Shacklette and Boerngen, 1984; TNRCC, 2001). The concentration at WM7 was also elevated in comparison to the value reported by Andreasen (1986) for the Blue Beaver Creek Smelter site. However, neither the level measured at WM7 nor the concentration detected at WM9, exceeded the higher ecological benchmark value reported by Efroymson *et al.* (1997).

[Selenium (Se)] According to Shacklette and Boerngen (1984), the estimated arithmetic mean for background selenium concentrations in surface soils in the western U.S. is 0.34 mg Se/kg. Selenium volatilizes from soils and sediments at rates that are modified by temperature, moisture, time, season of year, concentration of water soluble selenium, and microbial activity (Eisler, 1985b). Efroymson *et al.* (1997), proposed a soils toxicity screening benchmark value of 100 mg Se/kg. The TNRCC (2001) reports soil-selenium concentrations of 1 mg Se/kg dry weight as a benchmark value for terrestrial plants and 70 mg Se/kg as a benchmark value for earthworms. According to King *et al.*

(2001), no detectable amounts of selenium were measured in soils collected from the Sheep Tank Mine at Kofa National Wildlife Refuge in 1998. In sediments, elemental selenium has a tendency to predominate in reducing environments (Van Derveer and Canton, 1997). According to Van Derveer and Canton (1997), the predicted effects concentration of selenium in sediments would be 2.5 mg Se/kg, while the observed effects threshold for fish and wildlife toxicity would be 4.0 mg Se/kg. The 85th percentile selenium sediment screening criterion for lentic systems within the Red River watershed in Texas is 1.73 mg Se/kg (TNRCC, 1996). Selenium levels were detected above the analytical detection limits at Wichita Mountains Wildlife Refuge in sediment samples collected in 2000-2001 from Sites WM3, WM8, WM10, MW11, WM13, WM14, WM16, WM18, WM19, and WM20 (Table 10). The detected concentrations ranged from 0.2 mg Se/kg dry weight at Sites WM10, WM13, WM16, WM19, and WM20 to 0.7 mg Se/kg dry weight at Site WM8 (Table 10), all less than the reported sediment screening criteria (TNRCC, 1996; Van Derveer and Canton, 1997). Selenium concentrations were detected above the analytical detection limits in all of the soil samples collected from Sites WM1, WM2, WM7, and WM9 (Table 10). The detected concentration at Site WM2 (0.2 mg Se/kg dry weight) was below the background value estimated by Shacklette and Boerngen (1984). The levels measured at Sites WM1 (0.8 mg Se/kg dry weight) and WM7 (0.6 mg Se/kg dry weight) exceeded the expected background concentration (Shacklette and Boerngen, 1984), but were below the cited ecological benchmark values (Efroymson *et al.*, 1997; TNRCC, 2001). The concentration detected at Site WM9 (2.4 mg Se/kg dry weight) exceeded the background concentration and the lower ecological benchmark threshold (Shacklette and Boerngen, 1984; TNRCC, 2001), but was less than the higher ecological screening criteria proposed by Efroymson *et al.* (1997) and the TNRCC (2001).

[Zinc (Zn)] Shacklette and Boerngen (1984), estimated the arithmetic mean for background zinc concentrations in surface soils in the western U.S. at 65 mg Zn/kg. The TNRCC (2001), considers a soil-zinc concentration of 30 mg Zn/kg as background in the State of Texas. Efroymson *et al.* (1997), proposed a soils toxicity screening benchmark value of 100 mg Zn/kg. The ecological screening benchmark recommended by the USEPA for zinc in soils is 50 mg Zn/kg (RAIS, 2002). Zinc concentrations detected during a contaminants investigation conducted in 1985 by the USFWS at Wichita Mountains Wildlife Refuge ranged from 115 mg Zn/kg dry weight in soils collected from the Bonanza Mine Smelter site, to 150 mg Zn/kg dry weight in soil taken from the Blue Beaver Creek Smelter site (Andreasen, 1986). Soil samples collected in Arizona by the USFWS in 1998 from the Sheep Tank Mine contained 3,122 mg Zn/kg dry weight (King *et al.*, 2001). According to Eisler (1993), the majority of zinc introduced into an aquatic environment is partitioned into the sediment. Bio-availability of zinc from sediments is enhanced under conditions of high dissolved oxygen, low salinity, low pH, and high levels of inorganic oxides and humic substances (Eisler, 1993). Zinc concentrations in sediments less than 90 mg Zn/kg dry weight are considered supportive of aquatic biota, whereas zinc concentrations greater than 200 mg Zn/kg dry weight can be harmful to aquatic biota (Eisler, 1993). The OME recommends a sediment LEL of 120 mg Zn/kg dry weight and a SEL of 820 mg Zn/kg dry weight (Persaud *et al.*, 1993), while Long *et al.* (1995), consider 150 mg Zn/kg dry weight as the ER-L for zinc in sediments. MacDonald *et al.* (2000), suggest a sediment TEC of 121 mg Zn/kg dry weight and a PEC of 459 mg Zn/kg dry weight. Detected zinc concentrations in soils collected in 2000-2001 from Sites WM1, WM2, WM7, and WM9 at Wichita

Mountains Wildlife Refuge ranged from 150 mg Zn/kg dry weight to 597 mg Zn/kg dry weight (Table 10). These concentrations exceeded the suggested soil background concentrations, all of the recommended ecological benchmark values, and the soil-zinc concentrations previously measured at the Refuge (Shacklette and Boerngen, 1984; Andreasen, 1986; Efroymson *et al.*, 1997; TNRCC, 2001; RAIS, 2002), but were well below the soils concentration reported by King *et al.* (2001). Sediments collected from the Refuge in 2000-2001 contained zinc concentrations ranging from 14 mg Zn/kg dry weight at Site WM17 to 61 mg Zn/kg dry weight at Site WM6 (Table 10), all below proposed sediment screening criteria.

CONCLUSIONS

Results of the metals analyses for the four species of fish (bluegill, channel catfish, black bullhead, and largemouth bass) collected from 12 reservoirs at Wichita Mountains Wildlife Refuge indicate that fish inhabiting these reservoirs are contaminated with mercury. Every fish collected during the course of this study, regardless of species, contained detectable amounts of mercury. Of the species sampled, largemouth bass consistently contained elevated mercury concentrations. All whole body largemouth bass samples contained mercury concentrations exceeding the recommended avian predator protection limit of 0.1 mg Hg/kg wet weight. Every largemouth bass equal to or greater than 475 mm (19 inches) in length contained fillet-mercury concentrations in excess of the USFDA action level of 1 mg Hg/kg wet weight. In all, 33% of the largemouth bass fillet samples collected exceeded the USFDA level while 100% of these samples exceeded the USEPA criterion of 0.3 mg Hg/kg wet weight. In addition to the bass, mercury levels exceeding the USEPA criterion were also measured in almost 20% of the 60 bluegill sampled, 60% of the six bullheads collected, and 10% of the 35 channel catfish sampled. Based on the mercury levels detected in largemouth bass, Refuge Management initiated a limited fish consumption advisory for bass (Figure 7) at all 12 reservoirs on March 29, 2001 (Meador, 2001).

Figure 7. Consumption advisory posted at Wichita Mountains Wildlife Refuge.

In addition to the fish, all of the turtle samples and the composite frog sample contained detectable amounts of mercury. Since turtles function as mid-trophic level predators in aquatic systems, it appears that mercury contamination has extended into higher trophic levels at the Refuge.

Besides mercury, none of the other metals analyzed were detected in fish at levels that represent significant ecological or human health risks. Some metals were detected at elevated concentrations in comparison to cited studies in the frog and turtle samples collected from the Refuge; however, considering the limited amount of data currently available on toxicological effects to amphibians and reptiles from various contaminants including metals, more definitive toxicological information must be developed in the near future before any unambiguous conclusions can be ascertained.

All of the sediment samples collected from the Refuge contained aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, magnesium, manganese, molybdenum, nickel, selenium, and zinc concentrations below ecological screening criteria with the exception of the sample taken from Quanah Parker Creek upstream of Quanah Parker Lake, which contained elevated aluminum and iron levels. However, the aluminum and iron concentrations measured at this site were not at levels where significant adverse affects to fish and wildlife resources would be expected to occur. The reason mercury and other metals were not detected in significant amounts within the creeks may be attributed to the composition of the substrate of these streams. The majority of the sediments collected from these streams were dominated by course sands. Typically, metals do not bind as readily to course sands as they do to clays and silts (Giggleman *et al.*, 2002). In soils, lead was detected at highly elevated levels in the samples collected from the Bonanza Mine and Blue Beaver Creek smelter sites, while mercury was detected at elevated concentrations in samples collected from the Bonanza Mine and Blue Beaver Creek tailings piles. In addition, all of the soil samples collected contained elevated manganese and zinc concentrations, while the samples taken from the Bonanza Mine smelter site and Blue Beaver Creek smelter site and tailings pile contained elevated levels of iron. The lead and mercury levels were detected at much higher concentrations than would be expected to occur naturally, whereas the high iron, manganese, and zinc concentrations may be indicative of residual contamination from earth moving activities associated with the former gold mining operations within the area or they may be the natural breakdown products of the surrounding parent rock material (Whitten and Brooks, 1972; Horne and Goldman, 1994; Miller and Gardiner, 1998). Considering that lead levels were detected in nominal amounts in biological data collected during the course of this study, it appears that the lead contamination detected at the smelter sites is distributed in limited, localized areas and not readily available to fish inhabiting the Refuge's reservoirs. In contrast, the supportive biological data generated from this study indicate that mercury contamination is widely distributed throughout the Refuge.

RECOMMENDATIONS

Over time, the mercury concentrations in fish at the Refuge may fluctuate. For this reason, fish sampling, following the protocols of this study, should be performed in the future (not to exceed five-year intervals), to measure temporal trends of mercury contamination within fish. In turn, data collected from these sampling events can be incorporated to re-evaluate the fish consumption advisory that is currently in place at the Refuge.

Based on the elevated mercury levels detected in softshell turtle muscle tissues, Refuge Management may wish to consider whether it is necessary to establish a turtle consumption advisory. This type of advisory has already been initiated in Minnesota and Ohio for snapping turtle consumption and in Arizona for softshell turtle consumption with all employing similar restrictions typically associated with fish consumption advisories (USEPA, 1995; Bogart, 2002). For example, the Ohio snapping turtle advisory recommends that no more than 4 ounces (124 grams) of cleaned meat (excluding all skin, body fat, internal organs, and claws) should be consumed weekly. However, prior to establishing this type of advisory at the Refuge it is recommended that further sampling be conducted, targeting edible turtle species.

Determining definitive ecological effects to wildlife resources at the Refuge was not within the scope of this study. However, considering that elevated mercury levels were detected in turtles (mid-trophic level predators), it is recommended that future studies be conducted to define the site-specific effects of mercury contamination to piscivorus avian species and other aquatic dependent wildlife which inhabit the Refuge.

Prior to any physical remedial efforts targeting known mining operation sites, further, more definitive delineation of mercury contamination associated with these areas is warranted. It is also recommended that surveys be conducted to find all former hard rock mining operation sites located within the boundaries of the Refuge and that additional sampling be conducted in these areas to determine if they represent a source of mercury contamination. Furthermore, it is recommended that off-site soil sampling be conducted in the vicinity of the Refuge and away from historical mining activity, to determine if other potential contaminant sources (i.e., aerial deposition) may be impacting the Refuge.

REFERENCES

Albers, P.H., L. Sileo, and B.M. Mulhern. 1986. Effects of Environmental Contaminants on Snapping Turtles of a Tidal Wetland. Arch. Environ. Contam. Toxicol. 15. pp 39-49.

Alpers, C.N. and M.P. Hunerlach. 2000. Mercury Contamination from Historic Gold Mining in California (Fact Sheet FS-061-00). U.S. Geological Survey. Sacramento, California. 6 pp.

Andreasen, J.K. 1986. An Evaluation of Mercury Contamination at the Wichita Mountains Wildlife Refuge, Oklahoma. U.S. Fish and Wildlife Service. Tulsa, Oklahoma. 9 pp.

Baker, D.L. and K.A. King. 1994. Environmental Contaminant Investigation of Water Quality, Sediment, and Biota of the Upper Gila River Basin, Arizona. U.S. Fish and Wildlife Service. Phoenix, Arizona. 25 pp.

Baker, D.L., J.D. Lusk, and C.M. Giggleman. 1998. Phase II Contaminants Investigation of Buffalo Lake National Wildlife Refuge, Texas 1993-1994. U.S. Fish and Wildlife Service. Arlington, Texas. 35 pp.

Bartlett, R.D. and P.P. Bartlett. 1999. A Field Guide to Texas Reptiles and Amphibians. Gulf Publishing Company. Houston, Texas. 331 pp.

Becker, C.D. and T.O. Thatcher. 1973. Toxicity of Power Plant Chemicals to Aquatic Life. U.S. Atomic Energy Commission. Battelle Pacific Laboratories. Richland, Washington.

Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press. Madison, Wisconsin. 1052 pp.

Behler, J.L. and F.W. King. 1987. The Audubon Society Field Guide to North American Reptiles and Amphibians. Alfred A. Knopf, Inc. New York, New York. 743 pp.

Beyer, W.N. 1990. Evaluating Soil Contamination. U.S. Fish and Wildlife Service. Washington, D.C. 25 pp.

Beyer, N. 1994. Unpublished data on mercury in wildlife from the Panther National Wildlife Refuge.

Buchman, M.F. 1999. Screening Quick Reference Tables. National Oceanic and Atmospheric Administration, Coastal Protection and Restoration Division. Seattle, Washington. 12 pp.

Bogart, C. 2002. And Watch Out for those Snapping Turtles. The Advertiser-Tribune. Website at http://www.advertiser-tribune.com/Text/N031802b.html.

Chow, K.W. and W.R. Schell. 2002. Chapter 7: The Minerals. Website at http://www.fao.org/docrep/x5738e/x5738e08.htm.

Clark, D.R. Jr., R. Cantu, D.F. Cowman, and D.J. Maxson. 1998. Uptake of Arsenic and Metals by Tadpoles at an Historically Contaminated Texas Site. Ecotoxicology. Volume 7. pp 61-67.

Cole, G.A. 1983. Textbook of Limnology. The C.V. Mosby Company. St. Louis, Missouri. 401 pp.

Conant, R. 1975. A Field Guide to Reptiles and Amphibians of Eastern and Central North America. Houghton Mifflin Company. Boston, Massachusetts. 429 pp.

Custer, M., R. Roy, M. Wilson, T. Adornato, and J. Winckel.1993. An Investigation of Selenium, Mercury, and Lead Concentrations in Sediment and Biota from Maxwell National Wildlife Refuge, Colfax County, New Mexico. U.S. Fish and Wildlife Service. Albuquerque, New Mexico. 29 pp.

Degenhardt, W.G., C.W. Painter, and A.H. Price. 1996. Amphibians and Reptiles of New Mexico. University of New Mexico Press. Albuquerque, New Mexico. 430 pp.

Efroymson, R.A., M.E. Will, and G.W. Suter II. 1997. Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision. U.S. Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory, Tennessee.

Eisler, R. 1985a. Cadmium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 2). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 46 pp.

Eisler, R. 1985b. Selenium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 5). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 57 pp.

Eisler, R. 1986. Chromium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 6). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 90 pp.

Eisler, R. 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 10). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 90 pp.

Eisler, R. 1988a. Arsenic Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 12). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 92 pp.

Eisler, R. 1988b. Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 14). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 134 pp.

Eisler, R. 1989. Molybdenum Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 19). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 61 pp.

Eisler, R. 1993. Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 26). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 106 pp.

Eisler, R. 1998a. Copper Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 33). U.S. Department of the Interior, U.S. Geological Survey. Laurel, Maryland.

Eisler, R. 1998b. Nickel Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 34). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C.

Eisler, R., D.R. Clark Jr., S.N. Wiemeyer, and C.J. Henry. 1999. Sodium Cyanide Hazards to Fish and Other Wildlife from Gold Mining Operations. In J.M. Azcue, ed. Environmental Impacts of Mining Activities: Emphasis on Mitigation and Remedial Measures. Springer-Verlag, Berlin. pp 55-67.

Etnier, D.A. and W.C. Starnes. 1993. The Fishes of Tennessee. The University of Tennessee Press. Knoxville, Tennessee. 681 pp.

Gamble, L.R., G.A. Jackson and T.C. Maurer. 1988. Organochlorine, Trace Element, and Petroleum Hydrocarbon Contaminants Investigation of the Lower Rio Grande Valley, Texas, 1985-1986. U.S. Fish and Wildlife Service. Corpus Christi, Texas.

Garrett, J.M. and D.G. Barker. 1987. A Field Guide to Reptiles and Amphibians of Texas. Texas Monthly Press, Inc. Austin, Texas. 225 pp.

Giggleman, C.M., D.L. Baker, and J.D. Lusk. 1998. A Contaminants Survey of Three Lentic Systems Within The Cypress Creek Watershed, Texas 1993-1995. U.S. Fish and Wildlife Service. Arlington, Texas. 35 pp.

Giggleman, C.M., O.R. Bocanegra, M.P. Armstrong, and J.M. Lewis. 2002. The Impact of Anthropogenic Discharges on Arkansas River Shiner (*Notropis girardi*) Habitat within the South Canadian River Watershed in the Texas Panhandle, Texas 2001-2002. U.S. Fish and Wildlife Service. Arlington, Texas. 53 pp.

Golet, W.J. and T.A. Haines. 2001. Snapping Turtles (*Chelydra serpentina*) as Monitors for Mercury Contamination of Aquatic Environments. Environmental Monitoring and Assessment, Volume 71. pp 211-220.

Goyer, R.A. 1991. Toxic Effects of Metals. In M.O. Amdur, J. Doull, and C.D. Klaassen, eds. Casasrett and Doull's Toxicology (4th Edition). Pergamon Press. New York, New York. pp 623-680.

Guyton, A.C. 1981. Textbook of Medical Physiology (6th Edition). W.B.Saunders Company. Philadelphia, Pennsylvania. 1074 pp.

Helwig, DD.and M.E. Hora. 1983. Polychlorinated biphenyl, Mercury, and Cadmium Concentrations in Minnesota Snapping Turtles. Bull. Environ. Contam. Toxicol. Volume 30. pp 186-190.

Hodges, L. 1977. Environmental Pollution (2nd Edition). Holt, Rinehart, and Winston. Dallas, Texas. 496 pp.

Horne, A.J. and C.R. Goldman. 1994. Limnology (2nd Edition). McGraw-Hill, Incorporated. St. Louis, Missouri. 576 pp.

Irwin, R.J. 1988. Impacts of Toxic Chemicals on Trinity River Fish and Wildlife. U.S. Fish and Wildlife Service. Arlington, Texas. 82 pp.

Irwin, R.J. 1989. Toxic Chemicals in Fish and Wildlife at Big Bend National Park, Texas. U.S. Fish and Wildlife Service. Arlington, Texas. 36 pp.

Irwin, R.J. and S. Dodson. 1991. Contaminants in Buffalo Lake National Wildlife Refuge, Texas. U.S. Fish and Wildlife Service. Arlington, Texas. 90 pp.

Jaffe, R., Y. Cai, J. West-Thomas, M. Morales, and R.D. Jones. 1997. Occurrence of Methylmercury in Lake Valencia, Venezuela. Bulletin of Environmental Contamination and Toxicology Number 59. Springer-Verlag. New York, New York. pp 99-105.

Jester, D.B., A.A. Echelle, W.J. Matthews, J. Pigg, C.M. Scott, and K.D. Collins. 1992. The Fishes of Oklahoma, Their Gross Habitats, and Their Tolerance of Degradation in Water Quality and Habitat. Proc. Okla. Acad. Sci. 72: pp 7-19.

King, K.A., B.J. Andrews, C.T. Martinez, and W. G. Kepner. 1997. Environmental Contaminants in Fish and Wildlife of the Lower Gila River, Arizona. U.S. Fish and Wildlife Service. Phoenix, Arizona. 64 pp.

King, K.A., A.L. Velasco, J.A. Record, and R.L. Kearns. 2001. Contaminants in Bats Roosting in Abandoned Mines at Imperial National Wildlife Refuge, Arizona 1998-1999. U.S. Fish and Wildlife Service. Phoenix, Arizona. 35 pp.

Law, R.J. 1996. Metals in Marine Mammals. In W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. Lewis Publishers. New York, New York. pp 357-376.

Lee, M.C. and T.W. Schultz. 1994. Contaminants Investigation of the Guadalupe and San Antonio Rivers of Texas. U.S. Fish and Wildlife Service. Corpus Christi, Texas. 15 pp.

Lemly, A.D. 1996. Selenium in Aquatic Organisms. In W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. Lewis Publishers. New York, New York. pp 427-446.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.C. Calder. 1995. Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environmental Management Volume 19, Number 1. Springer-Verlag. New York, New York. pp 81-97.

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, Volume 39. Springer-Verlag, Inc. New York, New York. pp 20-31.

Mann-Klager, D. 1997. Preliminary Assessment of the Long Island National Wildlife Refuge Complex Environmental Contaminants Background Study (3rd year results). U.S. Fish and Wildlife Service. Cortland, New York.

Maptech. 1998. Terrain Navigator Lawton-Ardmore-Ada (Oklahoma). Maptech. Greenland, New Hampshire.

Meador, M. 2001. Mercury Too High In Refuge Bass. In The Lawton Constitution, March 29, 2001. Lawton, Oklahoma.

Meyers-Schone, L. and B.T. Walton. 1994. Turtles as Monitors of Chemical Contaminants in the Environment. Reviews of Environmental Contamination and Toxicology. Volume 135. pp 93-153.

Miller, R.W. and D.T. Gardiner. 1998. Soils In Our Environment (8th Edition). Prentice Hall. Upper Saddle River, New Jersey. 736 pp.

National Oceanic and Atmospheric Administration (NOAA). 1990. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program (NOAA Technical Memorandum NOS OMA 52). National Oceanic and Atmospheric Administration. Seattle, Washington.

National Research Council (NRC). 1980. Mineral Tolerances of Domestic Animals. National Academy Press, National Academy of Sciences. Washington, D.C. 577 pp.

Oklahoma Department of Wildlife Conservation (ODWC). 2001. Oklahoma Fishing Guide. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 30 pp.

Overmann, S.R. and J.J. Krajicek. 1995. Snapping Turtles (*Chelydra Serpentina*) as Biomonitors of Lead Contamination of the Big River in Missouri's Old Lead Belt. Environmental Toxicology and Chemistry. Volume 14, Number 4. pp 689-695.

Pain, D.J. 1995. Lead in the Environment. In D.J. Hoffman, B.A. Rattner, G.A. Burton Jr., and J. Cairns Jr. eds. Handbook of Ecotoxicology. Lewis Publishers. Ann Arbor, Michigan. pp 356-391.

Pennington, H.D. 1991. Arsenic Survey of Texas Soils. In Comprehensive Study of Texas Watersheds and Their Impacts on Water Quality and Water Quantity. Texas State Soil and Water Conservation Board. Temple, Texas. 14 pp.

Persaud, D., R. Jaagumagi, and A. Hayton. 1993. Guidelines for the Protection and Management of aquatic Sediment Quality in Ontario. Water Resources Branch, Ontario Ministry of the Environment. Toronto, Ontario.

Pflieger, W.L. 1991. The Fishes of Missouri. Missouri Department of Conservation. St. Louis, Missouri. 343 pp.

Pritchard, P.C.H. 1979. Encyclopedia of Turtles. T.F.H. Publications, Inc. Neptune, New Jersey. 895 pp.

Risk Assessment Information System (RAIS). 2002. Ecological Benchmarks. RAIS website at http://risk.lsd.ornl.gov/homepage/eco_tool.shtml.

Robison, H.W. and T.M. Buchanan. 1988. Fishes of Arkansas. The University of Arkansas Press. Fayettville, Arkansas. 536 pp.

Ryan, J.A., R.L. Chaney, G. Prince, A.D. Otte, and J.M. Walker. 1980. Review of the Soil Factors and the Concept of Annual and Cumulative Application Rate of Cd on Cd Content of Crops. U.S. Environmental Protection Agency. Washington, D.C.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National Contaminant Biomonitoring Program: Concentrations of Arsenic, Cadmium, Copper, Lead, Mercury, Selenium, and Zinc in U.S. Freshwater Fish, 1976-1984. Archives of Environmental Contamination and Toxicology. Volume 19: pp 731-747.

Schneider, R.F. 1971. The Impact of Various Heavy Metals on the Aquatic Environment. U.S. Environmental Protection Agency. Denver, Colorado.

Shacklette, H.T. and J.G. Boerngen. 1984. Element Concentrations in Soils and Other Surficial Material of the Conterminous United States (USGS PP 1270). U.S. Geological Survey. Washington, D.C. 105 pp.

Shukla, G.S. and R.L. Singhal. 1984. The Present Status of Biological Effects of Toxic Metals in the Environment: Lead, Cadmium, and Manganese. Canadian Journal of Physiology and Pharmacology, Volume 62. Ontario, Canada. pp 1015-1031.

Sievert, G. and L. Sievert. 1993. A Field Guide to Reptiles of Oklahoma. Oklahoma Department of Wildlife Conservation. Oklahoma City, Oklahoma. 104 pp.

Sparling, D.W. and T.P. Lowe. 1996. Environmental Hazards of Aluminum to Plants, Invertebrates, Fish, and Wildlife. Springer-Verlag, Inc. New York, New York. 127 pp.

Stone, W., E. Kiviat, and S.A. Butkas. 1980. Toxicants in Snapping Turtles. New York Fish Game Journal 27. pp 39-50.

Tetra Tech. 1997. Pena Blanca and Arivaca Lakes, Arizona: Mercury TMDL Reconnaissance. Tetra Tech, Inc. Fairfax, Virginia. 24 pp.

Texas Department of Health (TDH). 1997. Fish Advisories and Bans. Texas Department of Health Seafood Safety Division. Austin, Texas. 21 pp.

Texas Natural Resource Conservation Commission (TNRCC). 1996. The State of Texas Water Quality Inventory, 13th Edition, Volume 2 (SFA-50). Texas Natural Resource Conservation Commission. Austin, Texas. 758 pp.

Texas Natural Resource Conservation Commission (TNRCC). 2000. Guidance for Screening and Assessing Texas Surface and Finished Drinking Water Quality Data, 2000. Texas Natural Resource Conservation Commission. Austin, Texas.

Texas Natural Resource Conservation Commission (TNRCC). 2001. Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas. Texas Natural Resource Conservation Commission. Austin, Texas. 758 pp.

U.S. Army. 1995. Ecological Effects of Anthropogenic Contamination to Amphibians and Birds at J-Field, Aberdeen, Proving Ground, Edgewood Area, Maryland. Health Effects Research Study #87-23-3250-96. U.S. Department of the Army, Department of Defense.

U.S. Army Environmental Hygiene Agency. 1994. Aberdeen Proving Ground Snapping Turtle Consumption Health Risk Assessment (Project number 39-26-L173-91), Draft.

U.S. Department of the Interior (USDOI). 1998. Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment (National Irrigation Water Quality Program Information Report No. 3). U.S. Bureau of Reclamation. Denver, Colorado. 198 pp.

U.S. Environmental Protection Agency (USEPA). 1980. Ambient Water Quality Criteria for Arsenic (EPA-440/5-80-021). U.S. Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1989. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish (EPA-503/8-89-002). U.S. Environmental Protection Agency. Washington, D.C. 89 pp.

U.S. Environmental Protection Agency (USEPA). 1992. National Study of Chemical Residues in Fish (EPA 823-R-92-008a/b). U.S. Environmental Protection Agency, Office of Science and Technology. Washington, D.C. 166 pp.

U.S. Environmental Protection Agency (USEPA). 1994. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume II: Risk Assessment and Fish Consumption Limits. U.S. Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1995. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume I: Fish Sampling and Analysis (2nd Edition). U.S. Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1997. The Incidence and Severity of Sediment Contamination in Surface Waters of the United States: Volume I: National Sediment Quality Survey. U.S. Environmental Protection Agency. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 2000. Ecological Soil Screening Level Guidance (Draft). U.S. Environmental Protection Agency. Office of Emergency and Remedial Response. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 2001a.Water Quality Criterion for the Protection of Human Health: Methylmercury (EPA-823-R-01-001). U.S. Environmental Protection Agency. Office of Science and Technology/Office of Water. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 2001b. Mercury Update: Impact on Fish Advisories Fact Sheet (EPA-823-F-01-011). U.S. Environmental Protection Agency. Office of Water. Washington, D.C.

U.S. Fish and Wildlife Service (USFWS). 1986. Preliminary Survey of Contaminant Issues of Concern on National Wildlife Refuges. U.S. Fish and Wildlife Service. Washington, D.C.

U.S. Food and Drug Administration (USFDA). 1995. FDA Consumer - Mercury in Fish: Cause for Concern? U.S. Food and Drug Administration. Washington, D.C.

University of Texas at Dallas (UTD). The Geology of the Wichita Mountains Wildlife Refuge: A Thumbnail Sketch. University of Texas at Dallas Programs in Geosciences. Dallas, Texas. 2 pp.

Van Derveer, W.D. and S.P. Canton. 1997. Selenium Sediment Toxicity Thresholds and Derivation of Water Quality Criteria for Freshwater Biota of Western Streams. Environmental Toxicology and Chemistry. Volume 16, Number 6: pp 1260-1268.

Whitten, D.G.A. and J.R.V. Brooks. 1972. The Penguin Dictionary of Geology. Penguin Books. Baltimore, Maryland. 495 pp.

Wiener, J.G. and J.P. Giesy, Jr. 1979. Concentrations of Cd, Cu, Mn, Pb, and Zn in Fishes in a Highly Organic Softwater Pond. J. Fish. Res. Board Can., Volume 36. Ontario, Canada. pp 270-279.

Wiener, J.G. and D.J. Spry. 1996. Toxicological Significance of Mercury in Freshwater Fish. In W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. Lewis Publishers. New York, New York. pp 297-340.

Wren, C.D., S. Harris, and N. Harttrup. 1995. Ecotoxicology of Mercury and Cadmium. In D.J. Hoffman, B.A. Rattner, G.A. Burton Jr., and J. Cairns Jr. eds. Handbook of Ecotoxicology. Lewis Publishers. Ann Arbor, Michigan. pp 392-423.

PERSONAL COMMUNICATIONS

Bristow, B.A. 1999. U.S. Fish and Wildlife Service, Tishomingo Fishery Resources. Tishomingo, Oklahoma. (Telephone no.: 580/384-5710).

Conzelmann, P. 2001. U.S. Fish and Wildlife Service, Ecological Services. Lafayette, Louisiana. (Telephone no.: 337/291-3126).

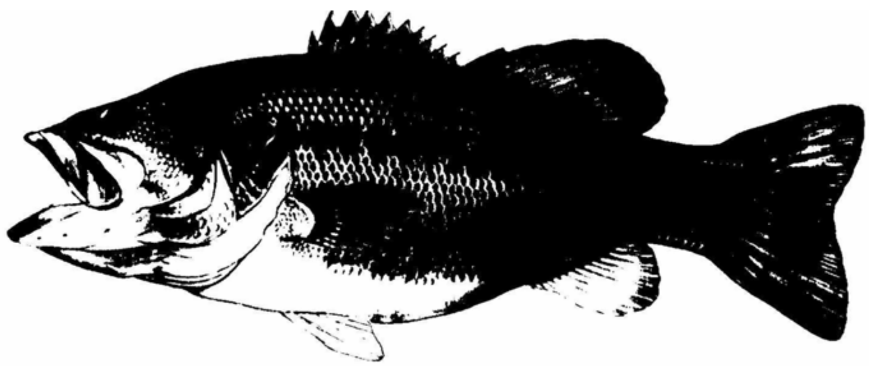
Waldstein, S. 2000. U.S. Fish and Wildlife Service, Wichita Mountains Wildlife Refuge. Indiahoma, Oklahoma. (Telephone no.: 580/429-3019).

APPENDIX A
(1997 FISHERIES SURVEY)

U.S. Fish and Wildlife Service
Region 2
Contaminants Program

AN EVALUATION OF MERCURY CONTAMINATION IN LARGEMOUTH BASS COLLECTED AT WICHITA MOUNTAINS WILDLIFE REFUGE, OKLAHOMA

for
Sam Waldstein
Refuge Manager, Wichita Mountains Wildlife Refuge



prepared by
Craig M. Giggleman
U.S. Fish and Wildlife Service
Arlington Ecological Services Field Office
711 Stadium Drive, East, Suite #252
Arlington, Texas 76011

November 1998

AN EVALUATION OF MERCURY CONTAMINATION IN LARGEMOUTH BASS COLLECTED AT WICHITA MOUNTAINS WILDLIFE REFUGE, OKLAHOMA 1997

INTRODUCTION

In October, 1997, whole body largemouth bass (*Micropterus salmoides*) samples were collected by Tishomingo Fishery Resources Office personnel, from seven reservoirs at Wichita Mountains Wildlife Refuge, Oklahoma, and analyzed for total mercury content. The results of this analysis were compared with screening criteria protective of predacious wildlife to evaluate the extent of mercury contamination in aquatic organisms within the Refuge.

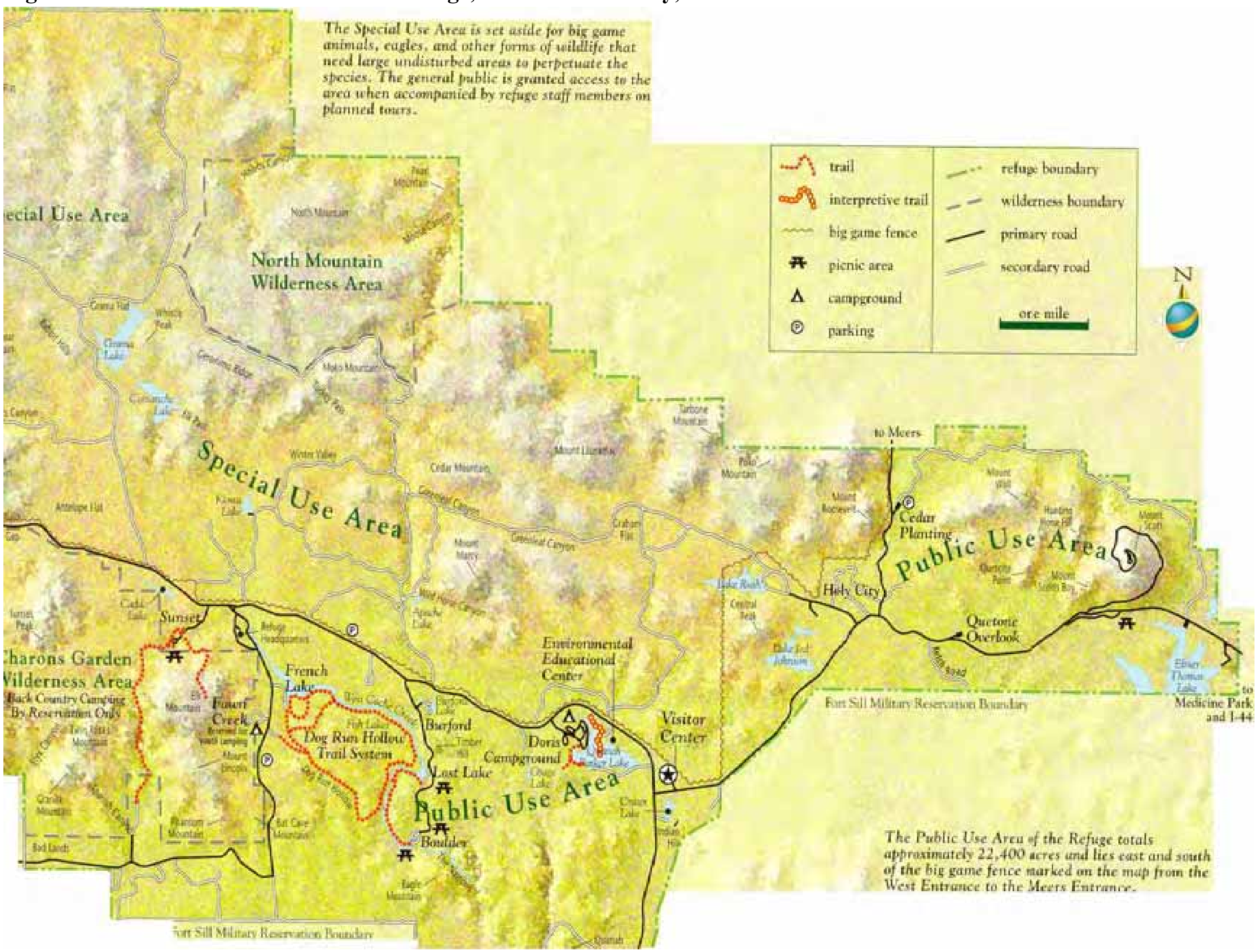
BACKGROUND

Wichita Mountains Wildlife Refuge (Figure 1) was established as a national wildlife refuge in 1905. The Refuge encompasses approximately 59,020.0 acres (23,885.4 hectares) and is located north of the Fort Sill U.S. Military Reservation and north of the City of Lawton in Comanche County, Oklahoma. The Refuge is situated at a higher elevation than the surrounding area and consequentially does not receive significant inflow from any off site streams. The Refuge provides mixed grass prairie, cross timber, rockland, and aquatic habitats that support approximately 806 species of plants, 36 fish species, 64 amphibian and reptilian species, 50 species of mammals, and 240 avian species (Southwest Natural and Cultural Heritage Association, 1997; U.S. Fish and Wildlife Service, 1997). Intensive gold prospecting and associated industries occurred in the Wichita Mountains area during the late nineteenth century. In the area now encompassed by the Refuge, ore smelter facilities were known to have been constructed at Blue Beaver Creek (located in the northeastern portion of the Refuge) and Fawn Creek (located in the southwestern portion of the Refuge), while arrastras (ore grinding sites) were known to have been in operation at Cedar Creek (located in the northeastern portion of the Refuge) and Panther Creek (located in the south central portion of the Refuge) (Andreasen, 1986). In 1984, the Oklahoma Water Resources Board analyzed soil collected in the vicinity of the Cedar Creek arrastra site for total mercury content. The results of this analysis indicated that mercury concentrations were extremely elevated (mean ($\bar{x}$) = 2,052.0 mg/kg dry weight). In 1986, the U.S. Fish and Wildlife Service, Ecological Services, Tulsa, Oklahoma, Field Office conducted a study at the smelter and arrastra sites to determine the extent of cadmium, chromium, copper, mercury, nickel, lead, strontium, vanadium, and zinc contamination (Andreasen, 1986). According to Andreasen (1986), the results of the 1986 study indicated that some metals including mercury, were present at elevated levels, but bound tightly to the soil particles. Andreasen (1986) further concluded that ". . . if erosion wash[ed] some of the [contaminated] soils into a water body the mercury [would] not be released at normal pH levels." However, the results of the 1997 study indicate that mercury from these sites may have become available to aquatic fauna inhabiting the reservoirs within the Refuge.

METHODS & MATERIALS

Sampling for this survey was conducted by Tishomingo Fishery Resources Office personnel from October 20 - 22, 1997. The lakes sampled included Grama Lake, Lost Lake, Quanah Parker Lake, Crater Lake, Lake Jed Johnson, Lake Rush, and Elmer Thomas Lake (Figure 1). Grama Lake is an impoundment of Deer Creek that contains approximately 114.0 surface acres (46.14 hectares) and is located in the north central portion of the Refuge. Lost Lake is an impoundment of West Cache Creek that contains about 10.2 surface acres (4.13 hectares) and is located in the south central portion of the Refuge. Quanah Parker Lake is an

Figure 1. Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma.



impoundment of Quanah Creek that contains approximately 96.0 surface acres (27.92 hectares) and is located approximately 2.0 miles (3.22 kilometers) east of Lost Lake. Crater Lake is located approximately 0.5 miles (0.81 kilometers) southeast of Quanah Parker Lake and is an impoundment of Crater Creek that contains approximately 9.3 surface acres (3.76 hectares). Lake Rush is an impoundment of Blue Beaver Creek that contains 51.6 surface acres (20.90 hectares) and is located approximately 2.0 miles (3.22 kilometers) northeast of Quanah Parker Lake. Lake Jed Johnson is located approximately 0.5 miles (0.81 kilometers) south of Lake Rush and also is an impoundment of Blue Beaver Creek which contains approximately 57.5 surface acres (23.27 hectares). Elmer Thomas Lake is located in the eastern most potion of the Refuge and is an impoundment of Medicine Creek that contains approximately 360.0 surface acres (145.69 hectares).

Five fish samples were collected from each lake using a direct-current-boom electrofishing boat. Once collected, samples were wrapped in plastic wrap, placed on ice, and submitted to the U.S. Fish and Wildlife Service's Patuxent Analytical Control Facility for total mercury analysis. Mercury concentrations were determined at the analytical laboratory by a cold vapor atomic absorption spectrophotometer.

RESULTS & DISCUSSION

The mean ($\bar{x}$) mercury concentrations detected in fish collected from each reservoir in mg/kg (ppm) wet weight are presented in Table 1. The results of the analysis for individual fish collected from the seven reservoirs are presented in Table 2.

Table 1. Arithmetic mean mercury concentrations in mg/kg (ppm) wet weight, weight, and length in largemouth bass collected from seven Reservoirs at Wichita Mountain Wildlife Refuge, 1997.

Parameters	Grama Lake	Lost Lake	Quanah Parker Lake	Crater Lake	Lake Jed Johnson	Lake Rush	Elmer Thomas Lake
Mercury (mg/kg)	0.219	0.219	0.212	0.203	0.137	0.413	0.214
Weight (g)	423.8	163.4	152.5	275.6	123.0	307.5	324.4
Length (mm)	335.6	245.6	240.6	291.4	227.2	302.0	291.0

(Note - where concentrations were not detected above the detection limit, the conservative approach of selecting the numeric value immediately below the detection limit value was employed in calculating the arithmetic mean; g is grams; and mm is millimeters)

Based on dietary thresholds, predator protection limits are recommended concentrations below which no adverse toxicological effects are observed. These concentrations are non-enforceable guidelines developed to assist in determining affects of levels of contamination. Fish collected from all seven reservoirs contained detectable mercury concentrations that exceeded the recommended avian predator protection limit of 0.1 mg/kg wet weight (Eisler, 1987) with 33 of the 35 fish sampled, containing mercury concentrations which exceeded this level. In addition, 27 of the 35 fish collected contained mercury concentrations which exceeded the national 85th percentile value of 0.17 mg/kg wet weight for largemouth bass determined by the National Contaminant Biomonitoring Program (Schmitt and Brumbaugh, 1990). However, none of the fish collected contained detectable mercury concentrations that approached the recommended mammalian predator protection limit of 1.1 mg/kg wet weight (Eisler, 1987).

Mercury is listed by the U.S. Environmental Protection Agency as a priority pollutant and unlike most other metals, it not only concentrates in biological tissue, but also biomagnifies in concentration in successive trophic levels. This element is used in metallurgy, mining amalgams, the preparation of dental amalgams, in switches, thermometers, barometers, pharmaceuticals, and the electrolytic preparation of chlorine.

Table A1. Individual results of mercury (Hg) analysis in mg/kg wet weight for 35 whole body largemouth bass samples collected from seven Reservoirs at Wichita Mountains Wildlife Refuge, 1997.

Fish Sample	Weight (g)	% Moisture	Length (mm)	Sex	Hg Concentration (mg/kg)	d.l. (mg/kg)
Grama Lake 1	368.3	76.7	330.0	Female	0.387	0.0189
Grama Lake 2	308.5	77.0	388.0	Female	0.210	0.0200
Grama Lake 3	971.4	78.2	422.0	Male	0.274	0.0189
Grama Lake 4	247.5	75.0	270.0	Male	0.105	0.0161
Grama Lake 5	223.1	75.8	268.0	Male	0.118	0.0196
Lost Lake 1	232.5	75.7	275.0	Male	0.196	0.0179
Lost Lake 2	153.2	77.8	247.0	Female	0.245	0.0182
Lost Lake 3	155.9	76.2	243.0	Female	0.231	0.0185
Lost Lake 4	117.3	72.7	222.0	Female	0.210	0.0200
Lost Lake 5	158.3	74.4	241.0	Male	0.212	0.0192
Quanah Parker Lake 1	163.2	75.5	251.0	Female	0.137	0.0196
Quanah Parker Lake 2	146.6	73.1	238.0	Male	0.178	0.0198
Quanah Parker Lake 3	113.3	73.8	224.0	Male	0.297	0.0198
Quanah Parker Lake 4	218.3	77.9	272.0	Male	0.182	0.0182
Quanah Parker Lake 5	121.3	76.2	218.0	Female	0.264	0.0189
Crater Lake 1	229.2	72.1	274.0	Female	bdl	0.0185
Crater Lake 2	336.7	77.1	302.0	Female	0.200	0.0190
Crater Lake 3	339.4	76.5	307.0	Female	0.319	0.0172
Crater Lake 4	236.5	76.9	281.0	Male	0.200	0.0174
Crater Lake 5	236.36	78.2	293.0	Female	0.277	0.0179
Lake Jed Johnson 1	99.4	71.4	211.0	Male	0.109	0.0198
Lake Jed Johnson 2	157.2	77.2	246.0	Male	0.140	0.0200
Lake Jed Johnson 3	158.9	79.7	250.0	Female	0.196	0.0196
Lake Jed Johnson 4	81.9	71.7	205.0	Female	0.092	0.0183
Lake Jed Johnson 5	117.7	77.6	224.0	Female	0.150	0.0200
Lake Rush 1	271.5	75.1	289.0	Male	0.240	0.0200
Lake Rush 2	209.6	71.1	273.0	Female	0.283	0.0189
Lake Rush 3	508.6	76.5	365.0	Male	0.571	0.0190
Lake Rush 4	254.9	81.1	283.0	Male	0.460	0.0177
Lake Rush 5	292.8	75.6	300.0	Female	0.509	0.0189
Elmer Thomas Lake 1	194.6	75.1	251.0	Male	0.200	0.0200
Elmer Thomas Lake 2	171.2	74.8	243.0	Male	0.182	0.0182
Elmer Thomas Lake 3	419.7	76.1	310.0	Male	0.200	0.0190
Elmer Thomas Lake 4	315.7	74.0	304.0	Male	0.229	0.0190
Elmer Thomas Lake 5	520.9	77.1	347.0	Female	0.260	0.0192

(Note - g is grams; mm is millimeters; d.l. is detection limit; and bdl is below detection limit)

APPENDIX B
(ANALYTICAL METHODS)

Method Code 002
Analytical Methodology for Mercury in Tissue
Laboratory: Midwest Research Institute

Summary: A 0.5 gram aliquot of wet homogenized tissue was digested in sulfuric and nitric acids at 60°C for one hour. Potassium permanganate and hydroxylamine sulfate were added to the digestate and the samples was returned to the water bath for an additional 30 minute digestion at 95°C. Excess permanganate was reduced with potassium persulfate and the sample was diluted to 200 mL. The determination was performed by cold vapor atomic absorption using a PSA Merlin Plus mercury analyzer. The nominal detection limit was 0.08 µg/g on a wet weight basis.

Reference: Methods For The Determination Of Metals In Environmental Samples, Environmental Monitoring Systems Laboratory, Office Of Research And Development, U.S. Environmental Protection Agency, Report No. EPA-600/4-91-010 (1991) Method 245.6.

Method Code 006
Analytical Methodology (ICP Scan) for Chromium, Copper, Iron, Magnesium, Manganese, Molybdenum, Nickel, and Zinc in Tissue
Laboratory: Midwest Research Institute

Summary: A one gram aliquot of freeze dried coarsely ground sample was weighed and digested using nitric acid and hydrogen peroxide[1]. The contents were transferred to a 100 mL volumetric flask and diluted to volume using reagent grade water. The analyses were performed using Thermo Jarrell Ash Model 61E simultaneous inductively coupled plasma emission spectrometer (ICP)[2].

References: [1]Methods For The Determination Of Metals In Environmental Samples, Environmental Monitoring Systems Laboratory, Office Of Research And Development, U.S. Environmental Protection Agency, Report No. EPA-600/4-91-010 (1991) Method 245.6.

[2]Test Methods For Evaluating Solid Waste, Physical/Chemical Methods, 3rd Edition, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, U.S. Government Printing Office, Washington, D.C., SW-846, Method 6010A (1986).

Method Code 007
Analytical Methodology for Arsenic, Cadmium, Lead, and Selenium in Tissue
Laboratory: Midwest Research Institute

Summary: A one gram aliquot of freeze dried coarsely ground sample was weighed and digested using nitric acid and hydrogen peroxide[1]. The contents were transferred to a 100 mL volumetric flask and diluted to volume using reagent grade water. The analyses were performed using Varian SpectrAA Graphite Furnace Zeeman Corrected single element atomic absorption spectrometer[2].

References: [1]Methods For The Determination Of Metals In Environmental Samples, Environmental Monitoring Systems Laboratory, Office Of Research And Development, U.S. Environmental Protection Agency, Report No. EPA-600/4-91-010 (1991) Method 200.3.

[2]Test Methods For Evaluating Solid Waste, Physical/Chemical Methods, 3rd Edition, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, U.S. Government Printing Office, Washington, D.C., SW-846, Method 7000 (1986).

Method Code 019
Analytical Methodology for Determination of Percent Moisture in Tissue
Laboratory: Midwest Research Institute

Summary: A suitable vessel was pre-weighed (vessel weight) and an aliquot of tissue sample was added to the tared vessel (aliquot weight). The sample was allowed to dry for 24 hours in an oven at 105°C. After drying the sample was placed in a desiccator to cool. The vessel plus the dry sample weight was recorded.

%Moisture = [1-((vessel + dry weight - vessel weight)/aliquot weight)] x 100

APPENDIX C
(BIOTIC SAMPLING RESULTS)

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Lake Rush	Large Mouth Bass	549.0	>1000.0	FT	RR001
	Large Mouth Bass	333.0	455.0	FT	RR002
	Large Mouth Bass	316.0	325.0	FT	RR003
	Large Mouth Bass	294.0	310.0	FT	RR004
	Large Mouth Bass	525.0	>1000.0	FT	RR025
RRLMBC (composite)	Large Mouth Bass	534.0	>1000.0	WB	RR026
	Large Mouth Bass	441.0	>1000.0	WB	RR027
	Large Mouth Bass	490.0	>1000.0	WB	RR028
	Large Mouth Bass	521.0	>1000.0	WB	RR029
	Large Mouth Bass	363.0	590.0	WB	RR030
	Bluegill Sunfish	191.0	135.0	FT	RR008
	Bluegill Sunfish	212.0	192.0	FT	RR009
	Bluegill Sunfish	195.0	150.0	FT	RR010
	Bluegill Sunfish	185.0	122.0	FT	RR011
	Bluegill Sunfish	183.0	132.0	FT	RR012
RRBGSC (composite)	Bluegill Sunfish	183.0	135.0	WB	RR013
	Bluegill Sunfish	179.0	120.0	WB	RR014
	Bluegill Sunfish	168.0	105.0	WB	RR015
	Bluegill Sunfish	184.0	125.0	WB	RR016
	Bluegill Sunfish	176.0	115.0	WB	RR017
	Channel Catfish	467.0	>1000.0	FT	RR005
	Channel Catfish	465.0	>1000.0	FT	RR006
	Channel Catfish	471.0	>1000.0	FT	RR007
	Channel Catfish	552.0	>1000.0	FT	RR018
	Channel Catfish	556.0	>1000.0	FT	RR021
RRCCC (composite)	Channel Catfish	331.0	340.0	WB	RR019
	Channel Catfish	476.0	>1000.0	WB	RR020
	Channel Catfish	492.0	>1000.0	WB	RR022
	Channel Catfish	352.0	360.0	WB	RR023
	Channel Catfish	415.0	695.0	WB	RR024

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Lake Jed Johnson	Large Mouth Bass	475.0	>1000.0	FT	JJ002
	Large Mouth Bass	481.0	>1000.0	FT	JJ007
	Large Mouth Bass	449.0	>1000.0	FT	JJ008
	Large Mouth Bass	385.0	720.0	FT	JJ009
	Large Mouth Bass	335.0	425.0	FT	JJ010
JJLMBC (composite)	Large Mouth Bass	312.0	380.0	WB	JJ015
	Large Mouth Bass	312.0	340.0	WB	JJ016
	Large Mouth Bass	305.0	380.0	WB	JJ017
	Large Mouth Bass	295.0	320.0	WB	JJ018
	Large Mouth Bass	305.0	340.0	WB	JJ019
	Bluegill Sunfish	178.0	90.0	FT	JJ001
	Bluegill Sunfish	205.0	180.0	FT	JJ003
	Bluegill Sunfish	198.0	170.0	FT	JJ004
	Bluegill Sunfish	180.0	150.0	FT	JJ005
	Bluegill Sunfish	194.0	155.0	FT	JJ006
JJBGSC (composite)	Bluegill Sunfish	185.0	120.0	WB	JJ011
	Bluegill Sunfish	195.0	140.0	WB	JJ012
	Bluegill Sunfish	188.0	125.0	WB	JJ013
	Bluegill Sunfish	175.0	80.0	WB	JJ014
	Bluegill Sunfish	175.0	80.0	WB	JJ028
	Channel Catfish	450.0	860.0	FT	JJ020
	Channel Catfish	436.0	>1000.0	FT	JJ021
	Channel Catfish	435.0	690.0	FT	JJ022
	Channel Catfish	411.0	620.0	FT	JJ029
	Channel Catfish	398.0	505.0	FT	JJ030
JJCCC (composite)	Channel Catfish	378.0	360.0	WB	JJ023
	Channel Catfish	320.0	315.0	WB	JJ024
	Channel Catfish	340.0	320.0	WB	JJ025
	Channel Catfish	320.0	280.0	WB	JJ026
	Channel Catfish	370.0	460.0	WB	JJ027

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Quanah Parker Lake	Large Mouth Bass	540.0	>1000.0	FT	QP021
	Large Mouth Bass	469.0	>1000.0	FT	QP022
	Large Mouth Bass	415.0	>1000.0	FT	QP023
	Large Mouth Bass	395.0	690.0	FT	QP024
	Large Mouth Bass	335.0	390.0	FT	QP025
QPLMBC (composite)	Large Mouth Bass	350.0	530.0	WB	QP016
	Large Mouth Bass	320.0	390.0	WB	QP017
	Large Mouth Bass	330.0	460.0	WB	QP018
	Large Mouth Bass	310.0	395.0	WB	QP019
	Large Mouth Bass	320.0	435.0	WB	QP020
	Bluegill Sunfish	190.0	120.0	FT	QP026
	Bluegill Sunfish	190.0	120.0	FT	QP027
	Bluegill Sunfish	193.0	125.0	FT	QP028
	Bluegill Sunfish	190.0	125.0	FT	QP029
	Bluegill Sunfish	192.0	120.0	FT	QP030
QPBGSC (composite)	Bluegill Sunfish	180.0	110.0	WB	QP011
	Bluegill Sunfish	175.0	90.0	WB	QP012
	Bluegill Sunfish	190.0	145.0	WB	QP013
	Bluegill Sunfish	185.0	110.0	WB	QP014
	Bluegill Sunfish	174.0	95.0	WB	QP015
	Channel Catfish	372.0	380.0	FT	QP006
	Channel Catfish	392.0	485.0	FT	QP007
	Channel Catfish	420.0	560.0	FT	QP008
	Channel Catfish	462.0	795.0	FT	QP009
	Channel Catfish	435.0	790.0	FT	QP010
QPCCC (composite)	Channel Catfish	340.0	300.0	WB	QP001
	Channel Catfish	345.0	310.0	WB	QP002
	Channel Catfish	354.0	335.0	WB	QP003
	Channel Catfish	352.0	340.0	WB	QP004
	Channel Catfish	350.0	325.0	WB	QP005

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Elmer Thomas Lake	Large Mouth Bass	422.0	>1000.0	FT	ET001
	Large Mouth Bass	404.0	920.0	FT	ET002
	Large Mouth Bass	446.0	>1000.0	FT	ET003
	Large Mouth Bass	401.0	735.0	FT	ET004
	Large Mouth Bass	390.0	695.0	FT	ET005
ETLMBC (composite)	Large Mouth Bass	384.0	720.0	WB	ET006
	Large Mouth Bass	355.0	621.0	WB	ET007
	Large Mouth Bass	331.0	518.0	WB	ET008
	Large Mouth Bass	332.0	464.0	WB	ET009
	Large Mouth Bass	300.0	310.0	WB	ET010
	Bluegill Sunfish	238.0	290.0	FT	ET021
	Bluegill Sunfish	211.0	215.0	FT	ET022
	Bluegill Sunfish	225.0	223.0	FT	ET023
	Bluegill Sunfish	191.0	149.0	FT	ET024
	Bluegill Sunfish	175.0	109.0	FT	ET025
ETBGSC (composite)	Bluegill Sunfish	157.0	80.0	WB	ET026
	Bluegill Sunfish	174.0	112.0	WB	ET027
	Bluegill Sunfish	170.0	93.0	WB	ET028
	Bluegill Sunfish	157.0	69.0	WB	ET029
	Bluegill Sunfish	153.0	70.0	WB	ET030
	Channel Catfish	558.0	>1000.0	FT	ET011
	Channel Catfish	464.0	>1000.0	FT	ET012
	Channel Catfish	536.0	>1000.0	FT	ET013
	Channel Catfish	643.0	>1000.0	FT	ET014
	Channel Catfish	653.0	>1000.0	FT	ET015
ETCCC (composite)	Channel Catfish	365.0	480.0	WB	ET016
	Channel Catfish	618.0	>1000.0	WB	ET017
	Channel Catfish	439.0	915.0	WB	ET018
	Channel Catfish	512.0	>1000.0	WB	ET019
	Channel Catfish	654.0	>1000.0	WB	ET020

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Lost Lake	Large Mouth Bass	446.0	>1000.0	FT	LL002
	Large Mouth Bass	537.0	>1000.0	FT	LL003
	Large Mouth Bass	458.0	>1000.0	FT	LL017
	Large Mouth Bass	340.0	561.0	FT	LL018
	Large Mouth Bass	532.0	>1000.0	FT	LL020
LLLMBC (composite)	Large Mouth Bass	458.0	>1000.0	WB	LL001
	Large Mouth Bass	343.0	530.0	WB	LL004
	Large Mouth Bass	331.0	410.0	WB	LL005
	Large Mouth Bass	305.0	330.0	WB	LL006
	Large Mouth Bass	302.0	305.0	WB	LL019
	Bluegill Sunfish	192.0	165.0	FT	LL007
	Bluegill Sunfish	201.0	145.0	FT	LL008
	Bluegill Sunfish	183.0	122.0	FT	LL009
	Bluegill Sunfish	177.0	111.0	FT	LL011
	Bluegill Sunfish	165.0	100.0	FT	LL014
LLBGSC (composite)	Bluegill Sunfish	186.0	122.0	WB	LL010
	Bluegill Sunfish	161.0	72.0	WB	LL012
	Bluegill Sunfish	180.0	100.0	WB	LL013
	Bluegill Sunfish	162.0	73.0	WB	LL015
	Bluegill Sunfish	154.0	74.0	WB	LL016
	Channel Catfish	494.0	>1000.0	FT	LL024
	Black Bullhead	245.0	199.0	FT	LL025
	Black Bullhead	345.0	518.0	FT	LL026
LLBBHC (composite)	Black Bullhead	230.0	142.0	WB	LL021
	Black Bullhead	247.0	192.0	WB	LL022
	Black Bullhead	331.0	425.0	WB	LL023
	Black Bullhead	246.0	195.0	WB	LL027

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
French Lake	Large Mouth Bass	432.0	>1000.0	FT	FL011
	Large Mouth Bass	523.0	>1000.0	FT	FL012
	Large Mouth Bass	466.0	>1000.0	FT	FL013
	Large Mouth Bass	407.0	943.0	FT	FL014
	Large Mouth Bass	342.0	552.0	FT	FL015
FLLMBC (composite)	Large Mouth Bass	305.0	370.0	WB	FL016
	Large Mouth Bass	330.0	509.0	WB	FL017
	Large Mouth Bass	345.0	572.0	WB	FL018
	Large Mouth Bass	356.0	600.0	WB	FL019
	Large Mouth Bass	323.0	418.0	WB	FL020
	Bluegill Sunfish	206.0	155.0	FT	FL001
	Bluegill Sunfish	200.0	150.0	FT	FL002
	Bluegill Sunfish	179.0	105.0	FT	FL003
	Bluegill Sunfish	181.0	120.0	FT	FL004
	Bluegill Sunfish	183.0	95.0	FT	FL005
FLBGSC (composite)	Bluegill Sunfish	170.0	95.0	WB	FL006
	Bluegill Sunfish	161.0	85.0	WB	FL007
	Bluegill Sunfish	170.0	100.0	WB	FL008
	Bluegill Sunfish	163.0	90.0	WB	FL009
	Bluegill Sunfish	160.0	75.0	WB	FL010
	Channel Catfish	380.0	435.0	FT	FL021
	Channel Catfish	630.0	2826.0	FT	FL026
	Black Bullhead	543.0	325.0	FT	FL027
FLWBBH (composite)	Black Bullhead	310.0	346.0	WB	FL022
	Black Bullhead	238.0	188.0	WB	FL023
	Black Bullhead	300.0	330.0	WB	FL024
	Black Bullhead	240.0	176.0	WB	FL025

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Crater Lake	Large Mouth Bass	473.0	1609.0	FT	CL001
	Large Mouth Bass	505.0	2102.0	FT	CL002
	Large Mouth Bass	492.0	2006.0	FT	CL003
	Large Mouth Bass	485.0	1968.0	FT	CL004
	Large Mouth Bass	469.0	1566.0	FT	CL005
CLWBLMB (composite)	Large Mouth Bass	332.0	519.0	WB	CL006
	Large Mouth Bass	327.0	471.0	WB	CL007
	Large Mouth Bass	361.0	685.0	WB	CL008
	Large Mouth Bass	311.0	379.0	WB	CL009
	Large Mouth Bass	339.0	530.0	WB	CL010
	Bluegill Sunfish	188.0	136.0	FT	CL011
	Bluegill Sunfish	184.0	131.0	FT	CL012
	Bluegill Sunfish	200.0	158.0	FT	CL013
	Bluegill Sunfish	190.0	150.0	FT	CL014
	Bluegill Sunfish	166.0	106.0	FT	CL015
CLWBBG (composite)	Bluegill Sunfish	167.0	98.0	WB	CL016
	Bluegill Sunfish	150.0	68.0	WB	CL017
	Bluegill Sunfish	150.0	70.0	WB	CL018
	Bluegill Sunfish	150.0	64.0	WB	CL019
	Bluegill Sunfish	150.0	62.0	WB	CL020
	Channel Catfish	392.0	572.0	FT	CL021
	Channel Catfish	428.0	682.0	FT	CL022
	Channel Catfish	457.0	1069.0	FT	CL023

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Burford Lake	Large Mouth Bass	405.0	930.0	FT	BL001
	Large Mouth Bass	401.0	1036.0	FT	BL002
	Large Mouth Bass	473.0	1530.0	FT	BL003
	Large Mouth Bass	409.0	1051.0	FT	BL004
	Large Mouth Bass	400.0	815.0	FT	BL005
BLWBLMB (composite)	Large Mouth Bass	338.0	591.0	WB	BL006
	Large Mouth Bass	335.0	641.0	WB	BL007
	Large Mouth Bass	319.0	445.0	WB	BL008
	Large Mouth Bass	362.0	735.0	WB	BL009
	Large Mouth Bass	391.0	861.0	WB	BL010
	Bluegill Sunfish	180.0	135.0	FT	BL011
	Bluegill Sunfish	175.0	125.0	FT	BL012
	Bluegill Sunfish	190.0	143.0	FT	BL013
	Bluegill Sunfish	190.0	152.0	FT	BL014
	Bluegill Sunfish	186.0	120.0	FT	BL015
BLWBBG (composite)	Bluegill Sunfish	180.0	119.0	WB	BL016
	Bluegill Sunfish	164.0	84.0	WB	BL017
	Bluegill Sunfish	175.0	106.0	WB	BL018
	Bluegill Sunfish	162.0	80.0	WB	BL019
	Bluegill Sunfish	158.0	74.0	WB	BL020
	Channel Catfish	440.0	741.0	FT	BL021
	Channel Catfish	479.0	1047.0	FT	BL022
	Channel Catfish	485.0	1191.0	FT	BL023

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Caddo Lake	Large Mouth Bass	384.0	884.0	FT	CAD001
	Large Mouth Bass	423.0	1126.0	FT	CAD002
	Large Mouth Bass	475.0	1841.0	FT	CAD003
	Large Mouth Bass	495.0	2216.0	FT	CAD004
	Large Mouth Bass	437.0	1318.0	FT	CAD005
CADWBLMB (composite)	Large Mouth Bass	410.0	1132.0	WB	CAD006
	Large Mouth Bass	400.0	930.0	WB	CAD007
	Large Mouth Bass	383.0	770.0	WB	CAD008
	Large Mouth Bass	400.0	784.0	WB	CAD009
	Large Mouth Bass	337.0	528.0	WB	CAD010
	Bluegill Sunfish	162.0	67.0	FT	CAD011
	Bluegill Sunfish	161.0	65.0	FT	CAD012
	Bluegill Sunfish	153.0	65.0	FT	CAD013
	Bluegill Sunfish	155.0	66.0	FT	CAD014
	Bluegill Sunfish	156.0	66.0	FT	CAD015
CADWBBG (composite)	Bluegill Sunfish	150.0	65.0	WB	CAD016
	Bluegill Sunfish	150.0	61.0	WB	CAD017
	Bluegill Sunfish	150.0	62.0	WB	CAD018
	Bluegill Sunfish	150.0	56.0	WB	CAD019
	Bluegill Sunfish	150.0	50.0	WB	CAD020
	Black Bullhead	262.0	248.0	FT	CAD021
	Black Bullhead	320.0	578.0	FT	CAD022
	Channel Catfish	520.0	1282.0	FT	CAD028
	Channel Catfish	538.0	1310.0	FT	CAD029
	Channel Catfish	515.0	1574.0	FT	CAD030
CADWBCC (composite)	Channel Catfish	473.0	876.0	WB	CAD023
	Channel Catfish	464.0	776.0	WB	CAD024
	Channel Catfish	488.0	1092.0	WB	CAD025
	Channel Catfish	501.0	1241.0	WB	CAD026
	Channel Catfish	505.0	1033.0	WB	CAD027

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Osage Lake	Large Mouth Bass	310.0	370.0	FT	OL001
	Large Mouth Bass	386.0	782.0	FT	OL002
	Large Mouth Bass	210.0	113.0	FT	OL013[1]
	Bluegill Sunfish	182.0	116.0	FT	OL003
	Bluegill Sunfish	175.0	116.0	FT	OL004
	Bluegill Sunfish	178.0	124.0	FT	OL005
	Bluegill Sunfish	177.0	114.0	FT	OL006
	Bluegill Sunfish	186.0	121.0	FT	OL007
OLWBBG (composite)	Bluegill Sunfish	184.0	120.0	WB	OL008
	Bluegill Sunfish	165.0	107.0	WB	OL009[2]
	Bluegill Sunfish	190.0	117.0	WB	OL010
	Bluegill Sunfish	183.0	135.0	WB	OL011
	Bluegill Sunfish	181.0	105.0	WB	OL012
	Black Bullhead	365.0	992.0	FT	OL014

FT is fillet; WB is whole body; mm is millimeters; and g is grams.
[1]Undersized bass analyzed because of limited number of bass collected from Osage Lake.
[2]Missing tail; assumed bitten off by turtle.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Post Oak Lake	Large Mouth Bass	350.0	557.0	FT	POL001
	Large Mouth Bass	445.0	1084.0	FT	POL015[1]
	Large Mouth Bass	222.0	132.0	FT	POL016[2]
	Bluegill Sunfish	188.0	139.0	FT	POL003
	Bluegill Sunfish	186.0	140.0	FT	POL004
	Bluegill Sunfish	179.0	126.0	FT	POL005
	Bluegill Sunfish	181.0	127.0	FT	POL006
	Bluegill Sunfish	200.0	144.0	FT	POL007
POLWBBG (composite)	Bluegill Sunfish	170.0	97.0	WB	POL008
	Bluegill Sunfish	165.0	95.0	WB	POL009
	Bluegill Sunfish	153.0	67.0	WB	POL010
	Bluegill Sunfish	174.0	99.0	WB	POL011
	Bluegill Sunfish	157.0	71.0	WB	POL012
	Channel Catfish	564.0	2047.0	FT	POL002
	Channel Catfish	545.0	1605.0	FT	POL014
	Channel Catfish	518.0	1663.0	FT	POL017
POLWBBH	Black Bullhead	210.0	154.0	WB	POL013

FT is fillet; WB is whole body; mm is millimeters; and g is grams.
[1]Missing head; assumed bitten off by turtle.
[2]Undersized bass analyzed because of limited number of bass collected from Post Oak Lake.

Reservoir	Species	Length (mm)	Weight (g)	Sample Type	ID Number
Treasure Lake	Large Mouth Bass	385.0	678.0	FT	TL011
	Large Mouth Bass	315.0	406.0	FT	TL012
	Large Mouth Bass	293.0	319.0	FT	TL013
	Large Mouth Bass	306.0	328.0	FT	TL014
	Large Mouth Bass	289.0	279.0	FT	TL015
TLWBLMB (composite)	Large Mouth Bass	273.0	273.0	WB	TL016
	Large Mouth Bass	219.0	115.0	WB	TL017
	Large Mouth Bass	218.0	107.0	WB	TL018
	Bluegill Sunfish	181.0	99.0	FT	TL001
	Bluegill Sunfish	174.0	138.0	FT	TL002
	Bluegill Sunfish	169.0	80.0	FT	TL003
	Bluegill Sunfish	171.0	90.0	FT	TL004
	Bluegill Sunfish	160.0	71.0	FT	TL005
TLWBBG (composite)	Bluegill Sunfish	145.0	56.0	WB	TL006
	Bluegill Sunfish	160.0	75.0	WB	TL007
	Bluegill Sunfish	131.0	48.0	WB	TL008
	Bluegill Sunfish	130.0	41.0	WB	TL009
	Bluegill Sunfish	131.0	42.0	WB	TL010
	Black Bullhead	325.0	471.0	FT	TL019

FT is fillet; WB is whole body; mm is millimeters; and g is grams.

Note - Samples were collected on 05/17/2000, 05/18/2000, 06/19/2000, 06/20/2000, 06/21/2000, 06/22/2000, 03/27/2001, 03/28/2001, 06/05/2001, 06/06/2001, and 06/07/2001 using electro-shocking boat, hook-and-line, gill nets, and trot lines. Gill nets and trot lines were used exclusively in Osage Lake, Post Oak Lake, and Treasure Lake to catch all three species because limited access prevented use of the electro-shocking boat. Trot lines were used in Caddo Lake, Crater Lake, French Lake, and Burford Lake to collect only catfish. Gill nets and trot lines were used in Lost Lake to collect only catfish. Bait for trot lines included blood bait, soap, chicken gizzards, hearts and livers, shrimp, bullhead minnows, and gizzard shad. Red-eared Sliders (*Trachemys scripta elegans*) were a problem in the gill nets while both Red-eared Sliders and Pallid Spiny Softshells (*Trionyx spiniferus pallidus*) were a nuisance on the trot lines. Trot lines set at Crater Lake, Burford Lake, and Treasure Lake were vandalized by unknown parties. Once collected, samples submitted through PACF as ECDMS Catalog Nos. 2030025, 2030027, and 2030047; Catalog No. 2030025 samples submitted to Midwest Research Institute, 425 Volker Boulevard, Kansas City, Missouri 65409-0530 (816/753-7600) through Fed-Ex on 07/18/2000. Catalog No. 2030027 samples submitted to Research Triangle Institute, 3040 Cornwallis Road, Building 6, Research Triangle Park, North Carolina 27709-2194 (919/541-6896) through Fed-Ex on 07/09/2001. Catalog No. 2030047 samples submitted to Texas A&M Research Foundation, 100 Bizzell Street, Ellar Building, Room 4, College Station, Texas 77843 (979/845-1568) through Fed-Ex on 08/27/2001.

Reservoir	Species	L x W (cm)	Weight (g)	Sample Type	ID Number
Lost Lake	Red-eared Slider	22 x 17	1387.0	WB	LLTT1
	Red-eard Slider	20 x 15	1199.0	WB	LLTT2
	Red-eard Slider	22 x 15	1152.0	WB	LLTT3
French Lake	Red-eared Slider	20 x 15	1052.0	WB	FLRE01
	Red-eared Slider	19 x 15	1082.0	WB	FLRE02
	Red-eared Slider	21 x 15	1364.0	WB	FLRE03
(FLWBSS)	Spiny Softshell	32 x 29	5250.0	WB	FLSS01
Burford Lake	Red-eared Slider	24 x 18	1963.0	WB	BLRE01
	Red-eared Slider	20 x 16	1265.0	WB	BLRE02
Osage Lake	Red-eared Slider	19 x 15	1144.0	WB	OLRE1
	Red-eared Slider	13 x 9	201.0	WB	OLRE2
	Red-eared Slider	15 x 11	397.0	WB	OLRE3
	Red-eared Slider	15 x 13	502.0	WB	OLRE4
Bonanza Mine (WM21 - composite)	Leopard Frog	L = 2.54	1.0	WB	BMF1
	Leopard Frog	L = 2.50	0.5	WB	BMF2

Note - L is length; W is width; cm is centimeters; and g is grams.

APPENDIX D
(GRAPHICS)


Figure D1. Lost Lake.


Figure D2. Lost Lake.


Figure D3. Lost Lake.


Figure D4. Lost Lake.


Figure D5. Canada Geese at Lost Lake.


Figure D6. Electro-Shocking Boat at Lost Lake.

Figure D7. Quanah Parker Lake.

Figure D8. Quanah Parker Lake.

Figure D9. Quanah Parker Lake.

Figure D10. Quanah Parker Lake.

Figure D11. Quanah Parker Lake.

Figure D12. Quanah Parker Lake.


Figure D13. Lake Jed Johnson.


Figure D14. Lake Jed Johnson.


Figure D15. Lake Jed Johnson.


Figure D16. Boat Ramp at Lake Jed Johnson.


Figure D17. Dam at Lake Rush.


Figure D18. Lake Rush.


Figure D19. Road overlooking Lake Rush.


Figure D20. Lake Rush.


Figure D21. Inflow channel of Blue Beaver Creek into Lake Rush.

Figure D22. Fishing Pier at Elmer Thomas Lake.

Figure D23. Elmer Thomas Lake.

Figure D24. East Shoreline of Elmer Thomas Lake.

Figure D25. Boat Ramp at Elmer Thomas Lake.

Figure D26. Elmer Thomas Lake.

Figure D27. Elmer Thomas Lake.

Figure D28. Caddo Lake.

Figure D29. Launching Electro Shocking Boat at Caddo Lake.

Figure D30. Electro-Shocking Boat at Caddo Lake.

Figure D31. Electro-Shocking Boat at upper end of Caddo Lake.

Figure D32. Caddo Lake.

Figure D33. Electro-Shocking Boat in upper end of Caddo Lake.

Figure D34. Channel Catfish collected from Rush Lake, 05/18/2000.

Figure D35. Black Bullheads collected from Lost Lake, 05/16/2000.

Figure D36. Largemouth Bass collected from Lost Lake, 05/16/2000.

Figure D37. Bluegills collected from Lost Lake, 05/16/2000.

Figure D38. Bonanza Mine on north slope of Mt. Lincoln.

Figure D39. Shaft entrance at Bonanza Mine.


Figure D40. Tailings pile below Bonanza Mine.


Figure D41. Smelter site below Bonanza Mine.


Figure D42. Slag pile below Bonanza Mine Smelter Site.


Figure D43. Vertical Mine Shaft on northern bank of Fawn Creek, downstream of Bonanza Mine and Smelter Site.

Figure D44. Blue Beaver Creek Smelter (southern view).

Figure D45. Slag slopping into Blue Beaver Creek from Smelter Site.

Figure D46. Blue Beaver Creek Smelter Site (eastern view).

Figure D47. Slag pile below Blue Beaver Creek Smelter Site.

Figure D48. Molten slag at Blue Beaver Creek Smelter Site.


Figure D49. Slag pile adjacent to Blue Beaver Creek Smelter Site.


Figure D50. Vertical mine shaft immediately west of Blue Beaver Creek Smelter Site.


Figure D51. Quanah Creek at southern fence-line.


Figure D52. Dam at Chain Lake (Cache Creek).

Historically, mercury was used in anti-fouling and mildew proofing of paints and in controlling fungal diseases in plants. Major anthropogenic sources of mercury include pulp and paper mills, mining and reprocessing of metallic ores, and the incomplete combustion of fossil fuels (Eisler, 1987). Mercury can exist in many forms in an aquatic environment, including elemental mercury, dissolved and particulate ionic forms, and/or dissolved and particulate methyl mercury (Wiener and Spry, 1996). The production of methyl mercury by methylation of inorganic mercury in sediments and in the water column is dependant on microbial activity, nutrient content, pH, and alkalinity (Eisler, 1987; Wiener and Spry, 1996). Mercury is toxic and has no known essential function in vertebrate organisms. Toxicologically, the target organ for mercury in vertebrates is the central nervous system. In fish, 95% to 99% of mercury present is in the form of methyl mercury even though very little of the total mercury in water and sediment exists as methyl mercury. Inorganic mercury is absorbed much less efficiently and eliminated much more rapidly than methyl mercury. In addition, inorganic mercury does not readily methylate in tissues, but can be methylated within the digestive tract. Fish tend to obtain the majority of methyl mercury from their diet and to a lesser extent, from water passing over the gills (Wiener and Spry, 1996).

CONCLUSIONS & RECOMMENDATIONS

No obvious trends of mercury contamination based on size class or sex were observed in the fish sampled during this survey (see Table 1). As previously stated, none of the fish collected contained detectable concentrations of mercury which approached the recommended mammalian predator protection limit; however, 95% of the fish collected contained mercury levels which exceeded the recommended avian predator protection limit while 77% of the fish sampled contained mercury levels that exceeded the national 85th percentile value. The fish sampled from Lake Rush contained the highest concentrations of mercury, while the fish collected from Lake Jed Johnson contained the lowest concentrations of mercury. The source of this mercury is unknown; it may be due to possible atmospheric deposition or it may be leaching from sites associated with the former gold mining operations conducted in the area. Therefore, it is recommended that further studies be conducted involving the collecting of sediment and water samples, as well as fish, to determine the extent and availability of mercury to fish and other wildlife resources at the Refuge, and to determine the source of the mercury. Additional reservoirs should be sampled. It is further recommended that fish from larger size classes be collected and that in addition to whole body fish samples, fillet samples be collected from fish and analyzed for total mercury content to address possible human health concerns.

REFERENCES

Andreasen, J.K. 1986. An Evaluation of Mercury Contamination at the Wichita Mountains Wildlife Refuge, Oklahoma. U.S. Fish and Wildlife Service. Tulsa, Oklahoma. 9 pp.

Eisler, R. 1987. Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review (CHR Rep. No. 10). U.S. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 90 pp.

Schmitt, C.J. and W.G. Brumbaugh. 1990. National Contaminant Biomonitoring Program: Concentrations of Arsenic, Cadmium, Copper, Lead, Mercury, Selenium, and Zinc in U.S. Freshwater Fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19 (1990). pp. 731-747.

Southwest Natural and Cultural Heritage Association. 1997. Wichita Mountains Wildlife Refuge. SouthwestNatural and Cultural Heritage Association. Albuquerque, New Mexico.

U.S. Fish and Wildlife Service. 1997. Wichita Mountains Wildlife Refuge. U.S. Fish and Wildlife Service. Indianhoma, Oklahoma.

Wiener, J.G. and D.J. Spry. 1996. Toxicological Significance of Mercury in Freshwater Fish. In W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, eds. Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. Lewis Publishers. New York, New York. pp 297-340.

APPENDIX E
(DRY WEIGHT WHOLE BODY ANALYSES)

Results of metals analyses in mg/kg dry weight for whole body composite channel catfish (CCC), bluegill (BGSC), and largemouth bass (LMBC) samples collected from Lake Rush (RR), Lake Jed Johnson (JJ), and Quanah Parker Lake (QP), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	RRCCC	RRBGSC	RRLMBC	JJCCC	JJBGSC	JJLMBC	QPCCC	QPBGSC	QPLMBC
Aluminum	511.00	60.40	9.81	102.00	14.40	9.39	87.00	106.00	17.20
dl	1.29	1.23	1.26	1.38	1.31	1.35	1.39	1.24	1.34
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.23	0.22	0.23	0.25	0.23	0.24	0.25	0.22	0.24
Cadmium	0.32	bdl	bdl	0.08	0.02	0.06	0.03	0.04	bdl
dl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Chromium	2.35	1.79	1.68	2.43	1.03	1.42	2.79	0.58	0.57
dl	0.21	0.20	0.21	0.23	0.22	0.22	0.23	0.20	0.22
Copper	1.46	1.32	0.95	3.09	1.49	1.56	1.64	1.23	1.58
dl	0.10	0.10	0.10	0.11	0.10	0.11	0.11	0.10	0.11
Iron	661.00	159.00	88.10	303.00	60.40	181.00	237.00	97.40	62.50
dl	0.23	0.22	0.23	0.25	0.23	0.24	0.25	0.22	0.24
Lead	0.74	0.19	0.20	0.98	0.16	0.61	0.39	0.21	0.23
dl	0.07	0.07	0.07	0.08	0.07	0.08	0.08	0.07	0.08
Magnesium	1,685.00	1,597.00	1,867.00	1,432.00	1,983.00	2,036.00	1,637.00	2,049.00	2,390.00
dl	2.57	2.46	2.52	2.75	2.62	2.70	2.78	2.47	2.67
Manganese	129.00	60.00	7.12	46.90	50.90	19.20	27.80	37.20	9.15
dl	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05
Mercury	0.18	0.60	4.05	0.18	0.32	1.29	0.30	0.34	1.52
dl	0.07	0.06	0.07	0.06	0.06	0.08	0.06	0.07	0.05
Molybdenum	bdl	bdl	bdl	bdl	0.11	bdl	bdl	bdl	bdl
dl	0.08	0.08	0.08	0.09	0.09	0.08	0.09	0.08	0.09
Nickel	2.16	1.43	2.56	1.35	2.42	1.94	1.82	2.17	2.71
dl	0.52	0.50	0.51	0.56	0.53	0.55	0.57	0.50	0.54
Selenium	0.17	1.41	1.04	0.71	1.40	1.76	1.04	1.24	bdl
dl	0.14	0.13	0.27	0.30	0.28	0.29	0.15	0.27	0.29
Zinc	61.70	89.30	53.10	66.20	87.60	74.50	79.70	89.30	78.10
dl	0.13	0.12	0.13	0.14	0.13	0.14	0.14	0.12	0.13

Results of metals analyses in mg/kg dry weight for whole body composite channel catfish (CCC), black bullhead (BHC or WBBH), bluegill (BGSC), largemouth bass (LMBC), and softshell turtle (WBSS) samples collected from Elmer Thomas Lake (ET), Lost Lake (LL), and French Lake (FL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	ETCCC	ETBGSC	ETLMBC	LLBHC	LLBGSC	LLLMBC	FLWBBH	FLBGSC	FLLMBC	FLWBSS
Aluminum	179.00	43.60	8.86	13.30	73.30	15.10	25.20	16.10	7.82	252.00
dl	1.30	1.32	1.19	1.22	1.36	1.33	5.30	1.19	1.23	4.03
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.23	0.24	0.21	0.22	0.24	0.24	0.53	0.21	0.22	0.40
Cadmium	0.03	0.02	bdl	0.04	0.03	0.02	0.02	bdl	bdl	0.03
dl	0.02	0.02	0.02	0.02	0.02	0.02	0.005	0.02	0.02	0.008
Chromium	2.38	2.15	1.82	1.89	1.57	1.44	0.65	1.22	1.40	1.54
dl	0.21	0.22	0.20	0.20	0.22	0.22	0.53	0.20	0.20	0.40
Copper	1.57	1.66	1.58	2.20	1.37	2.04	3.10	0.97	0.97	4.00
dl	0.10	0.10	0.09	0.10	0.11	0.10	0.53	0.09	0.10	0.40
Iron	558.00	117.00	80.80	104.00	156.00	165.00	84.80	73.60	59.00	453.00
dl	0.23	0.24	0.21	0.22	0.24	0.24	1.06	0.21	0.22	0.81
Lead	0.37	0.44	0.16	0.74	0.42	0.22	bdl	bdl	bdl	0.64
dl	0.07	0.08	0.07	0.07	0.08	0.08	0.37	0.07	0.07	0.28
Magnesium	1,299.00	1,592.00	1,562.00	1,620.00	1,891.00	2,038.00	1,670.00	1,789.00	1,933.00	1,000.00
dl	2.59	2.65	2.38	2.44	2.72	2.65	1.06	2.38	2.46	0.81
Manganese	58.40	55.00	9.75	18.70	46.40	13.60	18.50	42.10	9.75	12.30
dl	0.05	0.05	0.04	0.04	0.05	0.05	0.21	0.04	0.04	0.16
Mercury	0.28	0.13	0.83	0.59	0.33	2.52	1.29	0.43	1.44	0.92
dl	0.05	0.06	0.07	0.07	0.09	0.06	0.03	0.09	0.07	0.02
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.37	bdl	bdl
dl	0.33	0.34	0.31	0.31	0.35	0.34	1.06	0.31	0.32	0.81
Nickel	2.24	1.34	1.69	1.43	2.29	2.20	bdl	1.78	1.84	10.00
dl	0.53	0.54	0.49	0.50	0.55	0.54	0.53	0.49	0.50	0.40
Selenium	1.35	1.85	1.57	0.93	0.45	1.46	0.89	0.60	0.90	0.91
dl	0.28	0.28	0.26	0.13	0.29	0.14	0.02	0.13	0.26	0.02
Zinc	58.90	74.10	58.40	74.70	97.10	66.60	64.30	88.50	64.40	92.30
dl	0.13	0.13	0.12	0.12	0.14	0.13	0.53	0.12	0.12	0.40

Results of metals analyses in mg/kg dry weight for whole body composite channel catfish (WBCC), bluegill (WBBG), and largemouth bass (WBLMB) samples collected from Crater Lake (CL), Burford Lake (BL), and Caddo Lake (CAD), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	CLWBBG	CLWBLMB	BLWBBG	BLWBLMB	CADWBCC	CADWBBG	CADWBLMB
Aluminum	277.00	23.00	220.00	49.50	49.10	84.90	27.40
dl	4.75	4.94	4.60	4.86	4.97	4.64	4.91
Arsenic	2.40	2.86	2.79	2.98	bdl	3.65	2.66
dl	0.48	0.50	0.46	0.49	0.50	0.46	0.49
Cadmium	bdl	bdl	bdl	bdl	0.04	bdl	bdl
dl	0.10	0.10	0.09	0.10	0.005	0.09	0.10
Chromium	2.89	3.47	7.20	2.52	0.54	5.58	1.80
dl	0.48	0.49	0.46	0.49	0.50	0.46	0.49
Copper	1.39	0.97	1.37	1.59	3.14	1.04	0.87
dl	0.48	0.49	0.46	0.49	0.50	0.46	0.49
Iron	255.00	52.90	249.00	84.10	123.00	133.00	47.70
dl	9.51	9.90	9.17	9.73	1.00	9.28	9.82
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.95	0.99	0.92	0.97	0.35	0.93	0.98
Magnesium	1,832.00	2,183.00	1,925.00	2,058.00	1,190.00	2,714.00	1,955.00
dl	9.51	9.90	9.17	9.73	1.00	9.28	9.82
Manganese	66.70	11.20	24.30	11.10	59.80	62.30	7.70
dl	0.38	0.40	0.37	0.39	0.20	0.37	0.39
Mercury	0.40	1.23	0.60	1.41	0.48	0.38	1.23
dl	0.10	0.10	0.09	0.10	0.005	0.09	0.10
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.48	0.49	0.46	0.49	0.99	0.46	0.49
Nickel	bdl	bdl	1.07	bdl	bdl	bdl	bdl
dl	0.48	0.49	0.46	0.49	0.50	0.46	0.49
Selenium	1.93	1.94	2.44	2.05	0.75	2.60	2.25
dl	0.48	0.49	0.46	0.49	0.02	0.46	0.49
Zinc	107.00	57.00	113.00	65.60	58.50	112.00	57.60
dl	0.95	0.99	0.92	0.97	0.50	0.93	0.98

Results of metals analyses in mg/kg dry weight for whole body black bullhead (WBBH), bluegill (WBBG), and largemouth bass (WBLMB) samples collected from Osage Lake (OL), Post Oak Lake (POL), and Treasure Lake (TL), and a whole body leopard frog (WM21) sample collected from the Bonanza Mine, Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	OLWBBG	POLWBBG	POLWBBH	TLWBBG	TLWBLMB	WM21
Aluminum	231.00	99.20	30.90	229.00	38.40	1,080.00
dl	5.22	5.35	5.29	5.10	5.30	5.00
Arsenic	bdl	bdl	bdl	bdl	bdl	0.60
dl	0.52	0.54	0.53	0.51	0.53	0.50
Cadmium	0.019	0.108	0.071	0.130	0.136	bdl
dl	0.005	0.005	0.005	0.005	0.005	0.30
Chromium	0.83	0.73	bdl	0.88	0.72	bdl
dl	0.52	0.54	0.53	0.51	0.53	2.00
Copper	3.61	3.46	3.68	3.07	5.62	7.80
dl	0.52	0.54	0.53	0.51	0.53	0.80
Iron	209.00	138.00	422.00	286.00	89.20	7,550.00
dl	1.04	1.07	1.06	1.02	1.06	5.00
Lead	bdl	bdl	bdl	0.43	bdl	5.60
dl	0.37	0.38	0.37	0.36	0.37	0.50
Magnesium	1,940.00	1,390.00	1,500.00	1,430.00	1,760.00	1,040.00
dl	1.04	1.07	1.06	1.02	1.06	5.00
Manganese	45.20	18.60	39.50	28.20	14.10	238.00
dl	0.21	0.21	0.21	0.20	0.21	1.00
Mercury	1.19	1.33	0.93	1.04	2.36	0.73
dl	0.03	0.03	0.03	0.03	0.03	0.20
Molybdenum	4.64	bdl	bdl	bdl	bdl	bdl
dl	1.04	1.07	1.06	1.02	1.06	5.00
Nickel	bdl	bdl	bdl	bdl	bdl	8.30
dl	0.52	0.54	0.53	0.51	0.53	1.00
Selenium	0.90	1.13	0.68	1.41	1.26	1.80
dl	0.02	0.02	0.02	0.02	0.02	0.20
Zinc	94.00	81.10	72.70	86.60	74.70	318.00
dl	0.52	0.54	0.53	0.51	0.53	1.00

Results of metals analyses in mg/kg dry weight for brain tissues from red-eared slider (RE) and pallid spiny softshell (SS) samples collected from Lost Lake (LL), French Lake (FL), Burford Lake (BL), and Osage Lake (OL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	LLRE01	LLRE02	LLRE03	FLRE01	FLRE02	FLRE03	FLSS	BLRE01	BLRE02	OLRE01	OLRE02	OLRE03	OLRE04
Aluminum	7.01	bdl	10.00	bdl	bdl	bdl	bdl	8.14	bdl	19.10	bdl	50.90	bdl
dl	5.87	8.77	7.83	28.30	13.40	12.40	3.76	7.80	12.60	10.50	14.50	16.20	8.69
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.59	0.88	0.78	2.83	1.34	1.24	0.38	0.78	1.26	1.05	1.45	1.62	0.87
Cadmium	0.020	0.012	0.009	0.040	0.016	0.020	0.014	0.013	0.015	0.015	bdl	0.023	0.016
dl	0.006	0.009	0.008	0.028	0.013	0.012	0.004	0.008	0.013	0.011	0.015	0.016	0.009
Chromium	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	2.31	5.71	bdl
dl	0.59	0.88	0.78	2.83	1.34	1.24	0.38	0.78	1.26	1.05	1.45	1.62	0.87
Copper	10.70	10.40	7.40	6.39	4.07	11.40	7.44	14.80	6.40	4.77	9.43	14.20	10.70
dl	0.59	0.88	0.78	2.83	1.34	1.24	0.38	0.78	1.26	1.05	1.45	1.62	0.87
Iron	70.00	64.80	72.00	169.00	74.80	66.90	102.00	82.70	77.10	65.50	67.70	113.00	97.50
dl	1.17	1.75	1.57	5.66	2.69	2.49	0.75	1.56	2.53	2.09	2.90	3.24	1.74
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.41	0.61	0.55	1.98	0.94	0.87	0.26	0.55	0.88	0.73	1.02	1.14	0.61
Magnesium	580.00	727.00	748.00	823.00	796.00	742.00	621.00	846.00	906.00	761.00	749.00	721.00	682.00
dl	1.17	1.75	1.57	5.66	2.69	2.49	0.75	1.56	2.53	2.09	2.90	3.24	1.74
Manganese	4.93	2.97	2.75	bdl	3.53	2.12	1.52	3.10	2.41	1.89	1.64	2.21	3.47
dl	0.24	0.35	0.31	1.13	0.54	0.50	0.15	0.31	0.51	0.42	0.58	0.65	0.35
Mercury	0.30	0.30	0.20	0.10	0.13	0.17	1.22	0.58	0.21	0.30	0.25	0.50	0.16
dl	0.01	0.02	0.02	0.06	0.03	0.03	0.008	0.02	0.03	0.02	0.03	0.03	0.02
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	1.17	1.75	1.57	5.66	2.69	2.49	0.75	1.56	2.53	2.09	2.90	3.24	1.74
Nickel	bdl	bdl	bdl	6.22	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.59	0.88	0.78	2.83	1.34	1.24	0.38	0.78	1.26	1.05	1.45	1.62	0.87
Selenium	0.71	1.26	0.65	0.48	0.56	0.50	1.14	0.78	0.61	0.65	0.74	0.66	0.58
dl	0.08	0.11	0.11	0.38	0.18	0.16	0.06	0.10	0.17	0.14	0.18	0.33	0.12
Zinc	41.00	49.00	41.10	44.10	35.50	45.20	43.40	50.20	42.30	42.60	45.00	40.80	40.00
dl	0.59	0.88	0.78	2.83	1.34	1.24	0.38	0.78	1.26	1.05	1.45	1.62	0.87

Results of metals analyses in mg/kg dry weight for liver tissues from red-eared slider (RE) and pallid spiny softshell (SS) samples collected from Lost Lake (LL), French Lake (FL), Burford Lake (BL), and Osage Lake (OL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).													
Analyte	LLRE01	LLRE02	LLRE03	FLRE01	FLRE02	FLRE03	FLSS	BLRE01	BLRE02	OLRE01	OLRE02	OLRE03	OLRE04
Aluminum	99.40	30.10	42.80	6.62	5.56	9.42	308.00	52.10	19.10	26.00	5.86	bdl	73.60
dl	5.36	5.26	5.39	5.33	5.37	5.37	5.10	5.35	5.23	5.38	5.30	4.72	4.94
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.54	0.53	0.54	0.53	0.54	0.54	0.51	0.54	0.52	0.54	0.53	0.47	0.49
Cadmium	0.149	0.027	0.053	0.056	0.019	0.070	0.099	0.164	0.045	0.044	0.038	0.030	0.159
dl	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Chromium	1.09	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.54	0.53	0.54	0.53	0.54	0.54	0.51	0.54	0.52	0.54	0.53	0.47	0.49
Copper	83.40	15.80	20.20	21.10	3.60	16.80	7.32	7.62	4.90	5.12	11.10	5.89	35.10
dl	0.54	0.53	0.54	0.53	0.54	0.54	0.51	0.54	0.52	0.54	0.53	0.47	0.49
Iron	2,860.00	1,330.00	4,830.00	1,010.00	1,310.00	2,440.00	4,420.00	5,490.00	3,890.00	8,660.00	1,290.00	1,330.00	8,500.00
dl	1.07	1.05	1.08	1.07	1.07	1.07	1.02	1.07	1.05	1.08	1.06	0.94	0.99
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.49	bdl	1.02	bdl	0.41
dl	0.38	0.37	0.38	0.37	0.38	0.38	0.36	0.38	0.37	0.38	0.37	0.33	0.35
Magnesium	675.00	671.00	734.00	791.00	374.00	824.00	616.00	1,020.00	646.00	648.00	756.00	360.00	818.00
dl	1.07	1.05	1.08	1.07	1.07	1.07	1.02	1.07	1.05	1.08	1.06	0.94	0.99
Manganese	58.00	19.40	23.90	22.30	27.00	13.40	17.90	41.30	48.90	50.30	32.80	24.00	99.40
dl	0.21	0.21	0.22	0.21	0.22	0.22	0.20	0.21	0.21	0.22	0.21	0.19	0.20
Mercury	1.84	0.88	0.93	0.32	0.20	0.42	5.68	1.41	0.41	0.92	0.77	0.54	1.58
dl	0.03	0.03	0.03	0.005	0.005	0.005	0.06	0.03	0.005	0.005	0.005	0.005	0.03
Molybdenum	1.91	bdl	1.42	bdl	bdl	bdl	1.38	2.05	bdl	bdl	bdl	bdl	4.79
dl	1.07	1.05	1.08	1.07	1.07	1.07	1.02	1.07	1.05	1.08	1.06	0.94	0.99
Nickel	1.13	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.54	0.53	0.54	0.53	0.53	0.54	0.51	0.54	0.52	0.54	0.53	0.47	0.49
Selenium	3.25	2.14	2.04	1.15	0.70	1.24	4.46	2.54	0.98	1.39	1.57	0.92	1.95
dl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Zinc	137.00	88.20	83.90	81.10	39.30	84.70	65.70	96.80	53.90	65.20	70.50	36.80	77.50
dl	0.54	0.53	0.54	0.53	0.54	0.54	0.51	0.54	0.52	0.54	0.53	0.47	0.49

Results of metals analyses in mg/kg dry weight for muscle tissues from red-eared slider (RE) and pallid spiny softshell (SS) samples collected from Lost Lake (LL), French Lake (FL), Burford Lake (BL), and Osage Lake (OL), Wichita Mountains Wildlife Refuge, Comanche County, Oklahoma (Note - dl is the analytical detection limit; bdl is below the analytical detection limit).

Analyte	LLRE01	LLRE02	LLRE03	FLRE01	FLRE02	FLRE03	FLSS	BLRE01	BLRE02	OLRE01	OLRE02	OLRE03	OLRE04
Aluminum	bdl	10.90	6.73	bdl	19.00	bdl	bdl	17.50	bdl	bdl	22.50	14.90	30.90
dl	5.32	5.30	5.35	5.32	5.23	5.31	5.20	5.19	5.31	5.39	11.50	5.51	5.29
Arsenic	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.53	0.53	0.54	0.53	0.52	0.53	0.52	0.52	0.53	0.54	1.15	0.55	0.53
Cadmium	bdl	0.028	0.009	0.007	0.005	0.006	bdl	0.008	0.013	0.007	0.018	0.009	0.012
dl	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.012	0.006	0.005
Chromium	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	4.74	0.57	bdl
dl	0.53	0.53	0.54	0.53	0.52	0.53	0.52	0.52	0.53	0.54	1.15	0.55	0.53
Copper	3.45	3.40	3.61	4.49	3.02	3.02	1.82	4.14	4.06	2.39	4.54	3.66	3.69
dl	0.53	0.53	0.54	0.53	0.52	0.53	0.52	0.52	0.53	0.54	1.15	0.55	0.53
Iron	90.30	109.00	97.60	110.00	86.00	72.00	84.20	139.00	123.00	75.70	168.00	74.90	74.90
dl	1.06	1.06	1.07	1.06	1.05	1.06	1.04	1.04	1.06	1.08	2.30	1.10	1.07
Lead	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.37	0.37	0.38	0.37	0.37	0.37	0.36	0.36	0.37	0.38	0.80	0.39	0.37
Magnesium	787.00	937.00	860.00	1,010.00	940.00	1,100.00	779.00	896.00	900.00	852.00	944.00	958.00	897.00
dl	1.06	1.06	1.07	1.06	1.05	1.06	1.04	1.04	1.06	1.08	2.30	1.10	1.06
Manganese	2.10	10.00	3.23	1.88	2.73	2.51	1.08	2.01	4.37	2.59	3.82	1.76	11.70
dl	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.46	0.22	0.21
Mercury	0.23	0.20	0.19	0.10	0.14	0.13	2.47	0.44	0.18	0.37	0.24	0.56	0.20
dl	0.005	0.005	0.005	0.005	0.005	0.005	0.06	0.005	0.005	0.005	0.01	0.006	0.005
Molybdenum	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	1.06	1.06	1.07	1.06	1.05	1.06	1.04	1.04	1.06	1.08	2.30	1.10	1.06
Nickel	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
dl	0.53	0.53	0.54	0.53	0.52	0.53	0.52	0.52	0.53	0.54	1.15	0.55	0.53
Selenium	0.91	0.67	0.87	0.73	0.95	0.71	1.07	0.79	0.96	0.80	0.99	0.87	0.76
dl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.02	0.02
Zinc	102.00	105.00	129.00	134.00	126.00	119.00	117.00	165.00	143.00	139.00	87.40	97.60	112.00
dl	0.53	0.53	0.54	0.53	0.52	0.53	0.52	0.52	0.53	0.54	1.15	0.55	0.53