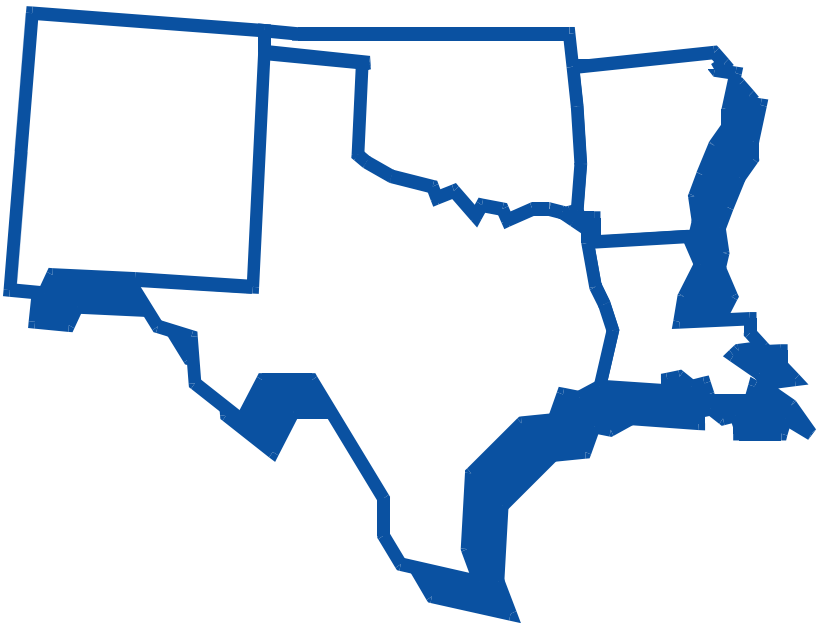
# RESPONSE ACTION CONTRACT

United States Environmental Protection Agency Region 6

Contract No. EP-W-06-021

**Hydrogeologic Characterization Study Report**
**Final**
**Tar Creek Superfund Site, Operable Unit 4**
**Ottawa County, Oklahoma**
**Task Order No. 0036-RDRD-06JW**
**Document Control Number 0036-02027**

**December 2010**



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*Final*

# Tar Creek Superfund Site, Operable Unit 4 Ottawa County, Oklahoma

# Hydrogeologic Characterization Study Report

Prepared for

## U.S. Environmental Protection Agency

**Contract No. EP-W-06-021**
**Task Order No. 0036-RDRD-06JW**
**CH2M HILL Project No. 380667**
**DCN 0036-03027**

**December 2010**

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# Executive Summary

This hydrogeologic characterization study (HCS) report describes the work performed for the HCS at the Tar Creek Superfund Site Operable Unit (OU) 4, Ottawa County, Oklahoma, and provides findings and conclusions.

The U.S. Environmental Protection Agency (EPA) has completed several pilot studies between 2004 and 2006 that evaluated the technical feasibility of injecting bulk chat and fine tailings into the flooded mine workings. The studies evolved in 2006 and 2007 to include the direct injection of fine tailings from active chat washing operations. These studies formed the basis for EPA's selection and inclusion of fine tailings injection as a preferred remedial alternative in the OU4 Record of Decision (ROD). The OU4 ROD states that underground injection control (UIC) regulations for Class V mining, sand, or other backfill wells (Title 40 *Code of Federal Regulations* [CFR] 144.81[8]) apply to the injection alternative. In particular, the owner/operator of a Class V injection well must meet the requirements of 40 CFR 144.12 and 144.82, prohibiting movement of a fluid into underground sources of drinking water (USDW) containing any contaminant if the presence of that contaminant causes the exceedence of the primary drinking water standards (expressed as maximum contaminant levels or MCLs) under 40 CFR 141 or other health-based standards or may otherwise adversely affect the health of persons (EPA, 2008).

The ROD specified in Section 19.2.4.3 that the HCS would be performed to assess the ability of the injection component of the selected remedy to be compliant with the UIC regulations. The objectives of the HCS are further discussed in **Section 1.4** of this report. This HCS report has been prepared for EPA in support of the remedial design (RD) for OU4 at the site. The overall purpose of this study is to document the geologic and hydrogeologic characteristics at the site and to assess the ability of the injection component of the selected remedy to be compliant with the UIC regulations.

The HCS was performed during 2008 and 2009. An extensive literature research and field program was implemented to collect the data necessary to complete the study. The data were used to construct a groundwater flow model and to perform geochemical modeling of the mine pool and Boone aquifer at the site. These activities form the basis for the conclusions and recommendation provided in this report.

The HCS concludes that source material injection is compliant with the UIC requirements and may proceed under the OU4 ROD on the basis that:

1. The primary drinking water standards under 40 CFR 141 apply to public water systems.
2. Public water systems are defined as any system that provides water to at least 15 service connections or 25 people for at least 60 days annually (40 CFR 141.2).
3. The USDW, the Boone aquifer, within and surrounding the immediate vicinity of the site, does not currently serve as a supply source to a public water system.

4. The Boone aquifer, within and surrounding the immediate vicinity of the site, is not reasonably expected to serve as potential future source of supply for a public water system given that:

    a. The ROD states, in Section 19.2.6, that institutional control IC will be a part of the OU4 remedy, including restricting future uses of groundwater from the Boone aquifer for potable or domestic supply that is impacted with site-related contaminants above the remedial goals.

    b. Treatment of Boone aquifer water would first be required to address pre-existing contamination.

    c. For the foreseeable future, the voluntary relocation of residents of Cardin, Picher, and Hockerville within the site has resulted in a significant drop in the population, and has lowered both current and future water demand, making it less likely that a public water system would attempt to obtain water locally from the Boone aquifer.

    d. For the foreseeable future, water demand, if any, can be supplied by the Roubidoux aquifer, making it less likely that a public water system would attempt to obtain water locally from the Boone aquifer.

    e. For the foreseeable future, rural water districts supplied by the Roubidoux aquifer exist and serve northern Ottawa County, including significant portions found within the OU4 site boundary, making it less likely that a public water system would attempt to obtain water locally from the Boone aquifer.

5. In the areas of the site where injection may occur, there are no known private potable wells in use for drinking water. In a limited number of instances the Boone aquifer is used as a water supply for domestic wells. Prior to injection at any source material location, a well search will be completed to confirm that no domestic wells are located within the area that may be influenced by injection. In addition to searching for private wells, a search for points of discharge will be made prior to selection of an injection site.

6. The deeper Roubidoux aquifer, a USDW and known primary source of supply for public water systems in Ottawa County, has limited hydraulic connection through the intervening strata with the shallow Boone aquifer and the potential for aquifer cross-contamination is low. However, the presence of improperly abandoned boreholes or other direct conduits for flow could result in Boone groundwater entering the Roubidoux and degrading groundwater quality in the Roubidoux. A program exists for abandonment of these conduits as they are identified and it is recommended that this program continue. In addition, the State of Oklahoma has special well construction requirements in place within the OU4 boundary that apply to any future wells drilled into the Roubidoux aquifer (Title 785 Oklahoma Administrative Code Chapter 45, Appendix H). The well construction requirements are intended to ensure that any wells drilled through the Boone aquifer and into the Roubidoux aquifer are constructed such that the Boone aquifer is properly sealed off prior to drilling into the Roubidoux aquifer.

    a. Groundwater model simulations also suggest that the travel time from the Boone aquifer to the Roubidoux aquifer through natural geologic materials is greater than 200 years.

b. The large difference in groundwater levels between the Boone and Roubidoux aquifers, with water levels in the Boone aquifer being greater than 200 feet higher than those in the Roubidoux, strongly suggest that the aquitard materials present between the aquifers represent a very effective barrier to vertical flow between the units.

c. The results of groundwater modeling simulations of the hydraulic interaction between the Boone and Roubidoux aquifers suggest that less than 11 gallons per minute (gpm) of Boone aquifer water per square mile of mine working reaches the underlying Roubidoux aquifer.

7. Data from past injection studies at the site performed by EPA Region 6 indicate that injection of chat has resulted in a temporary increase in trace metal concentrations in mine pool water. The metals were observed to decrease to concentrations at or near pre-injection levels after a few months.

8. The results of dilution and geochemical transport simulations predicted that, although mine pool water has and will continue to influence downgradient Boone aquifer chemistry, the effect of chat fines injection on Boone groundwater quality is both minor and temporary.

9. The results of the groundwater modeling and advective transport analysis performed as part of this study suggest that significant dilution in dissolved metals concentrations will occur during transport between the injection location and the closest natural discharge point of mine water into the Boone aquifer.

10. Geochemical modeling performed to evaluate the fate of dissolved metals leaving the mine workings and entering the Boone aquifer suggest that the metals contained in this discharge will attenuate rapidly with travel distance from the mine pool.

11. Environmental monitoring would be performed before, during, and after operations, in accordance with Section 19.2.6 of the OU4 ROD, to continuously assess and confirm UIC compliance, and would include monitoring of both the Boone and Roubidoux aquifers and surface water.

12. Injection wells will be properly abandoned after use (unless retained for longer-term monitoring purposes).

Based upon the above conclusion and supporting findings, injection of fine tailings into the abandoned mine workings can be conducted to be in compliance with the UIC regulations. It is recommended that a single fine tailings pond be injected and the effort studied before proceeding to full-scale implementation of the preferred injection remedy.

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# Abbreviations and Acronyms

| | |
|---|---|
| °F | degrees Fahrenheit |
| µg/L | micrograms per liter |
| µS/cm | microsiemens per centimeter |
| AATA | AATA International, Inc. |
| ac-ft | acre-feet |
| amsl | above mean sea level |
| AMW | acid mine water |
| AOC | Administrative Order on Consent |
| bgs | below ground surface |
| Bingham | Bingham Sand and Gravel, Inc. |
| BMP | best management practice |
| BTOC | below top of casing |
| CERCLA | Comprehensive Environmental Response Compensation Liability Act |
| CFP | conduit flow process |
| CFR | *Code of Federal Regulations* |
| cfs | cubic feet per second |
| cm/s | centimeters per second |
| COC | chemicals of concern |
| CY | cubic yard |
| DO | dissolved oxygen |
| DOI | U.S. Department of the Interior |
| EPA | U.S. Environmental Protection Agency |
| FR | *Federal Register* |
| FS | feasibility study |
| ft/d | feet per day |
| gpm | gallons per minute |
| HAA | high access areas |
| HCS | hydrogeologic characterization study |
| HFO | hydrous ferric oxide |
| IC | institutional control |
| LICRAT | Lead Impacted Communities Relocation Assistance Trust |
| MCL | maximum contaminant level |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| mgd | million gallons per day |
| mV | millivolts |
| NPL | National Priority List |
| NTU | nephelometric turbidity unit |
| OCC | Oklahoma Conservation Commission |
| ODEQ | Oklahoma Department of Environmental Quality |
| QC | quality control |
| ORP | oxidation reduction potential |

| | |
|---|---|
| OU | Operable Unit |
| OWRB | Oklahoma Water Resources Board |
| Picher Field | Picher Mining Field |
| PRP | potentially responsible party |
| RA | remedial action |
| RD | remedial design |
| RI | remedial investigation |
| ROD | Record of Decision |
| SC | specific conductance |
| SMCL | secondary maximum contaminant level |
| SNDCR | sand screw |
| SPLP | synthetic precipitation leaching procedure |
| SWMP | surface water monitoring program |
| TAL | total analyte list |
| TDS | total dissolved solids |
| TM | technical memorandum |
| UIC | underground injection control |
| USDW | underground source of drinking water |
| USGS | U.S. Geological Survey |
| Weston | Weston Solutions, Inc. |
| XRD | x-ray diffraction |

SECTION 1

# Introduction

The U.S. Environmental Protection Agency (EPA) signed the Record of Decision (ROD) for Operable Unit (OU) 4 of the Tar Creek Superfund Site in February 2008. The injection of source materials back into the flooded underground mine workings was selected as part of the final remedy for OU4. Any injection wells installed will be required to comply with the underground injection control (UIC) regulations as Class V mining, sand, or other backfill wells (Title 40 *Code of Federal Regulations* [CFR] 144.81[8]). In particular, the owner/operator of a Class V injection well must meet the requirements of 40 CFR 144.12 and 144.82, prohibiting movement of fluid into underground sources of drinking water (USDW) containing any contaminant if the presence of that contaminant causes the exceedence of primary drinking water standards (expressed as maximum contaminant levels or MCLs) or other health-based standards or may otherwise adversely affect the health of persons (EPA, 2008).

The ROD specified in Section 19.2.4.3 that a hydrogeologic characterization study (HCS) would be performed to assess the ability of the injection component of the selected remedy to be compliant with the UIC regulations. The HCS was designed to document the geologic and hydrogeologic characteristics at the site and assess the ability of the injection component of the selected remedy to be compliant with the UIC regulations.

## 1.1 Site Background

The Tar Creek Superfund Site is located along the southern portion of the Oklahoma-Kansas state line in Ottawa County, Oklahoma. The site covers approximately 40 square miles and includes the Oklahoma portion of the Tri-State Mining District of Oklahoma, Kansas, and Missouri. The principal communities within the site boundary are Cardin, Commerce, North Miami, Picher, and Quapaw. A map of the site and the site location are provided on **Figure 1-1**[1]. As discussed in the OU4 ROD (EPA, 2008), the site has been divided into five OUs: OU1 – Surface Water and Groundwater; OU2 – Residential Properties; OU3 – Former Eagle-Picher Office Complex – Abandoned Mining Chemicals; OU4 – Chat Piles, Other Mine and Mill Wastes, and Smelter Wastes; and OU5 – Sediments.

From 1904 to the early 1970s, the site was extensively mined for lead and zinc ores. Remnants of decades of mining are clearly visible on the ground surface in the form of mine waste known locally as chat. Chat is a local term used to describe mill tailings from lead-zinc mining, and consists of predominantly gravel-sized fragments of siliceous rock (chert), limestone, and dolomite. Today, approximately 50 million tons of chat reside at the surface in the form of hundreds of piles rising to heights of roughly 200 feet above the ground surface. Fine tailings, produced as part of the milling of ores and from chat washing operations, are also present at the surface in former dry tailings ponds (EPA, 2008). OU4 consists of noncontiguous, asymmetrical parts of the site (both urban and rural) that are not

[1] Figures are located at the end of this report.

presently used for residential purposes or which are sparsely used for residential purposes, where chat piles, mine and mill residues, and smelter waste have been deposited, stored, disposed of, placed, or otherwise come to be located as a result of mining, milling, smelting, or related operations. OU4 does include some residential yards located in Ottawa County outside of city or town limits. The majority of the residential yards at the site have been addressed under OU2 (EPA, 2003).

The Picher Mining Field (Picher Field), including most of the Tar Creek site, is located on the eastern edge of the Central Lowland Provinces. Eastern portions of the site are located on the Ozark Plateau. The Central Lowland Province is a nearly flat, treeless prairie. The Ozark Plateau is a broad, low structured dome centered in southwestern Missouri and northwestern Arkansas. The natural land surface at the site is mostly flat and gently slopes to the south towards the Neosho River, to the east towards the Spring River, and to the west towards Elm Creek. However, much of the land surface has been modified by the mining activities. In addition to the presence of the chat piles and tailings ponds, numerous collapsed structures from subsidence and cave-ins of mine workings and mine shafts are also present on the land surface (EPA, 2005).

In addition to the obvious aboveground remnants of mining, mining activities left an extensive network of mine workings underground. When the mines were active, groundwater pumping was required to maintain access to the tunnels. Once mining operations ceased, the pumps were removed and groundwater began filling the mine workings. Of the two main aquifers in the region, the shallow Boone and the deeper Roubidoux, mining activities were confined to the Boone. Once the extensive network of mine workings filled with water, the water became acidic and laden with metals. Contaminants from the mine workings have affected groundwater quality in the Boone aquifer. The underlying Roubidoux aquifer is the principal source of drinking water for the region. The cities of Commerce, Miami (located south of the site), Quapaw, and several rural water districts obtain their water supplies from the Roubidoux aquifer (EPA, 2005).

Historically, the Roubidoux had a higher hydraulic head than the Boone. However, as a result of groundwater withdrawals, the hydraulic head in the Roubidoux has been lowered several hundred feet. Because the groundwater levels in the Roubidoux aquifer are several hundred feet lower than those in the Boone aquifer and the mine workings, there is a potential for downward movement of groundwater. To date, the data collected regarding the connection between the Boone and Roubidoux aquifers indicate that the primary pathway for contaminants to migrate into the Roubidoux aquifer from the mine workings has been through abandoned wells, wells that have faulty casings and/or poor seals across the Boone aquifer, and through unplugged abandoned boreholes. Municipal water supply wells completed in the Roubidoux aquifer in Commerce, Picher, and Quapaw have been suspected of being affected by mine water and have been plugged. The OU1 remedial action (RA) included the plugging of numerous wells completed in the Roubidoux aquifer to reduce the potential for contaminants to migrate from the mine workings into the Roubidoux aquifer. The OU1 Roubidoux Groundwater Monitoring Program continues to monitor groundwater quality in the Roubidoux aquifer and provides for the abandonment of old Roubidoux wells at the site as they are identified. Limited data collected during the remedial investigation (RI) for OU1 indicated that the potential for groundwater and contaminants to migrate through the intervening strata was limited because of low

hydraulic conductivity (CH2M HILL, 2008; Oklahoma Department of Environmental Quality [ODEQ], 2006).

## 1.2 Site History

The following sections provide a discussion of the history of the site.

### 1.2.1 Mining History

The first ore discoveries and earliest mining operations in Ottawa County, Oklahoma, occurred in the vicinity of Peoria (6 miles east and 1 mile south of Lincolnville) in 1891 (Weidman, 1932). The next major ore discoveries occurred 1.5 miles northeast of Lincolnville near Quapaw in 1902, followed by discoveries in 1905 near Commerce. The real expansion of zinc and lead mining at the site occurred after a major ore discovery in 1914 near the current site of Picher, Oklahoma. Following this discovery, there was a major expansion of mining in what became known as the Picher Field of Oklahoma and Kansas. By 1918, the Oklahoma section of the Picher Field was well defined by producing mines, with 230 mills built or under construction (Luza, 1986).

During the early mining period, most mining was conducted by small operators on 20 to 40 acre tracts. Each operator conducted his or her own mining, drilling, and milling activities. Mining activities occurred primarily within a 50- to 150-foot-thick ore bearing zone within the Boone Formation. The maximum depth of mining was approximately 385 feet below ground surface (bgs). Mining was accomplished using room and pillar techniques. To remove the ore, large rooms, some with ceilings as high as 100 feet, were connected by horizontal tunnels known as drifts. Pillars were left within the rooms to support the ceilings. The lead and zinc ores were milled locally and generally sent to locations outside of Ottawa County for smelting. A small lead smelter (the Ontario Smelter) operated near Hockerville for a brief period from 1918 until the early 1930s. Rapid expansion of mining activities occurred during the 1920s, and mining activities reached their peak around 1925 (EPA, 2005).

In the 1920s, consolidation of milling began with one mill processing ore from several miners. By the 1930s, central mills were established, the largest being the Eagle-Picher Central Mill located between Cardin and Commerce, Oklahoma. Many miners ceased their own milling operations in favor of selling their ore production to one of the central mills or having their ore custom milled by these mills. This movement of ore between mines and the central mills resulted in an extensive network of haul roads and rail lines in the district (EPA, 2008).

During the peak of mining activities, 130,410 tons of lead and 749,254 tons of zinc were produced annually. Depletion of high-grade ores caused a marked decline in annual production after 1946, and depressed metal-market prices and decreased demand for lead and zinc metals forced a cessation of most mining activities in 1958 (Brichta, 1960). Smaller mining operations continued in the Picher Field through the 1960s. The last record of significant production from Ottawa County occurred in 1970 (McKnight and Fischer, 1970).

With few exceptions, the crude ore produced at the site was mined using underground mining methods. Based on production records maintained by the U.S. Department of Interior (DOI), Bureau of Mines, a total of 181,048,872 tons of crude ore was produced from

the Oklahoma portion of the district. Milling of this ore produced 8,884,898 tons of zinc concentrates and 1,686,713 tons of lead concentrates. With the exception of a limited amount of lead concentrates treated at the Ontario Smelter, all of the concentrates produced from the site were transported offsite for the conversion of the concentrates to metal by smelting (EPA, 2008).

The byproducts of the mining operation were discarded mining and milling tailings. The mill tailings are locally known as chat. Chat primarily consists of fine gravel-sized and coarse sand-sized rock fragments. Rock fragments are generally light gray to gray in color and are primarily sub-angular to angular pieces of chert, dolomite, and limestone. Chat is also composed of minor amounts of smaller intermingled source material such as medium to fine sands, silts, and clays. After the excavated rock was processed and the metal ore extracted, the mining tailings that remained were deposited into piles that were up to 200 feet in height. The piles of chat mining waste are collectively referred to as "chat piles" and many of these chat piles remain on the site. An inventory conducted in 2005 as part of the RI for OU4 identified 83 chat piles occupying 767 acres with an estimated volume of 31 million cubic yards (CY), and 243 chat bases (or former piles) occupying 2,079 acres with an estimated volume of 6.7 million CY (EPA, 2008).

In addition to piles of mining wastes, a large but lesser quantity of fine tailings ponds containing wastes from the flotation milling process and chat reprocessing operations were produced. Most of the flotation ponds have since evaporated, leaving behind a very fine mining waste sediment that remains on the site. During the field reconnaissance phase of the RI, it was discovered that fine tailings at the site actually consisted of two distinct materials: flotation tailings and washed fine tailings. Flotation tailings were generated during the extraction or milling process. Flotation tailings are gray to light brown in color and very fine-grained (mostly silt and clay with minimal fine sands). Washed fine tailings were generated as a byproduct of washing chat for commercial aggregate sale and from chat reprocessing through the mills. Washed fine tailings are generally light gray to yellowish brown and consist mostly of fine sands and silts with some clay and medium sands. Washed fine tailings typically contain 75 to 85 percent of very fine- to medium-grained sands and 15 to 25 percent of silt and clay. The washed fine tailings were usually discharged first into a pre-existing flotation tailings pond (if present) next to the chat pile being washed or processed. The ponds were often expanded as necessary to accommodate continued washing. As a result, and with few exceptions, almost all of the flotation tailings at the site are covered with washed fine tailings, and there are portions of most fine tailings ponds that contain only washed fine tailings. Fine tailings generated from milling and washing chat are currently found in 63 ponds occupying 820 acres and total approximately 9.1 million CY, with a makeup of approximately 7.2 million CY (78.7 percent) washed fine tailings and 1.9 million CY (21.3 percent) of flotation tailings (EPA, 2008).

Over the years, the mining wastes have been used for a variety of purposes including railroad ballast; concrete and asphalt aggregate; sandblasting sand; sandbag sand; roadway, driveway, alleyway, and parking lot aggregate; general fill material in residential areas; and impact-absorbing material in playgrounds. Chat is currently processed at the site by commercial chat washers for sale as aggregate, generating additional washed fine tailings as a byproduct. The washed chat is often sold as aggregate for use in road construction

projects in accordance with the requirements of EPA's chat use rule (40 CFR 278) and its preamble (72 *Federal Register* [FR] 39235). Washed chat is not proposed for injection.

When mining operations ceased, it is estimated that underground cavities with a volume of 100,000 acre-feet (ac-ft; 161,000,000 CY) had been created. In addition, approximately 100,000 exploratory boreholes were located within the Picher Field, mostly in Oklahoma. One thousand sixty-four (1,064) mine shafts existed within the Oklahoma portion of the mining district. In addition, numerous water wells, used for milling operations, were abandoned (EPA, 2005).

During the active mining period, groundwater infiltration into the mine workings was a continual problem. Large-scale pumping was required to remove groundwater and maintain dry conditions within the mine workings. The pumping created a large cone of depression, effectively dewatering the Boone aquifer in the mining field. The sulfide ores of lead (galena), zinc (sphalerite), and iron (pyrite and marcasite) were oxidized by exposure to the moist air in the mine workings. Sulfide is oxidized to soluble sulfate during this process, releasing the corresponding trace metal into solution. When mining activities ceased, pumping from the mine workings ceased as well. The abandoned mine workings began to fill with infiltrating groundwater and surface water inflow through abandoned shafts, open boreholes, and collapse/subsidence features. As the mine workings filled with water, the oxidized sulfide minerals began to dissolve, generating a weak acidic solution. The acidic water then reacted with the surrounding rock, further dissolving sulfide minerals still contained in the mine workings. This resulted in increases in the concentrations of heavy metals, particularly iron, cadmium, lead, nickel, and zinc, in the water contained within the mine workings. The water also contains high concentrations of sulfate and total dissolved solids (TDS), high levels of hardness, and low pH. This process generated what is termed acid mine water (AMW) (EPA, 2005; ODEQ, 2006).

The site first came to the attention of the State of Oklahoma and EPA in 1979 when AMW began flowing to the surface from the underground mine workings through abandoned mine shafts and boreholes. The Governor of Oklahoma formed the Tar Creek Task Force to investigate the effects of AMW discharges on the area's surface water and to the groundwater. Based upon the information discovered by the Tar Creek Task Force, EPA proposed to add the site to the Superfund National Priorities List (NPL; 40 CFR Part 300, Appendix B) in July 1981. The NPL is the list, compiled by EPA pursuant to the Comprehensive Environmental Response Compensation Liability Act (CERCLA) Section 105, of uncontrolled hazardous substance releases in the United States that are priorities for long-term remedial evaluation and response. The site was added to the NPL in September 1983 (EPA, 2008).

### 1.2.2 Operable Unit History

Because of the complex nature of contamination associated with the Tar Creek site, remediation has been handled through various removal response actions and RAs. As discussed in the OU4 ROD (EPA, 2008), the following five OUs have been designated at the site: OU1 - surface water/groundwater; OU2 – residential areas; OU3 - Eagle-Picher Office Complex – Abandoned Mining Chemicals; OU4 - Mine and Mill Waste, and Smelter Waste; and OU5 – Sediments. RODs have been signed for OU1, OU2, and OU4. OU3 was a removal action that requires no further action. OU5 is currently being assessed.

### OU1 History

In 1984, EPA issued its first site ROD for OU1. The 1984 OU1 ROD applied to two concerns: 1) the surface water degradation of Tar Creek by the discharge of AMW; and 2) the threat of contamination to the Roubidoux aquifer from downward migration of mine water through leaking well casings and poorly sealed wells. Pursuant to EPA's 1984 ROD, dikes and stream diversion channels were constructed to reduce the inflow of surface water to three mine shafts at the site and to reduce the outflow of AMW from the subsurface to Tar Creek. In addition, abandoned wells that went through the Boone aquifer to the deeper Roubidoux aquifer were plugged to prevent contamination from the Boone aquifer and mine workings from seeping through failed well casings and poorly sealed wells and migrating downward to the Roubidoux aquifer. Abandoned wells that could threaten the Roubidoux are still being discovered and plugged as part of the Roubidoux Groundwater Monitoring Program for OU1. Groundwater quality within the Roubidoux aquifer also continues to be monitored under the Roubidoux Groundwater Monitoring Program (EPA, 2005).

### OU2 History

OU2 was established to address contaminated soil in residential areas of the site. In 1994, Indian Health Service test results concerning the blood lead levels of Indian children living on the site indicated that approximately 35 percent of the children tested had concentrations of lead in their blood exceeding 10 micrograms per deciliter, the level of lead in the blood the Centers for Disease Control considers to be a health concern. In August 1994, to address the threat of lead exposure to children, EPA began sampling soils at high access areas (HAA) at the site such as day cares, schoolyards, and other areas where children congregate. EPA sampled 28 HAAs between August 1994 and October 1994. The sampling detected significant concentrations of lead, cadmium, and other heavy metals in surface soils. In March 1995, EPA expanded its sampling activity to include all residences on the site (EPA, 2005).

In 1995, EPA began to excavate contaminated soil at HAAs and at site residences using its removal action authority. Concurrently, EPA began the RI and feasibility study (FS) for site residential areas, which became OU2. In 1997, EPA issued a ROD to address contaminated soil in the residential areas of OU2. Through the removal actions and the RA required by the OU2 ROD, EPA has excavated lead-contaminated soil at more than 2,295 properties. The remediation of the yards and the public areas and the education and outreach programs implemented by the Ottawa County Health Department are helping to protect the children's health. In 1996, data from the Oklahoma State Department of Health showed that among young children (aged 1 to 5 years) living at the site, 31.2 percent had a blood lead level at or above 10 micrograms per deciliter. By 2003, data published by the Agency for Toxic Substances and Disease Registry indicated that 2.8 percent of the children in that age group had a blood lead level at or above 10 micrograms per deciliter, which is slightly higher than the national level of 2.2 percent (EPA, 2005).

### OU3 History

OU3 was a former office and laboratory complex operated by one of the former mining companies located in Cardin. Numerous containers of chemicals were found at the site during 1998 and 1999. The EPA addressed OU3 through a removal action in 2000, and no further action was required for OU3 (EPA, 2005).

### OU4 History

OU4 was established to address mining-related source materials and the transport of cadmium, lead, and zinc, the chemicals of concern (COC), to surrounding media within the historically mined areas of the site (CH2M HILL, 2007a). On December 9, 2003, EPA signed an Administrative Order on Consent (AOC) with three potentially responsible parties (PRP), including the DOI, Blue Tee Corporation, and Gold Fields Mining Corporation. The AOC required the PRPs to conduct the RI/FS for OU4. Under the terms of the AOC, EPA prepared the risk assessments for OU4 based on data collected by the PRPs and EPA. A three-phased site reconnaissance was conducted from March 29 to April 28, 2005. During the site reconnaissance, field characterization of the mine and source materials was conducted and sampling sites for the RI were selected with concurrence of EPA, ODEQ, the Quapaw Tribe and other participating organizations. Field sampling and investigations were conducted in May and concluded in October 2005 (EPA, 2008).

Between 2003 and 2007, EPA, ODEQ, and the Oklahoma Conservation Commission (OCC) completed several pilot study projects at the site related to OU4. The projects included injection of mining wastes back into the mine workings and backfilling subsidence features with mining wastes. The projects were implemented to assess the technical feasibility of different methods to remediate the site and to assess potential environmental impacts associated with these methods. The pilot studies are further described and discussed in **Section 4**.

### OU5 History

OU5 is an effort to address sediment and surface water contamination in the Spring River and Neosho River basins in Missouri, Kansas, and Oklahoma associated with the Tri-State Mining District. OU5 is a cooperative effort involving EPA Regions 6 and 7 and various other federal, state, and local stakeholders. OU5 is currently in the site characterization phase, and a ROD has not been signed for OU5.

## 1.3 Record of Decision for OU4

The EPA signed the ROD for OU4 on February 20, 2008. The ROD determined that contaminants associated with OU4 presented unacceptable risks to human health and ecological receptors. The selected remedy in the OU4 ROD addresses site source materials, including chat piles, chat bases, fine tailings (including washed fine tailings and flotation tailings), and smelter wastes. The selected remedy also addresses soils contaminated by source materials, including transition zone soils, soils underlying source materials, and smelter-affected soils, as well as affected soils in rural residential yards not addressed under OU2. OU4 generally does not address sediment, except where source material (predominately chat) is removed from in-stream or near-stream areas. OU4 does not address groundwater or surface water, except indirectly by eliminating some of the sources of groundwater and surface water contamination. The OU4 ROD does address groundwater where rural residential wells have been affected by site contamination (EPA, 2008).

The COCs identified for OU4 in the ROD are cadmium, lead, and zinc in source materials and soils, and lead in groundwater. The OU4 ROD specifies the remedial action objectives

and remediation goals for each medium addressed by the ROD. The remedial action objectives and remediation goals specified in the OU4 ROD are provided in **Table 1-1**[2].

### 1.3.1 Selected Remedy

The selected remedy for OU4, as specified in Section 19 of the ROD, includes voluntary relocation, phased consolidation of source materials, continued chat sales, and onsite disposal of source materials and contaminated media. The ROD specified that the remedy would occur in two phases and take 30 years to complete. The remedy selected in the OU4 ROD included the following elements:

- EPA included in the OU4 remedy the continuation of chat sales for use in transportation and non-transportation projects that comply with the Chat Use Rule and the preamble to the Chat Use Rule (40 CFR 278 and 72 FR 39235 [July 18, 2007]). Continued chat sales contribute to a more cost effective CERCLA remedy because continued sales will result in less chat remaining onsite that must be addressed with more expensive remedial alternatives (i.e., remedial alternatives that are more costly than chat sales). The removal of chat through chat sales will reduce exposure risks and reduce the volume of chat that will require onsite disposal (EPA, 2008).

**Phase 1:** Phase 1 will address voluntary relocation of residents and chat sales. It will also address source materials in a manner that will reduce the overall footprint of contamination and reduce the need for land use restrictions, institutional controls (IC), and operation and maintenance.

- Residents located in Picher, Cardin, and Hockerville will be voluntarily relocated following the procedures and priorities established by the Lead Impacted Communities Relocation Assistance Trust (LICRAT). EPA will provide relocation assistance funding to LICRAT for residences and businesses located in targeted areas of the site as shown on **Figure 1-2**.
- Chat and chat bases from distal areas, including associated historical chat-covered haul roads and non-operating railroad grades, will be excavated to the underlying native soil, transported and released to an onsite chat processor or future processing location located in a previously contaminated area of the site, injected into mine workings, or disposed of in an onsite repository.
- Transition zone soils (soils around and underneath source materials) will be addressed by excavation followed by natural soil rebuilding.
- Smelter wastes will be excavated and disposed of in an onsite repository. Smelter-affected soils will be managed in the same manner as transition zone soils.
- Fine tailings will be injected into mine workings or covered in place. The covered fine tailings may be consolidated to reduce the footprint of the final cover.
- Source material in Tar, Lytle, Elm or Beaver Creek, or other site waterways, will be addressed on a priority basis through either excavation and/or the installation of a flexible membrane liner, as needed, as determined by EPA. As an interim measure, sheet

[2] Tables are located at the end of this report.

piling, berms, constructed wetlands, or other engineering controls will be installed for near-stream source materials to help prevent contamination from migrating to surface water.

- An alternative water supply will be provided to any household where mining-related contaminants in water drawn from rural residential wells exceed 0.015 milligram per liter (mg/L) for lead for rural households. Rural households that are within the area that has been designated for relocation under the LICRAT relocation program, but which do not elect to participate in the relocation program, would be included in the households eligible for an alternative water supply (estimated two residences).
- Rural residential yards that are found to have concentrations of soil lead that exceed 500 parts per million will be excavated to a maximum depth of 12 inches, and the excavated area will be backfilled with clean soil, contoured to promote drainage, and re-vegetated. This includes residential yards that are identified for relocation. The provisions of the preceding sentence apply to approximately four households, based on the RI sampling. That is, if those eligible for relocation decide not to relocate, their yards will be remediated.
- Onsite repositories will be constructed to accept site source materials for final disposal. Onsite repositories will be closed when they reach capacity or at completion of the RA. Closure will be accomplished by covering the repository with a soil cover, contoured to promote drainage, and re-vegetated (EPA, 2008).

**Phase 2:** Phase 2 addresses certain source areas that remain after Phase 1 cleanup activities. These areas may include chat bases, tailings ponds, unmarketable chat piles and bases, and remaining chat from distal area consolidation. Chat sales will continue.

- The remedy will be reviewed, at a minimum, every 5 years because hazardous substances remain onsite with concentrations that exceed concentration levels that allow for unrestricted use and unrestricted exposure. The remedy will be reviewed to ensure protection of human health and the environment. As part of the five-year review, EPA will evaluate the progress of chat sales. Chat piles and bases remaining after 10 years will be evaluated for commercial viability. This determination will be made using input from the chat/land owners, appropriate tribal representatives, and the commercial operators.
- Unmarketable chat piles and bases will be excavated, transported, and released to an onsite chat processor or future processing location in a previously contaminated area of the site, injected into mine workings, or they will be disposed of in an onsite repository.
- Abandoned chat haul roads and non-operating railroad grades that are contaminated will be managed the same as unmarketable chat piles and bases. That is, they will be excavated, transported to an onsite chat processor, and released to that processor, or they will be disposed of in an onsite repository.
- IC and operation and maintenance activities will be implemented, as needed, as determined by EPA, at repositories and covered, fine tailings ponds.

- Environmental monitoring will be conducted, as needed, as determined by EPA, to test for contamination in ambient and near source air, surface water, groundwater, and sediment during remediation activities (EPA, 2008).

As part of the OU4 ROD, a watershed-based approach is being taken, including development of a baseline hydrology model to reflect the existing land uses in the basin and reflect any rainfall storage within the source materials. Runoff is expected to increase as the capacity of the soil to absorb rainfall onsite decreases, and the model may be used in the future to manage increased runoff and stream flow (EPA, 2008).

Under the selected remedy, ICs include deed notices placed on land parcels that are contained in the site. Such ICs would notify current and potential future deed holders of the presence of wastes left onsite. The IC instrument to restrict land use is a Deed Notice and Easement filed pursuant to Oklahoma Statute 27A § 2-7-123(B). An additional IC is to be implemented to restrict use of groundwater from the Boone aquifer (or shallower) for potable or domestic supply when that water source is affected with site-related contaminants above the final remediation goals (Section 19.2.6 of the ROD). The IC instrument in this case is to be implemented through the Oklahoma Water Quality Standards Title 785, Oklahoma Administrative Code Chapter 45, Appendix H (EPA, 2008). Appendix H currently states that toxic metals are present and that special well construction methods are required within the OU4 boundary because of contamination in the Boone aquifer. Special well construction is required for any wells drilled through the Boone aquifer and into the Roubidoux aquifer. New wells are required to be constructed in such a way that the Boone aquifer is sealed off prior to drilling into the Roubidoux aquifer. There are currently no limitations placed on the use of groundwater from the Boone aquifer for potable and domestic supply.

### 1.3.2 Injection and Hydrogeologic Characterization Study

The injection of source materials back into the flooded mine workings was selected as part of the final remedy for OU4. Injection will be the preferred remedy for the fine tailings; however, covering in place will be used for areas where injection is technically impracticable. Any injection wells installed as part of the remedy will be required to comply with the UIC regulations as Class V mining, sand, or other backfill wells (see **Section 1**). The ROD specified in Section 19.2.4.3 that this HCS would be performed prior to implementation of the injection component of the selected remedy. The objective of the HCS is to assess the ability of the injection component of the selected remedy to be compliant with the UIC regulations (EPA, 2008).

## 1.4 Study Objectives and Purpose

The primary objective of the HCS is to determine if injection can be implemented at the site in a manner that is compliant with the UIC regulations, especially with respect to the requirement that a USDW is not affected such that contaminant concentrations do not exceed the MCLs or other health-based standards. Secondary objectives include 1) determining if the source materials can be injected into the mine workings at strategic locations in such a way as to minimize impacts on the water quality of the mine discharges to surface water; and 2) assessing the possible hydraulic connection between the Picher

Field and the mine workings in the Commerce area. To meet these objectives, several activities were completed including the following:

- Various literature resources were reviewed to assess the potential impacts and technical issues associated with injection.
- Numerous pilot studies using injection have been performed to assess the impacts and technical feasibility of injection.
- Field activities were performed to collect sufficient environmental data related to the surface water system, the groundwater system, and the mine pool to construct a numerical model of the hydrogeologic system at the site.
- Geochemical modeling was performed to assess impacts of injection on the geochemistry of the mine pool and Boone aquifer to evaluate the potential for injection of source materials to affect site groundwater.
- The existing U.S. Geological Survey (USGS) groundwater flow model for the site was updated and expanded to account for the mine pool and to incorporate site-specific data collected during the field activities. The numerical model will be used to establish an overall water budget for the site and to evaluate remedial approaches that are consistent with the ROD (CH2M HILL, 2008).

The overall purpose of this report is to document the activities performed as part of the HCS and to assess whether injection can be implemented at the site in compliance with the UIC regulations.

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SECTION 2

# Mine Workings and Source Materials

This section discusses the mine workings and the characteristics of the source materials.

## 2.1 Mine Workings

Past mining activities left an extensive network of mine workings underground at the site. Mine workings are present under approximately 2,540 acres of land in 47 sections in northern Ottawa County. Most of the mining occurred within Township 29N, Range 23E. Mining occurred mostly at depths between 180 feet and 250 feet bgs. However, mining occurred at depths as shallow as 80 feet bgs near Lincolnville and at depths as deep as almost 400 feet bgs along the Miami Trough (see **Section 3.3** for a discussion of the site geology) near Commerce (McKnight and Fisher, 1970; Luza, 1986). In many areas, mining occurred at multiple depth intervals. The extent of the mine workings is shown on **Figure 2-1**. The main mining area was centered on the towns of Picher and Cardin. Within this central area, the mine workings are interconnected. The mine workings are primarily within the Boone Formation, although some mining of the overlying Chester Group occurred in some areas. Numerous exploratory boreholes were drilled during the mining period to explore for ore. Many of these boreholes were left cased at the surface and were not properly plugged and abandoned (ODEQ, 2006).

Once mining operations ceased, pumping was discontinued, and the mine workings began to fill with surface water and groundwater. Surface water flowed into the mine workings through direct runoff into mine shafts, collapses, and exploratory boreholes. Natural recharge from the Boone aquifer also filled the mine workings. During the period between 1975 and 1980, water levels within the mine workings increased an average of 2.6 feet per month, with the water level rises being greatest after periods of high precipitation (Playton et al., 1980; Oklahoma Water Resources Board [OWRB], 1983a; Luza, 1986). Eventually, groundwater within the Boone aquifer and mine workings became confined as water levels rose above the base of the overlying confining units. By late 1979, the water levels in the mine workings were near the land surface elevation. In November 1979, AMW began discharging from the mine workings through old exploratory boreholes, mine shafts, air vents, and mine collapse/subsidence features to the ground surface in areas where the water level within the mine workings and Boone aquifer was above the ground surface elevation. Discharges of AMW occurred primarily in three areas of the site: southeast of Commerce, in the area of the confluence of Tar Creek and Lytle Creek at the Douthat Bridge, and along Beaver Creek southeast of Quapaw. The AMW discharged to the surface eventually flowed into and contaminated the surface water and sediments within Tar Creek (OWRB, 1983b). Discharges of mine water continue to this day.

Several estimates on the volume of water contained within the mine workings are listed in the literature. The USGS provided an estimate of 100,000 ac-ft during 1976, prior to the mines becoming completely filled (Playton et al., 1980). As part of the RI for OU1, OWRB estimated that the mine workings contained an estimated total of 76,350 ac-ft of water, with

54,924 ac-ft of water being in the mine workings in Oklahoma and the remainder in the mine workings in Kansas. This estimate was based on the total acreage undermined at the site, accounting for areas with mine workings at multiple levels, as well as a volumetric subtraction of 30 percent to account for remaining support pillars and assuming an average height of the mine workings of 25 feet (OWRB, 1983c). ODEQ estimated that the mine workings in Oklahoma contained approximately 50,000 ac-ft of water. This estimate was based on the Bureau of Mines records for the total tonnage of crude ore mined and an average bulk density of the crude ore of 2.68 grams per cubic centimeter (ODEQ, 2006).

The flooded mine workings are in direct hydraulic communication with the Boone aquifer. Water levels within the mine workings and nearby surrounding Boone aquifer equilibrated at an approximate elevation of 800 feet above mean sea level (amsl) (Playton et al., 1980; OWRB, 1983a). Mine water and groundwater levels collected during many studies have similar elevations at near 800 feet amsl, indicating that the piezometric surface/water table within the mine workings and Boone aquifer is relatively flat under much of the site. The flat hydraulic gradient is an indication of the large degree of hydraulic connection in the mine workings and surrounding Boone aquifer (DeHay et al., 2004). The USGS had a pressure transducer installed within the mine workings at the Blue Goose No. 2 Mine (located approximately 1 mile west of the Douthat Bridge) that was used to record water levels within the mine workings. Data from this location were recorded between 1975 and 2004. Another pressure transducer is currently located in the Slim Jim Mine (located in Section 17, Township 29N, Range 23E). This transducer has been operating since 2002. Water level data from these locations have been used in numerous reports to demonstrate that the water levels in the mine workings rise rapidly in response to precipitation events (Playton et al., 1980; Parkhurst, 1988; EPA, 1994; DeHay et al., 2004; USGS National Water Information System, 2009).

Parkhurst, during his study and development of his discharge ratings curve (described in **Section 3.2**), estimated that the residence time for the water within the mine workings was 22 years (Parkhurst, 1988). The USGS collected samples during 2002 through 2003 and analyzed them for chlorofluorocarbons in an attempt to estimate the recharge-age dates for the water in the mine workings in the Picher Field. There were some issues with the data related to field conditions and the overall reducing conditions of the mine water, which degrades chlorofluorocarbons. The chlorofluorocarbon data indicated recharge-age dates between 1964 and 2001, with the younger dates occurring in the southeastern and northern portions of the Picher Field. The oldest recharge-age dates occurred in the western portion of the Picher Field near the Miami Trough. The report concluded that flow through the mine workings was faster in the central portions and slower near the eastern and western edges (DeHay et al., 2004).

A large number of studies have been conducted to evaluate the quality of the groundwater within the mine workings. Initial studies performed by the USGS in the late 1970s showed no obvious areal trend or seasonal variation in the water quality within the mine workings. This study did demonstrate that the mine water is stratified with higher specific conductance values, higher metals concentrations, and lower pH in the lower stratified layer within the mine workings (Playton et al., 1980). The mine water is characterized by low pH, high concentrations of sulfate, iron, zinc, cadmium, lead, and nickel, low dissolved oxygen (DO), and high values for hardness and TDS (ODEQ, 2006). Sulfate is the dominant anion in

the mine water and calcium, magnesium, iron, and zinc are the dominant cations (Christenson et al., 1990).

The most recent study performed on the mine water within the mine workings was completed by the USGS in 2002 through 2003. This study included comparisons of subsets of samples collected in 1983 through 1985 and in 2002. The USGS concluded that the concentrations of most mine water indicator constituents were greater in 1983 through 1985 samples than in 2002 samples. The pH values were greater in the 2002 samples (indicating that the pH was becoming more neutral or less acidic). Calcium concentrations did not change significantly between the two data sets. Water quality samples were also collected from mine shafts for comparison with data from the 1976 through 1977 USGS study. The 2002 data was found to have lower specific conductance, lower range of pH values (but the same median), and much lower metals concentrations. Stratification of the mine water quality with depth was observed in both studies (DeHay et al., 2004).

## 2.2 Source Materials

The RI confirmed that chat and fine tailings found in piles, bases, chat haul roads, non-operating railroad grades, and tailings ponds are significant, high-volume sources of contamination that occupy a large area at the site. These mine and mill wastes contain elevated levels of lead, zinc, and cadmium. Migration of contamination away from these source material areas has affected surrounding soils and surface water. The following discussion summarizes the 2005 Tar Creek OU4 RI of chat piles, chat bases, and fine tailings at the site.

### 2.2.1 Remedial Investigation Results Summary for Chat Piles

As stated in **Section 1.2.1**, 83 chat piles were identified at the site covering a total area of 767 acres. Because of previous chat processing and re-processing, many of the chat piles at the site contain several smaller chat accumulations within the footprint of the original chat piles. A total of 132 chat accumulations were identified within the footprints of the original 83 chat piles. The total volume of chat at the site was estimated to be 31.20 million CY at the time of the RI in 2005 (AATA International Inc. (AATA), 2005). Additional chat has been removed from the site by commercial processors and through implementation of the RA beginning in 2010. As a result, the actual volume of chat source materials currently onsite is less than the volume estimated in 2005. The locations of the chat piles are shown on **Figure 2-2**. The chat piles investigated as part of the RI, their accumulation identification, estimated area, and estimated volume are summarized in **Table 2-1**.

Multiple chat pile samples were collected for physical and chemical analysis:

- 41 chat pile samples were collected from all 34 major chat piles investigated and analyzed for pH, grain size distribution, and bulk density. Multiple samples were collected from the Pioneer, Kenoyer, Atlas (Tulsa), Western, and Central Mill piles because of varying size distribution of chat at these piles. The chat pile samples were collected at a depth of 1 foot below the surface of each pile. One chat pile sample was inadvertently collected at chat base CB047 (New Beck).
- 174 chat pile samples and 8 field duplicates were collected from 20 of the 34 major chat piles investigated and analyzed for moisture content and metals analysis. At 160

sampling locations, chat pile samples were collected at a depth of 1 foot below the surface for moisture content, and a five-point composite bulk chat sample was collected for metals analysis. At the remaining 14 sampling locations, chat pile samples were collected from the surface to a depth of 1 inch for moisture content analysis, and a five-point composite bulk chat sample was collected for metals analysis (AATA, 2005).

The chat piles investigated as part of the RI activities and the quantities and type of samples collected are summarized in **Table 2-2**.

### Analytical Summary

The results of the grain size distribution analysis of the 41 chat pile samples collected during RI activities indicated that chat is primarily composed of varying percentages of fine gravel-sized to fine sand-sized particles with only a few samples containing more than 1 percent greater than 3/8-inch fraction. The distribution of grain size particles less than 3/8 inch varies significantly as a result of historical chat processing and re-processing both between and within individual chat piles. The pH of the chat samples collected ranged from 6.7 to 9.0, with all but two samples having a slightly basic (greater than 7.0) pH. The basic pH of chat is attributed to the strong buffering capacity of the limestone and dolomite, which makes up a significant percentage of the chat (AATA, 2005).

Because chat is permeable and drains quickly, moisture content of chat piles is highly dependent upon precipitation events. Moisture content analysis of bulk chat samples collected during RI activities indicated highly variable percentages from 2.4 percent to 11.4 percent. This variability in moisture content is more likely a result of differences in precipitation prior to the sampling event than to differences in the properties of the chat piles. The draft RI report notes that, typically under dry conditions, the moisture content of the chat piles ranges from 3 to 5 percent (AATA, 2005). The chat piles are saturated at their base. Groundwater contained within the base of the chat piles is perched on underlying clay soils under water table conditions. This groundwater slowly drains out of the chat pile at the base and becomes runoff to surface water.

**Table 2-3** provides a complete summary of the RI results for grain size distribution, bulk density measurements, and pH analysis for each chat pile investigated.

All five-point composite bulk chat pile samples collected during RI activities were analyzed for the three COCs: cadmium, lead, and zinc. In addition, 10 percent of the five-point composite bulk chat pile samples and all of the five-point composite surface chat pile samples were analyzed for the complete list of target analyte list (TAL) metals. Most metals, except for aluminum, magnesium, and manganese, in surface chat pile samples consistently showed narrow concentration ranges and lower average values than bulk chat pile samples (AATA, 2005).

The analytical results for the COCs in the bulk chat pile samples are summarized below:

- **Cadmium:** Ranged from 43 to 199 milligrams per kilogram (mg/kg) with an average of 92 mg/kg.
- **Lead:** Ranged from 210 to 4,980 mg/kg with an average of 1,213 mg/kg.

- **Zinc:** Ranged from 10,200 to 40,300 mg/kg with an average of 23,150 mg/kg (AATA, 2005).

**Table 2-4** provides a complete summary of the RI results for cadmium, lead, and zinc for bulk chat samples collected from the 20 chat piles investigated.

### 2.2.2 Remedial Investigation Results Summary for Chat Bases

As stated in **Section 1.2.1**, 243 chat bases were identified at the site covering a total area of 2,079 acres. Chat bases were identified in the RI as areas previously occupied by a chat pile. Chat bases typically are flat, with little or no relief when compared with chat piles. Thicknesses of chat bases vary widely depending on the processing history of the parent chat pile associated with the chat base. Some chat bases are only a few inches thick while others are several feet thick. Overall, the average chat base thickness is 2 feet. The total volume of chat contained within the chat bases at the site was estimated to be 6.71 million CY at the time of the RI in 2005 (AATA, 2005). Additional chat base materials have been removed from the site through implementation of the RA beginning in 2010. As a result, the actual volume of chat base source materials currently onsite is less than the volume estimated in 2005. The locations of the chat bases are shown on **Figure 2-3**. The chat bases investigated as part of the RI, their accumulation identification, estimated area, and estimated volume are summarized in **Table 2-5**. Chat bases are associated with former or existing chat piles. Therefore, during the RI, the chat bases were assigned accumulation identification that was associated with the parent chat pile.

Multiple chat base samples were collected for physical and chemical analysis:

- Four chat base samples were collected from four chat bases and analyzed for pH, grain size distribution, and bulk density. These samples were collected according to the same procedures as the chat pile samples.
- Twenty-one chat base samples and one field duplicate were collected from six chat bases and analyzed for moisture content and metals analysis. At each sampling location, chat base samples were collected at a depth of 1 foot below the surface of the each chat base for analyzing moisture content, and a five-point composite bulk chat sample was collected for metals analysis (AATA, 2005).

The chat bases investigated as part of the RI activities and the quantities and type of samples collected are summarized in **Table 2-6**.

#### Analytical Summary

The results of the grain size distribution analysis of the four chat base samples collected during RI activities indicated that the chat bases are primarily composed of varying percentages of fine gravel-sized to fine sand-sized particles with only one sample containing material that was greater than 3/8-inch fraction. The majority of the material has a grain size larger than the No. 40 mesh screen, indicating that fine material was not enriched in the chat bases. The pH of the chat samples collected ranged from 7.1 to 8.7, which was within the range of the pH values measured for the bulk chat in the chat piles (AATA, 2005).

Because chat is permeable and drains quickly, moisture content of chat bases is highly dependent upon precipitation events. Moisture content analysis of chat base samples

collected during RI activities indicated highly variable percentages from 2.1 percent to 12 percent. This variability in moisture content is more likely a result of differences in precipitation prior to the sampling event than to differences in the properties of the chat bases. The draft RI report notes that the moisture content of the chat bases was similar to the chat piles (AATA, 2005).

**Table 2-7** provides a complete summary of the RI results for grain size distribution, bulk density measurements, and pH analysis for each chat pile investigated.

All five-point composite chat base samples collected during RI activities were analyzed for the three COCs: cadmium, lead, and zinc. In addition, two of the chat base samples were analyzed for the complete list of TAL metals. The TAL metals concentrations were similar to the concentrations for the bulk chat samples. Lead concentrations were higher in the chat base samples at the Lawyers and Pioneer locations (AATA, 2005).

The analytical results for the three COCs in the chat base samples are summarized below:

- **Cadmium:** Ranged from 51 to 151 mg/kg with an average of 96 mg/kg.
- **Lead:** Ranged from 650 to 3,020 mg/kg with an average of 1,863 mg/kg.
- **Zinc:** Ranged from 9,520 to 33,600 mg/kg with an average of 23,055 mg/kg (AATA, 2005).

**Table 2-8** provides a complete summary of the RI results for cadmium, lead, and zinc for chat samples collected from the six chat bases investigated.

### 2.2.3 Remedial Investigation Results Summary for Washed Fine and Flotation Tailings

As stated in **Section 1.2.1**, 63 fine tailing ponds were identified at the site covering a total area of 820 acres. The total volume of fine tailings at the site is estimated to be 9.16 million CY, with a makeup of approximately 7.21 million CY (78.7 percent) washed fine tailings and 1.95 million CY (21.3 percent) of flotation tailings (AATA, 2005). The locations of the tailings ponds are shown on **Figure 2-4**.

Ten major fine tailing ponds were investigated as part of the RI. These fine tailings ponds represent 59.5 percent of the total surface area covered by fine tailings, and 68.0 percent of the total volume of fine tailings at the site. Intrusive work consisted of advancing borings to determine type (flotation tailings or washed fine tailings) and thickness of the material and for the collection of samples. Chemical analyses were performed on a total of 169 fine tailings samples, which included 96 washed fine tailings samples, 53 flotation tailings samples, 13 surface fine tailings samples and 7 duplicates (AATA, 2005). The 10 tailing ponds investigated, their estimated area, volume and thickness, and the quantity and type of samples collected are summarized in **Table 2-9**.

The samples were collected in accordance with the following methodology:

- If a fine tailings pond was found to contain only one type of fine tailings at a sampling site, one depth-composite sample was collected;

- If a fine tailings pond was found to contain "two-layered" fine tailings (i.e., washed fine tailings and flotation tailings) at a sampling site, two composite samples (one for washed fine tailings and one for flotation tailings) were collected;
- If a fine tailings pond was found to contain mixed fine tailings (i.e., multiple layers of washed fine tailings and flotation tailings) at a sampling site, the material near the surface was sampled as a depth-integrated sample to provide data for the human risk assessment (AATA, 2005).

### Analytical Summary

All samples were analyzed for the three COCs: cadmium, lead, and zinc. In addition, the surface samples were analyzed for the complete list of TAL metals. With few exceptions, flotation tailings contained higher cadmium, lead, and zinc concentrations than the washed fine tailings. Metal concentrations in the surface samples were in the same range as reported from the depth integrated washed fine tailings samples.

The analytical results for washed fine tailings are summarized below:

- **Cadmium:** Ranged from 10 to 320 mg/kg with an average of 79 mg/kg.
- **Lead:** Ranged from 220 to 26,600 mg/kg with an average of 3,658 mg/kg.
- **Zinc:** Ranged from 1,730 to 70,000 mg/kg with an average of 15,964 mg/kg (AATA, 2005).

The analytical results for flotation tailings are summarized below:

- **Cadmium:** Ranged from 26 to 450 mg/kg with an average of 133 mg/kg.
- **Lead:** Ranged from 1,130 to 17,800 mg/kg with an average of 5,694 mg/kg.
- **Zinc:** Ranged from 4,690 to 103,000 mg/kg with an average of 29,842 mg/kg (AATA, 2005).

**Table 2-10** provides a complete summary of the RI results for cadmium, lead, and zinc for both washed fine tailings and flotation tailings for each tailing pond investigated.

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SECTION 3

# Site Characteristics

This section documents and discusses the site physical characteristics relative to the HCS.

## 3.1 Climate

The climate at the site is characterized as a humid, continental climate. Climate data were derived for the 1950 to 1980 period of record for the National Weather Service meteorological station in Joplin, Missouri. Joplin, Missouri is located 20 miles northeast of the site. The average annual temperature is 57.5 degrees Fahrenheit (°F). The region experiences hot summers, with average daily average temperatures of 80.1°F in July and 78.5°F in August. The spring and autumn are characterized by mild temperatures with warm days and cool nights. Winters are generally moderate, except when arctic air masses move through the area. The average temperature in January, typically the coldest month of the year, is 32.6°F (AATA, 2005).

The average annual precipitation is approximately 42 inches. Most rainfall in the area occurs in the spring and early fall. However, 3-inch rainfall events could occur in the area during summer thunderstorms. The period of the year between November and February is the driest. Annual snowfall averages approximately 12 inches. The prevailing winds are southerly in all months except January and February, when northerly winds predominate. Average yearly wind speeds are 10 to 12 miles per hour. Strong, gusty winds of 30 to 40 miles per hour could occur with summer thunderstorms and when winter cold fronts move through the area (AATA, 2005).

## 3.2 Surface Water

Surface waters that drain from the site flow into two principal regional watersheds: the Neosho River and Spring River basins. Streams that drain the central and western portions of the site include Tar, Lytle, Quapaw, Garrett, and Elm Creeks, and associated tributary drainages. Tar Creek drains the most intensively mined areas of the site. Tar Creek and its primary tributary Lytle Creek comprise the principal drainage system at the site. Tar Creek is characterized as a small ephemeral stream with standing pools. The headwaters of Tar Creek are located in Cherokee County, Kansas (located north of Ottawa County on the Kansas-Oklahoma border). Tar Creek flows through the Treece Subsite of the Cherokee County Superfund Site in Kansas, and then flows southward through the Picher Field between the towns of Picher and Cardin, to the east of Commerce and Miami, and it then flows to its confluence with the Neosho River. Tar Creek and Lytle Creek drain approximately 53 square miles. Elm Creek drains the western portion of the site and flows into the Neosho River. These streams are typically underlain by Pennsylvania shale and, as such, are subject to rapid runoff, flooding, and intermittent flow (AATA, 2005; EPA, 2005).

Surface drainages in the eastern portion of the site flow into the Spring River. The surface geology of these drainages typically is Mississippian limestone, especially for drainages east of Highway 66. These small streams have intermittent flows and include Hockerville,

Ontario, and Beaver Creeks, and associated unnamed drainages in the eastern portion of the site (AATA, 2005). Surface water features at the site are shown on **Figure 3-1**.

Historical mining activities have altered the drainage pattern of Tar Creek and its tributaries (Spruill, 1987; Luza, 1986). The mining areas of the Picher Field, including the Treece, Kansas subsite, and the Oklahoma mining areas at Commerce occur within the Tar Creek watershed (OWRB, 1983b). Tar Creek supplied water to the mills, received water pumped from the mine workings, and was channelized and directed to keep water from flowing into mine workings (Luza, 1986).

During the dry summer and winter months, stream flow is low to nonexistent in Tar Creek upstream of the confluence of Tar and Lytle Creeks. The majority of the stream flow that does occur is sustained by discharge from chat piles, chat bases, and tailings ponds (base flow). Downstream of the Douthat Bridge to the U.S. Highway 69 Bridge east of Commerce, the majority of base flow during the summer and winter months is sustained by mine water discharges to Tar Creek (Cope et al., 2008).

The USGS performed an evaluation in 1985 relating the water levels within the mine workings to the amount of discharge from the mine workings to Tar Creek. A ratings curve (provided on **Figure 3-2**) was developed relating the water level elevation in the mine pool to the amount of discharge from the mine workings to surface water. Based on the data, obtained between January 1984 and March 1985, it was estimated that the mean daily discharge from the mine pool was between 1.5 and 225 cubic feet per second (cfs). It was estimated that 3,400 ac-ft per year of mine water was discharged from the mine pool to surface water (Parkhurst, 1988). **Figure 3-3** shows a ratings curve using six different data sets of mine water discharge measurements from the mine pool between 1982 and 2007. These data sets were developed from data collected by OWRB, ODEQ, and Oklahoma University and provided by ODEQ. Both ratings curves indicate that a relatively significant increase in mine water discharge from the mine pool to surface water occurs as the mine pool elevation approaches 803 feet amsl.

EPA selected a remedy under OU1 to address AMW discharges into Tar Creek. The remedy involved constructed surface water diversion and diking structures around major inflow areas to prevent surface water inflow into the abandoned mine workings. Two of the inflow areas were identified as the abandoned mine shafts called Muncie and Big John, located in Cherokee County, Kansas. These two inflow areas combined were thought to represent 75 percent of the total surface inflows into the abandoned mine workings. It was thought that the elimination of these inflow points would cause the groundwater levels in the mine workings to drop and, as a result, the amount of AMW discharged to the surface would be reduced or eliminated. It was predicted that the Admiralty location, located northeast of the Douthat Bridge, would become an inflow point after the initial diking and diversion work was completed, so the ROD allowed for additional diking and surface water diversion around this location if deemed necessary. Construction at all three locations was performed and completed in December 1986 (EPA, 2005).

Water quality in the Tar Creek watershed is regulated by the State of Oklahoma. The State of Oklahoma designates the beneficial uses for Tar Creek. In 1985, the designated beneficial uses for Tar Creek were lowered to Habitat Limited Aquatic Community and Secondary

Body Contact Recreation. The designated uses were lowered as a result of irreversible human-made impacts on the surface water in Tar Creek (EPA, 2005).

## 3.3 Site Geology

Ottawa County is located on the western flank of the Ozark uplift, a broad dome centered in southern Missouri and extending into northeast Oklahoma. Because of the orientation on the western flank of this structural high, progressively younger formations crop out from the east to west. The uplift flank extends to the axis of the Miami Trough (described below). The predominant rocks in the study area are Paleozoic carbonate and clastic sedimentary rocks, which overlie a Precambrian granitic and igneous basement complex. The sedimentary rocks vary in age from Cambrian through Pennsylvanian, and range in total thickness from less than 1,200 feet in areas of granitic basement-rock highs to approximately 2,000 feet. The rocks at the surface within the site are Mississippian and Pennsylvanian age, while older rock units are only encountered in the subsurface. The regional dip of beds is toward the west and northwest at between 15 to 25 feet per mile. Minor folding and faulting cause local variations to the regional dip (Reed et al., 1955; McKnight and Fisher, 1970; Luza, 1986; Christenson et al., 1990; ODEQ, 2006).

The major structural features in the site area are the Miami Trough and associated faults, the Bendelari Monocline, and the Rialto Basin. A structural high area also exists in the Douthat area, where older strata are present at the surface. The Miami Trough is a narrow trough, syncline, or graben-type structural feature. The trough extends from the west of Miami towards the north-northeast, west of Commerce and Cardin, and continues into Cherokee County, Kansas. The Miami Trough varies in width between 300 and 2,000 feet, with an average width of 1,000 feet. Vertical displacement along faults associated with the trough can range up to 300 feet. The Bendelari Monocline extends in a southeast-to-northwest direction from near Picher up into Kansas. Strata dip to the northeast along the Bendelari Monocline. The Rialto Basin is a basin-like or synclinal feature that is approximately 1 mile long by one-quarter mile wide. The Rialto Basin trends east-west and is located in the northern portion of Section 29, Township 29N, Range 23E, just south of E30 Road. The major structural features are tectonic in origin, while the smaller features, such as the Rialto Basin, are possibly related to dissolution and subsidence along deep-seated fractures (Reed et al., 1955; McKnight and Fisher, 1970; Luza, 1986; Christenson et al., 1990; ODEQ, 2006).

The stratigraphy for the site is described in the following paragraphs. A stratigraphic column is provided on **Figure 3-4**. A geologic cross-section, constructed along the general direction of dip, is provided on **Figure 3-5**. The location of the cross-section is shown on **Figure 3-6**. This cross-section was constructed from available deep Roubidoux well cuttings logs available in Reed et al., 1955, and ODEQ 2006 and supplemented by geologic data and geophysical logs obtained from other references (McKnight and Fisher, 1970; Christenson et al., 1991; and ODEQ, 2006). Interpretation of faulting along the Miami Trough is based on the cross-section provided in Stanley and Luza, 2006. The cross-section on **Figure 3-5** is general in nature as a result of the varying log descriptions and data used in its construction, but is intended to show the overall stratigraphic relationships of the geologic units described below, as well as limited hydrogeologic and groundwater chemistry information available for the site.

### 3.3.1 Precambrian

Precambrian granite is the oldest strata encountered in the subsurface at the site. A number of wells and test holes in Ottawa County and in mining areas of Cherokee County, Kansas, have been drilled down to the Precambrian granite. The granite is generally encountered at depths ranging between approximately 1,000 and 2,000 feet bgs in the mining area. However, in several test holes west of Commerce near the Neosho River, the granite was encountered at depths as shallow as 300 feet. Older Paleozoic strata are not encountered in test holes where the Precambrian highs occur. Logging data from the wells and test holes indicate that the Precambrian granite has a highly irregular surface. The granite is encountered at relatively shallow depth in some locations and not encountered in deeper holes drilled nearby (Reed et al., 1955; McKnight and Fisher, 1970).

### 3.3.2 Cambrian – Lamotte Sandstone, Bonterre Dolomite, Potosi-Eminence Dolomites

Cambrian age strata have only been encountered in deep holes drilled at the site. As previously stated, these formations are not present in areas where the Precambrian highs are encountered. The Cambrian age units are, from oldest to youngest, the Lamotte Sandstone, Bonterre Dolomite, and Potosi-Eminence Dolomites. The Lamotte Sandstone is a mixture of sandstone, siltstone, and shale with a thickness of between 0 and 50 feet. The Bonterre Dolomite is a sandy dolomite also containing some chert, oolites, and shale. In some areas, the base is marked by a 20- to 40-foot-thick sand bed. The thickness ranges between 0 and 180 feet. The Potosi-Eminence Dolomites (typically undivided in the literature) are cherty dolomites containing some oolites, minor amounts of sand, and some shale. The thickness ranges between 0 and 160 feet (Reed et al., 1955; Christenson et al., 1990; McKnight and Fisher, 1970).

### 3.3.3 Ordovician – Gunter Sandstone, Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, and Cotter Dolomite

Ordovician age strata have only been encountered in the subsurface in the site area. Prior to impoundment of Grand Lake O' The Cherokees, there were a few outcrops of the Cotter Dolomite present along the Neosho River in southern Ottawa County. The Ordovician age units are, from oldest to youngest, the Gunter Sandstone Member of the Van Buren Formation, Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, and the Cotter Dolomite (Reed et al., 1955; McKnight and Fisher, 1970). These geologic units together comprise the Roubidoux aquifer in northeastern Oklahoma (Christenson, 1995).

The Gunter Sandstone Member is a sandstone and sandy dolomite that is up to 40 feet thick. The Gasconade Dolomite is a cherty dolomite and sandy dolomite with sandstone layers. Some references include the Gunter Sandstone as the basal member of the Gasconade Dolomite, and the combined thickness is reported as being between 0 and 350 feet thick with an average of 230 feet. The Roubidoux Formation is a cherty dolomite containing two or three sandstone layers in the middle and near the base. The Roubidoux in the area of the site ranges in thickness from 0 to 190 feet, and averages about 175 feet. The sandstone layers are typically between 15 and 30 feet thick. The Cotter and Jefferson City Dolomites are cherty dolomites with lenses of sandstone. The Jefferson City Dolomite contains between 10 and 50 percent chert and ranges in thickness between 270 and 340 feet thick. The Cotter

Dolomite contains some dolomitic limestone and shale and ranges in thickness between 140 and 180 feet thick. They are not differentiated in some wells in Ottawa County. The Swan Creek Sandstone Member is identified in some wells at the base of the Cotter Dolomite and is as much as 30 feet thick (Reed et al., 1955; McKnight and Fisher, 1970; Christenson et al., 1990; Christenson, 1995; ODEQ, 2006; OWRB, 1983c).

### 3.3.4 Devonian and Mississippian – Chattanooga Shale

The Chattanooga Shale, of Devonian and Mississippian age, overlies the Ordovician-age geologic units. The Chattanooga Shale is black, fissile, carbonaceous shale, and can contain thin sandstone lenses at or near the base in some areas. The maximum reported thickness for the Chattanooga Shale is 80 feet. In Ottawa County, thicknesses of up to approximately 30 feet are reported. Geologic logs indicate that the Chattanooga is about 10 feet thick in Miami, Oklahoma. The unit thins to the north and is mostly absent within the Picher Field. Where present within the mining area, the Chattanooga Shale is between 1 and 5 feet thick (Reed et al., 1955; McKnight and Fisher, 1970; ODEQ, 2006).

### 3.3.5 Mississippian – Compton Limestone, Northview Shale, Boone Formation, Quapaw Limestone, and Chester Series

In some locations within the mining field, the Compton Limestone and Northview Shale of Mississippian age overlie the Chattanooga Shale. The Compton Limestone is a shaley limestone that has a gradational contact with the overlying Northview Shale. The Northview Shale is a greenish-black or dull-blue shale. The combined thickness of these two units in Ottawa County is 30 feet or less. These units are noted on some logs for the mining area and not on others (Reed et al., 1955; McKnight and Fisher, 1970; Christenson et al., 1990; Christenson, 1995). ODEQ, as part of a drilling effort associated with the OU1 Roubidoux Groundwater Monitoring Program, notes the Northview Shale as a marker bed at the base of the Boone Formation on the logs for several wells installed as part of the program. The Northview Shale was noted on these logs with a thickness between 5 and 10 feet (ODEQ, 2006).

The Boone Formation is a sequence of cherty limestone strata that outcrops in the eastern half of the site. The Boone contains beds of bluish gray to light gray limestone and gray to white chert. Some of the limestone is fossiliferous. The percentages of limestone and chert vary, with some portions containing more chert than limestone. The Boone Formation also contains thin lenses of sandstone and shale and some dolomite. The formation varies in thickness between 350 and 400 feet at the site. The Boone Formation is the primary host rock of the lead (lead sulfide – galena) and zinc (zinc sulfide – sphalerite) ores and associated sulfide minerals in the Picher Field. The Boone Formation has been subdivided into seven members at the site (in order from oldest to youngest): St. Joe Limestone, Reeds Spring, Grand Falls Chert, Joplin, Short Creek Oolite, Baxter Springs, and the Moccasin Bend. The members were further subdivided into beds, given letter designations, by Fowler and Lyden (1932) and Fowler (1942). These beds are identified as B-H and J-R. The M bed was the primary focus of mining, with other ore bearing zones also occurring in the K, G, H, and E beds and as sheet ground deposits within the Grand Falls Chert Member. The member and bed divisions within the Boone Formation are shown on **Figure 3-4**. Deposition of the Boone Formation was interrupted on several occasions, and the formation was exposed to weathering processes. This weathering resulted in very porous and nonporous sequences,

and solution cavities within the Boone Formation in Ottawa County (Reed et al., 1955; McKnight and Fisher, 1970; Luza, 1986; Christenson et al., 1990; Christenson, 1995; ODEQ, 2006; OWRB, 1983d).

Several references refer to the Quapaw Limestone as the stratigraphic unit lying above the Boone Formation. The Quapaw Limestone is noted to occur in the eastern portions of the site. The unit is a gray, medium- to coarse-grained, crinoidal limestone. The Quapaw Limestone, where present, is up to 30 feet thick (McKnight and Fisher, 1970; Luza, 1986).

The Chester Series, composed of the Hindsville Limestone, Batesville Sandstone, and Fayetteville Shale (from oldest to youngest), overlie the Quapaw Limestone in eastern portions of the site and the Boone Formation in the remainder of the site. The Chester Series rock units have a combined thickness of up to approximately 200 feet, but in some areas of Ottawa County, it was eroded and partially to completely removed before deposition of the overlying strata. The Hindsville Limestone is a gray, dense limestone with minor amounts of chert and some interbedded sandstone and shale. The unit is the roof rock in many of the mine workings and was mined for lead and zinc ores in the mines near Commerce and in some mines in the eastern portion of the site near Lincolnville. The Hindsville Limestone has a gradational contact with the overlying Batesville Sandstone. The Batesville Sandstone is fine-grained sandstone that contains some interbedded limestone and shale. The upper formation in the Chester Series is the Fayetteville Shale. The Fayetteville Shale is marine shale containing some limey portions, limestone beds, and coal seams. The Fayetteville Shale is not present in the area of the site (Reed et al., 1955; McKnight and Fisher, 1970; ODEQ, 2006).

### 3.3.6 Pennsylvanian – Krebs Group

The Pennsylvanian aged Krebs Group overlies the Mississippian strata and outcrops at the surface in western Ottawa County and most of the site west of Quapaw. The Krebs Group is composed of the Hartshorne Formation, McAlester Shale, Savannah Shale, and Bluejacket Sandstone Member of the Boggy Formation (from oldest to youngest). The Krebs Group is also referred to as the Cherokee Shale and, as a whole, is composed of predominantly shales, with some sandstone, siltstone, limestone, and coal beds. The Krebs Group is up to 200 feet thick in Ottawa County. The Krebs Group caps the ore containing rocks over most of the site and also contains the sulfide minerals of iron, pyrite, and marcasite (Reed et al., 1955; McKnight and Fisher, 1970; ODEQ, 2006).

### 3.3.7 Quaternary Alluvium

The Quaternary aged alluvial deposits are materials deposited by streams during recent geologic time (the past 10,000 years). The Quaternary Alluvium is limited in extent to narrow areas along the flood plains of site streams. The deposits consist of clay to gravel materials, and are generally less than 30 feet thick (Reed et al., 1955; Stanley and Luza, 2006).

## 3.4 Site Hydrogeology

The Boone aquifer and Roubidoux aquifer are the two principal aquifers at the site. The Boone aquifer is made up of the Boone Formation. The Boone aquifer overlies the Roubidoux aquifer. The two aquifers are separated by the lower permeability strata within the Northview Shale, Compton Limestone, and Chattanooga Shale (which is absent or very

thin under a majority of the site). The Roubidoux aquifer is made up of the Cotter Dolomite, Jefferson City Dolomite, Roubidoux Formation, and the Gunter Sandstone Member of the Gasconade Dolomite (Reed et al., 1955; Christenson, 1995; ODEQ, 2006).

Groundwater is used as the main source of drinking water at the site and in Ottawa County. The Roubidoux aquifer is the primary source of drinking water supplied by municipalities and rural water districts in Ottawa County and is also used for industrial purposes. The Boone aquifer is used primarily for domestic and agricultural purposes in rural areas (Reed et al., 1955). Although specific uses of many of the Boone aquifer wells are not well documented, at least some of these wells belonging to rural residents are used as a source of drinking water. The OU4 RI included locating and identifying Boone aquifer wells within rural areas of OU4 that are used for supply of potable water. Homeowners of all rural residences within OU4 were contacted to determine the source of potable water to the residence. Thirteen domestic wells completed in the Boone aquifer were identified during the OU4 RI (AATA, 2005). The locations of the 13 wells are shown on **Figure 3-7**. Most of the wells are located in the east and southeast portion of the site. Two wells are located in the southwest corner of the site near Commerce. All of the wells are located away from the primary mining areas of the site and areas where source material injection is likely to occur. Use of the Boone aquifer as a groundwater source is expected to continue in the rural areas that are away from the primary mining areas.

### 3.4.1 Boone Aquifer

The Boone aquifer is the upper or shallow aquifer at the site. The Boone aquifer is considered a karst aquifer. In outcrop areas, the Boone Formation is characterized by karst features such as caves and solution openings, sinkholes, disappearing streams, and springs. Groundwater in the aquifer occurs due to secondary permeability within fractures, solution openings, and along bedding planes and erosional unconformities within the Boone Formation. These features are localized both vertically and horizontally as a result of the geologic processes that were active during the deposition of the Boone Formation and the structural history of the region. As a result of the heterogeneous distribution of permeability within the aquifer, the occurrence and availability of groundwater within the Boone aquifer varies widely (Reed et al., 1955; Osborn, 2001).

Recharge to the Boone aquifer occurs primarily as direct precipitation in areas where the Boone Formation crops out in Southwest Missouri, Northwest Arkansas, Southeast Kansas, and Northeast Oklahoma. The Boone Formation crops out in eastern portions of the site. The aquifer also receives some recharge from streams that flow over the outcrop of the Boone Formation and from disappearing streams. Within the mining area, the Boone aquifer also receives some recharge directly through abandoned mine shafts, mine collapses, and open exploratory boreholes. Groundwater discharges through springs and as base flow to streams and through pumping at wells. Where the underlying confining units are absent or very thin, such as within the mining area, the potential exists that groundwater migrates downward to the underlying Roubidoux aquifer (discussed further in **Section 3.4.4**). The karst features of the Boone aquifer result in rapid recharge and groundwater flow rates, and water levels and discharge to springs and streams respond rapidly to rainfall. However, the same features also make the aquifer susceptible to contamination from surface sources (Reed et al., 1955; Osborn, 2001).

The aquifer is unconfined in outcrop areas and confined where the Krebs Group overlies the Boone Formation. Groundwater occurs under both conditions at the site. Regionally, groundwater flows in the Boone aquifer down-dip towards the west and northwest. In outcrop areas, where the aquifer is unconfined, groundwater also flows down-slope towards springs and streams (Reed et al., 1955; Osborn, 2001).

Aquifer properties of the Boone aquifer vary widely as a result of the heterogeneous nature and distribution of porosity and permeability within the Boone Formation. Pumping test data on the aquifer are also limited. Portions of the aquifer that are competent rock lacking fractures and solution openings are impermeable. In the mining area, where the formation is highly fractured, the aquifer is capable of producing large quantities of water. Estimates of aquifer properties for the Boone aquifer available from literature references are provided in **Table 3-1**. Wells completed in the aquifer can yield from less than 1 gallon per minute (gpm) to over 100 gpm (Reed et al., 1955; Osborn, 2001).

During the period of active mining, dewatering of the Boone aquifer was required to maintain access to the mine workings. The large groundwater yields encountered in the Picher Field are probably the result of the geologic processes that resulted in enhancing the porosity of the rock. These same processes also resulted in the deposition of the ore deposits in the fractures and solution openings in the rock by mineral-laden groundwater that ascended from deeper in the subsurface. Water was typically extracted from the mine workings by channeling the water to the shafts, where the water was pumped out. The amount of pumping varied with time and the depths of mining. Withdrawals of 13 million gallons per day (mgd) were reported during the 1930s, increasing to approximately 14 mgd during World War II, and then decreasing to 9 mgd after the war as the lower grade ore deposits in the lower mine workings were abandoned. Individual well yields up to 5,000 gpm were documented within the mining area. Outside of the mining area, lower well yields are more typical of the Boone aquifer. Mining-related withdrawals of groundwater from the Boone aquifer ceased in the mid-1960s when the major mining operations ceased (Reed et al., 1955; McKnight and Fisher, 1970; OWRB, 1983d; Luza, 1986).

Groundwater in the Boone aquifer is a calcium-bicarbonate type. TDS are typically less than 300 mg/L in areas where the Boone Formation crops out. TDS increases to greater than 500 mg/L in confined portions of the aquifer. Groundwater quality is generally good outside of the mining area. Groundwater quality deteriorates towards the western boundary of the aquifer, where the aquifer mixes with saline waters from the Western Interior Plains confining system. The groundwater is a sodium-chloride type along the western boundary with increased concentrations of TDS, chloride, and sulfate (Reed et al., 1955; Osborn, 2001; Imes and Emmett, 1994).

The Boone aquifer is classified by the OWRB as a minor groundwater basin (the average basin-wide yield from wells is less than 50 gpm). Regionally, the Boone aquifer is used primarily for domestic and agricultural purposes, but there are some uses for municipal and industrial supply (Osborn, 2001). The Boone aquifer meets the definition of an USDW in 40 CFR 146.3, and no portion of the aquifer has been exempted under 40 CFR 146.4. The State of Oklahoma has not restricted the use of the Boone aquifer at the site. However, ODEQ has special well construction methods required when completing a well through the Boone Formation and into the underlying Roubidoux aquifer within the boundary of the site (Title 785 Oklahoma Administrative Code, Chapter 45, Appendix H). Additionally, the ROD

states in Section 19.2.6 that IC will be a part of the OU4 remedy, including restricting future uses of groundwater from the Boone aquifer for potable or domestic supply that is affected with site-related contaminants above the remedial goals. The responsible organization for this IC will be ODEQ.

### 3.4.2 Confining Units

The Northview Shale, Compton Limestone, and Chattanooga Shale are the confining units present beneath the Boone aquifer, and separate it from the geologic strata that comprise the Roubidoux aquifer. Many of the logs from the mining era do not show the Chattanooga Shale as present in the area of the site, but its presence is noted on some logs for deep wells in the area and on deep well logs going farther south in Ottawa County (Reed et al., 1955). ODEQ installed five wells into the Roubidoux aquifer as part of work related to OU1. ODEQ noted the presence of the Northview Shale with a thickness of up to 10 feet at depths between 375 feet and 468 feet bgs across the site. ODEQ noted that it represented a good marker bed at the base of the Boone Formation (ODEQ, 2006).

The absence of the Chattanooga Shale in the Picher Field is noted as one of the primary geologic factors that lead to the deposition of the sulfide ores within the Boone Formation. Highly mineralized waters from deeper depths ascended along deep fractures associated with structural bodies, such as the Miami Trough, until the confining units of the Krebs Group were encountered. The mineralized waters then spread horizontally into the Boone Formation, where the sulfide minerals were deposited in the solution cavities and porous spaces within the rock (McKnight and Fisher, 1970; ODEQ, 2006).

### 3.4.3 Roubidoux Aquifer

The Roubidoux aquifer is the lower or deep aquifer at the site. The Roubidoux aquifer is the primary water supply used within Ottawa County. The geologic units that comprise the Roubidoux aquifer are the Cotter and Jefferson City Dolomites, the Roubidoux Formation, and the Gasconade Dolomite (and particularly the Gunter Sandstone Member). Wells completed in the Roubidoux aquifer are typically open borehole construction that is uncased from the top of the Cotter Dolomite to total depth. Groundwater is produced from fractures and solution cavities within the dolomitic intervals and from porous zones and fractures within the sand-bearing layers of each unit. Groundwater is primarily produced from two to three sandstone layers that are 15 to 20 feet thick in the Roubidoux Formation. The degree to which the other formations produce water is not well understood but believed to be much less than the water obtained from the Roubidoux Formation. ODEQ reported obtaining significant amounts of water up to 300 gpm from sandstone layers within the Cotter and Jefferson City Dolomites when drilling the Commerce #5 well. Wells at the site have been drilled as deep as 1,790 feet, but most deep wells are completed to depths of 1,400 feet or less. The Roubidoux Formation itself is encountered at depths between approximately 800 feet and 1,000 feet below bgs at the site (Reed et al., 1955; OWRB, 1983d; Christenson et al., 1990; Christenson, 1995; ODEQ, 2006).

Recharge to the Roubidoux aquifer occurs primarily through direct precipitation and from seepage in streams that flow over the outcrops of the geologic units that comprise the aquifer. Outcrop areas for the formations making up the Roubidoux aquifer are fairly limited near Ottawa County. The primary outcrop areas are located 50 to 100 miles east of Ottawa County in the central part of the Ozark Mountains in south-central Missouri and

north-central Arkansas. These areas are at higher elevation and, regionally, the deep aquifer dips westward and into the subsurface from these recharge areas towards Ottawa County. Discharge from the aquifer within Ottawa County occurs through pumping at wells (Reed et al., 1955).

Groundwater in the Roubidoux aquifer in Ottawa County occurs under confined conditions. Before 1915, most wells completed into the Roubidoux aquifer in Ottawa County flowed at the surface (the wells were artesian). These wells reportedly stopped flowing during the period when mining production increased rapidly between 1916 and 1920. During this period, the population of the area increased significantly, increasing the need for municipal supplies of water. Also, expanding milling operations required vast amounts of water, and deep wells were drilled to supplement water supplies obtained from surface sources and water pumped from the mine workings (Reed et al., 1955).

Lowering of the potentiometric surface of the Roubidoux aquifer has been documented over the past 100 years. By the late 1930s, water levels were about 100 feet bgs, and by 1942, the water levels had declined to between 200 and 300 feet bgs. By 1944, groundwater withdrawal from the Roubidoux aquifer was approximately 2.25 to 2.5 mgd. B.F. Goodrich Company completed a tire manufacturing plant in Miami in 1944. Six wells were installed into the Roubidoux aquifer to supply water to the plant. Groundwater withdrawal from the aquifer increased significantly at that time and was approximately 4 mgd by 1948. The USGS estimated that 4.8 mgd were withdrawn from the Roubidoux aquifer by 1981, with 90 percent of the water withdrawn in Ottawa County. Seventy-five percent of the water withdrawn in Ottawa County was pumped by the City of Miami and B. F. Goodrich Company. The B. F. Goodrich Company plant closed in 1986, and water withdrawals from the aquifer decreased at that time (Reed et al., 1955; Christenson et al., 1990). A large cone-of-depression centered on Miami exists in the aquifer. Drawdown in the aquifer had reached as much as approximately 440 feet bgs between 1972 and 1986. The water levels recovered approximately 100 feet through 1993 after the B.F. Goodrich Company plant shut down (Christenson et al., 1990; Christenson, 1995; ODEQ, 2006). The potentiometric surface of the Roubidoux aquifer, as documented by ODEQ in 2008, is shown on **Figure 3-8**.

Aquifer properties of the Roubidoux aquifer vary as a result of the heterogeneous nature and distribution of porosity and permeability within the geologic units comprising the aquifer. A pump test was performed on three of the wells installed by B.F. Goodrich Company during 1944. The first test lasted over 8 days, while the other two tests were approximately 46 and 48 hours long. Water levels were collected from observation (non-pumping) wells before, during, and after the two shorter tests. Water level data were collected from an observation well only during the later stages of the 8-day test. Most of the aquifer properties reported for Ottawa County are based on different analyses performed on the data obtained from these tests. Estimates of aquifer properties for the Roubidoux aquifer available from literature references are provided in **Table 3-1**. Wells completed in the aquifer typically yield from 100 to over 1,000 gpm (Reed et al., 1955; OWRB, 1983d; Christenson et al., 1990).

Groundwater quality within the Roubidoux aquifer in Ottawa County varies from east to west. In the eastern part of the county, the water is typically a calcium magnesium bicarbonate type and is moderately hard to hard. TDS concentrations are typically less than 200 mg/L. The concentrations of sodium, chloride, and sulfate are low. The water

chemistry in the aquifer transitions through the central portion of the county to a sodium chloride-type chemistry in the western portion of the county. TDS concentrations increase to greater than 800 mg/L. This same transition also occurs with depth in the aquifer across the county. It was also noted in a USGS study (1990) that sodium and chloride concentrations increase across the county to the point that water in the westernmost part is unsuitable for most uses. Few wells, if any, are completed in the Roubidoux west of Range 20 East (Reed et al., 1955; Christenson et al., 1990; Christenson, 1995).

### 3.4.4 Interconnection of the Boone and Roubidoux Aquifers

The Boone aquifer is present above the Roubidoux aquifer. The two aquifers are generally separated by the presence of the confining units: the Chattanooga Shale, Compton Limestone, and Northview Shale. The Chattanooga Shale is absent throughout most of the Picher Field. Where present, the Northview Shale has a thickness of 10 feet or less within the Picher Field. In much of the area, the Boone aquifer is in direct contact with the upper geologic unit of the Roubidoux aquifer, the Cotter Dolomite. Groundwater present in the abandoned mine workings is known to be affected with high concentrations of metals and sulfate. The groundwater present in the abandoned mine workings is, therefore, considered to be a potential source of contamination to the Roubidoux aquifer (Christenson, 1995).

Historically, the Roubidoux had a higher hydraulic head than the Boone. However, as a result of groundwater withdrawals, the hydraulic head in the Roubidoux has been lowered several hundred feet. Because the groundwater levels in the Roubidoux aquifer are several hundred feet lower than those in the Boone aquifer and the mine workings, there is a potential for downward movement of groundwater from the Boone into the Roubidoux. To date, the data collected regarding the connection between the Boone and Roubidoux aquifers indicate that the primary pathway for groundwater and contaminants to migrate into the Roubidoux aquifer from the Boone aquifer and mine workings has been through abandoned wells, wells that have faulty casings and/or poor seals across the Boone Formation, and through unplugged abandoned boreholes. Municipal water supply wells completed in the Roubidoux aquifer in Commerce, Picher, and Quapaw have been affected by mine water and plugged. The OU1 RA and Roubidoux Groundwater Monitoring Program included the plugging of numerous wells completed in the Roubidoux aquifer to reduce the potential for contaminants to migrate from the mine workings into the Roubidoux aquifer (CH2M HILL, 2008; ODEQ, 2006).

Lowering of the potentiometric surface of the Roubidoux aquifer has been documented over the past 100 years as a result of pumping in Ottawa County, with a 400-foot decline from 1905 to 1947 and an additional 50-foot decline between 1947 and 1983 (Reed et al., 1955; OWRB, 1983d). Despite the increasing potentiometric difference between the Boone and Roubidoux aquifers, there has been no evidence to suggest that leakage from the Boone downward to the Roubidoux is a regionally important source of discharge from the Boone or recharge to the Roubidoux. Open drill holes or faulty well casings and poor wells seals have been determined to present the greatest contamination hazard to water supplies in the Roubidoux aquifer (OWRB, 1983d; Christenson et al., 1990; Christenson, 1995).

Numerous studies have been performed to assess the potential impacts of mine water contamination on the Roubidoux aquifer. A core study was performed during the OU1 RI in 1982. Existing cores from the Cotter and Jefferson City Dolomites and the Roubidoux

Formation were visually examined and testing was performed to evaluate the potential for groundwater to migrate through these formations from the Boone to the Roubidoux aquifer. The visual inspection of the cores showed that minor fracturing was present, with most fractures containing secondary deposition of calcite, which tends to seal off the fractures to further groundwater movement. There were some open fractures noted. Permeability testing demonstrated low permeability values of $3.1 \times 10^{-7}$ centimeters per second (cm/s) and $9.6 \times 10^{-9}$ cm/s, respectively, for the Cotter Dolomite and Jefferson City Dolomite. Testing was also done where mine water was mixed with Roubidoux aquifer water and then introduced into reconstructed cores of the Roubidoux Formation. The testing indicated that geochemical reactions occurred that reduced the permeability of the Roubidoux Formation (Encon Environs Control Services, Inc. [Encon], 1982). The data from this work indicates limited potential for direct migration of groundwater and mine water into the Roubidoux through the intervening strata. Also, mine water, once it does enter into the Roubidoux aquifer, would tend to react in such a way that a reduction in overall permeability of the Roubidoux aquifer material would occur. The OU1 RI concluded that the most likely route for mine water contamination to enter the Roubidoux aquifer was through faulty well casings of both active and inactive Roubidoux wells (OWRB, 1983d).

In the early 1990s, the USGS studied contamination in wells that were completed in the Roubidoux aquifer in the area of the Picher Field. Wells inside and outside of the mining field were sampled to allow for comparison, including 10 public supply wells within the mining field area. The study concluded that pH, sulfate, alkalinity, bicarbonate, magnesium, and iron concentrations consistently indicated that 7 of the 10 wells were contaminated by mining-related contaminants. The specific affected wells included Cardin (i.e., Cardin 1), Commerce 1, Commerce 3, Picher 2, Picher 3, Picher 4, and Quapaw 2. The other wells included in the study that were not affected included Commerce 2, Commerce 4, and Quapaw 4 (Christenson, 1995).

Analytical testing for tritium was also performed. The presence of tritium in groundwater is considered an indication of water that entered the aquifer or well after 1952 (when atmospheric testing of hydrogen bombs began). It was assumed that, based on the distance to recharge areas and groundwater flow rates, groundwater within the Roubidoux aquifer in Ottawa County would not naturally contain tritium. Groundwater within the Boone aquifer and mine workings would contain tritium as a result of more recent recharge. Tritium was present in six of the wells (Cardin 1, Commerce 1, Commerce 3, Picher 2, Picher 3, and Quapaw 2), indicating that some component of the water in these wells was recent (post-1952) water that most likely migrated from the Boone aquifer and/or mine workings into the wells (Christenson, 1995).

The USGS concluded that contaminated mine water from the Boone aquifer and mine workings was entering the Roubidoux aquifer through several possible routes primarily associated with well failure. The potential paths for contaminated mine water to reach the Roubidoux aquifer included discontinuities in well casings; water migrating in the annular space between the casing and the well bore and entering the well at the foot of the casing; water flowing downward through the geologic strata and flowing laterally into the well; and some combination of the above scenarios (Christenson, 1995).

ODEQ and USGS have performed sampling of the Roubidoux aquifer as part of Roubidoux Groundwater Monitoring Program for OU1 since the late 1980s. The overall purpose of the

program has been to assess potential impacts of mine water contamination on the Roubidoux aquifer. The work has proceeded in several phases and sampling efforts have been modified as the work has progressed with time (ODEQ, 2006).

Background concentrations for the Roubidoux aquifer were measured at 10 wells located outside of the mining area. Based on this sampling, sulfate, zinc, and iron were identified as indicator parameters of potential mine water impacts in the Roubidoux aquifer. These three constituents were selected based on large differences in the concentrations in Roubidoux groundwater as compared with mine water. Tolerance limits were established for these three constituents as indicators of concentrations exceeding background values for the Roubidoux and potential impact from mine water contamination (ODEQ, 2006).

The Roubidoux Groundwater Monitoring Program has included continued sampling of Roubidoux wells at and near the site to assess potential mine water impacts in the Roubidoux aquifer. Construction techniques of the Roubidoux wells resulted in large open-borehole portions of the wells remaining open to the Cotter and Jefferson City Dolomites. Discrete sampling of the portion of the wells open to the Roubidoux Formation through the installation of inflatable packers and/or sleeves was performed, sealing off the geologic units above the Roubidoux Formation, including the Cotter and Jefferson City Dolomites. ODEQ also installed five wells into the Roubidoux aquifer using modern well drilling and construction techniques that sealed off the Boone aquifer prior to drilling into the Roubidoux aquifer, thus sealing off the Boone and isolating it from the Roubidoux. These wells were installed for multiple purposes including 1) to monitor the Roubidoux aquifer, 2) to assess the ability to successfully install a Roubidoux supply well within the mining field, 3) to provide water supply wells if good quality water was encountered, and 4) to evaluate whether or not wells producing large volumes of water would induce drawdown and migration of contaminated groundwater from the Boone aquifer and mine workings into the Roubidoux aquifer (ODEQ, 2006).

ODEQ concluded in 2006 that the Roubidoux Groundwater Monitoring Program demonstrated that the Roubidoux aquifer was affected at least locally by contaminated mine water at a number of wells. This conclusion was based on data that showed indicator parameter concentrations exceeded tolerance limits. However, ODEQ noted that no primary drinking water standards (MCLs) had been exceeded in the Roubidoux and that the aquifer still was a usable source of drinking water. The mechanism of contaminant transport into the Roubidoux aquifer, whether through faulty and/or unplugged wells, through natural conduits, such as fractures in the rock, or through a combination of the two, was undetermined. The ODEQ report notes that there is evidence that suggests the Boone and Roubidoux aquifers are not hydraulically connected. ODEQ cited the core testing data reported in the OU1 RI by the OWRB. ODEQ also noted the fact that a potentiometric surface high exists in the Boone aquifer in the area of the mining field and just north of the large cone-of-depression in the potentiometric surface in the Roubidoux centered on Miami. ODEQ states that if large-scale downward groundwater leakage from the Boone to the Roubidoux aquifer were occurring, it would be expected that a potentiometric surface low in the Boone aquifer would develop over the cone-of-depression in the Roubidoux aquifer (ODEQ, 2006).

EPA tasked CH2M HILL to perform statistical trend analyses on data collected through the Roubidoux Groundwater Monitoring Program. Trend evaluations for 2003 through 2006

data indicated very little evidence of upward or downward trends for chemical parameter concentrations overall. Five percent of the cases examined demonstrated statistically significant increasing or decreasing concentration trends. Five percent is also the number of significant trends that would be expected from a random data set, which is an indication that the aquifer is stable. Statistically increasing trends were all associated with sulfate concentrations in three wells. The sulfate concentrations in these three wells are well below the secondary maximum contaminant level (SMCL; 250 mg/L) at concentrations of 20 mg/L or less. There were no aquifer-wide issues relative to the primary drinking water standards (MCLs) noted, although iron concentrations in one well were elevated above the SMCL. SMCLs are non-enforceable guidelines for chemicals that can cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The conclusion of this assessment was that groundwater quality in the Roubidoux aquifer appeared to be relatively stable (CH2M HILL, 2007b).

### 3.4.5 Public Water Systems near the Site

A public water system is defined at 40 CFR 141.2 as any system that provides water to the public for human consumption, if the system has at least 15 service connections or regularly serves 25 people for at least 60 days annually. Public water systems are regulated by EPA under the Safe Drinking Water Act. The Cities of Commerce, Miami, Quapaw, the Quapaw Tribe and Ottawa County Rural Water Districts 4 and 7 operate public water systems in the area of the site that obtain their water supplies from groundwater. Each public water system obtains water from wells completed in the Roubidoux aquifer. The locations of the water supply wells operated by the active public water systems are shown on **Figure 3-9**.

SECTION 4

# Previous Pilot Studies

EPA began a review of potential technologies for injecting chat into the mine workings at the site in 2004. This review led to the field implementation of a chat injection pilot study at the Montreal Mine. Pilot study activities were continued at the Tulsa Mine to evaluate the injection of fine tailings resulting from the chat washing process. EPA completed a third pilot study in September 2005 with the injection of chat into the Craig Mine. The results of the pilot studies were positive, indicating that this technology should be considered as a remedial alternative; however, based on these studies, it was determined that longer-term sampling might be necessary to fully understand the chemical fate of the injected materials.

The pilot study approach was refined to evaluate the direct injection of fine tailings from an active chat washing operation. This approach was first evaluated at the Tulsa Mine (Atlas Pile) and later expanded to include the LaSalle Mine (Ottawa Pile) and the Swift Mine and Moore #2 Mine (Sooner Chat Pile).

In addition to the pilot studies conducted by EPA, other pilot studies and projects were conducted by the OCC and ODEQ. The various pilot studies are summarized in the following sections. The locations for the EPA and OCC/ODEQ pilot studies are provided on **Figure 4-1**. A timeline for the various pilot studies is provided on **Figure 4-2**. Each of these areas was included in the monitoring program performed as part of the HCS to assist with understanding the impacts on mine water chemistry when source materials are injected into the mine workings.

## 4.1 State of Oklahoma Projects – OCC and ODEQ

Several pilot studies have been conducted by the OCC and ODEQ. These include the McNeely-Green Demonstration Project, West Commerce Abandoned Mine Land Reclamation Project, and Howerton Property pilot study. The timeline for implementation and completion of the first two studies are shown on **Figure 4-2** and described below. Although the Howerton pilot study was initiated by the installation of several injection borings, the injection portion of the project was not performed because of funding issues. As such, it is not included on **Figure 4-2**.

### 4.1.1 McNeely-Green Demonstration Project

The McNeely-Green Demonstration Project involved the reclamation of approximately 52 acres of land covered with chat to an average depth of 1.5 feet. Two open mine shafts and two large subsidence features were also addressed. The subsidence features were related to the collapse of the underground mine workings. Activities at the site included removal of the chat and reuse of approximately 82,000 CY of the material as backfill that was placed into the two subsidence features. Reclamation activities also included filling and sealing the mine shafts, burying onsite debris, construction of three ponds, and providing a clay cap to cover the chat filled subsidence features. The entire 52 acres was re-vegetated with ryegrass,

fescue, and clover following completion of the project (ODEQ, 2005). **Figure 4-3** shows the site after the project was completed. The outlines of the two chat bases are also shown.

Prior to backfilling, water samples were collected from surface water present in the subsidence features, groundwater present in an adjacent mine shaft, and a nearby well completed in the Roubidoux aquifer. Samples were analyzed for general water chemistry, total metals, and dissolved (filtered) metals. Results from these samples were used for comparison with samples collected following completion of the backfilling activities (ODEQ, 2005).

Following completion of backfilling operations, ODEQ installed a monitoring well in the chat-filled subsidence feature that had contained standing water. ODEQ staff sampled the well, along with water in the mine shaft and nearby Roubidoux well, several times over a period of 1 year to evaluate water level fluctuations and variations in leachate concentrations. Results were compared with those collected during the initial stages of the project (ODEQ, 2005).

Results suggested that the concentration trends for several metals and water quality parameters initially increased in samples collected from the monitoring well. Increases were up to an order of magnitude for some analytes. However, monitoring during the subsequent 12-month period suggested a gradual decline for most of these parameters (ODEQ, 2005).

The placement of an impermeable cover (clay cap) served to limit infiltration within the backfill. Compared with data collected from surface water in the subsidence feature prior to backfilling, the DO concentration decreased. Oxidation of sulfides and development of acidic conditions at the McNeely-Green site was not expected because of the low DO concentration in water samples collected from the monitoring well (ODEQ, 2005).

### 4.1.2 West Commerce Abandoned Mine Land Reclamation Project

This was a project bid by the State of Oklahoma in November 2005 and awarded in January 2006. The project was implemented through the OCC at the Southern Queen Mine site located west of Commerce. The project began in late 2006 and finished in early 2007 (Sharp, 2009, personal communication). **Figure 4-4** shows the project site.

According to the solicitation documents, the scope called for an estimated 32,000 CY of chat to be mixed with water and pumped using slurry pumps into the boreholes. However, information provided by the OCC suggests that a total volume of 10,000 CY was successfully injected into the mine workings. Chat was injected through two boreholes installed during the project. Chat slurries were pumped with the pipe extending down to the top of the mine room with the intent of providing enough slurry velocity and pressure such that the solids would spread out into the cavern. Existing boreholes at the site were used to supply water and provide monitoring points for sonar deployment during the injection process. Sonar was used to evaluate the size of the mine room and document the progress of chat injection (Sharp, 2009, personal communication).

Borings 3, 4, and 5 were installed during the design phase and were constructed as approximately 6-inch-diameter boreholes cased with 6-inch polyvinyl chloride pipe. All borings at this project site were surveyed in 2008 (CH2M HILL, 2009a). ODEQ monitors the

project site by performing semi-annual sampling of boring OCC-3. A pressure transducer was installed in 2008 in boring OCC-4 (CH2M HILL, 2009b).

### 4.1.3 Howerton Property

A source material pilot study was planned for this location. Several borings were drilled and completed into the underground mine workings. **Figure 4-5** shows the project site. However, funding for this OCC-lead project was transferred to the voluntary relocation efforts being conducted by the State of Oklahoma through LICRAT. The project has not been completed, but the OCC may complete this project in the future if funding becomes available. All borings at this project site were surveyed in 2008, and a pressure transducer was installed in 2008 in boring EB3 (CH2M HILL, 2009a and 2009b).

## 4.2 EPA Pilot Studies and Monitoring Program

The EPA pilot studies were performed by Weston Solutions, Inc. (Weston), and included contracted support for field operations by Northern Improvements Company. The work was initiated in 2004 and consisted of the injection of chat and chat fines into underground mine workings at the Craig, LaSalle, Montreal and Tulsa Mine sites (Weston, 2005 and 2006). During the pilot studies, effects of the injection on mine water quality were monitored by collecting pre-, and interim-injection water quality data. Some post-injection sampling events were completed by Weston, after which CH2M HILL started performing semi-annual sampling. A summary of each site's background and the pilot test activities and monitoring are provided below.

### 4.2.1 Montreal Mine

This pilot study included both components of chat placement and containment that were conducted in 2004 and 2005, respectively. Activities included drilling six borings into the flooded mine workings, conducting a sonar survey to evaluate the size of the mine room in the vicinity of the borings, and chat injection using a variety of techniques. Approximately 23,700 tons (11,262 CY) of chat was injected by gravity feed, water-assisted gravity feed, and reverse augering methods. Placement of more than 60 CY per hour of chat was achievable when adding 75 gpm of water to assist the flow of chat into an 8-inch-diameter conductor pipe. Documented rates were lower for methods that included less water or none at all (Weston, 2005 and 2006).

The mine water was sampled before, during, and after the injection to evaluate the impact of the injection on the mine water. With some exceptions, samples were analyzed for chlorides, sulfates, fluoride, hardness, cadmium, iron, lead, and zinc. Samples were not field-filtered and included field-preserved and non-preserved samples. Analytical results confirmed that while concentrations of cadmium, lead, and zinc initially increased following the first injections, they consistently decreased over the few months following cessation of injection. By 6 months, concentrations had decreased to levels at or below the pre-placement concentrations (Weston, 2006).

An additional 40,000 tons of chat was contained in an innovative trench system that formed the road base for a private ranch road located in a previously contaminated area on the site. The soils from the trench were used to provide cover for 35 acres of land (Weston, 2006).

Starting in 2007, mine water was sampled semi-annually following a consistent sampling program. All samples were submitted for laboratory analysis of TAL metals, hot acidity, alkalinity, chloride, fluoride, hardness, nitrate, sulfate, and TDS. The samples collected for TAL metals analysis were field-filtered using a 0.45-micron filter prior to placement in the preserved sample container (CH2M HILL, 2009c and 2009d). The data collected from these sampling efforts are incorporated into the HCS and discussed further in **Section 7** and **Section 10**. All borings at this project site were surveyed in 2008, and a pressure transducer was installed in 2008 in boring RMB4 (CH2M HILL, 2009a and 2009b). **Figure 4-6** shows the project site.

### 4.2.2 Craig Mine

This pilot study focused on collecting additional information on the movement of metals from the chat into the mine water to evaluate the long-term protectiveness of the technology. A total of 6,827 CY of chat were placed in the mine workings over a period of 14 days in 2005. Injection rates were approximately 71 CY per hour based on the actual time of injection (Weston, 2006).

Before sampling, an evaluation of mine water stratification was performed and determined to be present. The mine water was sampled before, during, and after the injection to evaluate the impact of the injection on the mine water. Subsequent evaluations imply that most trace element concentrations had little or no change after the chat injections. However, the dissolved-phase concentrations for arsenic, cadmium, cobalt, iron, lead, manganese, nickel, selenium, and zinc increased. The principle factors controlling the concentrations of trace elements entering the groundwater after injection were the abundance and availability of those elements in the chat piles. Follow-on sampling (months after chat emplacement) was not performed at this site (Weston, 2006).

Starting in 2007, mine water was sampled semi-annually following a consistent sampling program. All samples were submitted for laboratory analysis of TAL metals, acidity, alkalinity, chloride, fluoride, hardness, nitrate, sulfate and TDS. The samples collected for TAL metals analysis were field-filtered using a 0.45-micron filter prior to placement in the preserved sample container (CH2M HILL, 2009c and 2009d). The data collected from these sampling efforts are incorporated into the HCS and discussed further in **Section 7** and **Section 10**. All borings at this project site were surveyed in 2008, and a pressure transducer was installed in 2008 in boring FCB3 (CH2M HILL, 2009a and 2009b). **Figure 4-7** shows the project site.

### 4.2.3 Tulsa Mine/Atlas Chat Pile

Two separate pilot studies were conducted at the Tulsa Mine. The first was conducted in December 2004 and the second from February through June 2006. The studies included the installation of three borings into the mine workings for the purpose of injection. Approximately 9,000 tons (5,430 CY) of washed fine tailings were injected during the initial pilot testing effort in 2004. The initial study suggested washed fine tailings could be injected at up to 200 tons (1,230 CY) per hour (Weston, 2006).

The second study was performed to assess the ability to inject washed fine tailings directly from the chat washing unit. Estimates for the injection rates from the second pilot study varied from 10 to 90 CY of washed fine tailings injected each day. Injection rates at the high

end of the range were estimated based upon production rates of the chat washing operations coupled with the estimated bulk density of the fines. Low-end values were based upon measured slurry injection rates and measurements of percent solids within the slurry (Weston, 2006). The reason for the discrepancy in injection rates was not determined.

The mine water was sampled before, during, and after the injection to evaluate the impact of the injection on the mine water. With some exceptions, samples were analyzed for chloride, sulfate, fluoride, hardness, cadmium, iron, lead, and zinc. Samples were not field-filtered and included field-preserved and non-preserved samples. The analytical results for most of the trace elements were greater in acid-preserved samples because of the dissolution of suspended solids (Weston, 2006).

With respect to the concentrations of cadmium, lead, and zinc in groundwater, results suggested that increases in the dissolved-phase concentrations could be anticipated after the initial injection of fines into the mine pool. However, subsequent sampling results demonstrated that concentrations decreased during the following 6-month period. The available literature (Weston, 2006) did not identify if the decrease was related to an influx of groundwater in conjunction with reduced leaching of the injected washed fine tailings (Weston, 2006).

Starting in 2007, mine water was sampled semi-annually following a consistent sampling program. All samples were submitted for laboratory analysis of TAL metals, acidity, alkalinity, chloride, fluoride, hardness, nitrate, sulfate and TDS. The samples collected for TAL metals analysis were field-filtered using a 0.45-micron filter prior to placement in the preserved sample container (CH2M HILL, 2009a and 2009e). The data collected from these sampling efforts are incorporated into the HCS and discussed further in **Section 7** and **Section 10**. All borings at this project site were surveyed in 2008, and a pressure transducer was installed in 2008 in boring TMB2 (CH2M HILL, 2009a and 2009b). **Figure 4-8** shows the project site.

### 4.2.4 Testing Performed as Part of the Pilot Study Activities

EPA performed various tests in conjunction with these pilot studies. Testing including pre-, post-, and follow-up analytical testing of the mine water, chemical and mineralogical testing of the injected materials, and a leaching test using a modified synthetic precipitation leaching procedure (SPLP). Geochemical modeling was also conducted (EPA, 2007).

Testing performed on the injected materials showed elevated concentrations of cadmium, iron, lead, and zinc, which was consistent with other studies. The injected materials were composed mostly of quartz, with minor amounts of dolomite (5 percent), sphalerite (2 percent), magnetite, and clay minerals (1 percent each). Weathered grains of pyrite, galena, and realgar were also present. Pyrite, sphalerite, galena, and realgar are the sulfide minerals of iron, zinc, lead, and arsenic, respectively. Exposure at the surface had tended to weather and oxidize the sulfide minerals in varying degrees to sulfates (EPA, 2007).

The modified SPLP test used mine water and chat or fine tailings to simulate the leaching effects that would occur once the chat was placed into the flooded mine workings. The results of the modified SPLP tests indicated increases in the concentrations of cadmium (0.4 to 0.7 mg/L), lead (up to 1.3 mg/L), and zinc (30 to 80 mg/L) (EPA, 2007).

Each pilot test included pre- and post-injection sampling of the mine water to assess the effects on mine water chemistry that resulted from injection of the source materials. Post-injection sampling was performed several days after injection had ceased. The results showed increases in the concentrations of cadmium, lead, and zinc in the mine water post-injection at each pilot study location. The largest concentration increases occurred for cadmium. These results were consistent with the SPLP testing, but the concentration increases were less than the results obtained from the SPLP test. Follow-up testing was completed at the Montreal and Tulsa Mines to assess the longer-term effects of injection on the mine water chemistry. Samples were collected at 3 and 9 months following injection at the Tulsa Mine and 6 months following injection at the Montreal Mine. This testing showed that the concentrations of cadmium, lead, and zinc decreased with time after injection occurred, with some of the concentrations returning almost to the pre-injection levels (EPA, 2007).

Geochemical modeling was performed to assess the geochemistry associated with the pilot test projects. The geochemical modeling indicated that the controlling factor with respect to metals entering the mine water as a result of injection was the abundance and availability of each metal within the material being injected. The model calculations showed that the primary geochemical reactions caused by the injection were the dissolution of sulfate salts produced during the weathering of the source materials (EPA, 2007).

### 4.2.5 LaSalle Mine/Ottawa Chat Pile

The LaSalle Mine project was different from previous pilot studies. The commercial chat processor working at this location, Bingham Sand and Gravel, Inc. (Bingham), worked with EPA to further assess the ability to inject the washed fine tailings feed directly from the chat washer into the mine workings. Installation of the injection equipment was completed by Bingham, who started injecting washed fine tailings as part of its standard operating procedure. No pre-injection monitoring of the mine water was performed at this location. Weston performed some oversight of the installation of two borings near the end of its work related to the pilot studies (Weston, 2006). One boring was used to extract water from the mine workings for use as a water supply to the chat washer, and the second boring was used as the injection point. Injection began at this location during the summer of 2006.

EPA began monitoring the mine water at the LaSalle Mine/Ottawa Chat Pile location in February 2007. A third boring was installed in May 2007. This boring was installed to extract mine water for use as a water supply. The existing extraction boring was pumping out washed fine tailings injected into the mine workings, which was resulting in failure of the pump. Continuous injection at this location continued through the summer of 2007, while some sporadic injection continued through April 2008. At that time, the chat washing equipment was moved to the Sooner Chat Pile for use in operations there. Records on the volume of material injected at the LaSalle Mine/Ottawa Chat Pile site were not maintained by Bingham.

Starting in 2007, mine water was sampled semi-annually following a consistent sampling program. All samples were submitted for laboratory analysis of TAL metals, acidity, alkalinity, chloride, fluoride, hardness, nitrate, sulfate and TDS. The samples collected for TAL metals analysis were field-filtered using a 0.45-micron filter prior to placement in the preserved sample container (CH2M HILL, 2009c and 2009d). The data collected from these

sampling efforts are incorporated into the HCS and discussed further in **Section 7** and **Section 10**. All borings at this project site were surveyed in 2008, and a pressure transducer was installed in 2008 in boring LMB3 (CH2M HILL, 2009a and 2009b). **Figure 4-9** shows the project site.

### 4.2.6 Swift Mine and Moore #2 Mine/Sooner Chat Pile Pilot Study (Ongoing)

Bingham is currently processing chat from the Sooner Chat Pile. The Sooner Chat Pile is the location of an ongoing pilot study involving the long-term injection of washed fine tailings into the mine workings. The processed chat from the Sooner Chat Pile is primarily used for aggregate in asphalt. Bingham's processing involves washing the chat to remove fines and passing the washed chat through a screen to grade out the sand-sized fraction from the gravel. The washed fine tailings come off the chat washer as a slurry in a water stream. The slurry is conveyed by gravity flow through 8-inch pipelines to the injection boring well heads. The injection borings penetrate into the flooded mine workings underlying the Sooner Chat Pile (the Swift and Moore #2 Mines). Water for the washing operations is extracted from several extraction wells that are also completed into the mine workings. The layout of the pilot study is provided on **Figure 4-10**. Work associated with the Sooner Chat Pile pilot study is documented in an operations report (CH2M HILL, 2010). The paragraphs below provide a brief summary of the pilot study.

Since May 2007, a total of nine injection borings have been installed (SMB1 through SMB9). However, as a result of various problems encountered during construction and injection operations, only six of the borings can currently be used for injection. SMB1 became obstructed shortly after installation. SMB2 was used for approximately 2 months until the underlying void space in the mine room was filled to capacity at that location. SMB4 was used for injection for a brief period, but is now used as a drain for overflow in the pond used to place washed fine tailings in when injection is not occurring. SMB6 has been used primarily to monitor the injection. The void space in the mine room under SMB6 was determined to be filled to the roof at the end of 2009. Borings SMB7, SMB8, and SMB9 were installed as replacement injection borings, but have been used to monitor the injection process instead. Water supply to the chat washers is provided from a network of four extraction wells installed into the mine workings. Two monitoring wells, BMW01 and BMW02, have been installed at the Sooner Chat Pile to monitor the groundwater in the Boone aquifer. As a result of problems encountered during drilling, BMW03 was installed as a piezometer but was plugged off and is no longer functional. As a result of borehole collapse during drilling and well installation, BMW04 was installed to a shallower depth within the Chester Group. Five monitor wells have also been installed into the base of the chat pile to monitor groundwater within the pile (CH2M HILL, 2010).

Injection of fines from the chat washing operations at the Sooner Chat Pile began in summer 2007, but there is little documentation regarding operations available until January 2008. There were numerous operational issues encountered early during the pilot study. Injection at SMB2 filled the void space in the mine room underlying the injection point much quicker than anticipated. There were also issues associated with air entrainment into the injection borings and mine workings. EPA contracted with CH2M HILL to provide engineering and technical support for the pilot study in January 2008. The injection borings were reconfigured with internal drop pipes, which reduced the entrainment of air into the system and mine workings and resulted in better flow and distribution of the injected washed fine

tailings. Operational logs were developed and used, along with measurements of percent solids in the injected slurry, to better determine the volume of material injected. Measurements of the total depths in the injection borings are routinely collected to monitor the filling in of the void space in the mine room being injected into (CH2M HILL, 2010). Since 2007, the majority of washed fine tailings injection has occurred through five of the injection borings. Injection occurred between July 2008 and March 2010 in two borings (SMB3 and SMB5). The mine void space in the mine room at SMB3 was filled in March 2010, and injection has occurred in SMB5 and SMB7 since that time. An estimated 95,900 CY of washed fine tailings were injected in SMB3 between November 2007 and March 2010, and an estimated 86,100 CY have been injected in SMB5 since July 2008. Between November 2007 and September 2010, an estimated 215,000 CY of washed fine tailings have been injected into the mine workings at the Sooner Chat Pile. The mine room at injection borings SMB2, SMB3, and SMB6 is filled in with washed fine tailings (see **Figure 4-10**).

Starting in 2007, mine water was sampled semi-annually following a consistent sampling program at the Sooner Chat Pile. Sampling occurred on a quarterly basis beginning in July 2008. All samples were submitted for laboratory analysis of TAL metals, acidity, alkalinity, chloride, fluoride, hardness, nitrate, sulfate and TDS. The samples collected for TAL metals analysis were field-filtered using a 0.45-micron filter prior to placement in the preserved sample container (CH2M HILL, 2009c and 2009d). The data collected from these sampling efforts are incorporated into the HCS and discussed further in **Section 7** and **Section 10**. All borings and monitoring wells at this project site were surveyed in 2008 and 2009. Pressure transducers were installed in 2008 in SMB6, MMB3, BMW01, and CP013-MW2. A pressure transducer was installed in CP013-MW5 in 2009 (CH2M HILL, 2009a and 2009b).

Results of the ongoing pilot injection project at the Sooner Chat Pile have demonstrated that washed fine tailings generated from chat washing operations can be successfully injected into the flooded mine workings. Modifications to well and piping networks are necessary to inhibit and/or eliminate the entrainment of air during the injection process. Modifications, such as those implemented at the Sooner Chat Pile, may also serve to increase downhole flow velocities resulting in a greater distribution of fines within the mine workings. The injection velocity also increased as the pile of material beneath the injection borings grew towards the mine ceiling and the available space within the mine room became more restricted (CH2M HILL, 2010). These improvements have greatly extended the operational lives of the injection borings installed at the Sooner Chat Pile. Injection boring SMB3 operated for a period of 28 months, and SMB5 has been in operation for 27 months. Further, the volume of material injected per injection boring at the Sooner Chat Pile has exceeded estimates from previous pilot studies and those assumed in the FS (estimated at 17,600 CY per injection boring) by as much as 500 percent (CH2M HILL, 2007a). This suggests that capital costs needed to construct a network of injection borings could be lower based on the need for fewer wells (CH2M HILL, 2010).

SECTION 5

# Injection

The following sections provide a general discussion on injection relative to Class V mine backfill wells and the UIC regulations.

## 5.1 Class V Injection Wells

Under current UIC regulations, Class V injection wells include those intended to be used for injecting mixtures of water and sand, tailings, or other solids into subsurface portions of mine workings. Class V injection wells are currently envisioned as the mechanism for injection of the source materials associated with OU4 back into the mine workings as part of the selected remedy. Based upon the available literature, over 5,000 mine backfill wells have been reported in the United States, with more than 7,800 wells estimated to exist. As these estimates are over a decade old, the actual number of existing Class V mine backfill wells is likely higher (EPA, 1999).

Injection using Class V wells was selected as a portion of the OU4 remedy to reduce the volume of source materials present at the surface of the site. Injection was selected as the preferred remedy for the fine tailings, although Sections 19.2.4.1 and 19.2.5.1 of the ROD also allows for the injection of chat from chat piles and chat bases. The objective is to reduce the acreage of land where source materials are placed and capped, allowing for more land to be reused. The emplacement of source materials into the mine workings is deemed to be a long-term, permanent solution. Conventionally drilled vertical wells are the anticipated method to be used for injection of the materials back into the mine workings (EPA, 2008). Such applications can also prove useful for control of subsidence and mitigation of AMW (EPA, 1999).

A variety of materials have been used for injection and backfilling of underground mine workings. These include waste rock, mill tailings, or other byproducts generated from the mining process. Of these materials, mill tailings are likely the most commonly used because they are typically inexpensive and abundant (Underground Injection Practices Council Research Foundation, 1988). Mill tailings in this case are similar to the source materials present at Tar Creek. Additives, such as cement, may also be used as a means of providing structural support or to help with reducing flow regimes within the mine workings. Another factor that should be taken into consideration, especially if controlling subsidence is an objective, includes the compatibility of the additives with respect to the physical, hydrogeologic, chemical, and mineralogical stability of the selected backfill material. Long-term stability typically requires backfill components that resist infiltration and conductance of groundwater. A low permeability backfill can further reduce the potential for contaminant leaching into groundwater (Jude and Vandergrift, 1995). Some form of carrier, such as water or cement, is usually "slurried," or mixed with the backfill material during the injection process. The chemical characteristics of mill tailings used for backfill are generally controlled by that of the ore body or host rock from which they were derived. To a lesser extent, the extraction processes used may also impart some influence upon the

chemical characteristics as well. In many cases, the chemical characteristics of the injected mill tailings better represent those of the actual ore body before it was mined, even though the physical characteristics may have changed (EPA, 1999). The similarity in chemical characteristics between the injection zone matrix and the material to be injected minimizes the chances or likelihood of chemical incompatibilities occurring as a result of injection activities.

### 5.1.1 Typical Well Characteristics

Injection of materials back into underground mine workings is typically accomplished through either an array of wells or piping distributed into mine shafts. It is anticipated that an array of vertical wells will be the approach used for OU4. The methods of injection are typically site-specific and dependent upon the overall objectives.

Well design and construction materials are determined by a variety of factors that include depth of the mine workings and the geology of both the mine workings and overlying strata, combined with the selected process or mechanism for emplacement of the backfill material(s). For shallow applications (considered to be up to a few hundred feet for this evaluation), simplified wells consisting of well casing installed to the top of the mine workings are usually sufficient to facilitate injection of backfill. Previous pilot studies for OU4 have demonstrated that installing casing into competent bedrock is sufficient.

**Figure 5-1** provides a simple schematic diagram of a typical Class V injection well. Well casing is installed within a borehole of sufficient diameter that has been advanced into the mine workings. Borehole diameter and casing material would be based upon both the physical and chemical characteristics (e.g. particle size and chemical composition) of the backfill. Backfilling through the well generally continues until the mine workings at the well location cannot accept any additional material. Upon filling the mine workings at a location, the injection wells are plugged and abandoned. Additional injection wells are installed at new locations with open mine workings as necessary to meet the project objectives.

### 5.1.2 Typical Placement Methods

Emplacement of backfill into mine workings can be accomplished through a variety of methods that include hand, gravity, mechanical, pneumatic, and hydraulic methods. The most commonly used methods are pneumatic and hydraulic (Underground Injection Practices Council Research Foundation, 1988). The pneumatic method requires entrainment of the backfill material into a stream of continually flowing air. This approach would not likely be applicable to the Tar Creek site because the mine workings are flooded; therefore, further discussion is limited to an overview of the potential hydraulic methods.

Hydraulic backfilling facilitates placement of material into the mine workings by washing or pumping the backfill material as a slurry (EPA, 1999). This is typically done through a well or network of wells installed into the top of the mine workings. The three most common methods of hydraulic backfilling include controlled flushing, blind flushing, and pump slurry injection. Controlled flushing requires safe access by workers to the mine workings to help distribute the backfill either after or concurrently with the backfilling process. Access to the mine workings during backfilling is not considered a viable option because of flooding, and further discussion of controlled flushing methods is not provided.

Blind flushing and pumped slurry methods are potential options for emplacement of backfill into the mine workings at the site. Both are similar in that they can effectively accomplish the backfilling objectives without direct access by site workers to the underground mine workings. Both of these methods are discussed in the following sections.

#### Blind Flushing

The blind flushing approach uses gravity as the driver for emplacement of backfill material into the mine workings either by itself or as a slurry (EPA, 1999). The quantity of material that can be injected at individual locations is dependent upon the underground conditions within the mine room and the injection velocity and pressure, which is limited in gravity-based flushing. Factors that can influence the amount of backfill that can be introduced at individual injection locations include slope of the mine room floor, height of the mine room, and proximity to pillars or walls within the mine room. Injection velocity and pressure in a gravity system can be somewhat controlled through modifications to the injection boring construction. The injection operations at the Sooner Chat Pile pilot study have demonstrated that modified boreholes have improved injection velocities and successfully dispersed the slurry within the mine workings. Blind flushing gravity methods typically require multiple injection points, but it might not require an additional source of water or other material to act as a carrier for the backfill.

#### Pumped Slurry

The pumped slurry method is similar to blind flushing except that the backfill material is pumped under pressure into the mine workings rather than conveyed by gravity (EPA, 1999). This method has the potential to distribute backfill into a larger area within the mine workings because of the higher injection velocities. During initial injection, the slurry velocity decreases as it enters the mine workings, and solid particles within the slurry settle out close to the injection point (see **Figure 5-2**). However, continued injection and buildup of backfill within the mine room results in smaller areas through which the slurry can flow. The decrease in open area available for the slurry to flow results in higher flow velocities within the mine room, which results in greater lateral distribution of the slurry. To some extent, the magnitude of lateral distribution depends on the flow velocity of the slurry as it is introduced and the mass of individual backfill particles.

This method could also require a significant source of water to create and carry the slurry into the mine workings. The actual volume of water required may depend upon the characteristics of the backfill (e.g., particle size) and/or the volume of the mine workings (EPA, 1999). Depending upon the objectives and total number and distribution of injection points, numerous water sources may required. However, water from elsewhere in the underground mine workings is a possible source of the water to be used to generate the slurry. Pumping out of water from within the mine workings could set up stronger currents that will help distribute the backfilled materials in the mine workings farther from the injection points.

### 5.1.3 Best Management Practices

Best management practices (BMP) should be applied to any wells when implementing backfill injections into mine workings. Such BMPs are necessary to provide additional protection for USDWs. BMPs are generally developed and related to characteristics of the

injected materials, and the design, construction, operation, and closure or abandonment of the associated wells. Potential BMPs are discussed in the following sections.

### Characteristics of Injected Material

In addition to water, other materials can be specified for use during injection of backfill that impart cement-like properties. The use of these materials typically varies by site conditions and overall project objectives. Decreased permeability and structural support are the two most common benefits of using additives (e.g., cement) when designing a slurry injection program (EPA, 1999). Reduced permeability generally serves to reduce the dissolution of compounds from the backfill after being injected. Further, the decreased permeability can reduce flow rates; thus, limiting the availability of oxygen and release of constituents from the mine room surfaces and backfill material (EPA, 1999).

### System Design and Construction

BMPs should be developed for the system components needed to facilitate injection of backfill materials. Such BMPs should take into account site-specific conditions (e.g., geology, water chemistry, and backfill characteristics) along with the methods and materials needed to construct suitable injection points (e.g., wells). These require significant knowledge of the site, but may be modified or updated, as necessary, through the course of the injection activities to accommodate changing conditions. BMPs should be implemented to address potential impacts from dissolution of compounds from the injected backfill, injection methods, methods used for drilling, and well construction materials (EPA, 1999).

Dissolution of constituents from the injected backfill is possible depending upon the chemical nature of fluids within the mine workings. However, dissolution may be reduced by attempting to fill mine workings to the maximum extent possible, which reduces the availability of oxygen and the development of an acidic environment (EPA, 1999). Using a low permeability slurry with bonding properties could further limit dissolution of compounds from the mine room walls and/or backfill following injection. In either case, water quality and the compatibility with backfill materials proposed for placement into the mine workings should be evaluated prior to implementation.

Project objectives will govern development of the BMPs and are a critical part of developing and optimizing the injection well network. Development of BMPs with respect to the spatial distribution of the injection network is of special concern to inactive mines, especially those with limited access and/or availability and accuracy of detailed subsurface mapping. Detailed maps of the mine tunnels are available for most of the site and should be referenced prior to siting any type of well. Where detailed maps are not available, data gaps may necessitate additional mapping and/or research to evaluate and select the best locations for injection points. Drilling of proposed injection sites to verify mine voids are present at each location may be required prior to full-scale injection well construction.

BMPs for well construction may vary based on site conditions and the type of backfill being injected. Depending upon the site conditions and backfill, either cased or uncased wells can be used. Each method has its own benefits. Uncased (open-hole) wells are generally less costly to install, but are usually limited to relatively shallow applications within competent geologic formations over a short period of time. Uncased wells also might not protect

aquifers or USDWs located above the injection zone through which the injection point penetrates.

Cased wells are better suited for deeper applications, especially if it is needed to protect or limit infiltration of the injected material into an aquifer or other USDW (EPA, 1999). However, as a result of abrasion from injected backfill, the materials used to construct cased wells could be susceptible to degradation during prolonged injection periods. As such, cased wells might be better suited for injecting fluids with a low solids content. Prolonged injection timeframes might also require periodic integrity testing before placing wells into service and periodically during use (EPA, 1999).

### 5.1.4 Well Closure

Following completion of injection activities, each well would require abandonment unless a well was identified for use as a long-term monitoring well. Plugging and abandonment ensures that the well does not provide an ongoing conduit for potential contamination to be introduced into USDWs. Well abandonment would be conducted and overseen by a driller licensed in the State of Oklahoma and follow the well abandonment and plugging regulations set forth by the Oklahoma Water Resources Board (OWRB).

### 5.1.5 Potential Impacts on Underground Sources of Drinking Water

No incidents of contamination of an USDW have been identified that are directly attributable to injection using mine backfill wells (EPA, 1999). However, groundwater contamination is not uncommon at mining sites and specific causes are generally difficult to identify. The potential for backfill injection to contribute to groundwater contamination is highly dependent upon existing site conditions, mine mineralogy, site hydrogeology, backfill characteristics, and injection methods. These existing conditions can also affect the persistence and mobility of chemical compounds.

Several elements were identified as commonly exceeding health-based standards based upon results of toxicity characteristic leaching procedures associated with typical backfill from various mining locations across the United States (EPA, 1999). These included a variety of elements including cadmium, lead, and zinc. These three elements are of particular concern for the Tar Creek site.

With respect to metals, mobility is primarily dependent upon their tendency to dissolve. This is greatly influenced by fluctuations in pH and other water quality characteristics. Because water within mine workings is commonly acidic, metals tend to be mobile within these environments. However, in some instances, the backfill injected into the mine working can be beneficial and limit this mobility (EPA, 1999). Three potential means of limiting mobility through injection of backfill materials include the following:

- Introduction of backfill can reduce the flow rates through mine workings by decreasing the permeability and/or porosity within the voids, thus lowering the advective transport of dissolved-phase compounds
- Backfill can reduce oxidation of sulfides by reducing or eliminating direct contact with air via sealing or flooding of mine room void space

- Backfill with alkaline properties might be able to, at least temporarily, increase pH levels to limit dissolution and mobility of metals

To some extent, the processes of adsorption and diffusion also play a role in the mobility of chemical compounds. Adsorption, or the tendency for a compound to accumulate on the surface of a solid, depends on the physical and chemical characteristics of the medium such as carbon content and pH. Dissolved contaminants could also exhibit the tendency to diffuse within the mine workings or aquifer. Diffusion relies upon concentration gradients whereby dissolved-phase compounds migrate from areas of high to low concentrations. However, diffusion is a minor mechanism of mobility in the case of rapid groundwater flow such as with injection wells.

## 5.2 Underground Injection Control Regulations

The EPA UIC program is authorized by the Safe Drinking Water Act. The Safe Drinking Water Act required EPA to develop and implement a national regulatory program to protect USDWs from impacts resulting from injection. Management and regulation of these activities currently falls under these guidelines. In EPA Region 6, which includes Texas, Louisiana, Arkansas, Oklahoma, and New Mexico, each state has received EPA's approval and directly implements the UIC program in their respective jurisdictions. These states maintain the primary responsibility for enforcing the UIC regulations. Regulations for the federal UIC program can be found in 40 CFR 144 through 148. State of Oklahoma rules that apply to underground injection can be found in the Oklahoma Administrative Code, Title 252, Chapter 652.

EPA Region 6 has retained the authority to implement the UIC program on tribal lands within these states. However, its authority does not include the Five Civilized Tribes (including the Cherokee, Chickasaw, Choctaw, Creek, and Seminole tribes) in Oklahoma. No tribes have formally applied for primacy in EPA Region 6. Additional information regarding the authority of EPA Region 6 to implement UIC programs can be found on the EPA Region 6 Web site (http://www.epa.gov/region6/water/swp/uic).

As previously stated, 40 CFR 144.12 and 144.82 prohibit injection activities that result in the movement of a fluid into a USDW containing any contaminant if the presence of that contaminant causes the exceedence of primary drinking water standards (MCLs) or other health-based standards or may otherwise adversely affect the health of persons. The definition of a USDW, from 40 CFR 144.3, is:

An aquifer or its portion:

(a)(1) Which supplies any public water system; or

(2) Which contains a sufficient quantity of groundwater to supply a public water system; and

(i) Currently supplies drinking water for human consumption; or

(ii) Contains fewer than 10,000 mg/L TDS; and

(b) Which is not an exempted aquifer.

The Boone and Roubidoux aquifers both meet the definition of a USDW. The Roubidoux aquifer is a source of drinking water for a public water supply at the site. The Boone aquifer is used as a source of water for domestic wells at the site (see **Sections 3.4** and **3.4.5**).

The OU4 ROD, in Section 19.2.4.3, defines the injection wells under the proposed remedy as Class V mining, sand, or other backfill wells (40 CFR 144.81[8]). Federal regulations specific to Class V injection wells are listed in 40 CFR 144.79 through 144.89. In accordance with federal and state regulations, owners or operators of Class V injection wells are required to submit basic inventory information to the direct implementation state program (ODEQ). Required inventory information is specified in 40 CFR 144.83(a) and includes at least the following information for each Class V well: facility name, location, and ownership, nature and type of injection well, and operating status. Additional information specified under 40 CFR 144.83(a)(2)(ii) and (iii) is also required. Information under 40 CFR 144.83(b) may also be requested. Information submitted in accordance with 40 CFR 144.83(a)(2)(iii) is used to evaluate the potential for endangering a USDW and may include monitoring activities, analysis of the injected fluids, and evaluations of the geology through and into which injection takes place. When an owner has submitted the required inventory information and is operating injection wells in a manner that does not endanger an aquifer, a Class V injection well is authorized by rule (EPA, 1999). Additional information may also be requested by state and federal agencies to ensure protection of USDWs. Owners or operators that fail to submit information required under 40 CFR 144.83(a) (Inventory Requirements) and 40 CFR 144.83(b) (Information in Response to Requests) are prohibited from using their wells. Class V injection wells that are authorized by rule do not require a permit; however, permits may be requested in accordance with 40 CFR 144.25 if certain conditions apply. Notable conditions that might result in having to acquire a permit include the following:

- The injection well is not in compliance with any requirement of the rule.
- The injection well is not or no longer is within the category of wells and types of well operations authorized in the rule (for instance, the well is converted to serve as a monitoring well after it was used for injection).
- The protection of USDWs requires that the injection operation be regulated by requirements, such as for corrective action, monitoring and reporting, or operation, which are not contained in the rule.
- Failure to comply with the prohibition of fluid movement standard in 144.12(a) and described in 144.82(a).

It should be noted that under CERCLA, obtaining a permit is not required to implement the selected remedy. However, the remedy is required to comply with the substantive requirements that a permit would contain.

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SECTION 6

# Hydrogeologic Characterization Study Field and Data Collection Activities

Various field and data collection activities were conducted as part of the HCS. Well reconnaissance was performed to identify, locate, and assess existing wells for use during the study. Monitoring wells were installed to fill gaps in the monitoring network. A water level monitoring program was implemented. Water level data were collected both manually and using pressure transducers. Precipitation data were collected on a monthly basis from regional weather monitoring sites. Stream gage data were obtained from the USGS gages located at and near the site. Surveying was performed to provide accurate horizontal and vertical location data for all monitoring locations. Groundwater and mine water sampling were performed to collect general water quality parameter and analytical data. Aquifer testing was conducted at one well completed in the Boone aquifer and a second well completed in the Roubidoux aquifer to determine values for aquifer parameters at these wells for use in the groundwater flow model. A surface water data collection program was implemented to determine the amount of discharge coming from the mine pool and Boone aquifer to Tar Creek. Finally, all data were stored and managed using a database.

All HCS activities were performed in accordance with the various project plans, including the field sampling plan (CH2M HILL, 2009c), addenda 1 and 2 to the field sampling plan (CH2M HILL, 2009d and 2009e), quality assurance project plan (CH2M HILL, 2009f), site management plan (CH2M HILL, 2009g), and health and safety plan (CH2M HILL, 2009h). Several technical memoranda (TM) were prepared to document various aspects of the HCS field activities. These TMs are included as appendices to this report. The following sections describe the general details of the field and data collection activities.

## 6.1 Well Reconnaissance

Site well reconnaissance efforts were performed to establish the HCS OU4 Boone aquifer monitoring network. The reconnaissance effort did not include research into Roubidoux aquifer wells because the Roubidoux public supply wells are well known and documented. The OU4 monitoring network was used to collect water levels and groundwater quality data from the Boone aquifer and mine pool at the site. The objectives for the site reconnaissance were to locate and then evaluate well and mine pool locations for suitability and use in the collection of groundwater data. The groundwater data were used to develop the computer-based numerical groundwater flow model (see **Section 9**) and to perform geochemical modeling (see **Section 10**). Site well reconnaissance efforts were documented in the TM, *Site Reconnaissance and Establishment of Monitoring Network – Tar Creek Superfund Site, Operable Unit 4, Ottawa County, Oklahoma* (CH2M HILL, 2009i), and is provided in **Appendix A**.

Site reconnaissance efforts began in April 2008 and continued through May 2009. The site reconnaissance activities included both an office and field component. The office component consisted of record reviews to identify potential monitoring locations, prepare field maps, and establish property ownership to obtain access agreements. The field component included field verification of identified potential locations, determining if site access issues or restrictions were present, evaluating the suitability of each location for use, and obtaining an access agreement. For purposes of the site reconnaissance, the study area was defined as the area of Ottawa County bounded by the state line on the north, the Neosho River on the west and south, and the Spring River on the east and south.

An initial list of potential monitoring locations was developed through a records search that was initiated in March 2008. The records search included a review of published reports for the site area and searching online databases. The primary sources of published reports included the Oklahoma Geological Survey, OWRB, ODEQ, OCC, EPA, and USGS. Online searches were performed using the OWRB Water Well Record database and USGS National Water Information System search tools. All available information, including identification, location, use, ownership, construction details, and water level information was obtained through these sources. This information was evaluated to determine if any identified locations should be considered for field verification and inclusion in the OU4 monitoring network.

The initial site monitoring network was established in July 2008 and consisted primarily of locations known to exist, either through stakeholder input or through other actions at the site, such as pilot studies and available literature resources. Additional reconnaissance efforts and well drilling/installation occurred to fill data gaps identified in the initial site network. The OU4 monitoring network consists of Boone Formation (Boone aquifer) wells and Boone Formation mine pool locations. Locations are considered wells if they are completed in and terminate in competent rock. Wells include locations completed as an open borehole for use as a typical private well, cased exploratory boreholes, and constructed monitoring wells. Mine pool locations are completed into an underground mine working. Mine pool locations include air vents and current and former pilot study boreholes drilled to provide access to the mine pool. In addition, some locations (identified as other wells) included in the network are shallower than the Boone aquifer but are still monitored for water levels. Additional constructed monitor wells, identified as source material wells, are completed within the Sooner Chat Pile and Central Mill Tailings Pond to monitor groundwater contained within the source materials at these locations.

The site reconnaissance occurred after the initial records review, and then continued through May 2009 as new information became available. Field reconnaissance was not performed during any defined mobilization event. Efforts to confirm information obtained during record searches or in discussions with property owners were performed concurrently with other field efforts. As field work progressed during the study, additional locations were identified and evaluated based on discussions with property owners. In many instances, discussions with local property owners yielded information on the existence of private wells, cased exploratory boreholes, and cased air vents. Typically, these features range in size from 6 to 8 inches in diameter. As the work progressed, gaps in the monitoring network were addressed through additional reconnaissance efforts to locate

existing wells and mine pool locations and through the OU4 drilling program. Active reconnaissance efforts were completed in May 2009.

The OU4 monitoring network consists of 84 locations. There are 28 Boone aquifer locations (see **Figure 6-1**), 44 Mine Pool locations (see **Figure 6-2**), 4 shallow (other) wells, and 8 chat pile/tailings pond wells (see **Figure 6-3**). The four Roubidoux aquifer wells used as part of the study and one well completed in the Cotter Dolomite (identified as Powerhouse-C) are also shown on **Figure 6-3**. The entire OU4 monitoring network is listed in **Table 6-1** and shown on **Figure 6-4**.

## 6.2 Drilling and Monitoring Well Installation

The drilling and monitoring well installation work included drilling and installation of 15 Boone aquifer monitoring wells, 5 monitoring wells installed to the base of the Sooner Chat Pile, 3 monitoring wells installed to the base of the Central Mill Tailings Pond, and a single injection boring installed at the Sooner Chat Pile. All drilling and monitoring well installation activities were completed in accordance with the procedures outlined in the field sampling plan and addendum no. 1 (CH2M HILL, 2009c and 2009d).

The Boone aquifer monitoring wells and the single injection boring were drilled using air rotary drilling methods with a downhole air hammer. Four monitoring wells and the injection boring were drilled and installed at the Sooner Chat Pile during June 2008. A single monitoring well was drilled and installed for pump testing next to Roubidoux aquifer well Picher No. 7 in October and November 2008. The remaining 10 monitoring wells were drilled and installed between March and May of 2009.

The five monitoring wells installed at the base of the Sooner Chat Pile and the three monitoring wells installed to the base of the Central Mill Tailings Pond were drilled using hollow-stem auger drilling methods. Two monitoring wells were drilled and installed at the Sooner Chat Pile during June 2008. The remaining three monitoring wells at the Sooner Chat Pile and the three monitoring wells at the Central Mill Tailings Pond were drilled and installed during April 2009.

During drilling, lithology was logged by a field geologist and recorded on rock core and soil boring logs. Following well installation, each monitoring well was developed to settle the gravel or sand pack and to remove sand and silt from the wells. Copies of the rock core and soil boring logs, final well construction diagrams, and the well development logs are provided in **Appendix B**. **Table 6-2** provides a summary of the well construction details for the monitoring wells that were installed.

## 6.3 Water Level Monitoring Program

A water level monitoring program was implemented to record water levels from the site monitoring network during the HCS. Manual water level measurements were recorded from the site monitoring network on a monthly basis beginning in July 2008 and going through January 2010. The manual water level measurements are provided in **Table 6-3**. In addition to manual measurements, pressure transducers were installed in a subset of the site monitoring locations to record water level data. A TM documenting the installation of the pressure transducers is provided in **Appendix C**. The pressure transducers are non-vented,

which means that correction of the data to account for barometric pressure is required. A pressure transducer was installed at monitoring well BMW01 to record barometric pressure readings for this purpose. The locations where pressure transducers were installed are listed in **Table 6-4** and shown on **Figure 6-5**.

The pressure transducers are set to record data at 10-minute intervals. During each manual water level measurement event, the data from the pressure transducers were also downloaded and the transducers reset. A manual water level was collected at the start time for the transducer so that the readings could be assessed later. The data were transferred to the project database and corrected for barometric pressure to determine the final pressure readings for the water column above the transducer and to convert the pressure readings into a water level reading.

The water level and pressure transducer data were used to develop and calibrate the groundwater flow model. Groundwater flow at the site is discussed further in **Section 9**.

## 6.4 Precipitation Data Collection

Daily precipitation data were obtained from 13 weather monitoring stations in the area of the site. The precipitation data cover the period January 2008 through January 2010. This information has been compiled and loaded into the project database. The weather monitoring stations are listed in **Table 6-5**, and their locations are shown on **Figure 6-6**. Tabulated daily rainfall totals recorded at each station are provided in **Appendix D**.

## 6.5 Surveying

Surveying activities were performed as part of the HCS to establish the horizontal and vertical locations for the monitoring network. The surveying activities, methods, and procedures, were documented in a TM that is included as **Appendix E**. Horizontal control was referenced to the Oklahoma State Plane Coordinate System, North American Datum of 1983, with an accuracy of 0.1 foot. Vertical control was referenced to the North American Vertical Datum of 1988, with an accuracy of 0.01 foot.

Prior to starting the surveying efforts, it was determined that primary control monuments suitable for purposes of meeting the vertical accuracy desired were not present in close proximity to the site. As a result, four primary control monuments were built and their locations established at the site for use in surveying efforts. The primary control monuments were built and surveyed during June 2008. Surveying efforts for the HCS were performed in July 2008, December 2008, and May 2009. The location of each primary control monument is shown on **Figure 6-7**. The survey data for each location surveyed as part of the HCS is provided in **Table 6-6**. In most cases, the noted reference point elevation is the top of casing, which has been marked on the north side of the well casing.

## 6.6 Groundwater and Mine Water Sampling

Groundwater and mine water sampling were performed as part of the HCS to obtain general water quality and metals analytical data on the groundwater and mine pool. All sampling and sample analysis were completed in accordance with the procedures outlined

in the field sampling plan and addendum no. 1 (CH2M HILL, 2009c and 2009d) and the quality assurance project plan (CH2M HILL, 2009f).

A quarterly sampling program for the HCS was implemented in 2009. Sampling events were completed in April/May 2009, July/August 2009, and October 2009. Prior to implementation of this program, mine water sampling events associated with the previous pilot studies were performed in February 2007, July 2007, October 2007, April 2008, and October 2008. Groundwater and mine water sampling events associated with the Sooner Chat Pile pilot study were performed in July 2008, October 2008, and February 2009. Monitoring locations associated with these pilot studies were included in the HCS sampling events beginning in April 2009.

During each sampling event, general water quality parameter data were collected in the field using a field meter. DO measurements were also collected in the field using field test kits. Groundwater and mine water samples were collected for the analysis of TAL dissolved metals, alkalinity, carbonate/bicarbonate, chloride, fluoride, sulfate, TDS, nitrate, hardness, nitrate/ammonia, and sulfide. The TAL dissolved metals samples were filtered in the field using 0.45-micron filters. During the July/August 2009 sampling event, a subset of wells were also sampled and filtered using 0.10-micron filters to assess the potential impacts of small colloids, which are capable of passing through the 0.45-micron filters, on the analytical results. All samples were shipped via overnight delivery to the EPA Region 6 Laboratory in Houston, Texas, for analysis.

The monitoring locations that were sampled as part of the HCS are listed in **Table 6-7**, and the locations are shown on **Figure 6-8**. All sampling activities were recorded in field logbooks and data were recorded on well purge and sampling field record forms (provided in **Appendix F**). The analytical results are discussed in **Section 7** and **Section 10**.

## 6.7 Aquifer Testing

A single aquifer test was performed on the Roubidoux aquifer to assess the potential hydraulic connection between the Roubidoux aquifer and the Boone aquifer and mine pool. Roubidoux aquifer properties were also evaluated using data obtained from this test. This test was performed during December 2008. A Boone monitoring well (BMW05) was installed next to Roubidoux well Picher No. 7 (see Figure 3, **Appendix G**). Picher No. 7 was then pumped for 24 hours, and water levels were monitored in BMW05 (both manually and using a pressure transducer), several nearby Roubidoux wells (manually), and at several mine pool and Boone aquifer monitoring locations (pressure transducers) to evaluate drawdown at each location in response to the pumping at Picher No. 7. The field activities and evaluation of the results for this test were documented in a TM included as **Appendix G**.

Two aquifer tests were completed on wells completed in the Boone aquifer to determine site-specific aquifer properties for the Boone aquifer. The tests were performed in June 2009 at monitoring wells BMW12 and BMW13. The field activities and evaluation of the results for this test were documented in a TM included as **Appendix H**.

Aquifer properties and use of this information in the groundwater flow model are further discussed in **Section 9**.

## 6.8 Surface Water Flow and Mine Pool Discharge Data Collection Activities

To determine the contribution of mine pool discharges to surface water flows in Tar Creek, a surface water monitoring program (SWMP) was initiated in December 2009. The purpose, approach, and procedures of the SWMP are further described in the field sampling plan addendum no. 2 (CH2M HILL, 2009e). The program that was implemented was based upon input and support from the Quapaw Tribe of Oklahoma, ODEQ, and representatives of the University of Oklahoma.

The three primary objectives of the SWMP are to:

1. Develop surface water stage-discharge rating curves and continuous flow records for the duration of the monitoring period from gaging stations installed in Tar, Lytle, and Quapaw Creeks during the week of December 21, 2009 (see **Figures 6-9** and **6-10**).
2. Quantify the mine pool discharge to surface water in the Douthat area during high flow conditions using mine pool elevation data in combination with surface water flow data from the new gages in Tar, Lytle, and Quapaw Creeks; as well as the USGS stream gage in Tar Creek at Highway 69 (USGS Site No. 07185090; see **Figure 6-10**).
3. Refine the upper end (mine pool elevation above approximately 802.5 feet amsl) of the mine pool elevation versus mine pool discharge rating curves previously developed and shown on **Figures 3-2** and **3-3**.

The following paragraphs provide a general overview of the SWMP. The findings of the study are presented in **Section 8** of this report.

Mine pool discharge to Tar Creek has been measured multiple times in the past, primarily during low flow conditions when streams were able to be waded and mine pool elevations were less than or equal to about 802.5 feet amsl. The general approach has been to identify outlets from the mine pool and measure them individually (Parkhurst, 2009; Cates, 2009, personal communications). During high flows, the general approach has been to measure flows upstream and downstream of the mine pool discharges and attribute the difference in flow to mine pool contribution (Parkhurst, 2009, personal communication). Results of these past efforts are presented graphically in a mine pool elevation versus mine pool discharge rating curves provided on **Figures 3-2** and **3-3**. The locations where the data were collected to generate these curves are shown on **Figures 6-9** and **6-10**. For an overview of the past measurement efforts, including some of the limitations during high flow conditions, refer to the field sampling plan addendum no. 2 (CH2M HILL, 2009e).

Because the results of past efforts show good agreement during low flow conditions, the focus of the SWMP is to quantify the mine pool contribution to surface water during wet weather, high flow conditions. Mine pool elevations are anticipated to be at or above 802.5 feet amsl during high flow conditions. The area of interest for the study is where the majority of the mine pool discharges to surface water near the Douthat Bridge, between E30 Road to the north and Highway 69 to the south. Based on field observations during wet and dry weather conditions, ground topography, and mine pool elevations, this area is believed

to be the primary source of mine pool discharge to surface water. This is also where past monitoring efforts were focused.

Data collected during the SWMP will be used to update and refine the upper portion of the mine pool rating curves developed during previous efforts. The mine pool rating curve is used in the groundwater model to assess the relationship between mine pool elevation and mine pool discharge to surface water. Based upon results of this effort to update the upper portion of the mine pool rating curves, future modifications to the groundwater model will be considered.

As part of the SWMP, four surface water gaging stations have been established at the following locations (the type of data collected is shown in parentheses):

- Tar Creek at E30 Road bridge (flow and stage)
- Lytle Creek at E30 Road bridge (flow and stage)
- Lytle Creek at Highway 69 bridge (flow and stage)
- Quapaw Creek near the mouth: QC-DS (flow and stage); and, QC-US (stage only)

Refer to **Figures 6-9** and **6-10** for locations of the surface water gages. Flow records from these gages and the existing USGS Tar Creek gage at Highway 69 (Site No. 07185090), together with an estimate of overland precipitation runoff from the drainage area between the gages, will allow for the quantification of mine pool discharge, $Q_{mine\ pool}$, using the equation below:

$$Q_{mine\ pool} = Q_{TC\ d/s} - (Q_{TC\ u/s} + Q_{LC\ u/s}) - Q_{QC} - Q_{runoff}$$

where:

$Q_{TC\ d/s}$ = Tar Creek discharge downstream of the mine pool; contribution to surface water (USGS gage at Highway 69)

$Q_{TC\ u/s}$ = Tar Creek discharge upstream of the mine pool contribution to surface water (TC-US);

$Q_{LC\ u/s}$ = Lytle Creek discharge upstream of the mine pool contribution to surface water (LC-30);

$Q_{QC}$ = Quapaw Creek discharge (QC-DS); and,

$Q_{runoff}$ = overland flow runoff from precipitation between the upstream and downstream surface water gages.

Each stream gage location is equipped with a staff gage and continuous (10-minute interval) recording pressure transducer. A current meter is used to measure discharge at the upstream stations along E30 Road under the full range of flows, and during safe wading conditions in Quapaw Creek. Because there is no bridge to deploy a current meter during high flows at the Quapaw Creek gage site, a slope-area method is used to estimate high flows in Quapaw Creek. A graphical relationship, called a rating curve, is developed between surface water flow and elevation. The rating curve is used to convert continuous stage (elevation) measurements to continuous flow values.

Flow data from the USGS Tar Creek gage is being downloaded periodically from the National Water Information System Web site and used for the downstream Tar Creek station. These data are reported in 15-minute intervals.

Precipitation data from the regional National Oceanic and Atmospheric Administration weather stations and Oklahoma Mesonet stations (see **Figure 6-6**) are being used to analyze the flow data and mine pool elevation data in relation to precipitation events. The precipitation data, in combination with the stream flow data, are also used to compute local runoff volumes from the 3.6-square-mile drainage area between the stream gages.

## 6.9 Data Management

All data collected during the HCS were stored and managed in a project database. The database contains all field and laboratory-generated data for the HCS.

SECTION 7

# Groundwater and Mine Water Chemical and Analytical Summary

The following sections present the water quality, general chemistry, and trace metals results obtained during the sampling efforts at the site as part of the HCS. Sampling associated with previous pilot studies has occurred since 2007. Groundwater and mine water sampling have occurred from the Boone aquifer and mine pool as part of these efforts. Mine pool locations sampled prior to implementation of the quarterly sampling program performed during the HCS in 2009 include FCB2, FCB3, LMB2, MMB2, RMB3, RMB4, SMB2, SMB3, SMB5, SMB6, SMB7, TMB2, and TMB3. These locations are all associated with source material placement pilot studies. Boone aquifer monitoring wells BMW01 and BMW02 were also sampled during 2008 as part of monitoring for the ongoing pilot study at the Sooner Chat Pile.

Samples were collected for the analysis of general chemistry parameters and TAL metals, and general field water quality parameter data were obtained during sampling. The project chemist performed analytical data validation for the general chemistry and TAL metals results as the analytical reports were received from the laboratory. The data validation flags were then loaded into the project database at the direction of the project chemist. A data quality review TM, documenting the results of the data validation, is provided in **Appendix I**.

Laboratory analytical data were reviewed for quality based on guidance presented in the EPA National Functional Guidelines (EPA, 2004). The data review focused on the potential impact of laboratory performance and matrix effects on the validity of the analytical results. Data sets were reviewed to determine if the samples were analyzed according to project requirements and quality control (QC) specifications of the analytical methods. The quality of the analytical data was found to be within the QC limits established by the project data quality objectives, the analytical methods, and review criteria presented in the EPA National Functional Guidelines. Some analytical results were qualified as a result of QC issues, as described in **Appendix I**, but no serious QC issues were encountered, and no analytical data were rejected during the review process.

The following sections discuss the analytical results, along with the field water quality parameter data collected during each sampling event. In discussing the results for the Boone aquifer, the data are discussed in a general sense relative to the groundwater quality within and away from the mining field. The data are also compared with the Roubidoux aquifer water quality as well.

## 7.1 Field Water Quality Parameters

Field water quality parameters were collected during each sampling event. The data collected prior to sample collection during each sampling event are provided in **Tables 7-1** and **7-2** for the Boone aquifer and mine pool, respectively. Select data associated with the

July 2009 event is not included because the field sheets were misplaced during the event. For comparison, field parameters for Roubidoux wells, sampled between 1996 and 2008, are provided in **Table 7-3**.

During each sampling event, field water quality parameters were collected at different depth intervals within the mine pool at the mine pool monitoring locations. These data were collected to assess potential stratification of the water within the mine pool and are included on the well purge and sampling field record forms (provided in **Appendix F**). All mine water samples were collected within 5 feet of the bottom of the mine room. This approach was taken to obtain the most conservative (i.e., highest concentration) metals concentrations. This approach is based on the assumption that the water column in the mine workings is potentially stratified, with higher metals concentrations occurring in the lower stratified layer of the water column, as documented by previous USGS studies (see **Section 2.1**).

### 7.1.1 Boone Aquifer

Field water quality parameter data for the Boone aquifer are provided in **Table 7-1**.

The pH in the Boone aquifer was slightly acidic to neutral, with pH values most commonly between 6.0 and 7.5. Highly alkaline pH values over 10.0 were observed in monitoring wells BMW06 and BMW14. These two wells produced water very slowly during development. Initial high pH values were observed during development at several installed Boone monitoring wells. The high pH values in these two wells likely indicate that additional well development is necessary and/or that grout has intruded into the screened intervals of these wells. The pH values ranged from 5.6 up to 8.6, excluding the values obtained from BMW06 and BMW14. Lower pH was typically measured in wells located within the mining area, such as BMW09, BMW11, BMW12, and BW06. Higher pH was typically measured in wells located on the edges of or outside of the mining area such as BMW13, BW13, and BW14.

Specific conductance (SC), or conductivity, values varied widely, ranging between 472 and 4,224 microsiemens per centimeter (µS/cm). The values obtained from BMW01 and BMW02 during July 2008 were the result of a faulty probe and are not considered valid. The SC values in the Boone aquifer also varied in relationship to where a well was located relative to the mining field. SC values greater than 2,000 µS/cm were typically encountered in wells located within the mining field, with SC values decreasing away from the mining field to less than 1,000 µS/cm. Well BW11, located on the far western edge of the site, was the only well not located near the mining field to have measured SC values greater than 2,000 µS/cm.

Measuring DO concentration in the field can be difficult because of the need to minimize contact with the atmosphere prior to and during measurement to prevent aeration of the water. As a result of difficulties associated with collecting the measurement, DO concentrations were collected in the field using both water quality meters with air-tight flow-through cells used to collect the other parameter data and using field test kits. DO concentration is also an indicator of the redox state of the groundwater, and the DO concentrations are generally related to oxidation reduction potential (ORP) measurements. Negative ORP values are generally associated with lower DO concentrations and indicate a

less oxidizing to more reducing redox state. Positive ORP values are generally associated with higher DO concentrations and indicate an oxidizing redox state.

The ORP data from the Boone aquifer were mostly negative values. Where negative ORP values were measured, the values ranged between -17.0 and -329.8 millivolts (mV). Positive ORP values were consistently measured in several of the Boone aquifer wells. These wells include BW06, BW07, and BW13. ORP was positive in well BW16 during July and October 2009. Positive ORP values were measured during single sampling events in wells BMW11 (April 2009), BMW14 (October 2009), and BMW15 (October 2009). ORP values in these wells ranged between 3.7 and 266.1 mV.

DO concentrations in the Boone aquifer were generally low at concentrations less than 1.0 mg/L. The field meter and test kit values were relatively close to each other for most measurements collected using both methods. Where the two methods did not yield similar values, the ORP data were usually more closely related to the field test kit measurements, indicating that this method was more reliable for measuring DO in the field. A DO concentration greater than 1.0 mg/L was only consistently measured in well BW06. Well BW07 had a DO concentration near 1.0 mg/L in July 2009 and a DO concentration over 1.0 mg/L in October 2009. Wells BMW15, BW13, and BW16 had a DO concentration greater than 1.0 mg/L and a corresponding positive ORP value in October 2009.

### 7.1.2 Mine Pool

Field water quality parameter data for the mine pool are provided in **Table 7-2**.

The pH of the mine pool water was acidic to slightly acidic, with most pH values generally between 5.0 and 7.0. Slightly alkaline pH values between 7.0 and 8.0 were measured in a few borings associated with previous pilot studies during sampling events prior to July 2008. Slightly alkaline pH values between 7.0 and 8.0 were consistently measured in the area of the injection borings associated with the ongoing injection pilot study at the Sooner Chat Pile. Mine pool monitoring location MP06 was the only location not associated with a pilot study to exhibit a pH greater than 7.0 (during both events in which this location was sampled during August and October 2009).

The SC values in the mine pool generally ranged between 2,000 and 3,000 µS/cm. Exceptions were mine pool locations FCB3, MD2, and MP17, which consistently had SC values less than 1,000 µS/cm.

The ORP of the mine pool was positive in the injection borings associated with the injection pilot study at the Sooner Chat Pile and in a few monitoring locations associated with previous pilot studies during October 2007 and April 2008. The positive ORP values ranged between 20 and 269 mV. Positive ORP values were observed only at the Sooner Chat Pile during 2009. Negative ORP values, ranging between -3 and -344.4 mV, were measured in the remaining mine pool locations.

The DO concentrations in the mine pool were generally low, at concentrations less than 1.0 mg/L, with the exception of the injection borings at the Sooner Chat Pile. The injection borings typically had high DO concentrations exceeding 2.0 mg/L. The field meter and test kit values were relatively close to each other for most measurements collected using both

methods. Where the two methods did not yield similar values, the ORP data were usually more closely related to the field test kit measurements.

### 7.1.3 Roubidoux Aquifer

Field parameters for Roubidoux aquifer wells are provided in **Table 7-3**. Because the Roubidoux aquifer is a non-ore-bearing dolomitic formation, the pH is generally higher than that of the Boone. The observed range in pH is 6.4 to 8.6, with most values in the 7.0 to 7.5 range. Several of the samples with slightly acidic pH (6.4 to 6.9) were wells that were believed to be impacted with water from the mine pool (CH2M HILL, 2007b). Those wells (Cardin #1, Commerce #3, Commerce #4, Picher #2, Picher #3, Picher #4, and Quapaw #2) were not consistently below pH 7, and slightly acidic samples have been observed in other Roubidoux wells (Fernandez Well, Picher #5, Picher #6, Picher #7, Quapaw #5, RWD4 #3, and RWD7#2).

Specific conductance of Roubidoux samples is generally low, ranging from 239 to 1,503 µS/cm. There is likely a low bias in this parameter because the Roubidoux wells were open across more favorable water quality zones for use as domestic and municipal wells, but it is assumed that the average SC is lower than the mine pool and Boone aquifer.

DO was highly variable in measured samples, likely owing to various methods of data collection. Turbidity and ORP data were not available for Roubidoux samples.

## 7.2 General Chemistry

Samples for the analysis of general chemistry were collected during each sampling event. General chemistry parameters included alkalinity, chloride, fluoride, hardness, ammonia, nitrate, nitrite, sulfate, sulfide, TDS, and the TAL metals calcium, iron, magnesium, manganese, potassium, and sodium.

Redox sensitive parameters include ammonia, nitrate, nitrite, iron, manganese, and sulfide. A dominance of ammonia, iron, manganese, sulfide, or a combination of these species generally indicates more reducing conditions are predominant. The absence of these species, coupled with presence of nitrate, DO, and positive ORP, is typical of more oxidizing conditions.

The general chemistry analytical results from each sampling event are provided in **Tables 7-4** and **7-5** for the Boone aquifer and mine pool, respectively. For comparison, the general chemistry results for the Roubidoux aquifer are provided in **Table 7-6**. The different water sources are compared on a general chemistry Piper diagram on **Figure 7-1**. For each sample, the cations (sodium, calcium, magnesium) are plotted by relative percentage on a triangular field at the bottom left, while major anions (chloride, bicarbonate, sulfate) are plotted at the bottom right. The cation and anion points for each sample are extended onto the middle diamond-shaped field to form a combined single point for each sample. A sample's water chemistry is thus shown in three ways on the Piper diagram, for comparison with other samples. **Figures 7-2**, **7-3**, and **7-4** show map views of Boone aquifer, mine pool, and Roubidoux aquifer wells, respectively, with chemical Stiff diagrams plotted next to each well location. Each Stiff diagram shows the cations on the left (plotted in milliequivalents per liter) and anions on the right. The largest bulges in the diagram geometry represent the

more dominant ions, and the overall size of each diagram is proportional to the TDS. Each diagram provides a visual "fingerprint" of the water chemistry for each well.

### 7.2.1 Boone Aquifer

General chemistry analytical results for the Boone aquifer are provided in **Table 7-4**.

The general chemistry of the Boone aquifer within the mining field is typified by the analytical results from wells BMW01, BMW02, BMW05, BMW07, BMW09, BMW11, BMW12, and BW06. Groundwater in the Boone aquifer within the mining field is strongly dominated by calcium and sulfate, with TDS in the 2,000-2,500 mg/L range. These samples plot in the top corner of the diamond field of the Piper diagram shown on **Figure 7-1**. Some wells with greater TDS have a strong magnesium component. Well BW15 is typical of these wells, with a calcium-magnesium-sulfate chemistry and a TDS of 3,160 mg/L. It is likely that most of the wells with higher TDS are showing the influence of mine pool water in the Boone aquifer.

Away from the main mineralized zone in the Picher-Commerce area, the TDS tends to be lower and calcium and sulfate are not as dominant. **Figure 7-2** shows a map view of Boone wells, with chemical Stiff diagrams representing the general chemistry of representative samples from each well. Note that while most wells still show a calcium-sulfate dominance, it is not as pronounced as in the mineralized zone and, in several cases, other ions are dominant. For example, well BW13 to the west of Commerce has a sodium-bicarbonate chemistry. This may be more representative of the non-mineralized Boone aquifer, and was used to represent the pre-mining, downgradient water chemistry in the geochemical transport simulations, presented in **Section 10**.

Groundwater in the Boone aquifer within the mining field is characterized by indicators of mildly to strongly reducing conditions, including ammonia, dissolved iron and manganese, and occasionally sulfide. The presence of these constituents, combined with non-detect or low concentrations of nitrate, indicate that chemically reducing conditions are prevalent in the Boone aquifer. The elevated dissolved iron is derived from the oxidative dissolution of pyrite (iron sulfide) in the unsaturated zone and mined areas. The reaction oxidizes the sulfide to sulfate and releases iron and sulfate to the water, along with acidity. The dissolved iron present in the Boone is in the reduced (ferrous or +2) state; in areas of groundwater-to-surface water discharge, the ferrous iron is quickly oxidized to the ferric (+3) state and ferric oxyhydroxide precipitation is evident from the yellow and red staining observed in nearby creeks. A generalized view of the actively mined area of the Boone aquifer may be constructed by contouring the concentrations of sulfate, which is the product of the oxidized sulfide minerals that were mined from the formation. A sulfate contour map of the Boone aquifer is provided as **Figure 7-5**.

An MCL has been set for fluoride, nitrate, and nitrite. No wells had an exceedence of an MCL. SMCLs have been set for chloride, fluoride, sulfate, TDS, iron, and manganese. The SMCL for fluoride is exceeded in wells BMW02, BMW07, BMW09, and BMW11. The SMCLs for sulfate, TDS, and iron are exceeded in 9 wells, and the SMCL for manganese is exceeded in all 11 wells.

Vertical variation in groundwater chemistry within the Boone aquifer has been observed in a well cluster near Douthat. Well BMW08 is part of a cluster of wells, including BMW07

and BMW09 that were installed in close proximity to each other but screened at different depths (see **Table 6-2**). This well cluster is located approximately 250 feet south of the mine workings at the Quebec Mine. The cluster was installed such that the three wells were screened in the Boone aquifer across the same depth interval as the mine workings in the Quebec Mine, with BMW08 being the middle well. This well is screened across a more competent portion of the Boone Formation that is less fractured and produced less water during drilling, when compared with wells BMW07 and BMW09 (see boring logs in **Appendix B**). BMW08 has a different general chemistry when compared with BMW07 and BMW09 and the other Boone aquifer wells within the mining field (see **Figure 7-2**). BMW08 has a mixed-ion chemistry with TDS less than 500 mg/L and pH close to 8. By contrast, BMW07 and BMW09 are typical of the mineralized Boone, with calcium-sulfate chemistry, TDS around 2,000 mg/L, and pH below 7. These wells combine to represent the variations in water chemistry with depth in the Boone aquifer. There are no other well clusters like this within the Boone aquifer, but it is assumed that this variation exists throughout the mineralized zone.

Wells BMW06 and BMW14 are not considered representative of the Boone aquifer, as evidenced by their excessively high pH values (both above 10), as discussed in the previous section.

### 7.2.2 Mine Pool

General chemistry analytical results for the mine pool are provided in **Table 7-5**. The distribution of mine pool water chemistry is shown on **Figure 7-3** using Stiff chemical diagrams (explained at the beginning of **Section 7.2**).

At most locations sampled (19 of 22), water in the mine pool is dominated by calcium and sulfate. TDS typically ranges between 2,000 and 3,000 mg/L. As in the Boone aquifer, mine pool samples with the highest TDS have a calcium-magnesium-sulfate chemistry. The highest TDS was found in SMB8 (4,100 mg/L), completed in a separate mine room at the Sooner Chat Pile where injection is not occurring.

The three exceptions to the prevailing mine pool general chemistry are FCB3, MD2, and MP17, all of which show a much lower TDS (177 to 510 mg/L) and stronger bicarbonate presence. Sampling location FCB3 was shown to exhibit higher TDS and calcium-sulfate chemistry when sampled from a greater depth, thus demonstrating stratification in the Craig mine pool. The shallower depth of FCB3 is considered to represent a greater influence of local recharge, resulting in a more dilute solution.

Location MD2 is located along Beaver Creek in the far southeast corner of the site and outside of the main portion of the Picher Field. Location MP17 is located on the southeast edge of the main portion of the Picher Field in the mine room next to Boone aquifer well location BW16. This mine room is not directly connected to the mine workings in the rest of the Picher Field. It is likely that MD2 and MP17 also represent the shallower, recharge-influenced zone of the mine pool, but may also be sufficiently separated from the main mining areas where dissolution of ore minerals has not been as significant.

Redox parameters for mine pool water are highly variable. Reducing conditions are indicated by elevated dissolved iron and manganese in deeper, undisturbed mine pool waters. However, the concentrations are much lower in some shallow waters and in

borings where injection of chat or chat fines has occurred. These waters tend to exhibit more oxidizing conditions, with relatively low iron and manganese, and dominance of nitrate over ammonia (e.g. SMB3 and MMB2, wells active in the Sooner Pile injection pilot study).

The SMCLs for sulfate and manganese are exceeded in 19 mine pool locations. The SMCL for TDS is exceeded in 18 mine pool locations. The SMCL for fluoride is exceeded in 14 mine pool locations, and the SMCL for iron is exceeded in 13 mine pool locations. The MCL for fluoride is exceeded in MP06.

### 7.2.3 Roubidoux Aquifer

General chemistry parameters for the Roubidoux are provided in **Table 7-6**. The groundwater of the Roubidoux aquifer is a mixed chemistry, dominated by the cations calcium and magnesium and by the anions bicarbonate and sulfate. The TDS is much lower than the mineralized Boone and mine pool, typically between 200 and 300 mg/L, although it has been observed to be as high as 1,080 mg/L in Quapaw #5. The exceptions to the general chemical signature have been wells Miami #1, Miami #3, Miami #11, and RWD7 #2, all of which had more sodium presence, and even dominance in the case of RWD7 #2. The wells cited in **Section 7.1.3** as historically being identified as impacted by mine pool water have shown the most elevated sulfate compared with other Roubidoux wells. This, along with elevated trace metals, has been the main chemical parameter cited as evidence of mine water impacts in these wells. The distribution of chemistry in the Roubidoux is shown using Stiff diagrams (explained at the beginning of **Section 7.2**) on **Figure 7-4**.

Redox data are not complete for the Roubidoux wells, but the data that exist suggest more oxidizing conditions than in the Boone aquifer. This is based mainly on the relatively low iron and manganese of Roubidoux samples; nitrate, ammonia, sulfide, and ORP data are not available. DO data are not consistent enough to be used to evaluate redox. It is assumed that iron concentrations in the Roubidoux are controlled by precipitation of amorphous iron hydroxides such as ferrihydrite.

## 7.3 Trace Metals

Samples for the analysis of trace metals were collected during each sampling event. All of the samples were filtered in the field, so the analytical results are for dissolved metals. The trace metal analytical results from each sampling event are provided in **Tables 7-7** and **7-8**, and **7-9** for the Boone aquifer, mine pool, and Roubidoux aquifer, respectively. Summary statistics for the trace metals data from the Boone aquifer and mine pool 2009 sample results are provided in **Table 7-10**. Only the 2009 data are discussed in the following sections because of the lack of adequate Boone aquifer data prior to 2009, and because many of the mine pool locations were not sampled prior to 2009. However, all sample results from sampling events performed since 2007 in the Boone aquifer and mine pool are provided in **Tables 7-7** and **7-8**. Roubidoux aquifer data go back as far as 1996.

The trace metals aluminum, antimony, barium, beryllium, chromium, cobalt, copper, mercury, nickel, selenium, silver, thallium, and vanadium were either not detected in any sample, not detected frequently, or were not detected at concentrations of concern. There was a single thallium detection that exceeded the MCL in SMB6 during April 2008.

Aluminum is detected in several mine pool locations, including exceedences of the SMCL in locations OCC3 and MP04, and in one sample each from RMB3 and MP06. Aluminum is not frequently detected in the Boone aquifer. Roubidoux aquifer samples were not analyzed for aluminum, barium, beryllium, cobalt, copper, molybdenum, silver, and vanadium. Concentrations of other trace metals were either non-detect or below the concentrations observed in the Boone aquifer and mine pool samples.

The trace metals cadmium, lead, and zinc are COCs for the site. Arsenic is detected frequently at concentrations exceeding the MCL. These are the trace metals for consideration when examining the groundwater and mine water chemistry at the site. The following sections discuss these four metals. Concentrations for trace metals are typically much lower than general chemistry parameters and, therefore, are expressed in micrograms per liter (µg/L).

### 7.3.1 Boone Aquifer

Trace metals analytical results for the Boone aquifer are provided in **Table 7-7**. Cadmium and lead are detected infrequently in the Boone aquifer. Based on previous studies, the analytical parameters iron, sulfate, and zinc have been used to characterize mine water contamination. **Figure 7-6** shows the analytical results for iron, sulfate, and zinc, as well as arsenic (because it exceeds the MCL of 10 µg/L in a number of locations), and cadmium and lead (COCs for OU4) in the Boone aquifer wells.

Arsenic is detected in 12 of the 20 Boone aquifer wells. Arsenic concentrations range from not-detected to 67.6 µg/L and exceed the MCL in all samples collected from BMW02, BMW07, BMW08, BMW09, and BW06. Arsenic exceeds the MCL in one sample from BMW01, BMW11, BMW12, and BMW14 (all in October 2009).

Cadmium is detected in one sample, at a concentration of 7.0 µg/L, in the April 2009 sample from BW16. This result exceeds the MCL of 5 µg/L.

Lead is detected in three samples (one from BMW02 and two from BW13). The highest lead concentration is 2.7 µg/L in the sample collected from BMW02 in October 2009.

Zinc is detected in all but one Boone aquifer well (BMW14 is the lone exception). Where detected, zinc concentrations range from 21.9 to 9,410 µg/L. The zinc concentrations are highest in wells within the mining field. The SMCL of 5,000 µg/L is exceeded in BMW02, BMW09 (August 2009), and BW06.

### 7.3.2 Mine Pool

Trace metals analytical results for the mine pool are provided in **Table 7-8**. **Figure 7-7** shows the arsenic, cadmium, iron, lead, sulfate, and zinc concentrations in the mine pool locations.

Arsenic is detected in all but 4 of the 21 mine pool locations. Arsenic concentrations range from not-detected to 69.3 µg/L. Arsenic is not detected in locations MP17, SMB3, SMB5, and SMB9. Arsenic concentrations are less than the MCL in OCC3 and SMB6. Arsenic exceeds the MCL in all samples collected from FCB2, MD2, MP04, MP05, RMB3, RMB4, and SMB8. Arsenic exceeds the MCL in one sample from FCB3 (October 2007), MP06 (October 2009), MP20 (July 2009), SMB2 (July 2007), and SMB7 (July 2008).

Cadmium is detected in 13 mine pool locations. Cadmium concentrations range from not-detected to 275 µg/L. Cadmium is not detected in FCB3, MD2, MP05, MP06, MP17, MP20, SMB8, and TMB2. Cadmium exceeds the MCL in all samples collected from OCC3, SMB2, SMB3, SMB6, SMB7, and SMB9.

Lead is detected in 14 mine pool locations. Lead concentrations range from not-detected to 171 µg/L. Lead is not detected in LMB2, MD2, MP05, MP06, MP17, MP20, and RMB3. Lead concentrations are less than the MCL in FCB3, MP04, OCC3, RMB4, TMB2, and TMB3. Lead exceeds the MCL in all samples collected from SMB3 and SMB9. Lead exceeds the MCL in one sample from SMB8 in July 2009.

Zinc is detected in all of the mine pool locations. Zinc concentrations for individual samples range from not-detected to 58,800 µg/L. The SMCL was exceeded in at least one sample collected from FCB2, MP06, RMB4, SMB3, SMB5, and TMB3. The SMCL was exceeded in all samples collected from LMB2, MP04, MP05, OCC3, SMB2, SMB6, SMB7, SMB8, and SMB9.

### 7.3.3 Roubidoux Aquifer

Trace metals for the Roubidoux aquifer are provided in **Table 7-9** for comparison with Boone aquifer and mine pool samples. Only dissolved samples are shown, to be more consistent with the more recent Boone aquifer and mine pool samples. Arsenic ranged from 2 to 11 µg/L. The MCL for arsenic was exceeded by one 11 µg/L sample from Quapaw #5. This was the only one of 13 samples from that well that exceeded the MCL. Cadmium was detected in only two Roubidoux samples, both from Commerce #5, and both at the detection limit of 2 µg/L. Lead was detected in Miami #1 (two samples) and the Fernandez well (five samples), with concentrations ranging from 5 to 56 µg/L. Two of the seven detections exceeded the MCL for lead, both from the Fernandez well. Lead was not detected in this well after 2004. Zinc detections ranged from 5 to 464 µg/L, all well below the SMCL of 5,000 µg/L. The trace metal concentrations in the Roubidoux aquifer are clearly below those of the Boone aquifer and mine pool because of the non-mineralized nature of the formation. In addition, the wells sampled are water supply wells that are open to higher quality water zones.

### 7.3.4 Effects of Small Colloids on Metals Analytical Results

During sampling performed for the Sooner Chat Pile injection pilot study during 2008, discrepancies were noticed in the data for the redox parameters (ORP, pH, ammonia, nitrate, nitrite, sulfide, iron, and manganese). It was recommended that samples be collected for dissolved metals using 0.10-micron filters to compare with the analytical results from the samples collected using 0.45-micron filters. The data would be used to assess the potential that small colloids, capable of passing through the 0.45-micron filters, were resulting in elevated metals analytical results. This sampling was performed on a subset of the sampling locations during July 2009.

The analytical results for the locations where dissolved metals samples were collected using the 0.10- and 0.45-micron filters are provided in **Table 7-11**. The data show no significant difference in the analytical results from the samples collected using the 0.10- and 0.45-micron filters. Based on these data, it does not appear that small colloids are affecting the analytical results obtained using the 0.45-micron filters.

## 7.4 Discussion and Interpretation of Results

The following sections provide a discussion and interpretation of the general chemistry, redox conditions, and trace metals results.

### 7.4.1 General Chemistry

Representative samples from locations in the Boone aquifer, Roubidoux aquifer, and mine pool chemistries are compared on the Piper diagram on **Figure 7-1**. Using the same data set, summary statistics are compiled for the different water sources in **Table 7-12**. Locations with pH above 10 (BMW4, BMW6, and BMW14) were excluded, as these samples are not considered representative of aquifer conditions.

The Boone aquifer within the mining field and the mine pool are dominated by calcium and sulfate. By contrast, the Roubidoux samples show a stronger magnesium and bicarbonate presence. Away from the most extensively mined areas the Boone aquifer water chemistry is more variable and can be very similar to that of the Roubidoux aquifer. The mine pool samples strongly overlap the Boone samples in the mined areas, indicating significant intermixing of mine pool water and Boone aquifer groundwater in many areas. A plot of TDS versus pH is provided on **Figure 7-8**, and shows the distinctly lower TDS in the Roubidoux compared to the other water sources. The Boone and mine pool locations away from the major mining locations plot closer to Roubidoux data on **Figure 7-8**. A related plot that highlights the separation between these groups further is presented on **Figure 7-9**, where TDS is plotted against bicarbonate (as a percentage of anion equivalents). On this figure, the lower TDS wells plot with higher percentages of bicarbonate, where the more highly mineralized samples plot in the upper left of the figure. Elevated concentrations of trace metals are associated with the same samples.

Well BW13, with its low TDS and sodium-bicarbonate chemical composition, was chosen to represent the non-mineralized Boone aquifer in the geochemical simulations. In reality, the non-mineralized Boone aquifer chemistry is likely variable and could tend more toward that of the Roubidoux aquifer, but this chemistry provides a clear contrast to mine pool water to easily identify influences of mine pool water during simulated transport (see **Section 10** for details).

### 7.4.2 Redox Conditions

The redox-sensitive parameters used to assess redox state in the groundwater were a mixture of field parameters (ORP, DO) and laboratory analysis (nitrate/ammonia, iron, manganese, and sulfide). The results are discussed in detail in **Sections 7.1** and **7.2**. Each of these data is not always consistent with the redox condition, but the assessment of redox was based on the propensity of data at each location. Using this method, it was determined that redox conditions in the mine workings and in the Boone aquifer within the mining field are generally reducing. Significant concentrations of dissolved iron and manganese, along with negative ORP values and DO less than 1 mg/L are typical of these waters. Exceptions to this rule include the Sooner Chat Pile mine pool borings, where active injection is taking place.

At some distance away from the mine workings, the Boone aquifer is generally more oxidizing, with much lower levels of dissolved iron and manganese, and more elevated

ORP and DO values. The lesser amount of natural sulfide mineralization in these areas is the likely explanation for the redox difference. Amorphous iron hydroxides are assumed to be in equilibrium with the groundwater in these areas. These minerals, along with carbonates and clay minerals, provide adsorption surfaces to attenuate trace metals, as discussed in the transport simulations in **Section 10**.

The Roubidoux aquifer is more oxidizing, similar to the Boone aquifer in locations away from the mine workings.

### 7.4.3 Trace Metals

The trace metals discussed in this study, arsenic, cadmium, lead, and zinc, are all associated with the sulfide deposits in the mineralized sections of the Boone Formation. Arsenic is a common minor component of pyrite, the common iron sulfide mineral. Sulfides of zinc and lead were the principal ore minerals (sphalerite and galena, respectively), and cadmium is a common minor component of sphalerite. Because these sulfide deposits are not found in significant quantity away from the mined areas, the groundwater in these areas of the Boone and Roubidoux aquifers do not show significant quantities of these metals. Also, areas of the Boone aquifer that do contain sulfides but were not mined would not be expected to have high trace metals concentrations. This is because the sulfides have not been exposed to the atmosphere or to oxygen-rich waters. The metals would, therefore, be stable in their original sulfide form.

As mining activity exposed the ore minerals and other sulfides to the atmosphere, a portion of the sulfides was dissolved by reaction of sulfide with oxygen. Though the reaction is complicated, with several intermediate steps, the overall result is that sulfide is oxidized to sulfate, which is more soluble than the original sulfide, and thus sulfate is released into solution along with the associated metals. The reaction also releases acidity to the water, although the carbonate host rock in the Tar Creek area is a strong pH buffer and, therefore, the resulting pH is only mildly acidic. The result is the mine pool chemistry, with pH between 6 and 7, rich in calcium (and in some cases also magnesium) from surrounding carbonates and with dominant sulfate from the dissolution of the sulfides. These waters are rich in dissolved iron and manganese, along with the associated trace elements. The redox conditions are anaerobic, preventing the oxidation of iron, which only occurs when the mine rooms are actively disturbed, such as during pilot injection activities.

By contrast, the areas away from the mines are subaerobic to aerobic, in which iron is oxidized from the soluble $Fe^{2+}$ to the insoluble $Fe^{3+}$ state. Its concentration in the non-mineralized Boone and Roubidoux aquifers is controlled by precipitation of iron oxyhydroxides. The geochemistry of the chat, chat fines, and the injection process is discussed and modeled in **Section 10**.

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SECTION 8

# Surface Water Flow and Mine Pool Discharge

## 8.1 Overview

A stage-discharge rating curve is a graphical presentation of the relationship between water surface elevation or stage, and discharge or flow. Such curves have been developed for surface water gaging stations established in Tar (TC-US), Lytle (LC-30), and Quapaw (QC-DS) Creeks. The rating curves are based on data collected between December 21, 2009, and June 2, 2010. The gage locations are shown **Figures 6-9** and **6-10**.

The surface water rating curves were developed from periodic flow measurements made during base- and high flow conditions. At TC-US and LC-30, flow (i.e., velocity and depth) was measured directly either by wading or from a bridge deck. Because there is not a bridge near the mouth of Quapaw Creek, synoptic stage measurements from two locations (QC-US and QC-DS) were used to compute water surface slopes for input to a HEC-RAS hydraulic model. The model was used to compute flow associated with a given water surface slope and stage. This procedure was used to generate data points on the high end (stage and flow) of the rating curve for high flow conditions at QC-DS. When Quapaw Creek could be safely waded, flow was measured directly at QC-DS.

As presented in **Section 6.8**, measurements during high surface water flows and elevated mine pool conditions were the primary objective of this study. The goal being to verify or revise previously developed mine pool elevation discharge rating curves, particularly mine pool discharge associated with mine pool elevations above 802.0 feet amsl. As a result, greater confidence can be placed on such an important quantitative tool. Further details regarding the objectives and methods of the surface water monitoring program are presented in **Section 6.8**.

## 8.2 Surface Water Stage-discharge Rating Curves

The measured stage (elevation) and discharge (flow) data used to generate the surface water stage-discharge rating curves is provided in **Table 8-1**. The rating curves are shown graphically on **Figures 8-1**, **8-2**, and **8-3** for TC-US, LC-30, and QC-DS, respectively. The highest flow, and associated water surface elevation, measured at these locations for the purpose of developing the surface water stage-discharge rating curves were:

- 697 cfs (807.35 feet amsl) at TC-US
- 504 cfs (807.18 feet amsl) at LC-30
- 210 cfs (798.97 feet amsl) at QC-DS

The TC-US rating curve is based on eight data points; LC-30 and QC-DS are based on nine data points. Trend lines were plotted through the data points using linear, logarithmic, polynomial, and power functions to achieve the best-fit curve. The best-fit curve equations are displayed on the figures. The rating curves fit the raw data very well, and a wide range of flows and elevations are represented at each gaging station.

## 8.3 Surface Water Stage and Flow Hydrographs

### 8.3.1 Stage (Elevation)

Charts illustrating the 10-minute interval, water surface elevation data recorded by the pressure transducers at TC-US, LC-30, and QC-DS are shown on **Figures 8-4, 8-5,** and **8-6** respectively. The data span late December 2009 through May 2010; except at QC-DS, where, as a result of problems associated with freezing conditions, the data begins in mid-February 2010. Also plotted on these figures are instantaneous, staff gage readings, measured periodically during site visits by field personnel.

The pressure transducer data correspond very well to the manual staff gage readings, revealing quality data from the pressure transducers. Summary statistics of stage data are provided in **Table 8-2**.

### 8.3.2 Flow Hydrographs

Stage data was converted to discharge (flow) using the surface water stage-discharge rating curves presented above and shown on **Figures 8-1, 8-2,** and **8-3**. Hydrographs (flow versus time) for TC-US, LC-30, and QC-DS are shown on **Figures 8-7**, **8-8**, and **8-9**. The hydrograph from the USGS Tar Creek gage near Commerce, Oklahoma, at Highway 69 (Site No. 07185090) is shown on **Figure 8-10**. **Figures 8-11**, **8-12**, **8-13**, and **8-14** illustrate the same hydrographs plotted on a logarithmic scale to better illustrate the low flow values. Summary statistics of the flow data are provided in **Table 8-2**.

For a comparison of mean monthly flow conditions in Tar Creek, measured at the USGS gage at Highway 69, between the 2010 study period and the period of record for the gage, refer to **Table 8-3**. Although the available period of record for the months of January through May only spans 4 years, the information in **Table 8-3** reveals that surface water flows measured during the study period were comparable to the average monthly flows during 2005 through 2009. The average of the January through May mean monthly flows for the 5-ear period of record is 60 cfs, compared with 58 cfs for the same months in 2010.

### 8.3.3 Composite Flow Hydrograph

Individual hydrographs from TC-US, LC-30, and QC-DS were composited into a single hydrograph by adding synoptic flows from each. **Figure 8-15** is a plot of the composite hydrograph and the hydrograph measured at Highway 69. **Figure 8-16** is the same data with flow plotted on a logarithmic scale.

The two hydrographs are similar, as expected, given the proximity of the upstream gages to the downstream gage at Highway 69. The difference is attributable to a combination of factors that include  mine pool contribution to surface water in the Douthat area, within the 3.6-square- mile area between the gages; local runoff and groundwater recharge to the stream channels between the upstream and downstream gages; and factors that influence the shape and routing of the hydrographs, such as peak attenuation as a result of variations in availability and access of flows to overbank storage; channel and floodplain hydraulic roughness and constrictions; flow path length and slope; and rainfall distribution.

The difference between the composite and downstream hydrographs is evaluated further in **Section 8.6**, where the mass balance computation of mine pool discharge to surface water is

presented. Because the information in **Section 8.6** relies heavily upon the composite hydrograph during individual runoff events; data from TC-US, LC-30, and QC-DS are plotted with the resultant composite hydrograph during the six most significant runoff events of the study period on **Figures 8-17**, **8-18**, **8-19**, **8-20**, **8-21**, and **8-22**. These figures reveal that the composite storm hydrographs are predominately made up of flows from TC-US and LC-30; however, flow from QC-DS is not insignificant. Some variation in the time-to-peak among the three individual hydrographs can be observed; however, it does not vary significantly.

## 8.4 Mine Pool Elevation

Mine pool elevations, measured every 10 minute between December 21, 2009, through May 25, 2010, are shown on **Figure 8-23** for the following monitoring wells: MP02, MP03, MP04, MP14, and RMB4. Refer to **Figures 6-9** and **6-10** for the location of these wells.

MP02 is located in the Blue Goose air shaft. Mine pool elevations from this well were used in previous efforts to develop the mine pool discharge rating curves shown on **Figures 3-2** and **3-3**. Detailed plots of MP02 data during significant precipitation events are included in **Section 8.6**. The updated mine pool discharge rating curves presented in **Section 8.6** are based on mine pool elevation data from MP02.

Summary statistics of the mine pool elevations shown on **Figure 8-23** are included in **Table 8-4. Figure 8-23** reveals what are believed to be short periods of erroneous data for MP14 that occurred during elevated mine pool events on March 25, May 14, May 15, and May 20, 2010. In some instances, MP14 data exceeded the rim elevation (807.78 feet amsl) of the well by more than 1 foot. Although some wells can overflow their rim under the right circumstances, a 1-foot column of water above the rim is not likely. Aside from the magnitude of temporary spikes, the timing of the elevation rise and fall was similar to the other wells. Because the four data spikes are considered erroneous, the y-axis scale on **Figure 8-23** was truncated to 805.5 feet amsl. Summary statistics for MP14 are excluded from **Table 8-4**; however, it can be seen on **Figure 8-23** that MP14 elevations were consistently about 0.2 foot above MP02 elevations.

For any given statistical parameter in **Table 8-4**, values between MP02, MP03, MP04, and RMB4 differ less than 1 foot. The median and average mine pool elevation measured at MP02 during the study period was 802.52 and 802.54 feet amsl, respectively.

## 8.5 Precipitation

**Table 8-5** provides a summary of precipitation data collected at the Oklahoma Mesonet station (OK-1) in Miami, Oklahoma (see **Figure 6-6**). This long-term, rainfall data collection site is located at the southern end of the Tar Creek watershed. The data is "liquid" precipitation that accounts for snowfall.

The 2010 January through May study period experienced monthly rainfall depths slightly below the long-term average. The 2010 January through May monthly total was 15.75 inches. The comparable, 5-month total of monthly averages from 1917 through 2000 was 17.19 inches; and 21.45 inches from 1994 through 2004.

Although the monthly and 5-month total precipitation data provide insight to 2010 conditions relative to the long-term record; data from individual events are used to update the mine pool discharge rating curves. The dates and precipitation depths associated with the six largest events during the study period used to compute mine pool discharge to surface water are:

- February 21, 2010: 0.62 inch
- March 21, 2010: 1.14 inches
- March 25, 2010: 1.73 inches
- April 5, 2010: 0.58 inch
- May 13, 2010: 3.77 inches
- May 19, 2010: 2.11 inches

In **Section 8.6**, hourly precipitation data from the above events are plotted in conjunction with the surface water hydrographs and mine pool elevation data.

Each of the six events occurred as rainfall; however, stream flows and mine pool elevations during the March 21 and March 25 events were influenced by snowmelt. Beginning just after midnight on March 20, rainfall began to shift to freezing rain and eventually snow. By about 8 a.m. on March 20, approximately 7 to 8 inches of wet snow had accumulated on the ground. Snowmelt began the afternoon of March 21 and continued into the morning of March 22. By the evening of March 22, approximately all snow had melted, although additional rainfall occurred during the snowmelt process. The result was significantly elevated surface water flows and mine pool water, leading into the next precipitation event that occurred shortly thereafter on March 25. It should be noted that the computation of overland runoff described below accounts for preceding stream flow conditions, even if they are elevated above base flow.

# 8.6 Mine Pool Discharge to Surface Water

## 8.6.1 Solving the Mass Balance Equation for Mine Pool Discharge to Surface Water

As previously introduced in **Section 6.8**, a mass balance approach was used to compute the mine pool discharge to surface water, $Q_{mine\ pool}$, for individual runoff events, *i*, so that a mine pool elevation and discharge data point could be added to the mine pool discharge rating curve for each event, *i* . This was accomplished using the following equation:

$$(Q_{mine\ pool})_i = (Q_{TC\ d/s})_i - (Q_{TC\ u/s} + Q_{LC\ u/s} + Q_{QC})_i - (Q_{runoff})_i$$

where:

$Q_{TC\ d/s}$ = Tar Creek discharge (flow) downstream of the mine pool contribution to surface water (USGS gage at Highway 69);

$Q_{TC\ u/s}$ = Tar Creek discharge upstream of the mine pool contribution to surface water (TC-US);

$Q_{LC\ u/s}$ = Lytle Creek discharge upstream of the mine pool contribution to surface water (LC-30);

$Q_{QC}$ = Quapaw Creek discharge (QC-DS); and,

$Q_{runoff}$ = overland flow runoff from precipitation between the upstream and downstream surface water gages.

Units of cubic feet per second were used for each variable. An associated mine pool elevation was determined for each(cfs) computed discharge so that a plotting point can be added to the mine pool discharge rating curve. A stepwise description of the mine pool discharge computation is provided here:

1. From the surface water continuous stage and flow hydrographs, the significant runoff events were identified. Six significant runoff events occurred during the study period as described in **Section 8.5**.

2. For each runoff event, *i*, the following data were plotted: 1) the composite hydrograph from the TC-US, LC-30 and QC-DS gages ("upstream" gages); 2) the hydrograph from the USGS Tar Creek gage at Highway 69 ("downstream" gage); 3) the mine pool elevations from MP02 during the runoff event; and 4) hourly precipitation during the runoff event measured at the Oklahoma Mesonet station (OK-1) in Miami, Oklahoma. These plots are included as **Figures 8-24**, **8-25**, **8-26**, **8-27**, **8-28**, and **8-29**.

3. For each surface water hydrograph, the volume of flow (i.e., area under the curve) was computed for each event, *i*, and divided by the duration of runoff. This equaled the average flow (cfs) during each runoff event, *i*. These values were used in the above equation for $(Q_{TC\ d/s})_i$ and $(Q_{TC\ u/s} + Q_{LC\ u/s} + Q_{QC})_i$.

4. The average and maximum mine pool elevations were determined for each event, *i*.

5. $(Q_{runoff})_i$, was computed as described in the paragraphs below. Then, mine pool discharge, $(Q_{mine\ pool})_i$, was computed for each event using the mass balance equation. Values of $(Q_{mine\ pool})_i$ were plotted versus mine pool average and maximum elevations on the mine pool discharge rating curve, which provides the contribution of mine pool water to surface water as a function of mine pool elevation.

At the onset of the surface water monitoring program, it was anticipated that a site-specific rainfall-runoff model would be available to compute individual event runoff volumes for the 3.6-square-mile basin between the upstream (TC-US, LC-30, and QC-DS) and downstream (USGS Tar Creek gage at Highway 69) surface water gages. Because the model was not available in time for this report, rainfall runoff estimates from the drainage area between the surface water gages, $(Q_{runoff})_i$, was computed using precipitation data from the Miami, Oklahoma, Mesonet station in conjunction with flow data measured at the upstream surface water gages. This was done as follows:

1. For each event, *i*, the precipitation volume upstream of TC-US, LC-30, and QC-DS was computed by multiplying the event precipitation depth (inches) times the drainage area (31.7 square miles) upstream of the three gages, making the necessary unit conversions. The event duration, defined by the shape of the runoff hydrographs, was divided into the rainfall volume to compute an average precipitation flow rate in cubic feet per second, $x_i$. The average flow rate (i.e., area under the hydrograph divided by the runoff duration) from the composite hydrograph of three surface water gages during event, *i*,

was divided by the average precipitation flow rate, $x_i$, to generate an event-specific, runoff ratio, $y_i$. That is, the portion of the total event precipitation that occurred over 31.7 square miles that manifested itself as surface water flow at the three gages serving the 31.7-square-mile drainage area.

2. Using the same approach, the average precipitation flow rate, $z_i$, was computed for the 3.6-square-mile basin between the three upstream gages and the USGS Tar Creek gage at Highway 69. This value, $z_i$, was then multiplied by the runoff ratio computed from the 31.7 square mile basin, $y_i$, to compute $(Q_{runoff})_i$, for each event, $i$.

The advantage of the above method used to derive event-based, average precipitation runoff rates is that it is based on measured runoff rates within the watershed (i.e., storm hydrographs), which account for real-time local land use, cover types, and antecedent rainfall and soil moisture conditions. Also, the method does not rely on any estimated parameters for model input or simulation.

Computed values for each variable in the mass balance equation, per storm event, are included in **Table 8-6**.The runoff ratio values, $y_i$, and average and maximum mine pool elevations measured at MP02 are included as well. The six computed mine pool discharge rates ranged from 9 to 149 cfs; the latter occurring when the average and maximum mine pool elevations during the storm event were 803.22 and 804.37 feet amsl, respectively.

### 8.6.2 Updated Mine Pool Rating Curves

**Figure 8-30** shows the original Parkhurst rating curve (see **Figure 3-2**) populated with data generated during this study. This includes an unpublished data point from Parkhurst obtained from ODEQ (Cates, personal communication, 2009). **Figure 8-31** shows the mine pool rating curve from various sources (see **Figure 3-3**), updated with the same data plotted on **Figure 8-30.**

Mine pool discharge rates computed during this study are referenced on **Figures 8-30** and **8-31** as "Hydrograph Volumetric Method" data points. The term refers to the method of computation for deriving the mine pool discharge rates. This method was required to account for hydrograph peak attenuation that occurs as hydrographs are routed downstream. The volumetric approach is based on a known quantity of water passing the gage locations over a measured duration, depicted as a flow hydrograph. Although the shape of the hydrograph changes from location to location as flow translates downstream, the method lends itself well to the mass balance approach because no matter what extent of peak attenuation occurs between the upstream and downstream gage locations, the volume of water passing the upstream gages during these runoff events must eventually pass the downstream gage. The difference would be equivalent to mine pool contribution and local runoff between the gages. Because the mine pool elevations are dynamic during these events, both the average and maximum elevations are plotted on the updated rating curve.

It is important to note that during the runoff events of May 13 and May 19, the composite hydrograph peak exceeded that of downstream gage at Highway 69. Strict interpretation of those occurrences would suggest the creeks in the Douthat area became losing reaches during those significant runoff events. During the runoff event of May 25, the composite and downstream hydrographs peaks were nearly identical; again, strict interpretation would suggest no contribution from mine pool or local runoff sources during that event.

This is known to not be the case, as it is counterintuitive and contrary to field observations during significant runoff events when mine pool discharge to surface water was observed at many locations in the Douthat area. In fact, what these particular hydrographs exhibit are attenuation of peak flows, because the volume of water under the downstream hydrograph is in fact greater than that of the upstream composite hydrograph, the instantaneous peak was just not as high.

**Figure 8-32** shows the updated Parkhurst mine pool rating curve with two graphically fit curves. The red curve is fit through the mine pool discharge values plotted against the average mine pool elevations during each of the six runoff events. The blue curve is fit through the mine pool discharge values plotted against the maximum mine pool elevations during each of the six runoff events. Both curves are shown to bracket the mine pool discharge associated with these higher mine pool elevations.

Also included on **Figure 8-32** is the frequency of occurrence associated with different mine pool elevations, based on the mine pool frequency curve shown on **Figure 9-7**. An analysis of data presented in these two figures reveals that mine pool discharge exceeds 5 to 6 cfs only 25 percent of the time; and, approximately 50 cfs 10 percent of the time. Similarly, mine pool discharge that exceeds approximately 100 cfs occurs less than 2 percent of the time. The annual volume of mine pool discharge is 3,755 ac-ft based on the blue curve, or 6,934 cfs based on the red curve shown on **Figure 8-32**. Parkhurst (1988) estimated the annual volume of mine discharge as 3,400 ac-ft using the rating curve shown on **Figure 3-2**.

## 8.7 Summary of Key Findings

Based on data collected between late December 2009 through May 2010, some key findings include:

- Tar, Lytle and Quapaw Creeks exhibited flashy stream flows, commonly experiencing little to no flow, subject to rapid increases into the hundreds of cubic feet per second in response to precipitation, with relatively quick recession.
- During the six significant runoff events of the study period, the initiation of mine pool elevation rise in the Douthat area occurred at essentially the same time as stage/flow increases in Tar and Lytle Creeks along E 30 Rd. This can be observed on **Figures 8-24**, **8-25**, **8-26**, **8-27**, **8-28**, and **8-29**. For a closer inspection of synoptic mine pool (MP02) and surface water elevations in Tar and Lytle Creeks during these events, refer to **Figures 8-33**, **8-34**, **8-35**, **8-36**, **8-37**, and **8-38.** The rapid response of the mine pool is indicative of fully saturated mine workings in the Tar and Lytle Creek watersheds. The underground mine workings in this area can be thought of as a fully saturated, closed-pipe system; such that incoming water to any point along the system results in a rapid increase in water level throughout the system.
- Except for very brief periods, the surface water elevations in Tar and Lytle Creeks remained above the mine pool elevations measured at MP02 (see **Figures 8-33**, **8-34**, **8-35**, **8-36**, **8-37**, and **8-38**). This indicates the surface water gage locations along E 30 Rd, TC-US, and LC-30 were placed at locations suitable for minimizing or excluding contributions from the mine pool.

- The upward-trending "hook," beginning at mine pool elevations of approximately 805.5 feet amsl, observed in the previously developed mine pool rating curves was supported by data collected during this study.
- Runoff event-based, average mine pool discharge rates, and instantaneous peak elevations indicate that the slope of the updated mine pool discharge rating curve begins to flatten out when mine pool elevations exceed approximately 803.5 feet amsl. Mine pool discharge rates associated with elevations of 803.5 feet amsl, range from about 60 to 120 cfs.
- Based on the updated mine pool discharge rating curve (see **Figure 8-32**), and mine pool elevation frequency data (see **Figure 9-7**), discharge rates equaling or exceeding approximately 65 to 140 cfs occur no more than 2 percent of the time.

SECTION 9

# Groundwater Modeling

One of the primary activities of the HCS effort is to support the development of a three-dimensional groundwater model of the Tar Creek site. This modeling tool was used to better define the water budget of the hydrogeologic system at the site, including the interaction between the mine workings and the surrounding Boone aquifer. The key findings of the field efforts performed to support the HCS as they pertain to the characteristics of the groundwater flow system at the site are discussed below. This is followed by a description of the construction and calibration of the groundwater flow model of the site, as well as the results of the groundwater modeling analysis performed.

## 9.1 Site Groundwater Conditions

This section presents the general characteristics of the groundwater flow systems at the site. The information contained herein results from the collection and analysis of a large quantity of hydrogeologic data during implementation of the field effort associated with the HCS (see **Section 6**). These field activities focused on collecting data needed to improve the understanding of both the groundwater and surface water systems at the site. In addition to the site characterization data collected as part of the HCS, available information from the literature was also collected and integrated into this analysis.

### 9.1.1 Groundwater Flow

Groundwater flow at the Tar Creek site occurs primarily as bedrock flow through a complex suite of aquifer materials and is complicated by the presence of an extensive network of mine workings extending through a large portion of the Boone aquifer. The primary sources of recharge to the aquifer system include deep percolation of precipitation, leakage from surface streams, and groundwater underflow from upgradient areas in Kansas. Primary discharge mechanisms include groundwater pumping primarily from the deeper Roubidoux aquifer, and discharge to surface seeps and other surface water bodies. Additional groundwater discharge to the land surface also occurs through human-made structures, such as air shafts and exploratory borings, which provide conduits for flow during high flow periods when the mine pool is under artesian conditions.

Groundwater flow directions at the site are driven by several major site features: the Spring River to the east, the Neosho River to the southwest, and the mine workings within the Boone aquifer. A groundwater contour map constructed using water level data collected during average hydrologic conditions and measured in wells screened in the Boone aquifer, as well as mine pool monitoring locations is presented on **Figure 9-1**. This map shows that groundwater flows into the mine pool from the surrounding Boone formation from the east and west, and discharges to the south at Douthat. Also apparent on **Figure 9-1** is that a groundwater divide is present that parallels the Spring River, with groundwater on the eastern side of the divide flowing toward the river and groundwater on the western side of the divide flowing toward the mine workings. This divide is sustained by deep percolation of precipitation, which then flows east and west toward the Spring River and the mine

workings, respectively. The presence of the mine workings create an extensive area of relatively uniform groundwater levels, resulting from the extremely high hydraulic conductivity of the mine workings. Over most of the site, groundwater levels adjacent to the mine pool are higher than the mine pool elevation, and groundwater flows into the mine pool. In the southern portion of the mining field, near the Douthat Bridge, groundwater levels are lower than the mine pool elevation, and mine pool levels become artesian, resulting in mine pool water discharging both into Tar Creek and other surface seeps, as well as into the adjacent Boone aquifer. The mine pool itself also apparently forms a (convergent) groundwater divide, in that groundwater travels toward it from both east and west according to the contours on **Figure 9-1**. Finally, groundwater in the western portion of the site flows to the southwest toward the Neosho River.

As a result of extensive regional groundwater pumping from the Roubidoux aquifer, groundwater levels in the Boone aquifer are several hundred feet higher than those in the underlying Roubidoux aquifer. This creates a strong downward gradient between the Boone and the Roubidoux aquifers, but the quantity of flow into the Roubidoux aquifer is limited by the low permeability aquitard present between the two aquifers. This will be discussed more fully in the aquifer properties section below.

### 9.1.2 Water Level Trends

Groundwater elevations at the site primarily vary in response to pumping stresses and the timing of recharge events resulting from precipitation events. Water levels in the different aquifer units at the site are influenced by different hydraulic stresses. For instance, groundwater levels in the Boone aquifer are driven mainly by local stresses such as the deep percolation of precipitation and leakage from surface water bodies, as very little pumping occurs from this aquifer. Water levels in the deeper Roubidoux aquifer, on the other hand, are driven primarily by regional stresses such a regional groundwater production and region-wide water level trends.

A groundwater elevation hydrograph for a Boone monitoring well is shown on **Figure 9-2**. This hydrograph is for well BW16, which is located on the east edge of the Picher Field and is not significantly influenced by the presence of the mine workings. The hydrograph of a mine pool monitoring location, MP02, is included on this plot for direct comparison. The location of BW16 is shown on **Figure 9-3**. Water level data from the Boone monitoring wells at the site are limited as pressure transducers have only been installed since late 2008. However, available data suggest that water levels at the site vary seasonally by 6 or 7 feet, with the highest water levels occurring in the late spring. The lowest groundwater elevations occur in the late fall months. Groundwater in the mine pool observation point MP02 closely mirrors that in Boone monitoring well BW16, suggesting that similar hydraulic stresses drive changes in groundwater levels both in the mine pool and the Boone aquifer, and suggesting that the two are hydraulically well connected.

Another set of monitoring locations target water levels in the mine pool. **Figure 9-4** presents mine pool elevation data for five monitoring locations spread throughout the mining field. The locations of these five monitoring points are shown on **Figure 9-3**. These data also show that the variation in mine pool elevation throughout the mining field is relatively small, on the order of 0.7 foot, suggesting that the different portions of the mine workings are also hydraulically connected.

The groundwater level trends in the Roubidoux aquifer are shown on **Figure 9-5**. These data were collected from Miami Well No. 9, whose location is shown on **Figure 9-3**. It is clear from these data that the magnitudes of seasonal groundwater fluctuations in the Roubidoux aquifer are much greater than in the Boone aquifer, with seasonal fluctuations of between 15 and 18 feet. This is primarily a result of the greater quantities of pumping from the Roubidoux aquifer, which serves as the primary source of water supply in the area. Groundwater elevations in the Roubidoux aquifer tend to peak in the spring, and show the greatest declines in the fall. This trend is likely a result of the greater water demand, and associated pumping, over the summer months.

### 9.1.3 Interactions between Boone Formation/Mine Workings

The relationship between the mine pool and the Boone aquifer is complex, both spatially and temporally. This is because the mine pool surface is relatively flat compared with the gradient of the water table in the Boone aquifer. The result is that, under base flow conditions, the mine pool acts as a drain in the northern portion of the mining field, where groundwater levels are higher than the mine pool. Moving south, the groundwater levels in the Boone aquifer begin to approach the elevation of the mine pool and, eventually, in the Douthat area, the mine pool surface exceeds the level of the groundwater table in the Boone aquifer, resulting in mine pool discharge into the Boone aquifer. During wet weather events, rises in mine pool elevation on the order of 3 to 5 feet or more occur very rapidly. As the mine pool elevation rises, the portion of the mine pool that exceeds the level of the surrounding groundwater increases, and both the area over which outflow occurs, and the overall rate of outflow from the mine pool into the Boone aquifer increases. Following the precipitation event, as mine pool levels trend downward toward base flow levels, the rate of mine pool outflow also progressively decreases until base flow conditions return.

### 9.1.4 Aquifer Properties

During the HCS field program, aquifer tests were performed on three separate monitoring wells to acquire site-specific estimates of aquifer transmissivity and storage properties for the Boone and Roubidoux aquifers. Two wells completed in the Boone Aquifer were included in the testing program: BMW12 and BMW13. One well, Picher No. 7, owned and operated by the City of Picher, was also included in the aquifer testing program to acquire information on the Roubidoux aquifer.

Both step-drawdown and constant rate aquifer tests were conducted on the Boone aquifer wells. Step-drawdown tests were performed first, and the results of these tests were used to select an appropriate flow rate for the long-term constant rate test. During each test, water levels data were collected both manually and with electronic pressure transducers. Groundwater elevation data was collected during both the pumping and recovery phases of all tests. Where possible, nearby monitoring wells were also instrumented with pressure transducers to evaluate the magnitude of drawdown at varying distances from the pumping well. Results from the testing efforts are summarized below.

#### Boone Aquifer Testing Results

Wells were tested both outside of and within the core of the mining field. Results were used to evaluate the hydraulic characteristics in both areas. Key results from the aquifer testing are summarized below and included in **Appendix H**.

- The horizontal hydraulic conductivity in the Boone aquifer in the vicinity of BMW12 is 180 feet per day (ft/d). The horizontal hydraulic conductivity in the Boone aquifer in the vicinity of BMW13 is 36 ft/d. The higher hydraulic conductivity estimate obtained from the test on BMW12 could be a result of fracturing of the bedrock at that location associated with the nearby mine workings.
- The vertical hydraulic conductivity in the Boone aquifer as measured in the vicinity of BMW12 is 0.05 ft/d. The lack of response in any well, except the pumping well in the area of BMW13, precluded an independent measurement of vertical hydraulic conductivity in the BMW13 area.
- The only observation well to demonstrate a response to pumping during the aquifer test was BMW11, located approximately 15 feet away from BMW12, and with a screen interval 34 feet higher than BWM12. This is consistent with a very low bedrock vertical hydraulic conductivity that will tend to limit the quantity of mine water discharge through intervening strata. This suggests that the majority of the mine pool discharge to the surface occurs through mining-related conduits (e.g., air vents, exploratory boreholes, mine shafts, and subsidence features) (CH2M HILL, 2009j).
- The lack of response in nearby monitoring wells precluded estimation of the storativity of the Boone aquifer.

### Roubidoux Aquifer Testing Results

The purpose of testing the Roubidoux well (Picher No. 7) was to evaluate the degree of connection between the Roubidoux and Boone aquifers. Testing was coordinated with the City of Picher and involved a 24-hour constant rate test. Results from the testing are summarized below and included in **Appendix G**.

- The transmissivity of the Roubidoux aquifer in the vicinity of the Picher No. 7 well is 820 square feet per day and the storativity is $2.7 \times 10^{-4}$.
- Drawdown was not detected in Boone aquifer wells during pumping of the Roubidoux aquifer well (Picher No. 7).
- The vertical hydraulic conductivity between the Boone and the Roubidoux is less than $2 \times 10^{-4}$ ft/d or $7 \times 10^{-8}$ cm/sec.
- The vertical flux of groundwater between the Boone and the Roubidoux is less than 11 gpm per square mile.
- The travel time for groundwater to move from the Boone to the Roubidoux is greater than 220 years (CH2M HILL, 2009k).

## 9.2 Purpose and Objectives of the Groundwater Model

The next step in the hydrogeologic analysis of the site was to use the information obtained from the literature review and field efforts to develop a three-dimensional groundwater flow model of the site. This tool was developed to better integrate the various independent estimates of site properties into a single consistent quantitative conceptual model of the site. The primary objectives of the groundwater modeling effort are summarized below:

- Develop a comprehensive water budget of the aquifer systems and the mine workings throughout the Tar Creek site.
- Develop a metals budget within the mine pool and surrounding Boone aquifer system to better understand the movement of metals at the site.
- Evaluate the potential interaction between the Boone and Roubidoux aquifers.
- Use the numerical model, along with associated geochemical analysis, to evaluate the movement of metals through the mine workings and potential impacts on surrounding groundwater as a result of the injection of fine tailings into the mine workings.
- Use the model to evaluate other potential remedial options such as targeted mine tunnel plugging and controlling mine pool discharge through water management options.

## 9.3 Groundwater Modeling Approach

The overall approach used to develop the Tar Creek groundwater model was to use the existing USGS groundwater model developed for the site and modify it based on recently collected data and hydraulic testing. A brief summary of the original USGS model of the site along with the modifications made during this effort are described in the following sections.

### 9.3.1 Description of the Original USGS Model

Previous groundwater modeling was completed by the USGS in 2006. The purpose of the modeling was to investigate potential effects upon the direction, quantity, and velocity of groundwater flow that could result from the emplacement of various volumes of chat. Groundwater systems were modeled using MODFLOW-2000 to simulate the three-dimensional flow through the Boone aquifer (Reed and Czarnecki, 2006). Both a preliminary and a subsequent refined model were developed during the USGS investigation.

The preliminary model was used to evaluate whether the mine workings could be modeled on a regional scale and to assess the magnitude of groundwater flow between the Boone and Roubidoux aquifers. A total of five model layers were needed to evaluate these objectives. Model results were successful in approximately simulating mine workings; however, results also suggested that flow from the Roubidoux aquifer upward into the Boone were minimal. This would serve to justify using the base of the Boone Formation as a no-flow boundary in the subsequent USGS model.

The USGS subsequently developed a refined model with finer grid spacing and three model layers. The upper layer represented the overburden on top of the Boone Formation; the second (middle) layer represented the mined portion of the Boone Formation; and the remainder of the Boone Formation was represented by the third (bottom) layer of the model.

Initial starting heads for the Boone aquifer were based upon historical mean water levels. Hydraulic head data for layers, for which no historical data were available, were estimated or derived from those used in the Boone aquifer. The major discharge points of the Boone include the Neosho and Spring Rivers and, to a lesser extent, Tar and Lytle Creeks. Groundwater withdrawal was not simulated in the models because the Roubidoux aquifer

is the primary source for public supply well withdrawal (Reed and Czarnecki, 2006); only minimal pumping occurs in the Boone aquifer.

The model was calibrated using known groundwater elevations in the Boone aquifer, surface water elevations from the streams, and the land surface altitude. The calibrated model assumes a horizontal hydraulic conductivity of the Boone aquifer (Layers 2 and 3) ranging from 1.3 to 35 ft/d in the mined portion of the Boone. To simulate bedrock fracturing that may be associated with the Miami Syncline, a horizontal anisotropy factor of 10 was assumed in the central portion of the model (excluding the mine workings). This resulted in a north-south hydraulic conductivity of 350 ft/d in this area.

Vertical hydraulic conductivity was estimated to be 2 percent of horizontal, except for cells within the mined zone. Isotropic conditions were assumed in these cells whereby vertical and horizontal hydraulic conductivity were equal. The specific yield of the aquifer was assumed to be 0.20, and the specific storage to be 0.00001.

Once calibrated, the model was used to simulate different hypothetical situations in which portions of the mine workings were completely filled with chat. The flow model results were used in conjunction with MODPATH, a program used to compute groundwater flow paths. This analysis was conducted to determine whether chat injection resulted in significant changes to simulated groundwater flow paths compared with the calibration simulation. The travel time between the mine pool and downgradient discharge points was also evaluated. In general, the modeling suggested that the placement of chat had minimal effect on the direction and rate of movement of groundwater in the vicinity of the mine workings.

### 9.3.2 Primary Revisions to the USGS Model

The existing USGS model was modified and refined based upon the new data acquired during the HCS field program. Modifications to the model included the following:

- The inclusion of two additional model layers required to represent the Roubidoux aquifer in the model. Layer 4 represents the aquitard between the Boone and Roubidoux aquifers, and Layer 5 represents the Roubidoux aquifer itself.
- Assignment of new hydraulic conductivity estimates for the Boone aquifer based upon the aquifer testing performed at wells BWM12 and BMW13.
- Implementation of the conduit flow process (CFP) to represent the flow of water through the mine workings as well as the exchange of groundwater between the mine pool and the Boone aquifer.

Each of these modifications will be described in more detail below.

#### Model Layering

The final version of the USGS model of the site did not include the Roubidoux aquifer as no information was available as to the degree of hydraulic connection between the Boone and the Roubidoux aquifers. However, as part of the HCS field program, an aquifer test on the Roubidoux aquifer was conducted, and an estimate of the vertical hydraulic conductivity of the aquitard between the Boone and Roubidoux aquifers obtained. For this reason, two

additional model layers were added to the Tar Creek model, to incorporate any leakage from the Boone aquifer to the Roubidoux aquifer.

The aquitard between the Boone and Roubidoux aquifers was added to the model as Layer 4. This layer was assigned a constant thickness of 630 feet based on observations during drilling in the area. The hydraulic conductivity of the layer was assigned a value of $2x10^{-4}$ ft/d, or $7x10^{-8}$ cm/s, which is the vertical hydraulic conductivity estimated from the Roubidoux aquifer test data. As is typical with low permeability units, it was assumed that the aquitard was isotropic.

The Roubidoux aquifer was included in the model as Layer 5; however, the purpose of including the Roubidoux aquifer in the model was to allow simulation of potential leakage from the Boone aquifer, not to explicitly model groundwater levels or pumping stresses within the Roubidoux aquifer. For this reason, the Roubidoux aquifer was assigned a constant head boundary condition throughout the layer of 570 feet amsl based on a Roubidoux aquifer potentiometric surface map published by the USGS (Christenson et al., 1990). This is more than 150 feet higher than the heads indicated for Miami Well No. 9, as indicated on **Figure 9-5**, but it is also more reflective of average conditions across the model domain according to the USGS potentiometric surface map.

### Boone Aquifer Properties and Addition of the Conduit Flow Process

During the calibration of the refined Tar Creek model, the properties of the Boone aquifer were modified from those assumed in the USGS model of the site. These revisions were made based on both the aquifer testing conducted in Boone aquifer wells and during the calibration process to a larger set of calibration targets (see **Section 9.4.1**). The overall hydraulic conductivity zonation developed by the USGS was retained; however, the assumed hydraulic conductivity values were modified. The distribution of hydraulic conductivity of the Boone aquifer assumed in the Tar Creek model is shown on **Figure 9-6**. The main changes that were made are that the hydraulic conductivity of the far western zone was increased from 10 to 80 ft/d, and the hydraulic conductivity of the central zone, that previously was assigned a north-south hydraulic conductivity of 350 ft/d and an east-west hydraulic conductivity of 35 ft/d, was assigned a hydraulic conductivity of 80 ft/d. The hydraulic conductivity value of 80 ft/d was selected because it is the geometric mean of the hydraulic conductivities calculated from the two aquifer tests conducted in this study (see **Section 9.1.4**). The hydraulic conductivities of the eastern zones remained unchanged from the USGS model values.

Preliminary simulations performed using the USGS model of the site suggested that an assumed hydraulic conductivity of 50,000 ft/d for the cells representing the mine workings was not high enough to produce simulated heads that reflect the relatively flat mine pool elevations observed throughout the mining field. To produce this distribution of heads, a hydraulic conductivity value much higher than 50,000 ft/d would be required. However, when higher values were incorporated into the model, the hydraulic conductivity contrast between the cells representing the mine pool and the adjacent cells representing the Boone aquifer was too high to allow the model solver to successfully converge. In cases where the model did converge, the water budget error for the model solution was unacceptably high.

To address this problem, and develop a model that was capable of more accurately simulating the influence of the mine workings on the surrounding aquifer system, the CFP,

recently developed by the USGS, was implemented (Shoemaker et al., 2007) in the Tar Creek model. The CFP was written to be compatible with MODFLOW-2005 and, therefore, implementation of the CFP for this application required conversion of the USGS model to MODFLOW-2005.

While the mine pools are explicitly accounted for by the CFP conduits, the bulk Boone aquifer is consolidated bedrock in which flow is thought to primarily occur in fractures. The use of a MODFLOW code to simulate the Boone aquifer implies that an equivalent porous medium has been assigned to represent the combined fracture and porous medium flow, because the code does not have the capacity to explicitly simulate fractures. However, even if a code that explicitly calculates fracture flow were chosen, the fractures could not be reliably simulated without some knowledge of their extent, principal directions (dip and strike) aperture, and connectivity. Because such knowledge is generally unavailable for most fractured bedrock aquifers, it is frequently assumed (as in this case) that bulk aquifer properties, such as hydraulic conductivity, are a reasonable approximation to the sum of flows in individual fractures.

However, the use of the CFP conduits also obviates the need to use higher conductivities to represent the Boone aquifer in the vicinity of the mine pools. The conduits explicitly provide the required high conductance for water flow. Most of the flow in the model nodes that include both bulk aquifer and mine pool occurs through the CFP conduit representing the mine pool. Thus, the simulation reflects the actual partitioning of groundwater between the mine pool (which receives the majority of the flow) and the bulk Boone aquifer.

#### Boundary Conditions

The boundary conditions assumed in the refined Tar Creek model are similar to those used in the USGS model. The lateral boundaries were assigned a general head boundary condition on the northern edge of the model, and head-dependent river boundary conditions on the southwest (Neosho River) and southeast (Spring River) edges of the model. The upper model boundary is a specified flux boundary that represents the deep percolation of precipitation and, as discussed above, the lower boundary is now a constant head boundary representing the piezometric head in the Roubidoux aquifer. Finally, Tar Creek and Lytle Creek are represented in the model using the MODFLOW river package, while smaller tributaries are represented using the drain package.

### 9.3.3 Conduit Flow Process

The CFP has the ability to simulate non-Darcian groundwater flow conditions within the mine workings by coupling the traditional groundwater flow equation with formulations for a discrete network of cylindrical pipes. Conduit flow pipes may represent dissolution or biological burrowing features in carbonate aquifers, voids in fractured rock (such as mine workings), and/or lava tubes in basaltic aquifers, and can be fully or partially saturated under laminar or turbulent flow conditions. Specific input parameters required to define the pipe network include conduit pipe locations, lengths, diameters, tortuosity, internal roughness, critical Reynolds numbers, and exchange conductances. The CFP solves the pipe network equations in a matrix that is independent of the porous media equation matrix, which could mitigate numerical instability associated with solution of dual-flow components within the same matrix.

### 9.3.4 Implementation of the CFP in the Tar Creek Model

CFP grids, which represent the various mine workings in the model are separate sets of nodes, which are superimposed upon the aquifer grid. The CFP nodes are connected by conduit flow pipes. Exchange between the aquifer and the mine pool occurs discretely at the nodes, while transport within the mine pool occurs within the conduit flow pipes. The resulting dual-domain subsurface flow model requires simultaneous, consistent solutions for the groundwater flow model (the aquifer grid), the mine pool flow model (the CFP grid), and the exchange flows between the groundwater and the mine pool.

The nodes that were incorporated into the CFP model grid were the same nodes that were assigned "mine pool" hydraulic properties in the USGS model (e.g., Figure 8 in Reed and Czarnecki, 2006). The only adaptation that was required was to establish conduit connections between adjacent CFP nodes in the model. The resulting CFP node network can only be an approximation of the actual workings, for which many geometric details are largely unknown. Nevertheless, the CFP simulates the presence of a network of open conduits within the lower permeability groundwater flow within the Boone aquifer.

To reasonably represent the extensive network of mine features present at the Tar Creek site, a CFP model consisting of a very large array of CFP nodes and conduit pipes was required. Early trial runs with the refined Tar Creek model suggested that using the grid resolution of the original model grid was exceeding the practical limitations of the CFP application. Excessive run times and numerical arrays exceeding the size that could be manipulated using a high-end computer were encountered. To facilitate the application of the CFP to the Tar Creek site, it was necessary to increase the size of the model cells in the vicinity of the mine workings from 50 to 100 meters on a side. The assumed geometry of the individual mine tunnels in the CFP formulation was circular pipes with a diameter of 40 feet.

## 9.4 Groundwater Model Calibration

This section presents the approach used to calibrate the refined Tar Creek model, describes the calibration targets that were used, and presents the results of the calibration effort.

### 9.4.1 Model Calibration Approach

The first step in the model calibration process is to define a set of calibration targets. At the Tar Creek site, the data available to define calibration targets consisted of groundwater elevations in Boone aquifer monitoring wells, mine pool elevations measured in mine pool monitoring points, and approximate mine discharge rates to Tar Creek under base flow conditions.

If a groundwater model is calibrated to head targets alone, the solution can be non-unique, because many combinations of water budget and hydraulic properties may be used to achieve similar heads. However, if a groundwater model can approximately replicate both head targets and water budget targets, then the aquifer properties used in the model will be more highly constrained. The overall approach to the calibration process involved adjusting model input parameters within a reasonable range of values until the model yielded steady-state simulated groundwater levels that matched the measured values, while also honoring the observed average discharge of groundwater to Tar Creek near Douthat. Once

this was achieved, the model was then used to make estimates of groundwater flow conditions and solute transport in the mine pool under average flow conditions.

The specific calibration targets defined for this calibration effort included a combination of 1) 2004 groundwater levels that were gathered by the USGS as part of its modeling effort, 2) groundwater levels and mine pool elevations that were measured in Boone aquifer monitoring wells and mine pool monitoring points in April 2008, and 3) the average rate of mine pool discharge to Tar Creek at Douthat, which was estimated to be between 1.5 and 2 cfs. This estimated average rate of mine pool discharge was estimated by first computing the median mine pool elevation measured between 1979 to the present (elevation 801.2 feet amsl) as shown on **Figure 9-7**. Second, it was determined that the median mine pool elevation of 801.2 feet amsl corresponds to a flow of about 1.5 cfs as shown on a "rating" curve obtained from ODEQ and included as **Figure 3-3** (Cates, 2009, personal communication).

During the calibration process, the assumed aquifer properties, mine pool aquifer (CFP aquifer) exchange parameters, and water budget components (particularly recharge) of the Tar Creek groundwater model were adjusted until a satisfactory match to the calibration targets was achieved in a steady-state simulation.. A convenient summary of model calibration quality is provided by a variety of statistical measures including the mean error, mean absolute error, and root mean square error over range calibration statistic (Anderson and Woessner, 1992); these statistics were calculated during the course of the calibration as a measure of the overall quality of the model calibration.

### 9.4.2 Calibration Results

One common graphical depiction of model calibration is to develop a scatter gram that plots the simulated versus the observed groundwater elevations for all calibration targets. The location of the calibration target wells are shown on **Figure 9-8**. These calibration targets are grouped into two sets: a set that consists of the wells in the vicinity of the mine workings, and other areas of interest, such as the Douthat discharge area; and another set consisting of the target well that lie distant from the mine workings. This was done because it was noted during calibration that the accuracy of the calibration was significantly better in areas near the mine pool, where the model is being applied to support decision making, than it was in areas remote from the mine pool, where the calibration accuracy is of lesser concern. This is likely due to the fact that the Boone aquifer is characterized by a bedrock flow system with a very complex hydraulic conductivity distribution, and much fine-scale structure with flow occurring along individual fractures and bedding planes. It was not possible to capture this type of complexity in a groundwater flow model of this scale. The result is that water levels in individual wells that are in many cases located miles from the mine pool are not matched as well as those existing in the more fractured bedrock environment near the mine workings that behaves more like a porous media.

A scatter gram depicting the state of calibration of the Tar Creek model is shown on **Figure 9-9**. The two sets of calibration data discussed above are also distinguished on this figure using the same symbols as shown on **Figure 9-8**. As expected, the model fit to the mine pool elevation calibration targets, and those in the vicinity of the mine pool, is excellent. Boone aquifer groundwater elevation targets that are farther away from the mine pool, particularly those near the Neosho and Spring Rivers, were not as well matched.

Factors that could contribute to the calibration error include 1) Non-Darcian flow in the fractured rock of the Boone Formation, 2) the use of a simplified hydraulic conductivity field in the model, which contains only four zones of hydraulic conductivity for the entire Boone formation, and 3) the use of an areal average recharge rate over the groundwater model domain, where, in reality, there may be significant spatial variability in the recharge rates that create local variability in groundwater levels. It should be noted that the primary objective of this modeling tool is to describe the interaction between the Boone aquifer and the mine pool, as well as the rate of mine pool discharge to overlying surface streams. The quality of the model calibration in these areas is significantly better than model-wide statistical parameters suggest. The calibration target names, along with the measurement dates, frequency of measurement, simulated heads at the target locations, and residuals (measured heads minus simulated heads) are provided in **Table 9-1**. The mean of the absolute value of the residuals was 10.32 feet.

As mentioned above, another primary objective of this modeling effort is to improve the understanding of the water budget of the mine pool and surrounding Boone aquifer. It is not possible to directly measure the groundwater inflow to the mine workings or the discharge of mine pool water into the Boone aquifer. However, by using surface water flow measurements during average flow conditions, it is possible to estimate the quantity of mine pool water that discharges to the surface water system. Various measurements of this type taken at the site suggest that the mine pool discharge rate is on the order of 1.5 to 2 cfs. The discharge from the mine pool to the surface water system simulated by the Tar Creek model in the vicinity of Douthat is approximately 1.5 cfs, which agrees well with these field measurements, and suggests that the model is capable of simulating the water budget components of the Boone aquifer-mine pool system.

## 9.5 Groundwater Model Results

This section presents the predictions of the calibrated model with regards to the water budget of the mine workings, rate and direction of flow within the mine pool, and rate and nature of the exchange between the mine pool and the surrounding Boone aquifer.

### 9.5.1 Simulated Water Budget of the Mine Workings

One of the primary benefits of developing and calibrating a groundwater flow model of the Tar Creek site is to obtain estimates of the water budget components of the mine pool aquifer system that cannot be directly measured. A schematic view of the water budget of the mine pool and surrounding Boone aquifer under average conditions is summarized on **Figure 9-10**. A summary of the magnitudes of the primary water budget components are summarized below.

The inflows to the mine pool in the model include the following:

- 2.3 cfs recharge from precipitation
- 2.1 cfs seepage from Tar Creek and Lytle Creek (combined)
- 9.0 cfs inflow from the Boone aquifer upgradient of the mine pool

The outflows from the mine pool include the following:

- 1.5 cfs discharge to surface water in the Douthat area
- Less than 0.4 cfs discharge to the regional Roubidoux aquifer below the Boone aquifer. Given that the footprint of the mine pool is approximately 20 square miles, this 0.4 cfs total implies approximately 9 gpm of discharge to the Roubidoux per square mile of mine pool. This result is consistent with the Boone aquifer test evaluation (CH2M HILL, 2009k).
- 11.5 cfs outflow to the Boone aquifer downgradient of the mine pool

### 9.5.2 Forecasts of Mine Pool Flow Conditions and Mine Pool Aquifer Exchange Flows

**Figures 9-11** through **9-13** illustrate the groundwater and mine pool flow modeling results of the updated Tar Creek model. The backgrounds of these figures are USGS 7.5-minute quadrangle maps of the region.

The simulated exchange rates between the mine pool and the Boone aquifer are shown on **Figure 9-11**. An arbitrary sign convention was assigned to the exchange flows so that recharge to and discharge from the mine pool could be represented on a continuum. Exchange flows from the Boone aquifer to the mine pool are represented as positive values, and flows from the mine pool to the groundwater system are represented as negative values.

The modeling indicates that Boone aquifer groundwater discharges to the mine pool in the north and northwest, and mine pool water discharges back to the Boone aquifer in the south and southeast. The magnitude of the exchange varies throughout the mine pool, but is considerably larger along the fringes of the pool at both the upgradient and downgradient edges of the mining field.

Each model node within the various mine pools represents a 100-meter-by-100 meter (328 feet by 328 feet) area. The maximum exchange flows within these nodes along the edge of the mine pool range from 71 gpm mine pool recharge to 74 gpm mine pool discharge. However, a majority of the mine pool nodes have lower exchange flow rates, with the minimum being less than 5 gpm of groundwater mine pool exchange flow.

Another characteristic of mine pool flow that can be obtained from the CFP is the direction of flow through the mine workings (conduit pipes). The simulated flow directions (flow vectors) within the mine pool are shown on **Figure 9-12**. This figure shows that south- and west-trending flow dominates throughout the mine pool, which closely mirrors the flow through the aquifer. The flow between CFP nodes in the mine pool is discretized into a network of mostly orthogonal flow pipes, as indicated by the flow direction arrows which mostly point due south and due west. A few CFP nodes are connected to the rest of the network through a diagonal pipe where there is no adjacent CFP node in a cardinal direction. These discrete flows combine to create a net flow to the southwest in the aggregate, at the scale of the mine pool. However, smaller-scale flow or transport problems, on the order of the 100-meter CFP node spacing or less, would require additional refinement of the model.

Finally, the CFP also predicts the flow rates that occur within each of the conduit flow pipes of the model network. The simulated flow rates in the modeled mine workings are shown on **Figure 9-13**. The model predicts that the highest flow rates tend to be concentrated around regions where the mine pool is thought to be relatively constricted. This result is consistent with basic continuity and hydraulic theory. Conversely, lower flow rates are simulated in areas where the volume of mine working available to conduct flow significantly increases, or in areas adjacent to low permeability bedrock. It should be noted that the complex geometry of the individual mine workings, and the degree of hydraulic connection between different portions of the mine pool is poorly understood. As such, the results presented herein should be interpreted as generalized flow patterns within a mine pool with this overall configuration. But because the questions that are being investigated using this modeling tool are of a regional nature (where, generally, does mine pool water discharge from the mine and at what rate), as opposed to specific in nature (what happens in a particular mine working), this level of analysis is deemed sufficient to meet project objectives.

## 9.6 Dilution Transport Simulations

As discussed in **Section 10.4**, increased metals concentrations have been observed in mine pool water during and immediately following injection of chat and washed fine tailings. This metal-enriched water is referred to herein as "post-injection water." In past injection pilot studies with short injection durations, the metals concentrations have been observed to decrease significantly in the months following termination of injection. As a result, a pulse of post-injection water is produced during injection, and concentrations later decay back to pre-injection levels. This section describes the modeling of the dilution process that post-injection water undergoes during movement through the mine workings up to the mine pool interface with the Boone aquifer near Douthat. In **Section 10.7**, continued transport in the Boone aquifer is simulated with detailed chemical reactions included.

The USGS's MODFLOW-2005 plus CFP (MODFLOW-2007) software that was used to update the Tar Creek groundwater flow model is only capable of simulating the movement of water in a coupled groundwater conduit (or groundwater mine pool) system. It does not have solute transport capabilities in its current form. A computer program that simulates solute transport in the mine pool was developed by CH2M HILL to bridge the gap between the subsurface water flow simulations and the need to forecast the possible impact of the injection of fine tailings on downgradient mine pool and Boone aquifer groundwater quality.

This software, called "CFP Advector," uses the flow output resulting from the MODFLOW-2005 with CFP simulations to estimate the dilution, which results from the mixing of solutes introduced at any location within a network of CFP nodes as they travel to a downgradient discharge point.

The algorithm for CFP Advector is relatively simple. The solute concentration at the source CFP node is carried through the conduit pipes to those CFP nodes that are immediately downgradient. The travel time (or residence time) in the conduit pipes is reported as output from the CFP flow simulation, and is used by CFP Advector to keep track of when the solute arrives at the next downgradient CFP node. Once a solute concentration reaches the

downgradient node, it is mixed with the solute concentrations coming in from other upstream CFP nodes, as well as clean water (if any) entering from upstream nodes. Solute concentrations entering the node are assumed to be instantaneously mixed, and the node begins discharging at the mixed concentration to the out-flowing pipes that drain it. If the exchange flow from the surrounding porous media is inward to a CFP node, the water is assumed to have zero solute concentration and so dilutes the solute concentration at that node. If the exchange flow drains water from the CFP network to the porous media, the solute concentration in the CFP network remains unaffected.

Mathematically, this is:

$$C_{Node} = C_{Outflowing\ pipe} = \frac{\sum(Q_{inflowing\ pipe} * C_{inflowing\ pipe})}{\sum Q_{inflowing\ pipe} + Q_{incoming\ exchange}}$$

where the summations are over all inflowing pipes, $C$ is solute concentration, and $Q$ is flow rate.

With this simple set of rules, CFP Advector simulates the transport of a solute, which is introduced at any source node in the CFP network. The solute will then cascade through all nodes, which are downgradient from the source. At each node along the way, incoming solute concentrations may be mixed with 1) other solute streams arriving via other nodal pathways, 2) clean water from a nodal pathway that is unaffected by the source, and/or 3) clean water entering from the Boone aquifer.

At present, CFP Advector can only simulate transport in steady-state flows, can only accept prescribed concentration (Type 1) source conditions, and cannot simulate the exchange of solutes between the porous media and the CFP network. Variable source concentrations can be modeled with CFP Advector by the mathematical principle of superposition. This principle provides the rules for the linear combination of multiple constant source concentration simulations to form a single variable source concentration.

The pipe flows and residence times from the calibrated Tar Creek groundwater flow model's representation of the mine pool were used as input to the CFP Advector code. Solute transport was simulated for two source locations (see **Figure 9-14**): the Sooner Chat Pile, and a chat pile, which is split by Lytle Creek and, therefore, will be referred to herein as the "Lytle Creek site." This latter pile was chosen as an injection location because it was closer and more directly upgradient from the Douthat discharge area, according to the model. As such, these two locations provide a depiction of the variability in dilution magnitudes that could occur as a result of injection at different locations within the mine pool. The source concentrations at both locations were constant for 5 years, then were assumed to attenuate through exponential decay for an additional 5 years. In physical terms, these source concentrations represent 5 years of injection of fine tailings, followed by attenuation of the source once injection ceases. It is assumed that the decay rate of the source concentration following the end of injection will be similar to the rapid source decay, decay that was observed at Craig Mine following the 2005 injection.

To estimate the rate of source decay at the Craig Mine, an exponential model was fit to the measured concentrations of three metals: lead, cadmium, and zinc. The resulting decay curves were quite similar, with a very rapid drop-off in concentration following the cessation of injection. **Figures 9-15**, **9-16**, and **9-17** show the Craig Mine cadmium, lead, and

zinc data, respectively, and the exponential decay curves fit to those data. Of the three metals, the cadmium data proved to be the best fit to the exponential decay model and, therefore, the cadmium source decay curve was selected to represent the attenuation of post-injection concentrations for each constituent. Use of the zinc or lead decay curves instead of cadmium would have made very little difference to either the concentrations estimated to reach the downgradient edge of the mine pool, or the results of the geochemical modeling discussed in **Section 10.7**. The cadmium source half-life represented by the decay curve on **Figure 9-15** is 302 days. Data from the Montreal and Tulsa Mine pilot studies were also examined, and though data from those studies contained more noise, the decay patterns were generally the same as that of the Craig Mine. The Ottawa Mine pilot study data were inconsistent and could not be used for analysis.

The source concentration during the injection of fine tailings was assigned a value of 100, with arbitrary units. This is a useful choice because the downgradient concentrations can be easily expressed as a percentage of the source concentration. Moreover, the results of this simulation can be easily converted to specific concentrations for a specific contaminant by multiplying the simulation result by the assumed concentration released at the injection location, and dividing by 100. The total contaminant source mass released in the CFP Advector simulations for the Sooner Chat Pile over the 10-year simulation period was 104 kilograms for an assumed 100 µg/L concentration. For the Lytle Creek site, the total contaminant source mass over the 10-year simulation was 213 kilograms for an assumed 100 µg/L concentration. The difference in source mass is a result of the difference in model forecasted conduit flows through the mine workings at the two sites. The Lytle Creek site was estimated by the model to have slightly more than twice the discharge of the Sooner Chat Pile site. Therefore, a constant concentration released at the Lytle Creek site results in slightly more than twice the contaminant mass being introduced into the mine workings. These results can be easily scaled to the actual site conditions once actual source area contaminant concentrations are obtained.

**Figure 9-18** shows still views at selected time intervals from an animation of model forecasted solute transport that would occur as a result of injection at the Sooner Chat Pile into the mine pool. As indicated by the figures, the simulation forecasts that the contaminant plume will travel southwest (in the same direction as the prevailing groundwater gradient) and eventually reach the edge of the mine pool. After the 5 years of injection, it is predicted that most of the concentrations along the centerline of the plume in the mine pool will have achieved a steady-state concentration that is in equilibrium with the source concentration. Following the end of the fine tailings injection after year five, the source concentration rapidly decays. However, the contaminant plume at the downgradient edge of the mine pool continues to expand and develop as the contamination that was previously released at the Sooner Chat Pile arrives. As with the creation and expansion of the plume, dissolution and dispersion following the end of injection begins near the source and, by 9.9 years, very little of the plume remains in the mine pool.

As **Figure 9-19** shows, the simulation of contaminant transport resulting from injection of fine tailings at the Lytle Creek site generated a similar result. The primary difference is that the Lytle Creek site is much closer to the downgradient edge of the mine pool than is the Sooner Chat Pile. As a result, the concentrations forecasted at the downgradient edge due to

the Lytle Creek site injection are higher, arrive earlier, and disappear faster following the cessation of injection than the Sooner Chat Pile injection forecasted concentrations.

The animations that are the result of the Sooner Chat Pile and Lytle Creek site CFP Advector simulations (of which **Figures 9-18** and **9-19** are excerpts) are provided on compact disk with this document. Most software which can read the Audio Video Interleave (.avi) format, including Windows Media Player©, should be able to run these animations. However, a freeware program called Imagen© (Gromada.com, 2009) is provided on the same compact disk to allow viewing of the animations.

**Figure 9-20** shows the model-forecasted (source-normalized) concentrations of post-injection water constituents at the downgradient edge of the mine pool along the plume centerline, resulting from the Sooner Chat Pile injection. The downgradient edge concentrations rise relatively quickly after the first arrival between 3 and 4 years after the start of fine tailings injection. Just after the start of year five, the maximum downgradient edge concentration exceeds 6 percent of the original post-injection concentration and, thereafter, asymptotically approaches a maximum concentration of approximately 7 percent. As stated above, the rising concentrations continue after the end of fine tailings injection. The concentrations at the downgradient edge fall off rapidly after approximately 8.8 years, in response to the cessation of injection.

**Figure 9-21** shows that the results of the Lytle Creek site injection simulation were similar, in that concentrations at the downgradient edge rise and fall sharply. However, because the Lytle Creek site is much closer to the downgradient edge of the mine pool, the post-injection water pulse arrives much more quickly. Solutes are forecasted to begin to arrive at the Douthat area after 1.6 years, and reach a maximum of 31 percent of the source concentration 2 years after the start of injection. In other words, the elevated concentrations of trace metals observed during fines injection are transported within the mine pool and by the time the pulse of injected water arrives at the Douthat area, it has mixed with mine pool water to form a 31 percent injection chemistry plus 69 percent non-injection mine pool water mixture. At this point in time, the impact of the source on the downgradient edge of the mine pool is being fully expressed. Subsequently, the downgradient concentration remains constant for 4.7 years (6.7 years since the start of injection), then declines rapidly in response to the diminishing source concentrations. Transport of this pulse into the unmined Boone aquifer was simulated with a geochemical transport model, described in **Section 10**.

The simulated concentration percentages resulting from the CFP Advector simulations, shown on **Figures 9-20** and **9-21**, were applied as input to the geochemical transport modeling for mine pool water entering the Boone aquifer. This work is described in detail in **Section 10.7**.

## 9.7 Depiction of Mine Workings in Groundwater Model

Because of constraints on the available resolution of the groundwater flow model grid and model vertical layering, the depiction of the mine workings in the model is somewhat simplified. While the overall geographic layout of the mine workings in the model is accurate, and generally reflects the information in the detailed mine maps, the fine detail of mine room extents and the vertical elevation changes along manways and in mine rooms and stopes could not be captured. The effects of these simplifications on model simulations

is that the model predicted flow patterns and rates between the Boone aquifer and the mine workings are accurate, but any small scale variability in flow directions and rates within a complex of individual mine working will not be represented. The mine tunnels were also assumed to be fully open, with no blockage by sediment piles or caved areas. This assumption is conservative with respect to the forecasts of metals dilution during transport within the mine because, in reality, there could be more blockage to flow than is being considered in the model. It should be noted that the use of the model to simulate the effects of mine tunnel plugging on mine pool levels and flow conditions could result in overly optimistic forecasts of plugging effectiveness because mine tunnel flow in the model is assumed to occur through a limited network of high permeability tunnels that are available for plugging. In reality, there are many smaller tunnels, rooms, or other mine features that would be more difficult to effectively plug, and likely less effective.

## 9.8 Potential Future Use of the Groundwater Model to Conduct Predictive Transient Modeling to Evaluate Tar Creek/Mine Pool Interactions at Higher Flow Conditions

As indicated above, simulations involving such a relatively large CFP conduit network are numerically quite intensive. A modern, high-end computer required approximately a week for each steady-state calibration simulation, because of the coupled flow problem involved in having the mine pool and surrounding aquifer in close hydraulic contact. A transient simulation roughly multiplies the run times required for a steady-state simulation by the number of time steps in the transient run. It is estimated that a transient model that could be applied to simulate a Tar Creek flood event would require a minimum of approximately 10 time steps. Therefore, time constraints and the limits of modern computers make such a transient simulation difficult and likely impractical at this time.

However, through judicious use of prescribed fluxes in place of the CFP network, the model might be able to simulate a reasonable approximation of the exchanges with the mine pool during a transient flood event. A relatively small effort could be performed to determine whether this is a viable work-around in principle, with a more significant effort to follow if it should turn out to be so.

USGS could also improve the CFP code in the future to reduce the MODFLOW-plus-CFP run time. If that were the case, or if computers with much higher processing speeds became generally available, then it might be possible to run a transient flood simulation in the Tar Creek groundwater model with the CFP network implemented.

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SECTION 10

# Geochemical Modeling

The geochemical modeling performed as part of the HCS is described in this section.

## 10.1 Groundwater and Mine Water Chemistry in the Tar Creek Region

Mine water samples have been collected on a regular basis from mine pool monitoring locations at the Craig, LaSalle, Montreal, Swift/Moore No. 2, and Tulsa Mines since February 2007. The Boone Formation in which the mining took place was originally a limestone-dolomite that was replaced by the siliceous, sulfide-rich fluids that were the source of the lead and zinc ore. The Boone aquifer groundwater in the mining field is dominated by calcium and sulfate, reflecting the limestone and sulfide mineralization. TDS typically ranges from 2,000 to 3,000 mg/L. The pH ranges between 5.6 and 8, with the average around 7. Where mineralized, the high TDS, along with the low oxidizing to reducing conditions (which allow high concentrations of dissolved iron and manganese) of the natural groundwater, makes it undesirable as a drinking water source.

Mining created large subsurface caverns in the Boone Formation that are now filled with groundwater. Chemistry of the mine pool water is similar to that of nearby portions of the mineralized Boone aquifer groundwater, except in areas where source materials injection has taken place. In these cases, the injected slurry contains higher DO concentrations, which produces more oxidizing conditions in the mine pool. As a result, iron is essentially removed from solution as an oxide precipitate, and manganese concentrations also decrease as a result of the oxidation process. Trace metal concentrations in the mine pool have been observed to variably increase in the pilot study injection areas and then decrease to pre-injection conditions.

Several injection pilot studies have been performed at the site as described in **Section 4**. The chat injection pilot study at the Craig Mine was the most closely studied, with chat mineralogical analysis, laboratory leach testing, and geochemical modeling in addition to groundwater monitoring (Weston, 2006). In that study, x-ray diffraction (XRD) analysis of three bulk chat samples showed that chat is composed mainly of quartz (over 90 percent of detectable mineral abundance), with about 5 percent calcite and dolomite, 2 percent sphalerite, and the remainder being iron oxide and clay minerals. The XRD method is limited to detecting the more well-crystallized forms of minerals, present at several percent. Poorly crystallized forms of lead, iron, and other sulfide minerals, along with secondary sulfates, would not be expected to be determined by XRD analysis. Even though lead was a primary ore metal of interest, the mineral galena was not present in sufficient amount to be detected by XRD. This suggests that nearly all of the galena was removed by the mining and milling process, and that lead could exist in the form of poorly crystallized sulfide and sulfate minerals. Other trace metals are likely associated as impurities with detected sphalerite, undetected galena, or in poorly crystallized forms. For example, cadmium is commonly associated with sphalerite. These analyses are, thus far, the only mineralogical

data for injected material at the Tar Creek site. A slurry of bulk chat and local mine water was injected into the mine pool at the Craig Mine for a period of 14 days (Weston, 2006). Mine water samples were collected before and after injection. Data were collected in a similar manner for pilot studies at the Atlas and Montreal Mines. Although these studies were of longer duration and the Atlas Mine test used chat fines, the groundwater samples were not analyzed for all general chemistry parameters, whereas the Craig Mine samples were complete. In addition, the decay patterns of trace metals in the Montreal and Atlas tests were similar to the concentration decay rate observed in the Craig Mine data.

## 10.2 Groundwater and Mine Water Monitoring at the Sooner Chat Pile

An injection pilot study of washed fine tailings into the mine pool beneath the Sooner Chat Pile has been in more or less continuous operation since the fall of 2007. Samples were collected from the initial injection boring, SMB2, before and soon after the pilot study began. This injection boring quickly filled to the mine room ceiling and was taken off line at the end of 2007. It was replaced by injection borings SMB3 and SMB5, which have been in operation since that time. Regular quarterly samples were collected from a variety of monitoring wells and mine pool locations at the site beginning in July 2008, making this pilot study a well-documented case study of the effects of chat injection. Much of the information discussed in the sections below is provided in the operations report for the pilot study (CH2M HILL, 2010).

### 10.2.1 General Chemistry

Seven mine pool borings (SMB3, SMB5, SMB6, SMB7, SMB8, SMB9, and MMB2), two Boone aquifer monitoring wells (BMW01 and BMW02), and the slurry from the Sooner-1 chat washer (sand screw) were sampled quarterly between July 2008 and October 2009 for general chemistry and dissolved TAL metals analysis. Refer to **Tables 7-3** through **7-6** for the analytical data.

In terms of general water chemistry, all mine pool borings and Boone aquifer wells are dominated by calcium and sulfate (with one exception) and have TDS values in the approximate range of 1,800 through 2,800 mg/L. Mine pool boring SMB8 (completed in a separate mine room where injection is not occurring) is dominated by calcium, magnesium, and sulfate with TDS above 4,000 mg/L. A piper diagram showing major ion chemistry for all the groundwater and mine water samples is provided on **Figure 10-1**. There was no significant change in general chemistry parameters over the course of the quarterly sampling events for any of the sampling sources. However, in addition to SMB8, described above, groundwater from the Boone aquifer monitoring well BMW01 shows a slightly higher magnesium percentage than the other calcium-sulfate samples, possibly reflecting an increased influence from dolomite at this well location.

### 10.2.2 Redox Parameters

Chemical ORP (redox) appears to be suboxic to reducing in mine pool water near the Sooner Chat Pile, based on the presence of elevated concentrations of dissolved iron and dissolved manganese in most samples, and general support of this condition with the absence of nitrate and detection of ammonia, although both these species are detected at very low

concentrations. Areas where injection is occurring show more oxidizing conditions as documented by injection borings SMB3 and SMB5. Water from the chat washing operation supply well MMB2 shows variable iron and manganese concentrations. At times, concentrations of both parameters are below their respective detection limits (see **Table 7-4**).

Samples from Boone aquifer monitoring wells BMW01 and BMW02 showed generally higher concentrations of dissolved iron and dissolved manganese than the mine pool samples (with the notable exception of iron in SMB8, which was the highest at the site), along with field ORP values less than -100 mV and detectable ammonia (the reduced form of nitrogen). DO was less than 1 mg/L in the Boone aquifer monitoring wells, in somewhat better agreement with the other supporting redox data from the Boone aquifer. The DO readings in the mine pool borings were not always in agreement with the other redox data.

In 2008, observed disagreements between ORP/DO data and dissolved iron and manganese data suggested that suspended colloidal material could be influencing sample analytical results. Colloids can produce false positive results for iron, manganese, and trace metals if they are included in the acid-preserved samples. To address this question, selected field duplicate samples were collected in July 2009 and filtered through 0.10-micron filters, in addition to the normal 0.45-micron filters as discussed in **Section 7.3.4**. The purpose of this filter comparison was to detect the potential presence of fine colloidal material in the samples. The results of the tests indicated essentially identical concentrations in both sets of filtered samples, suggesting that colloidal materials are not present in sufficient quantity to affect the analytical results. The detected iron and manganese concentrations are, therefore, assumed to represent truly dissolved states.

## 10.3 Chat Mineralogy

Published chat and chat fines mineralogical analyses from the Tri-State region have demonstrated that trace metals are associated with both primary and secondary source minerals. The primary minerals are sulfides of zinc (sphalerite), lead (galena), and iron (pyrite). Cadmium most commonly occurs as an impurity in sphalerite (O'Day et al., 1998), and arsenic is found in combination with iron in pyrite. Secondary minerals form when the primary minerals are subjected to weathering by exposure to the atmosphere and rainfall. The sulfur in the sulfide minerals is oxidized to sulfate, and the host carbonate rock partially dissolves, liberating carbonate and bicarbonate. These ions recombine with trace metals to form metal sulfates and carbonates, along with metal oxides and hydroxides in the more oxidizing environment created by the exposure to surface conditions. Hydrozincite is a common carbonate form of zinc, and cadmium may be found in the form of the carbonate mineral otavite (Zachara et al., 1993). Lead and iron can also form carbonates (cerussite and siderite, respectively), as well as sulfates (anglesite and jarosite). Zinc has also been identified in silicate form, as the mineral hemimorphite (Schaider et al., 2007).

The principal ores in the Picher Field were the ore minerals galena and sphalerite. These two minerals would be expected to be associated with the chat to varying degrees. Three samples taken from the Craig Mine chat pile were analyzed for mineralogical content (Weston, 2006). XRD of those samples showed 90 to 95 percent quartz, 2 to 6 percent dolomite (plus trace calcite), 2 percent sphalerite, and 1 to 2 percent each of clay minerals and magnetite (an iron oxide). These analyses provide the mineralogy of the dominant

well-crystallized minerals in the chat samples, but XRD does not detect poorly crystallized weathering products of the ore minerals. It is reasonable to assume that trace metals also occur in the variably soluble weathered forms of sulfate, carbonate, and oxide salts, as discussed above.

In summary, chat consists predominantly of quartz with dolomite/calcite (95 to 97 percent), reflecting the mineralogy of rocks surrounding the ore zones of the area. The remaining few percent consists of a combination of remnant sulfide minerals and weathering products, both of which could contain trace metals. Trace metal concentrations can vary widely in chat samples, but this general composition of chat has been widely observed in the region (AATA, 2005; CH2M HILL, 2010). It should also be noted that the fine fraction of chat has been demonstrated to contain greater concentrations of trace metals than coarse fractions (Andrews et al., 2009; Schaider et al., 2007; Nairn et al., 2005; Datin and Cates, 2002). There is also greater surface area in chat fines compared with bulk chat, which exposes more of the solid material to weathering/leaching processes.

## 10.4 Proposed Geochemical Reactions during Injection

Geochemical reactions occurring during injection are important in explaining observed water chemistry and form a basis for fate and transport modeling. How injected source materials will influence groundwater depends on the chemical reactions that occur, particularly mineral precipitation and adsorption reactions. These reactions can control the concentrations of trace metals and major ions in the groundwater.

As described in the previous section, arsenic, cadmium, lead, and zinc are assumed to be present in sulfide minerals in the fine tailings. They may also be associated with secondary sulfate, carbonate, and oxide minerals. When the fine tailings are slurried at the surface with local groundwater or mine water, the metals-containing minerals would be expected to variably dissolve, releasing trace metals, sulfate, and other salts to the water. The acidity normally associated with the sulfide dissolution reaction would be buffered by the dissolution of carbonate minerals (calcite, dolomite) present in the fine tailings.

When the oxygen-rich slurry is injected into the mine pool, this water mixes with the less oxidized or reduced water in the mine pool. Where the two waters mix, the iron dissolved in the more reducing mine pool water would be oxidized at the injection point and precipitate out as iron oxides. Common metals and trace metals concentrations could be limited by precipitation or co-precipitation of metal carbonate, oxide, or hydroxide salts, and also by adsorption to these mineral surfaces. Arsenic in particular has a strong affinity for iron oxides, both co-precipitating with and adsorbing to the surfaces of these minerals (Stollenwerk, 2003).

Previous data collected at the Craig, Montreal, and Tulsa Mines, where short-term chat and washed fine tailings injection pilot studies were conducted, indicate that metals concentrations become elevated during injection but drop to much lower levels some time afterward, typically returning to pre-injection levels within a few months. This observed concentration decay is used in the dilution modeling, discussed in **Section 9.6**. The reason for this decay is believed to be more physical than chemical. The force of the injection maintains an active, turbid mixing zone in which mineral dissolution and exchange with the mine pool water takes place. When injection stops, the pile in the mine room stabilizes, with

the entrained water existing in a stable geochemical environment. The main mine pool water tends to flow around the pile, taking the path of least resistance. As a result, the entrained water of the injected chat pile interacts with the mine pool mainly by diffusive exchange, which is very slow compared with advective water movement. According to this conceptual model, mine rooms will be mostly but not completely filled with chat fines upon completion of injection. Even the small gaps between the walls and ceilings of the chat rooms are assumed to conduct the vast majority of groundwater flow through the room, given the low permeability of the chat fines consolidated in the injected pile. As a result, the flux of metals from the entrained water within the fines pile would be very minor compared with the advective flux around the pile. Geochemical equilibrium modeling is used to examine whether chemical processes can also contribute to limiting the trace metal concentrations.

## 10.5 Geochemical Equilibrium Model Setup

The geochemical reaction model code PHREEQC (Parkhurst and Appelo, 1999) was used to postulate chemical reactions to account for observed chemical changes and to identify reactions that control concentrations of chosen elements. PHREEQC was used previously with data from the Craig Mine pilot injection study (Weston, 2006). In that case, data from the chat mineralogical analysis, along with a modified SPLP applied to chat samples, were used to estimate changes in trace element concentrations in the mine pool water. The changes were simulated by assuming the trace metals cadmium, lead, and zinc were in the form of sulfate salts, effectively skipping the process of sulfide oxidation that occurs during the slurrying process. Model simulations indicated that the mineral gypsum (hydrated calcium sulfate) can limit the amount of calcium in the mine pool system, but that trace metal salts remained under-saturated. In other words, precipitation of specific minerals is not controlling the trace element concentrations in the waters.

The Craig Mine geochemical modeling exercise was also performed for this study, with a two-step reaction process: 1) mixing chat with pre-injection mine pool water (well FCB2, August 2005) to simulate slurry production, and 2) mixing the simulated slurry water with variable amounts of mine pool water. The reported chat XRD and SPLP results (Weston, 2006) were used to estimate the mass of carbonate and metal sulfide minerals added to the pre-injection mine water. Also present in the simulation were carbonate and sulfate minerals that were expected to be relevant in controlling trace element solubility. The initial chemical reactions were simulated assuming equilibration with atmospheric oxygen because the slurry process takes place at the surface. A simulated slurry water was produced as Step 1 of the simulation, with the mineral phases calcite, dolomite, iron oxide, otavite (cadmium carbonate), and hydrozincite (zinc hydroxyl-carbonate) controlling solubility. This slurry water was then mixed with the FCB2 well water in various proportions. For each mixture, relevant carbonate and sulfate minerals were expected to precipitate if concentrations of their component ions became sufficiently high to be limited by solubility.

In addition to the Craig Mine data, more recent data collected during the Sooner Chat Pile injection pilot study were used for PHREEQC simulations. The operations have been described previously in this document, as well as in the operations report (CH2M HILL, 2010). Only washed fine tailings have been injected at the Sooner Chat Pile. Although no

mineralogical analysis of washed fine tailings have been performed, it is expected to contain a higher fraction of available metals but essentially the same mineralogy and a lower permeability than the coarse, silica-rich bulk chat. Injection at the Sooner Chat Pile began in the summer of 2007 and has proceeded nearly continuously since that time. The initial injection boring, SMB2, became plugged early on and was replaced with SMB3 in late 2007. Since the summer of 2008, injection borings SMB3 and SMB5 have been used for injection. Chemical data from the Sooner Chat Pile pilot study include water chemistry for 1) the mine pool prior to injection (boring SMB2, July 2007), 2) nearby mine pool water used to slurry the washed fine tailings (extraction well MMB2), 3) slurry water containing the washed fine tailings (sand screw discharge, coded SNDSCR), and 4) mine pool chemistry at various times after injection began (borings SMB2, SMB3, SMB5, SMB6, SMB7, and SMB9) (CH2M HILL, 2010).

During the chat washing process, the chat is separated into coarse- and fine-sized fractions using water from the mine pool (extraction well MMB2). Coarse chat is removed while the combination of the washed fine tailings and MMB2 water slurried at the sand screw at the surface becomes the first step of the simulation. The second step of the simulation involves processes occurring when the slurry is injected into the mine pool. The first injection well used at the Sooner Chat Pile was SMB2, and that well's pre-injection chemistry from July 2007 is used to represent the starting condition. A review of regional monitoring data shows that mine pool water chemistry is highly variable in trace metal concentrations, presumably as a result of the natural variation within the ore zone. For example, the pre-injection zinc concentration at the Craig Mine was 2,200 µg/L; whereas, at the Sooner mine pool, it was 11,800 µg/L. The SMB2 analysis is being used in combination with the post-injection Sooner Chat Pile data for consistency at this specific location. In the second step of the simulation, the SNDSCR (sand screw) water was mixed with the pre-injection mine pool water in different proportions to best match the observed post-injection water. During mixing, mineral phases would commonly be expected to control concentrations of aqueous species, and were included to provide an upper limit on metals concentrations, as was done in the Craig Mine simulations.

## 10.6 Geochemical Equilibrium Model Results and Discussion

The PHREEQC output files and results summary for the Craig Mine simulations are provided in **Appendix J-1** and the water chemistries and comparison with PHREEQC results are provided in **Table 10-1**. The results were similar to those found previously (Weston, 2006), with gypsum reaching saturation and thus controlling calcium concentrations. None of the trace metal minerals reached saturation. The water chemistry that best matched the post-injection water chemistry (FCB2, November 2005) was one in which the slurry water mixed with mine pool water in a 1:2 ratio. This exercise confirmed the simulated reactions to be reasonable estimates of chemical reactions that occur during chat washing and injection, and were used in later simulations. The results suggest that there are no precipitation reactions that would reduce metals concentrations during and following injection of chat. This supports the conceptual model discussed in **Section 10.4** that physical entrainment of slurry water is more responsible for the observed post-injection concentration decreases than a chemical process. Some adsorption reactions could take place, but there were no significant decreases observed in the more recent Sooner Chat Pile

injection data, suggesting that while injection is proceeding, there are no significant chemical controls on trace metal concentrations.

The potential exception to this conceptual model is arsenic, which is much more variable than cadmium, lead, and zinc in pilot study data. Arsenic appeared to be elevated above background following injection at Craig Mine monitoring well FCB2, but not in nearby well FCB3. No pre-injection arsenic data were collected at the Tulsa and Montreal Mines. At the Sooner Pile, arsenic has been below detection limit in most samples, and the sole pre-injection concentration at SMB-2 was 6.9 µg/L. As arsenic can be released by dissolution of sulfide minerals in the chat fines at the surface, it would be expected to quickly adsorb to or co-precipitate with iron oxides during this process. In this way, water samples would not be expected to show elevated arsenic concentrations. Because of the inconsistency of data from Craig Mine data and the dominant non-detect concentrations at the Sooner Pile, arsenic was not included in the model discussion below.

Results of the Sooner Chat Pile washed fine tailings injection simulation are provided in **Appendix J-2** and water chemistries with comparison with PHREEQC results are shown in **Table 10-2**. Based on model results, the sulfide mineral sources of cadmium, lead, and zinc are dissolved along with calcium/magnesium carbonate during the first stage (washed fine tailings slurried with supply water). The ratio of calcium to magnesium was adjusted to better match the observed data. During mixing, the water is assumed to be in equilibrium with atmospheric oxygen, which quickly oxidizes the ferrous iron in the water and precipitates out as iron oxide (represented by the mineral goethite in this simulation). The carbon dioxide level remains elevated above that of the atmosphere because of the intimate contact with carbonate minerals in the washed fine tailings. The pH rises only slightly above the typical mine water pH of 6.4 to about 6.9 because of the buffering capacity of the carbonate minerals present. The simulated chemistry of the resulting water is shown in **Table 10-2**, along with the observed data (SNDSCR [sand screw]) for comparison. The data generally agree well, given that laboratory analytical data may vary by 20 percent between duplicate samples. Modeling predicts that, following dissolution of the minerals in the washed fine tailings, there is partial re-precipitation as carbonates of calcium (calcite), cadmium (otavite), and zinc (hydrozincite). These precipitates of cadmium and zinc have been noted as the carbonates that most commonly control concentrations of these elements in the presence of carbonate minerals (Zachara et al., 1989 and 1991; Garcia-Sanchez and Alvarez-Ayuso, 2002; Carroll et al., 1998).

The PHREEQC output file for the second step (mixing of washed fine tailings slurry with mine pool water) is provided in **Appendix J-3** and the basic results are compared with observed data in **Table 10-2**. The simulations predicted a slight dissolution of gypsum during the slurry mixing, and a precipitation of iron oxide, resulting in the removal of iron from solution. The match between simulated and observed was best when the ratio of mine pool water to injected slurry was 2:1. The simulated concentrations were not as consistently close to observed values as they were in the chat mixing simulation, but the general chemical trends were reasonably duplicated. One likely reason the match was not as close is that the pre-injection water chemistry is from 2007, whereas the slurry water sample was from 2008 (the earliest available). By 2008, the mine pool was already affected by the injection, so the extraction water from MMB2 used to mix with the chat was different than it would have been in 2007. It is also likely that at least some adsorption of trace metals onto

iron oxides and carbonate minerals occurs during this phase, but quantification of this process at the point of injection was not considered reliable and, therefore, not simulated.

Precipitation and dissolution reactions that form the observed post-injection mine pool water chemistry were verified through the use of the PHREEQC simulations. These reactions were applied to transport modeling with the PHAST code, which is described below. The simulations support the conceptual model discussed in **Section 10.4**, in which chemical controls on trace metals in the injected fines pile are relatively minimal compared with the physical entrainment of the water within the fines pile. Continued monitoring at the Sooner Pile will provide more conclusive evidence that metals concentrations will eventually return to pre-injection levels following the completion of injection at this site.

## 10.7 Trace Metal Transport in the Boone Aquifer

Transport of mine pool water into the Boone aquifer was simulated to assess the potential effects of washed fine tailings injection on Boone aquifer groundwater quality. Since mining activity ceased at the end of the 1960s, the mine pool has been discharging mine water into the Boone aquifer at various points in the Douthat area, according to the groundwater flow model. Boone monitoring wells have been installed in this area to observed water quality near the interface between the mine workings and the Boone aquifer. The Boone well cluster consisting of BMW07, BMW08, and BMW09 are estimated to be most representative of the water quality near the mine pool-Boone aquifer interface. The well cluster is estimated to be between about 200 and 2,000 feet from the interface.

### 10.7.1 PHAST Model Setup: Stage 1

The USGS program PHAST (Parkhurst et al., 2004) is a groundwater flow and transport model that incorporates PHREEQC equilibrium and reaction components. With this tool, mine pool flow into the Boone aquifer was simulated using standard flow parameters from the groundwater flow model along with dispersion and chemical reaction simulations that are known to take place during transport.

According to the regional groundwater flow conceptual flow model, groundwater flows into the mine workings from the northeast flows through the intricate tunnel and room system of the workings and emerges in the southwest as flow in the Boone aquifer. As a result, mine pool water flows into the Boone aquifer, not as a point source, but as the principal source of recharge to the aquifer in the Douthat area. The PHAST model was, therefore, set up as a one-dimensional model, with continuous flow from the upgradient mine workings flowing through the Boone aquifer under an estimated gradient. The model domain was limited to a length of 600 meters (about 2,000 feet) because no Boone data are available for calibration farther from the mine workings. A hydraulic conductivity of 80 ft/d was estimated based on the average conductivity used in the groundwater flow model (see **Section 9.3.2**). Constant head boundaries were assigned to the upgradient and downgradient ends of the model resulting in a gradient of 0.0063. The resulting specific discharge (the product of hydraulic conductivity and gradient) of 0.51 ft/d represents the upper end of the simulated specific discharge in the flow model (see **Section 9.3**). The assumed effective porosity was 0.05, given the fractured rock nature of the aquifer. This produces an average groundwater velocity of about 10 ft/d. Thus, the most conservative approach to transport was taken by simulating the highest groundwater flow that has been

assigned to the Boone aquifer. The dispersivity for the model was set at 9.8 meters, based on the scale-dependent dispersion formula developed by Xu and Eckstein (1995), corresponding to the modeled scale of 600 meters.

The first stage of the PHAST model simulated continuous flow of mine pool water into the Boone aquifer for 40 years, representing the approximate time from when mining activity stopped to the present day. The chemistry of Boone groundwater not affected by mine pool water was assumed to be that of Boone aquifer well BW13 (April 2009 analysis), a Boone well located to the west and cross-gradient from the mine pool interface. This well is a sodium-bicarbonate water of relatively low TDS (between 500 and 600 mg/L), with an alkaline pH (8.6), low zinc concentration (76 µg/L), and non-detect arsenic, cadmium and lead. By contrast, the representative pre-injection mine pool water (Sooner injection boring SMB2, July 2007) is calcium-sulfate dominated water with a TDS of 2,300 mg/L, slightly acidic pH (6.3), high zinc (11,800 µg/L), and detectable arsenic (6.9 µg/L), cadmium (8.3 µg/L) and lead (3.3 µg/L). The chemistry of these waters is provided in **Table 10-3**. Because arsenic concentrations are so highly variable in the mine pool, a more conservative estimate of 30 µg/L was substituted for transport modeling purposes.

Because the BW13 groundwater has a low concentration of dissolved iron (0.128 mg/L), it was modeled to be in equilibrium with hydrous ferric oxide (HFO), using the mineral phase amorphous ferric hydroxide, or $Fe(OH)_3(a)$, in the PHAST database. Adsorption to HFO was modeled by assuming a total HFO of 0.085 mole for each liter of groundwater. The binding constants for trace metals and other species to HFO are included in the PHAST database, and these constants were used to calculate the amount of adsorption to HFO in the transport simulation. In reality, these trace metals also adsorb to other minerals present in the aquifer matrix, such as manganese oxides and clay minerals. The concentration of HFO is viewed as a representative value for all non-carbonate adsorbents in the aquifer matrix.

It was assumed that, away from the lead-zinc mineralized zone, the Boone Formation contains substantial amounts of calcite (calcium carbonate). This mineral acts as an adsorbent of trace metals in groundwater (Uygur and Rymmer, 2000; Zachara et al., 1988), and published equilibrium constants from the literature were added to account for zinc and cadmium adsorption to calcite (Zachara et al., 1991 and 1993). Based on observed data for other minerals, it is anticipated that lead adsorbs to calcite at least as strongly as cadmium, but no equilibrium constants were found for lead in this reaction. As will be shown below, lead adsorption to the small amount of iron oxide alone is effective at removing essentially all lead from solution. The same is essentially true for arsenic. No equilibrium constants were available for arsenic adsorption to calcite, so only HFO adsorption was modeled.

During transport, the mineral phases identified in the PHREEQC modeling to be potential concentration limiters were set to precipitate if their components' concentrations became large enough. Besides $Fe(OH)_3(a)$ and calcite, described above, these minerals were siderite (ferrous iron carbonate), cerussite (lead carbonate), otavite (cadmium carbonate), and hydrozincite (zinc hydroxy-carbonate). These minerals were chosen not because they were necessarily expected to precipitate, but that if the precipitation of trace metals does occur, these minerals would be the first to form.

A conceptual diagram of the first stage of modeling is shown on **Figure 10-2**. The pre-injection mine pool water, represented by the July 2007 SMB2 water analysis, is continuously flowing into the Boone aquifer, represented by the April 2009 BW13 water analysis. The reactions that take place during flow into the Boone are shown on the figure.

### 10.7.2 PHAST Model Setup: Stage 2

As described in **Section 9.6**, the groundwater flow model was used to simulate the dilution that occurs as the pulse of post-injection water moves through the mine workings towards the Boone aquifer interface.

Following the 40-year Stage 1 simulation, injection of washed fine tailings over a 5-year period was simulated at two selected locations. The first selected location was the Sooner Chat Pile, where the current injection pilot study data have been collected. The October 2009 analysis from injection boring SMB3 was used to represent the post-injection mine pool water at the injection point. The simulated concentration profile of arsenic, lead, cadmium, and zinc at the interface is shown on **Figure 9-18** with the y-axis representing the percentage of post-injection water in the mine pool water at the Boone aquifer interface over time. As determined by the dilution transport simulations discussed in **Section 9.6**, the maximum percentage of post-injection water emerging at the Boone aquifer interface was about 7 percent, given the substantial distance from the Sooner Chat Pile to the interface. The remaining 93 percent is existing mine system water, represented by the pre-injection water chemistry. To incorporate these results into the PHAST model, the pulse curve on **Figure 9-18** was simplified into a single representative curve, then divided into five representative waters with fixed percentages of post- and pre-injection mine pool water. These divisions are shown on **Figure 10-3**. The water chemistry of each representative water was calculated by using PHREEQC to mix pre-injection water (July 2007 SMB2) with post-injection water (October 2009 SMB3) in the proportions listed on **Figure 10-3**. The five waters were introduced into the Boone aquifer for the corresponding time periods shown on **Figure 10-3**. After the fifth water duration ended, the pre-injection mine pool water was resumed at the model source. The conceptual diagram of this second stage of modeling is provided as **Figure 10-4**. The washed fine tailings injection was modeled as occurring over a 5-year period at the Sooner Chat Pile, followed by a 20-year post-injection period.

The second stage of modeling was repeated for a potential injection location closer to and more directly upgradient from the mine pool-Boone aquifer interface. The location, a chat pile area adjacent to Lytle Creek, is shown on **Figure 9-14**. No groundwater or mine pool analytical data are available from this area, so the same Sooner Chat Pile data were applied to the Lytle Creek location. The simulated concentration profile at the interface resulting from injection at the Lytle Creek site is provided on **Figure 9-19**. As this location is much closer to the Boone aquifer interface, the maximum percentage of post-injection water was about 30 percent (based on the dilution transport simulation discussed in **Section 9.6**), as opposed to 7 percent for the Sooner Chat Pile simulation. Because the simulated concentration pulse wave was nearly rectangular in shape, a single water of composition 70 percent SMB2 (July 2007), representing the mine system water, and 30 percent SMB3 (October 2009) , representing post-injection water, was inserted into the PHAST model over the time period shown on **Figure 9-19**.

Although only one 5-year injection was modeled at a time, it is not anticipated that any more than two such injections would ever take place simultaneously, given the availabilty of funding, materials, and equipment.

A pair of input files is required for the PHAST model: chemical data input and flow and transport input. The input files for the Sooner Chat Pile and Lytle Creek simulations are provided in **Appendices J-4** through **J-7**.

### 10.7.3 PHAST Model Results and Discussion

Stage 1 of the PHAST model was modeling mine pool water flow into the Boone aquifer for 40 years, the approximate time since mining activity ceased. **Figures 10-5**, **10-6**, and **10-7** show concentration profiles for arsenic, cadmium, lead, and zinc at 10, 20, and 40 years of simulation, respectively. At the interface between the mine pool and the Boone aquifer (zero distance on the x-axis), the concentration of each metal is fixed at the measured July 2007 SMB2 values (with the more conservative arsenic concentration of 30 µg/L described above). The non-mineralized Boone aquifer was modeled as having the chemistry of well BW13, having non-detect arsenic, cadmium and lead, and 76 µg/L zinc, as shown in **Table 10-3**. The concentration curves on the three figures show the progression of mine pool water into the Boone aquifer, coupled with attenuation of the four metals. According to the model output, the concentrations decrease as a result of adsorption onto iron oxide and calcite. Concentrations were not high enough to precipitate as insoluble minerals, based on the simulations. By the time of the present day (see **Figure 10-7**), concentrations of the metals are still at levels from 40 years before at 1,000 feet from the Boone aquifer interface.

Three downgradient monitoring wells, BMW07, BMW08, and BMW09 are screened across different depth intervals in the Boone aquifer. These three wells are below detection limits for cadmium and lead. Arsenic concentrations vary between 10.1 and 36.1 µg/L for 2009 samples. Zinc concentrations in these three wells are variable between non-detect and 5,120 µg/L. Observed zinc concentrations in well BMW09, located within the first 2,000 feet of the Boone aquifer interface, are around 5,000 µg/L (see **Table 10-3**). This is the highest zinc concentration observed in a downgradient Boone aquifer well, and may represent natural mineralization at the edge of an ore body. Regardless, the simulations for cadmium, lead, and zinc are consistent with the observed data, assuming well BMW09 is approximately 700 feet from the interface. The precise distance can only be estimated because the position of the mine pool interface is variable and likely gradational. Wells BMW07 and BMW08 are shallower Boone wells at the same location as BMW09, and both show a much lower concentration of zinc (see **Table 10-3**), so the BMW09 well may be viewed as an upper end member at this location and can be considered a conservative value for the purposes of this model. There are no other Boone aquifer wells in the monitoring network that are farther downgradient from this well cluster.

The model underestimates the concentration of arsenic at the well cluster location, predicting at or below the detection limit of 2 µg/L. This is due to the prediction of strong adsorption of arsenic to HFO surfaces, which strongly attenuates arsenic in the simulations. The model predicts a constant concentration of about 4,700 µg/L for iron, controlled by the solubility of HFO in the model. The well cluster data report between 41.9 and 51,400 µg/L, showing a very large variation. Part of this variation could be a result of suspended iron

oxide particulates in the sample water, small enough to pass through the 0.45-µm filter. Arsenic would be expected to be associated with suspended iron oxide and, therefore, the analyses may overestimate the amount of truly dissolved arsenic in the sample. It is also possible that natural arsenic concentrations around the Boone aquifer and mine pool are so highly variable that prediction of downgradient concentration in this simplified model is not achievable with a high degree of accuracy. The model predicts that the assigned mine pool concentration of sulfate (1,500 mg/L) is present at the BMW07/08/09 cluster from early stages of mine development. The observed concentrations at the well cluster range up to 1,460 mg/L, in general agreement with the model. Because the model predicts constant concentrations of both sulfate and iron through time, these constituents are not plotted on the figures.

Stage 2 of the PHAST modeling used the dilution curves produced from the groundwater flow model output (see **Section 9.6**), assuming a 5-year washed fine tailings injection at the Sooner Chat Pile and the Lytle Creek location (see **Figure 9-14**). For the Sooner Chat Pile simulation, PHAST results for arsenic, cadmium, lead, and zinc are shown for two simulation times, 5 years and 20 years, on **Figures 10-8** and **10-9**. Five years marks the end of the simulated injection, and the concentration pulse is shown emerging into the Boone aquifer at this time. At 20 years, the mine pool has returned to its original metals concentrations, and the pulse has moved forward and decreased in amplitude as a result of dispersion (see **Figure 10-9**). This trend would continue into the future if the simulation time were extended. The simulations predict very minor effects of washed fine tailings injection on the concentration profile of trace metals in the Boone aquifer.

At the modeled groundwater velocity and dispersivity, concentrations of conservative groundwater components, such as sodium and chloride, reach the end of the 2,000-foot model domain within 1 year of simulation time. The large difference between the conservative elements and the trace metals illustrates the strong attenuation that is predicted for the metals.

Results for the Lytle Creek injection site are shown on **Figures 10-10** and **10-11**, again showing simulated metals concentrations at 5 years and 20 years. In this case, the concentrations in the pulse (see **Figure 10-10**, left side of graph) are much greater than those of the Sooner Chat Pile simulation, given the higher percentage of post-injection water in the pulse. The results are similar to those of the Sooner simulation; however, with the pulse showing minor and temporary increases in concentrations resulting from washed fine tailings injection.

The advancement of the zinc concentrations in both sets of Stage 2 figures is the result of the PHAST model predicting gradual saturation of available zinc adsorption sites over time. The amount of adsorption sites that was assigned to the model was based on estimated total mass of rock surrounding each liter of groundwater (51.5 kilograms, given an assumed porosity of 0.05 and a rock density of 2.71 kilograms per liter) and the published adsorption site density for calcite (3.42e-6 moles per gram; Zachara et al., 1991 and 1993). It was also assumed that other Boone minerals would adsorb metals in a similar manner to calcite (e.g., dolomite, clay minerals), and these were combined with estimated calcite abundance in the formation. Finally, the calcite abundance was adjusted in Stage 1 to roughly match observed data at the BMW07/BMW08/BMW09 well cluster (this resulted in an adsorption

site density of 0.05 mole per liter of groundwater). Future monitoring at these wells and other downgradient wells will allow refinement of the model parameters.

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SECTION 11

# Conclusions and Recommendations

This report documents the work performed and results from the HCS. The HCS was performed to meet the objectives as stated in **Section 1.4**. The following sections present the conclusions of the HCS relative to the objectives based on the results of the HCS.

## 11.1 Conclusions

The conclusions from the HCS are provided in the following sections.

### 11.1.1 Groundwater and Mine Water Analytical Results

The analytical results for general chemistry show that the Boone aquifer within the mining field and the mine pool are both affected by high concentrations of iron and sulfate. TDS and hardness are both high, and pH is acidic at between 5 and 7. The groundwater and mine water, with a few exceptions, is generally reducing, with low DO concentrations and low ORP. The SMCLs for fluoride, sulfate, TDS, iron, and manganese are exceeded in most monitoring locations in the Boone aquifer and mine pool within the mining field. The water quality in the Boone aquifer improves away from the mine pool. Outside of the mining area, groundwater in the Boone aquifer has high hardness. The SMCL for TDS is typically exceeded, while the SMCL for fluoride, sulfate, iron, and manganese are exceeded at some monitoring locations. The concentrations of these analytes generally decrease away from the mining field. The highest sulfide concentrations measured during the HCS were in Boone aquifer wells BW02 and BW11, both of which lie outside of the mining field. Water quality in the Boone aquifer degrades towards the west, as the general chemistry results for well BW11 demonstrate. This well has high hardness, and TDS, sulfate, iron, and manganese concentrations exceed SMCLs. The data from this well are consistent with the general decrease in overall water quality in the aquifer towards the west as discussed in **Section 3.4.1**.

The trace metals analytical results show that the Boone aquifer within the mining field and the mine pool are both affected in localized areas by high concentrations of arsenic. Arsenic concentrations exceed the MCL in both the Boone aquifer within the mining field and in the mine pool. Arsenic concentrations exceed the MCL in the Boone aquifer and mine pool at monitoring locations that are and are not associated with previous injection pilot studies. Arsenic is detected infrequently at concentrations less than the MCL in the mine pool monitoring locations where injection is currently occurring at the Sooner Chat Pile pilot study. The occurrence of arsenic in locations not attributable to the pilot studies suggests that the arsenic detections are naturally occurring within the mining field. Arsenic is not detected in the Boone aquifer outside the mining field except in well BMW14, which is located approximately one-half mile south and downgradient of the mine pool.

The cadmium, lead, and zinc analytical results show that injection of source materials does increase the concentrations of these trace metals in the mine pool. Injection increases the concentrations of cadmium and lead to above MCLs, and zinc concentrations increase in the

mine pool at the injection location. Zinc concentrations already exceed the SMCLs in portions of the mine pool. The analytical results show that the Boone aquifer, even within the mining field, is not affected to a large degree by cadmium or lead, with all results except one being non-detect or below MCLs. Cadmium was detected in one sample (BW16 in April 2009), and this concentration slightly exceeded the MCL. Zinc concentrations in the Boone aquifer exceed the SMCL in some areas. However, the impact of injection on the zinc concentration in the Boone aquifer is not clear. The zinc concentration in well BMW02 has been increasing since the well was installed at the Sooner Chat Pile, and this increase is probably associated with the injection.

### 11.1.2 Groundwater Flow and Modeling Results

Data collected during the HCS were used to further refine the hydrogeologic characterization of the site and to construct a groundwater flow model of the mine pool and Boone aquifer. The primary conclusions from the modeling effort are summarized below:

- A refined groundwater flow model of the Tar Creek site has been developed using a significant quantity of new field data collected as part of the HCS.
- The groundwater model implies that the mine workings act as a drain in the northern portions of the site with groundwater entering the mine pool, and as a discharge source in the southern portion of the site (near the Douthat bridge) with mine pool water discharging into the Boone aquifer.
- The implementation of the CFP in the groundwater model has resulted in a much more accurate representation of the effects of the mine workings on the surrounding Boone aquifer groundwater system.
- The refined groundwater flow model has been used to develop a detailed water budget of the mine workings and the surrounding Boone aquifer. The water budget provides refined estimates of the quantity of groundwater inflow to the mine pool, quantity of mine pool outflow to the Boone aquifer, and patterns and rates of mine water flow through the mine tunnel system.
- The groundwater flow modeling evaluation, as well as the Roubidoux aquifer testing conducted as part of the HCS, suggest that the quantity of groundwater moving from the Boone aquifer into the Roubidoux aquifer is very small (less than 0.4 cfs), and the travel time for groundwater flow from the Boone aquifer to the Roubidoux aquifer is greater than 220 years.
- The groundwater flow model developed under this effort has been used to support the evaluation of the potential impacts of the injection of fine tailings into the mine pool on downgradient Boone water quality.
- This modeling tool can also be used to evaluate the effectiveness of other potential remedial strategies such as targeted mine plugging and water management strategies.

### 11.1.3 Geochemical Modeling Results

Injection of washed fine tailings at the Sooner Chat Pile and of bulk chat at other pilot study sites has resulted in a temporary increase in trace metal concentrations in mine pool water, with cadmium and lead concentrations increasing to above the MCLs and zinc concentrations above the SMCL. In past injection pilot studies of limited duration, the metals were observed to decrease to concentrations at or near pre-injection levels after a few months, and the cadmium and lead concentrations decreased to below their MCLs. Washed fine tailings injection has continued at the Sooner Chat Pile for over 2 years, and trace metal concentrations have remained relatively stable in the mine pool water during the 2-year period.

Geochemical equilibrium modeling with the PHREEQC code supported the assumed chemical reactions that release metals from chat and washed fine tailings and that control concentrations within the mine pool via mineral precipitation reactions. The modeling estimates that during washed fine tailings injection, sulfide minerals containing cadmium, lead, and zinc dissolve during chat washing and the injection process increases their concentration in the mine pool water at the site of injection. Arsenic was not modeled because of the lack of consistent historical data and consistent non-detects in the Sooner slurry, injection and supply wells. There are no apparent chemical solubility limitations on metals concentrations during injection, as trace metal mineral phases remain under-saturated. It appears that the observed decrease in metal concentrations following the short-term injection pilot studies is caused mostly by the physical stabilization of the injected slurry in the mine room, and less by chemical transformation.

The potential effect of washed fine tailings injection on downgradient Boone aquifer water quality was examined by 1) modeling dilution from the point of injection to the mine pool-Boone aquifer interface using groundwater model output (see **Section 9.6**), and 2) using the geochemical transport code PHAST to model mine pool water fate in the Boone aquifer. Transport was simulated from two injection locations, and showed that injection distance from the Boone aquifer interface strongly influences modeled concentration entering the Boone aquifer. The results of both simulations predicted that, although mine pool water has and will continue to influence downgradient Boone aquifer chemistry, the effect of injection on Boone groundwater quality is both minor and temporary.

### 11.1.4 Overall Assessment and Conclusions of the Hydrogeologic Characterization Study

The Boone and Roubidoux aquifers meet the definition of a USDW as defined in 40 CFR 144.3. The Roubidoux currently serves as the primary source of drinking water supply in Ottawa County, and it is anticipated to continue to serve as the primary source of drinking water in the future. The Boone aquifer is not used within Ottawa County as a source of public water supply. However, it is used by individuals for domestic and agricultural supply in Ottawa County. Within the mining field, there are no wells completed in the Boone aquifer that are known to currently be in use. However, there are residents within the site boundary who have and use wells completed in the Boone aquifer for drinking water purposes (see **Figure 3-7**). Finally, the State of Oklahoma considers the water within the Boone aquifer, including the mine pool, to be a treatable domestic supply of water (ODEQ, 2006).

The analytical data collected during this study show that the Boone aquifer is not affected by any site contaminants at concentrations exceeding the MCLs. The mine pool is affected with concentrations of cadmium and lead that exceed MCLs, and these contaminants are demonstrated to increase in concentration as a result of injection of source materials into the flooded mine workings. Monitoring data indicate that the concentrations of cadmium and lead attenuate fairly rapidly after injection ceases, and these results are also supported by geochemical modeling. Arsenic concentrations, not associated with injection, exceed the MCL in both the Boone aquifer and mine pool within the mining field. At the current pilot study location at the Sooner Chat Pile, injection of washed fine tailings does not appear to be increasing the concentrations of cadmium or lead in the Boone aquifer above MCLs, but the injection is likely increasing the zinc concentration to levels above the SMCL in one monitoring well. Geochemical and solute transport modeling demonstrate that the concentrations of cadmium, lead, and zinc attenuate fairly rapidly after injection ceases.

The groundwater quality of the Boone aquifer within the mining field is poor as a result of past mining and the presence of the mine pool. The SMCLs are exceeded for fluoride, sulfate, TDS, iron, manganese, and zinc, and the hardness is high. Although not health-based standards, the exceedences of the SMCLs are an indication that the water contained within the mine pool and Boone aquifer would require treatment for aesthetic purposes to be usable as a drinking water source. More suitable water can be obtained from the Roubidoux aquifer that does not require treatment. For these reasons, it is unlikely that the Boone aquifer or mine pool within the mining field will be used as a source of drinking water in the future.

There is no evidence to suggest that significant amounts of groundwater migrate from the mine pool and Boone aquifer to the Roubidoux aquifer through the intervening strata. Aquifer testing and the groundwater flow model indicate that the travel time for groundwater movement from the Boone to the Roubidoux aquifer through the intervening strata is greater than 200 years. ODEQ has documented localized mine water impacts in the Roubidoux aquifer, and the most likely causes are faulty well casings and/or poor annular seals of wells completed into the Roubidoux aquifer through the mine workings and/or Boone aquifer within the mining field. These mechanisms remain the only confirmed contaminant migration pathway between the mine pool and Boone aquifer into the Roubidoux aquifer. The OU1 RA resulted in the plugging of numerous abandoned Roubidoux wells at the site. Properly plugging any remaining abandoned Roubidoux wells further reduces the potential for contaminated mine water to migrate into the Roubidoux aquifer.

The HCS concludes that source material injection is compliant with the UIC requirements and may proceed under the OU4 ROD on the basis that:

1. The primary drinking water standards under 40 CFR 141 applies to public water systems.
2. Public water systems are defined as any system that provides water to at least 15 service connections or 25 people for at least 60 days annually (40 CFR 141.2).
3. The USDW, the Boone aquifer, within and surrounding the immediate vicinity of the site, does not currently serve as a supply source to a public water system.

4. The Boone aquifer, within and surrounding the immediate vicinity of the site, is not reasonably expected to serve as potential future source of supply for a public water system given that:

    a. The ROD states in Section 19.2.6 that IC will be a part of the OU4 remedy, including restricting future uses of groundwater from the Boone aquifer for potable or domestic supply that is affected with site-related contaminants above the remedial goals.

    b. Treatment of Boone aquifer water would first be required to address pre-existing contamination.

    c. For the foreseeable future, the voluntary relocation of residents of Cardin, Picher, and Hockerville within the site has resulted in a significant drop in the population, and has lowered both current and future water demand, making it less likely that a public water system would attempt to obtain water locally from the Boone aquifer.

    d. For the foreseeable future, water demand, if any, can be supplied by the Roubidoux aquifer, making it less likely that a public water system would attempt to obtain water locally from the Boone aquifer.

    e. For the foreseeable future, rural water districts supplied by the Roubidoux aquifer exist and serve northern Ottawa County, including significant portions found within the OU4 site boundary, making it less likely that a public water system would attempt to obtain water locally from the Boone aquifer.

5. In the areas of the site where injection may occur, there are no known private potable wells in use for drinking water. In a limited number of instances the Boone aquifer is used as a water supply for domestic wells. Prior to injection at any source material location, a well search will be completed to confirm that no domestic wells are located within the area that may be influenced by injection. In addition to searching for private wells, a search for points of discharge will be made prior to selection of an injection site.

6. The deeper Roubidoux aquifer, a USDW and known primary source of supply for public water systems in Ottawa County, has limited hydraulic connection through the intervening strata with the shallow Boone aquifer and the potential for aquifer cross-contamination is low. However, the presence of improperly abandoned boreholes or other direct conduits for flow could result in Boone aquifer entering the Roubidoux aquifer and degrading groundwater quality in the Roubidoux aquifer. A program exists for abandonment of these conduits as they are identified and it is recommended that this program continue. In addition, the State of Oklahoma has special well construction requirements in place within the OU4 boundary that apply to any future wells drilled into the Roubidoux aquifer (Title 785 Oklahoma Administrative Code Chapter 45, Appendix H). The well construction requirements are intended to ensure that any wells drilled through the Boone aquifer and into the Roubidoux aquifer are constructed such that the Boone aquifer is properly sealed off prior to drilling into the Roubidoux aquifer. Additional information indicating that the Boone and Roubidoux aquifers have a limited hydraulic connection include:

a. Groundwater model simulations also suggest that the travel time from the Boone aquifer to the Roubidoux aquifer through natural geologic materials is greater than 200 years.

b. The large difference in groundwater levels between the Boone and Roubidoux aquifers, with water levels in the Boone aquifer being greater than 200 feet higher than those in the Roubidoux aquifer, strongly suggest that the aquitard materials present between the aquifers represent a very effective barrier to vertical flow between the units.

c. The results of groundwater modeling simulations of the hydraulic interaction between the Boone and Roubidoux aquifers suggest that less than 11 gpm of Boone aquifer water per square mile of mine working reaches the underlying Roubidoux aquifer.

7. Data from past injection studies at the site performed by EPA Region 6 indicate that injection of chat has resulted in a temporary increase in trace metal concentrations in mine pool water. The metals were observed to decrease to concentrations at or near pre-injection levels after a few months.

8. The results of dilution and geochemical transport simulations predicted that, although mine pool water has and will continue to influence downgradient Boone aquifer chemistry, the effect of chat fines injection on Boone groundwater quality is both minor and temporary. Additional geochemical modeling should be included to predict the effects on discharges to surface water.

9. The results of the groundwater modeling and advective transport analysis performed as part of this study suggest that significant dilution in dissolved metals concentrations will occur during transport between the injection location and the closest natural discharge point of mine water into the Boone aquifer.

10. Geochemical modeling performed to evaluate the fate of dissolved metals leaving the mine workings and entering the Boone aquifer suggest that the metals contained in this discharge will attenuate rapidly with travel distance from the mine pool.

11. Environmental monitoring would be performed before, during, and after operations, in accordance with Section 19.2.6 of the OU4 ROD, to continuously assess and confirm UIC compliance, and would include monitoring of both the Boone and Roubidoux aquifers and surface water.

12. Injection wells will be properly abandoned after use (unless retained for longer-term monitoring purposes).

Based upon the above conclusions and supporting findings, injection of fine tailings into the abandoned mine workings can be conducted to be in compliance with the UIC regulations. It is recommended that a single fine tailings pond be injected and the effort studied before proceeding to full-scale implementation of the preferred injection remedy.

Recommendations for consideration in implementing source materials injection are provided in the following section. Certain recommendations, such as performing

environmental monitoring, are required by the OU4 ROD to ensure compliance with the UIC requirements and to monitor and ensure the protectiveness of the remedy.

## 11.2 Recommendations

The following sections provide recommendations based on the findings of the HCS that should be considered and potentially implemented in proceeding with source material injection into the mine workings at the site.

### 11.2.1 Develop an Environmental Monitoring Program for Injection

Implementation of injection would require environmental monitoring to ensure that injection is protective as a remedy and does not adversely affect a USDW or surface water at the site. The following sections provide general details for development of an environmental monitoring program to meet the requirements of Section 19.2.6 of the OU4 ROD and UIC regulations.

#### Continue Existing Groundwater Monitoring Program

The rationale to continue with the groundwater monitoring program would be to build upon the baseline pre-injection water quality and water level data sets for the Boone aquifer and mine pool. Expanding upon the baseline water quality data set would provide additional data to support the conclusions of this HCS, provide answers to any uncertainties associated with the data and modeling efforts, and establish pre-injection water quality baseline data for the site. Additional water level data would be used to continue to monitor the hydrogeologic system and changing conditions prior to, during, and after injection. Longer-term hydrogeologic conditions within the Boone aquifer and mine pool could be established and changes monitored. Also, changes to the hydrogeologic system that result from the RA at the Cherokee County Superfund Site in Kansas, where subsidence features are being filled in, could be assessed. Finally, environmental monitoring of injection activities is required by both the OU4 ROD and the UIC regulations. Additional monitoring activities may include the following:

- Annual, semi-annual, or quarterly groundwater and mine water sampling (the frequency may depend upon when injection actually starts, the injection frequency, and intensity or number of locations where injection occurs).
- Monthly or quarterly water level collection, pressure transducer data collection and downloads, and associated data compilation. The pressure transducer monitoring network could be expanded, reducing the frequency of manual water level collection events.
- Continued collection and management of precipitation and stream gage data.

#### Roubidoux Monitoring

In addition to the activities detailed above, once injection is implemented at the site as part of the RA, monitoring of the Roubidoux aquifer should continue to be performed to verify that the injection does not affect the water quality in the aquifer per the UIC requirements.

#### Mine Pool, Boone Aquifer, and Roubidoux Aquifer Groundwater Quality Data Compilation

A large amount of water quality data have been collected over several decades at the site by various stakeholders and government agencies. Much of these data are from the mine pool. The historical mine pool and any available Boone aquifer and Roubidoux aquifer groundwater quality data should be compiled into the project database to provide a comprehensive and centrally stored data set for the site. The data could then be used to establish baseline conditions to evaluate long-term trends and possible impacts resulting from injection and/or discharge from the mine pool to the Boone aquifer, Roubidoux aquifer, and surface water.

#### Install Additional Boone Formation Monitoring Wells

The groundwater flow model indicates that the majority of the mine water is moving out of the mine pool into the Boone aquifer south of the Douthat area. Several monitoring wells in the area suggest that the mine water is not contaminating the Boone aquifer with site-related contaminants in excess of the MCLs downgradient of the mine pool. The geochemical modeling supports this conclusion. However, installation of additional wells farther downgradient of the BMW07/BMW08/BMW09 well cluster would be beneficial to better calibrate the current geochemical model. Also, based upon the groundwater modeling results, some downgradient gaps could exist in the current monitoring network, and elimination of these gaps are likely necessary to provide UIC-compliant monitoring and to better detect changes and trends in Boone aquifer chemistry.

#### Continue Surface Water/Mine Pool Discharge Monitoring

Significant effort has been put into establishment of the current SWMP, and now the infrastructure is in place for potential extended use. Continued monitoring would allow for data collection to examine various seasonal patterns of surface water flow and mine pool discharge to surface water. Per Section 19.2.4.3 of the ROD, surface water quality will be monitored to determine if additional measures, such as temporary water treatment, are needed. Sampling in areas of mine pool discharges should be implemented to assess baseline conditions in the discharges prior to injection and to monitor for potential impacts on surface water that could be the result of injection.

### 11.2.2 Continue with Sooner Chat Pile Washed Fines Injection Pilot Study

The Sooner Chat Pile pilot study has resulted in collection of a significant amount of valuable data and lessons learned related to the technical feasibility, operations, and groundwater and mine water impacts of injection. Support and monitoring of the injection system at the Sooner Chat Pile should continue in order to learn from this operation such that the knowledge can be applied to future injection operations. Section 19.2.6 of the OU4 ROD states that pilot studies can continue during the RD phase for OU4.

The frequency of data collection efforts should be sufficient to allow trends and any changes in water quality and hydrogeologic conditions to be monitored and evaluated. The data should also be used for the purpose of continuing to track injection volumes and distribution of the washed fine tailings within the mine workings at the Sooner Chat Pile.

### 11.2.3 Continue Updating and Using the Groundwater Flow Model

A significant investment has been made by EPA to develop the groundwater flow model. Many benefits and advantages could be realized by continuing to use and update the groundwater flow model in the future. The groundwater flow model can be used to support future RD/RA efforts associated with injection. This would include evaluating the potential impacts of injection on the site hydrogeologic system and water quality resulting from injection.

In addition to evaluating the potential impacts on groundwater quality resulting from the injection of fine tailings into the mine workings, the groundwater flow model developed for the site could provide other potential benefits to support site remediation and management decisions. The groundwater flow model would be a useful tool in the long term to develop and implement a wider scale site-wide groundwater management strategy and possibly used to evaluate various future remedial alternatives and approaches. Potential future uses of the groundwater flow model include the following:

- Explore the effects of various injection strategies for fine tailings, including location, magnitude, and site sequencing on downgradient groundwater quality.
- Evaluate the effects of targeted mine tunnel plugging on mine pool discharge rates, migration patterns, and water quality effects.
- Evaluate the potential to implement water management strategies to create available storage in the mine workings that could then be used to contain future high flow events and prevent uncontrolled discharge to the surface water system.
- Test other site management strategies that may be developed in the future.

Assuming additional monitoring data are collected (as discussed in **Section 11.2.1**) the model can be updated and re-calibrated accordingly in the future to support multiple uses.

### 11.2.4 Perform Bench-scale or Treatability Studies

A limited column leach testing study could be performed to assess the short- and long-term chemical release potential of the proposed injection source materials (washed fine tailings and flotation tailings). To date, these source materials have not been subjected to this type of testing. Such testing would allow for the direct measurement of metals release over time under controlled chemical environments that represent the expected range of site conditions. Also, mineralogical analysis of flotation tailings and washed fine tailings would provide useful data to verify potential metals loading during injection of these materials. The data obtained from this additional testing would be used to further refine the solute transport and geochemical models as part of RD efforts to evaluate the potential impacts of injection at specific locations.

### 11.2.5 Implement Injection Using a Phased Approach

Initially, injection should be implemented using a phased approach. As an initial step, one fine tailings injection project should be completed for a single tailings pond. This project should include the injection of washed fine and flotation tailings, so that the likely impacts associated with full-scale injection implementation can be further evaluated.

It should be noted that, to date, a project involving the injection of flotation tailings has not been performed. The potential impacts on groundwater and mine water quality resulting from the injection of flotation tailings should be determined using a single study prior to full-scale implementation of injection under the RA.

The initial project should involve all anticipated aspects of an injection operation. Pre-injection mine water and groundwater data should be collected to establish baseline conditions. Data needed to design the injection system, such as physical properties of the fine tailings, site layout, and location and availability of mine workings should also be collected and evaluated. The project should include monitoring during and post-injection to assess the impacts of the injection on mine pool and Boone aquifer chemistry. Lessons learned could be used to design and implement future injection operations at the site. Data and information learned from the first study would be used to decide whether additional, smaller-scale projects should be completed prior to full-scale injection operations.

Implementing injection initially as a single project or series of smaller projects will present opportunities to learn what works and what does not work with respect to injection operations (such as design considerations, machinery and equipment, scale of operations, and cost information). Finally, this approach will provide additional protectiveness in that the effects of injection on the Boone aquifer, Roubidoux aquifer, and site surface water can be monitored initially at a smaller scale.

SECTION 12

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# Tables

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TABLE 1-1
Remedial Action Objectives Summary
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Environmental Medium | Remedial Action Objective | Preliminary Remediation Goal |
|---|---|---|
| Source Materials and smelter waste, transition zone soil, and soil, which underlies source material and smelter waste | Prevent adolescents from coming in direct contact, through the ingestion and inhalation exposure pathways, with lead-contaminated source material and smelter waste where lead concentrations exceed 500 mg/kg. The purpose of this objective is to reduce the central estimate of blood lead concentration in adults (i.e., the mature adolescents in question) that have been exposed to Site source materials to a level which ensures that the 95th percentile fetal blood lead concentration in their offspring does not exceed 10 µg/dl. This objective will also be protective for children who live on-site in the event they come in direct contact with the source material through the ingestion and inhalation exposure pathways. | Adolescents: 500 mg/kg lead in source material and smelter waste, in transition zone soil, and in the soil which underlies source and smelter waste. |
| | Prevent terrestrial fauna from coming in direct (or indirect through plant ingestion) contact, the ingestion exposure pathway, with cadmium-, lead-, or zinc-contaminated source materials and smelter waste where cadmium, lead, or zinc exceed their respective remediation goals of 10.0 mg/kg, 500 mg/kg, and 1,100 mg/kg. | Terrestrial Fauna: 10.0 mg/kg for cadmium 500 mg/kg for lead, and 1,100 mg/kg for zinc in source material, smelter waste, in transition zone soil, and in the soil which underlies source and smelter waste. |
| | Prevent riparian biota including waterfowl from coming into contact, through the ingestion exposure pathway, with dangerous concentrations of lead, cadmium, and zinc in surface water and sediment by eliminating all discharge of cadmium, lead, and zinc from source materials to surface water. | Zero discharge of cadmium, lead, and zinc from source materials to surface water. Zero discharge is defined as discharge concentration levels that would be consistent with the concentration levels that would be expected from soil that has background concentrations of these chemicals. |
| Soils | Prevent children who live on the Site from coming in direct contact, through the ingestion and inhalation exposure pathways, with lead contaminated soil where soil concentrations exceed 500 mg/kg. The purpose of this objective is to limit exposure to soil lead levels such that a typical (a hypothetical) child or group of similarly exposed children living on-site would have an estimated risk of no more than 5% exceeding 10 µg/dl blood lead level. | Children: 500 mg/kg lead in soil (See OU2 Record of Decision for Tar Creek Residential Areas). |
| | Prevent terrestrial fauna from coming in direct (or indirect through plant ingestion) contact, the ingestion exposure pathway, with cadmium-, lead-, or zinc-contaminated source materials and smelter waste where cadmium, lead, or zinc exceed their respective remediation goals of 10.0 mg/kg, 500 mg/kg, and 1,100 mg/kg. | Terrestrial Fauna: 10.0 mg/kg for cadmium, 500 mg/kg for lead, and 1,100 mg/kg for zinc in source material, smelter waste, in transition zone soil, and in the soil which underlies source material and smelter waste |
| Groundwater | Prevent Site residents from the ingestion of water from private wells that contain lead in concentrations exceeding the National Primary Drinking Water Standards. | 0.015 mg/l lead at water tap. |

**Notes:**
mg/kg - milligrams per kilogram
µg/dl - micrograms per deciliter
mg/l - milligrams per liter

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TABLE 2-1
Summary of Chat Piles Investigated during the OU4 Remedial Investigation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Estimated Area (Acres) | Estimated Volume (CY) |
|---|---|---|---|
| Lennan | CP001 | 3.99 | 47740.47 |
| – | CP002 | 0.76 | 2468.15 |
| – | CP003 | 0.78 | 10897.39 |
| Bird Dog | CP004 | 1.8 | 151866.52 |
| Adams-Mudd (Barret) | CP005 | 8.87 | 303280.26 |
| Pioneer | CP006 | 31.58 | 1678064.03 |
| Wilson | CP007 | 2.97 | 111790.81 |
| Tam-ah-hah | CP008 | 4.7 | 35122.81 |
| Scammon Hill | CP009 | 2.23 | 49111.52 |
| Semple | CP010 | 13.89 | 265332.75 |
| – | CP011 | 3.05 | 8143.74 |
| WMW-Brewster | CP012 | 7.37 | 66337.59 |
| Sooner | CP013 | 90.25 | 5736331.27 |
| – | CP014 | 6.96 | 25019.44 |
| Consolidated #3 | CP015 | 6.15 | 85317.94 |
| Hunt | CP016 | 3.74 | 117032.96 |
| Cortez | CP017 | 2.14 | 47115.67 |
| – | CP018 | 0.53 | 3333.67 |
| – | CP019 | 0.66 | 6834.49 |
| Ottawa | CP020 | 12.45 | 87039.12 |
| Howe | CP021 | 10.37 | 325678.02 |
| Ottawa | CP022 | 8.8 | 481157.92 |
| Ottawa | CP023 | 2.32 | 42604.3 |
| Ottawa | CP024 | 1.38 | 18128 |
| Howe | CP025 | 0.93 | 8520.83 |
| Gordon | CP026 | 5.22 | 333053.15 |
| Pelican | CP027 | 4.63 | 57722.92 |
| – | CP028 | 1 | 22055.18 |
| Anna Beaver | CP029 | 44.1 | 3026510.21 |
| John Beaver | CP030 | 6.75 | 163690.9 |
| Crystal-Central | CP031 | 2.16 | 41071.67 |
| Rialto (northeast) | CP032 | 34.5 | 920805.35 |
| St. Joe | CP033 | 24.75 | 1531303.23 |
| Kenoyer | CP034 | 24.92 | 1119876.24 |
| Rialto (north) | CP035 | 12.3 | 155652.6 |
| OKO | CP036 | 7.72 | 263865.48 |
| Slim Jim | CP037 | 3.34 | 126237.8 |
| Vintage (east) | CP038 | 3.17 | 183154.81 |
| Premier | CP039 | 2.96 | 132662.96 |
| Rialto (north) | CP040 | 2.49 | 39560.44 |
| Vintage (west) | CP041 | 1.71 | 42497.96 |

TABLE 2-1
Summary of Chat Piles Investigated during the OU4 Remedial Investigation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Estimated Area (Acres) | Estimated Volume (CY) |
|---|---|---|---|
| Kenoyer (northeast) | CP042 | 1.63 | 51809.18 |
| – | CP043 | 1.04 | 22434.81 |
| Kenoyer (northeast) | CP044 | 0.51 | 313.08 |
| Kenoyer (northeast) | CP045 | 0.66 | 21036.28 |
| Kenoyer (northeast) | CP046 | 0.15 | 4686.43 |
| Fisher | CP047 | 32.83 | 1808905.14 |
| – | CP048 | 4.56 | 33218.13 |
| Royal (Thompson) | CP049 | 3.81 | 89888.55 |
| – | CP050 | 2.18 | 32007.41 |
| – | CP051 | 2.09 | 33056.5 |
| – | CP052 | 0.68 | 14267.93 |
| Atlas | CP053 | 16.49 | 694564.97 |
| – | CP054 | 4.55 | 9727.15 |
| – | CP055 | 2.75 | 30466.62 |
| St. Louis #4 | CP056 | 7.7 | 91572.15 |
| Davenport | CP057 | 3.91 | 60939.02 |
| – | CP058 | 2.09 | 23980.56 |
| – | CP059 | 1.02 | 6815 |
| – | CP060 | 1.07 | 16255.52 |
| Lawyers | CP061 | 28.67 | 2421673.43 |
| Skelton (east) | CP062 | 7.86 | 71327.15 |
| – | CP063 | 0.36 | 6014.08 |
| Admiralty | CP064 | 42.15 | 2542651.67 |
| Rialto (south) | CP065 | 34.48 | 554978.52 |
| Skelton | CP066 | 31.15 | 1716246.53 |
| Domado | CP067 | 11.09 | 551472.24 |
| Admiralty | CP068 | 6.4 | 408432.56 |
| – | CP069 | 2.94 | 19546.89 |
| – | CP070 | 1.33 | 4013.67 |
| – | CP071 | 0.56 | 18586.5 |
| Blue Goose | CP072 | 33.51 | 236604.05 |
| Ritz | CP073 | 8.72 | 261151.24 |
| Woodchuck | CP074 | 7.3 | 311609.5 |
| Woodchuck | CP075 | 0.78 | 20247.18 |
| Woodchuck | CP076 | 4.19 | 130909.63 |
| – | CP077 | 3.03 | 35809.41 |
| Woodchuck | CP078 | 0.79 | 6825.05 |
| Blue Goose | CP079 | 0.19 | 26677.93 |
| Blue Goose | CP080 | 0.13 | 786.93 |

TABLE 2-1

Summary of Chat Piles Investigated during the OU4 Remedial Investigation

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Estimated Area (Acres) | Estimated Volume (CY) |
|---|---|---|---|
| Central Mill Pile | CP081 | 18.17 | 631623.53 |
| – | CP082 | 2 | 23985.81 |
| – | CP083 | 0.58 | 5027.81 |
| – | CP084 | 1.96 | 10049.08 |
| – | CP085 | 0.72 | 10007.69 |
| – | CP086 | 0.44 | 3585.46 |
| – | CP087 | 0.86 | 13090.96 |
| – | CP088 | 0.68 | 15041.48 |
| – | CP089 | 0.74 | 15150.33 |
| – | CP090 | 0.36 | 4891.83 |
| Pearl (Baily) | CP091 | 6.13 | 128582.77 |
| – | CP092 | 1.81 | 14920.52 |
| – | CP093 | 1.01 | 9713.85 |
| – | CP094 | 0.23 | 1576.69 |
| – | CP095 | 0.42 | 3422.6 |
| – | CP096 | 0.3 | 2541.75 |
| – | CP097 | 0.26 | 2082.31 |
| – | CP098 | 0.23 | 1878.11 |
| – | CP099 | 0.19 | 1866.2 |
| – | CP100 | 0.1 | 788.69 |
| – | CP101 | 1.47 | 11820.43 |
| – | CP102 | 0.7 | 7448.92 |
| – | CP103 | 0.7 | 7148.27 |
| – | CP104 | 0.66 | 7431.21 |
| – | CP105 | 0.62 | 333.04 |
| **Total** | | **767.05** | **31199508.51** |

Notes:

Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).

CY = cubic yard

– = a name is not associated with the chat pile

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TABLE 2-2
Chat Pile Sampling Summary
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Total Number of Samples | Number of Samples Colllected for pH, Grain Size, Bulk Density Analysis | Number of Samples Collected for Moisture Content and Metal Concentration Analysis | Field Duplicates |
|---|---|---|---|---|---|
| Bird Dog | CP004 | 9 | 1 | 8 | - |
| Adams-Mudd (Barret) | CP005 | 9 | 1 | 8 | 1 |
| Pioneer | CP006 | 11 | 3 | 8 | - |
| Wilson | CP007 | 1 | 1 | 0 | - |
| Tam-ah-hah | CP008 | 1 | 1 | 0 | - |
| Scammon Hill | CP009 | 1 | 1 | 0 | - |
| Semple | CP010 | 9 | 1 | 8 | 1 |
| Sooner | CP013 | 12 | 2 | 10 | - |
| Consolidated No. 3 | CP015 | 1 | 1 | 0 | - |
| Hunt | CP016 | 1 | 1 | 0 | - |
| Cortez | CP017 | 1 | 1 | 0 | - |
| Howe | CP021 | 9 | 1 | 8 | - |
| Ottawa | CP022 | 11 | 1 | 10 | - |
| Gordon | CP026 | 9 | 1 | 8 | - |
| Gordon No. 3 (North) | CP028 | 1 | 1 | 0 | - |
| Western (Ann Beaver) | CP029 | 9 | 1 | 8 | - |
| Western (John Beaver) | CP030 | 11 | 1 | 10 | 1 |
| St. Joe | CP033 | 9 | 1 | 8 | 1 |
| Kenoyer | CP034 | 12 | 2 | 10 | 1 |
| OKO | CP036 | 11 | 1 | 10 | - |
| Slim Jim | CP037 | 1 | 1 | 0 | - |
| Vintage (East) | CP038 | 1 | 1 | 0 | - |
| Premier | CP039 | 1 | 1 | 0 | - |
| Fisher/Mahutska | CP047 | 8 | 0 | 8 | 1 |
| Royal (Thompson) | CP049 | 11 | 1 | 10 | 1 |

TABLE 2-2
Chat Pile Sampling Summary
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Total Number of Samples | Number of Samples Colllected for pH, Grain Size, Bulk Density Analysis | Number of Samples Collected for Moisture Content and Metal Concentration Analysis | Field Duplicates |
|---|---|---|---|---|---|
| Atlas (Tulsa) | CP053 | 3 | 3 | 0 | - |
| Lawyers | CP061 | 9 | 1 | 8 | - |
| Admiralty No. 4 | CP064 | 7 | 0 | 7 | - |
| Admiralty No. 4 | CP068 | 1 | 0 | 1 | - |
| Skelton | CP066 | 9 | 1 | 8 | - |
| Blue-Goose | CP072 | 10 | 1 | 9 | - |
| Ritz (NE Satellite of Blue Goose) | CP073 | 2 | 1 | 1 | - |
| Woodchuck | CP074 | 1 | 1 | 0 | - |
| Woodchuck | CP076 | 1 | 1 | 0 | - |
| Central Mill | CP081 | 2 | 2 | 0 | - |
| Pearl (Bill Baily) | CP091 | 9 | 1 | 8 | 1 |
| New Beck[a] | CB047 | 1 | 1 | 0 | - |
| Subtotal | | 223 | 41 | 174 | 8 |

Notes:

Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).

[a]Draft Remedial Investigation Report indicates that a chat base was sampled instead of a chat pile

TABLE 2-3
Chat Pile Data Summary (pH, Grain Size Distribution, Bulk Density)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Location Identification | Dry Bulk Density ($lbs/ft^3$) | pH | Size Distribution (dry weight %)[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | > 3/8 inch | > #4 | > #40 | < #40 |
| Bird Dog | CP004 | S084 | 81.4 | 8.16 | 0.70 | 53.83 | 37.11 | 8.36 |
| Adams-Mudd (Barret) | CP005 | S037 | 77.0 | 8.25 | 0.00 | 1.65 | 69.49 | 28.86 |
| Pioneer | CP006 D | S019 | 91.8 | 7.64 | 0.46 | 16.56 | 66.87 | 16.10 |
| Pioneer | CP006 B | S020 | 84.1 | 8.72 | 0.00 | 1.52 | 81.28 | 17.20 |
| Pioneer | CP006 A | S022 | 77.7 | 9.01 | 0.00 | 2.73 | 89.07 | 8.20 |
| Wilson | CP007 | S138 | 92.5 | 8.54 | 1.84 | 21.78 | 61.35 | 15.03 |
| Tam-ah-hah | CP008 | S113 | 88.2 | 7.12 | 0.32 | 9.49 | 68.65 | 21.54 |
| Scammon Hill | CP009 | S139 | 79.7 | 8.74 | 0.00 | 4.06 | 79.01 | 16.93 |
| Semple | CP010 | S090 | 76.6 | 7.65 | 0.55 | 10.54 | 87.25 | 1.66 |
| New Beck 1 | CB047 | S098 | 83.8 | 7.95 | 0.84 | 18.24 | 59.63 | 21.28 |
| Sooner | CP013 | S040 | 87.2 | 8.73 | 0.16 | 2.76 | 73.33 | 23.74 |
| Sooner | CP013 | S042 | 82.4 | 8.77 | 0.00 | 2.58 | 77.11 | 20.31 |
| Consolidated No. 3 | CP015 A | S046 | 79.2 | 8.29 | 0.00 | 0.89 | 88.73 | 10.38 |
| Hunt | CP016 | S044 | 84.7 | 7.65 | 0.17 | 20.74 | 72.41 | 6.69 |
| Cortez | CP017 | S048 | 77.6 | 8.09 | 0.00 | 17.92 | 73.67 | 8.41 |
| Howe | CP021 | S060 | 82.4 | 6.71 | 0.34 | 30.07 | 67.35 | 2.23 |
| Ottawa | CP022 | S062 | 91.6 | 7.92 | 0.00 | 1.08 | 76.47 | 22.45 |
| Gordon | CP026 | S102 | 87.7 | 7.80 | 0.48 | 58.00 | 28.92 | 12.60 |
| Gordon No. 3 (North) | CP028 | S100 | 81.0 | 7.34 | 0.00 | 52.89 | 44.48 | 2.63 |
| Western (Ann Beaver) | CP029 A | S034 | 78.3 | 7.80 | 0.18 | 25.32 | 63.29 | 11.21 |
| Western (John Beaver) | CP030 A | S031 | 70.0 | 7.92 | 0.00 | 5.07 | 70.39 | 24.54 |
| St. Joe | CP033 | S049 | 88.5 | 8.21 | 0.48 | 34.29 | 54.33 | 10.90 |
| Kenoyer | CP034 A | S116 | 87.8 | 6.90 | 0.00 | 15.16 | 69.19 | 15.65 |
| Kenoyer | CP034 B | S119 | 82.7 | 8.33 | 0.00 | 0.17 | 71.06 | 28.77 |
| OKO | CP036 | S057 | 84.0 | 8.80 | 0.00 | 0.84 | 90.88 | 8.28 |
| Slim Jim | CP037 | S054 | 85.8 | 7.59 | 0.00 | 19.50 | 75.70 | 4.79 |
| Vintage (East) | CP038 | S059 | 90.2 | 9.01 | 0.00 | 10.85 | 79.56 | 9.59 |
| Premier | CP039 | S056 | 80.4 | 8.55 | 0.00 | 9.01 | 74.73 | 16.25 |
| Royal (Thompson) | CP049 | S120 | 83.1 | 7.67 | 3.41 | 53.15 | 38.50 | 4.94 |
| Atlas (Tulsa) | CP053 | S086 | 84.0 | 8.21 | 0.00 | 0.34 | 76.05 | 23.61 |
| Atlas (Tulsa) | CP053 | S085 A | 90.6 | 7.87 | 0.00 | 0.63 | 78.40 | 20.97 |
| Atlas (Tulsa) | CP053 | S085 B | 90.6 | 7.83 | 0.33 | 36.38 | 45.85 | 17.44 |
| Lawyers | CP061 | S073 | 84.5 | 8.80 | 0.00 | 13.95 | 59.83 | 26.22 |
| Skelton | CP066 | S036 | 88.4 | 7.84 | 0.00 | 18.11 | 73.24 | 8.65 |
| Blue-Goose | CP072 A | S023 | 70.5 | 8.73 | 0.00 | 1.41 | 79.68 | 18.91 |
| Ritz (NE Satellite of Blue Goose) | CP073 | S024 | 71.1 | 7.51 | 0.00 | 19.96 | 61.68 | 18.36 |
| Woodchuck | CP074 | S028 | 70.4 | 8.75 | 0.00 | 9.27 | 76.21 | 14.52 |
| Woodchuck | CP076 | S029 | 91.2 | 8.83 | 0.31 | 30.59 | 57.45 | 11.65 |
| Central Mill | CP081 A | S132 | 97.6 | 8.80 | 3.93 | 15.72 | 60.55 | 19.80 |
| Central Mill | CP081 A | S134 | 96.1 | 8.35 | 7.82 | 13.86 | 37.91 | 40.41 |
| Pearl (Bill Baily's) | CP091 | S126 | 83.3 | 7.86 | 0.17 | 33.28 | 47.95 | 18.60 |

Notes:
Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).
[a]No. 4 mesh = 0.187 inch; No. 40 mesh = 0.0165 inch
$lbs/ft^3$ - pounds per cubic foot

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TABLE 2-4
Summary of Remedial Investigation Cadmium, Lead, and Zinc Analytical Results for Chat Piles
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Bulk Chat | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cadmium (mg/kg) | | | Lead (mg/kg) | | | Zinc (mg/kg) | | |
| **Remediation Goal (mg/kg)** | | **10** | | | **500** | | | **1,100** | | |
| **Chat Pile** | **n** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** |
| Adams-Mudd (Barret) | 9 | 74 | 116 | 99 | 360 | 1390 | 829 | 14500 | 28600 | 21089 |
| Admiralty | 8 | 57 | 104 | 77 | 450 | 1320 | 849 | 14100 | 20300 | 17400 |
| Anna Beaver | 8 | 65 | 104 | 78 | 957 | 1860 | 1370 | 16700 | 23500 | 20750 |
| Pearl (Bill Baily's) | 9 | 64 | 131 | 95 | 210 | 1440 | 477 | 18300 | 31800 | 23789 |
| Bird Dog | 8 | 49 | 105 | 84 | 620 | 3470 | 1764 | 10200 | 25000 | 19075 |
| Blue Goose | 8 | 72 | 138 | 98 | 630 | 2300 | 1578 | 17400 | 33900 | 22525 |
| Fisher/Mahutska | 9 | 56 | 114 | 83 | 1240 | 4980 | 3534 | 22300 | 39300 | 32233 |
| Gordon | 8 | 91 | 125 | 110 | 1510 | 4400 | 2324 | 22300 | 27100 | 24388 |
| Howe | 8 | 69 | 125 | 92 | 1710 | 4200 | 2878 | 23000 | 35600 | 28625 |
| Western (John Beaver) | 9 | 43 | 83 | 67 | 1540 | 2600 | 1964 | 18300 | 22500 | 19989 |
| Kenoyer | 9 | 65 | 102 | 81 | 990 | 3320 | 2027 | 22900 | 26200 | 24300 |
| Lawyers | 8 | 58 | 103 | 75 | 230 | 1490 | 961 | 13800 | 22600 | 17938 |
| Royal (Thompson) | 9 | 80 | 130 | 102 | 350 | 770 | 560 | 21300 | 40300 | 30256 |
| OKO | 8 | 100 | 164 | 143 | 300 | 580 | 482 | 21100 | 39700 | 33800 |
| Ottawa | 8 | 112 | 135 | 125 | 1220 | 1590 | 1415 | 23100 | 27900 | 25600 |
| Pioneer | 8 | 91 | 199 | 121 | 750 | 2760 | 1829 | 19200 | 38200 | 27088 |
| Semple | 9 | 60 | 103 | 74 | 220 | 1440 | 422 | 10700 | 18800 | 13889 |
| Skelton | 8 | 75 | 199 | 108 | 340 | 960 | 589 | 22700 | 32700 | 26825 |
| Sooner | 8 | 77 | 113 | 93 | 990 | 2950 | 1610 | 15300 | 27500 | 21200 |
| St. Joe | 9 | 58 | 124 | 85 | 1320 | 2460 | 1778 | 19500 | 38200 | 25011 |
| **All Bulk Chat** | **168** | **43** | **199** | **92** | **210** | **4980** | **1213** | **10200** | **40300** | **23150** |

**Notes:**
Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).
mg/kg - milligrams per kilogram
n - number of bulk chat samples collected

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TABLE 2-5
Summary of Chat Bases Investigated
during the OU4 Remedial Investigation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Base Identification | Area (acres) | Estimated Volume (CY) |
|---|---|---|
| CB001 | 25.25 | 81471.19 |
| CB002 | 13.71 | 44232.75 |
| CB003 | 9.47 | 30548.93 |
| CB004 | 9.19 | 29638.02 |
| CB005 | 8.31 | 26828.32 |
| CB006 | 7.29 | 23527.53 |
| CB007 | 4.75 | 15326.1 |
| CB008 | 3.55 | 11470.01 |
| CB009 | 11.64 | 37556.29 |
| CB010 | 0.92 | 2973.46 |
| CB011 | 12.56 | 40513.04 |
| CB012 | 1.01 | 3261.79 |
| CB013 | 11.98 | 38668.95 |
| CB014 | 0.22 | 722.43 |
| CB015 | 1.71 | 5519.2 |
| CB016 | 1.55 | 5011.97 |
| CB017 | 8.45 | 27261.87 |
| CB018 | 8.45 | 27253.85 |
| CB019 | 4.82 | 15557.74 |
| CB020 | 1.16 | 3743.81 |
| CB021 | 52.41 | 169123.57 |
| CB022 | 29.88 | 96398.33 |
| CB023 | 26.52 | 85564 |
| CB024 | 19.88 | 64157.47 |
| CB025 | 1.29 | 4172.3 |
| CB026 | 11.22 | 36214.24 |
| CB027 | 10.9 | 35155.8 |
| CB028 | 6.87 | 22154.32 |
| CB029 | 1.45 | 4691.33 |
| CB030 | 0.65 | 2083.03 |
| CB031 | 0.44 | 1430.18 |
| CB032 | 55.05 | 177623.44 |
| CB033 | 17.27 | 55734.42 |
| CB034 | 19.34 | 62397.65 |
| CB035 | 17.77 | 57330.46 |
| CB036 | 0.51 | 1648.33 |
| CB037 | 0.25 | 813.28 |
| CB038 | 16.16 | 52150.9 |
| CB039 | 10.29 | 33201.29 |
| CB040 | 6.86 | 22142.86 |
| CB041 | 3.26 | 10510.72 |
| CB042 | 1.5 | 4837.88 |
| CB043 | 21.74 | 70138.41 |
| CB044 | 15.64 | 50478.02 |
| CB045 | 15.64 | 50477.66 |
| CB046 | 11.44 | 36902.89 |
| CB047 | 9.04 | 29176.73 |
| CB048 | 8.81 | 28431.67 |

| Chat Base Identification | Area (acres) | Estimated Volume (CY) |
|---|---|---|
| CB050 | 4.34 | 13994.12 |
| CB051 | 3.83 | 12359.83 |
| CB052 | 2.39 | 7725.22 |
| CB053 | 2.37 | 7658.01 |
| CB054 | 0.35 | 1132.89 |
| CB055 | 23.47 | 75719.64 |
| CB056 | 12.74 | 41099.65 |
| CB057 | 9.05 | 29199.59 |
| CB058 | 8.39 | 27081.36 |
| CB059 | 8.38 | 27026.18 |
| CB060 | 4.53 | 14606.23 |
| CB061 | 2.92 | 9418.66 |
| CB062 | 2.71 | 8743.26 |
| CB063 | 2.66 | 8576.87 |
| CB064 | 1.68 | 5417.04 |
| CB065 | 1.34 | 4335.74 |
| CB066 | 0.75 | 2409.85 |
| CB067 | 0.67 | 2171.65 |
| CB068 | 49.26 | 158942.18 |
| CB069 | 24.85 | 80190.26 |
| CB070 | 23.13 | 74628.36 |
| CB071 | 13.18 | 42517.39 |
| CB072 | 11.49 | 37060.45 |
| CB073 | 10.51 | 33902.2 |
| CB074 | 7.41 | 23900.53 |
| CB075 | 6.74 | 21734.45 |
| CB076 | 4.23 | 13633.69 |
| CB077 | 1.75 | 5640.3 |
| CB078 | 32.49 | 104842.17 |
| CB079 | 6.8 | 21933.17 |
| CB080 | 6.42 | 20717.49 |
| CB081 | 4.76 | 15350.36 |
| CB082 | 2.96 | 9535.98 |
| CB083 | 2.02 | 6517.52 |
| CB084 | 1.98 | 6398.12 |
| CB085 | 1.61 | 5207.33 |
| CB086 | 26.02 | 83945.08 |
| CB087 | 23.97 | 77330.71 |
| CB088 | 22.32 | 72024.57 |
| CB089 | 19.72 | 63639.56 |
| CB090 | 16.03 | 51716.07 |
| CB091 | 10.98 | 35420.03 |
| CB092 | 10.43 | 33652.26 |
| CB093 | 9.49 | 30610.73 |
| CB094 | 5.25 | 16927.24 |
| CB095 | 4.59 | 14818.03 |
| CB096 | 2.69 | 8683.98 |
| CB097 | 25.76 | 83126.2 |

TABLE 2-5
Summary of Chat Bases Investigated
during the OU4 Remedial Investigation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Base Identification | Area (acres) | Estimated Volume (CY) |
|---|---|---|
| CB049 | 5.33 | 17182.16 |
| CB099 | 14.26 | 46016.77 |
| CB100 | 14.23 | 45922.13 |
| CB101 | 12.2 | 39352.31 |
| CB102 | 11.83 | 38173.86 |
| CB103 | 8.99 | 29013.78 |
| CB104 | 7.02 | 22653.29 |
| CB105 | 5.72 | 18465.23 |
| CB106 | 5.69 | 18349.91 |
| CB107 | 5.1 | 16468.21 |
| CB108 | 4.58 | 14782.1 |
| CB109 | 1.91 | 6155.89 |
| CB110 | 1.45 | 4693.42 |
| CB111 | 0.83 | 2679.16 |
| CB112 | 0.76 | 2458.04 |
| CB113 | 0.12 | 401.56 |
| CB114 | 23.99 | 77409.51 |
| CB115 | 15.55 | 50165.08 |
| CB116 | 13.53 | 43664.03 |
| CB117 | 10.53 | 33961.97 |
| CB118 | 10 | 32272.59 |
| CB119 | 9.06 | 29242.64 |
| CB120 | 8.58 | 27679.04 |
| CB121 | 8.34 | 26916.93 |
| CB122 | 8.02 | 25875.39 |
| CB123 | 7.86 | 25359.73 |
| CB124 | 6.73 | 21712.85 |
| CB125 | 6.22 | 20065.42 |
| CB126 | 5.48 | 17671.02 |
| CB127 | 5.4 | 17432.19 |
| CB128 | 5.34 | 17231.83 |
| CB129 | 4.91 | 15833.2 |
| CB130 | 3.02 | 9748.1 |
| CB131 | 1.11 | 3575.21 |
| CB132 | 27.96 | 90224.51 |
| CB133 | 15.13 | 48804.67 |
| CB134 | 6.12 | 19738 |
| CB135 | 2.42 | 7792.93 |
| CB136 | 2.16 | 6956.35 |
| CB137 | 2.1 | 6791.25 |
| CB138 | 0.43 | 1402.4 |
| CB139 | 0.2 | 640.62 |
| CB140 | 12.5 | 40347.57 |
| CB141 | 8.95 | 28872.95 |
| CB142 | 7.24 | 23350.05 |
| CB143 | 6.9 | 22273.64 |
| CB144 | 5.61 | 18089.01 |
| CB145 | 5.2 | 16791.54 |
| CB146 | 4.74 | 15293.93 |

| Chat Base Identification | Area (acres) | Estimated Volume (CY) |
|---|---|---|
| CB098 | 20.18 | 65118.22 |
| CB148 | 2.11 | 6812.57 |
| CB149 | 2.07 | 6665.51 |
| CB150 | 1.8 | 5813.09 |
| CB151 | 9.62 | 31053.87 |
| CB152 | 5.81 | 18761.58 |
| CB153 | 2.32 | 7500.35 |
| CB154 | 3.5 | 11292.18 |
| CB155 | 2.4 | 7745.42 |
| CB156 | 1.78 | 5744.29 |
| CB157 | 0.82 | 2659.18 |
| CB158 | 6.84 | 22076.16 |
| CB159 | 4.41 | 14215 |
| CB160 | 2.41 | 7778.06 |
| CB161 | 1.38 | 4455.31 |
| CB162 | 1.35 | 4353.5 |
| CB163 | 0.29 | 951.25 |
| CB164 | 22.67 | 73153.2 |
| CB165 | 17.26 | 55689.02 |
| CB166 | 7.89 | 25449.71 |
| CB167 | 7.8 | 25169.2 |
| CB168 | 7.22 | 23291.77 |
| CB169 | 6.91 | 22286.16 |
| CB170 | 4.69 | 15148.45 |
| CB171 | 4.43 | 14310.12 |
| CB172 | 4.25 | 13717.97 |
| CB173 | 0.91 | 2944.2 |
| CB174 | 0.88 | 2855.39 |
| CB175 | 0.52 | 1693.76 |
| CB176 | 0.48 | 1545.14 |
| CB177 | 0.44 | 1414.18 |
| CB178 | 40.83 | 131731.71 |
| CB179 | 34.75 | 112139.41 |
| CB180 | 28.51 | 91996.76 |
| CB181 | 24.29 | 78363.14 |
| CB182 | 14.65 | 47260.65 |
| CB183 | 8.88 | 28659.09 |
| CB184 | 5.11 | 16499.98 |
| CB185 | 1.07 | 3462.65 |
| CB186 | 0.23 | 756.41 |
| CB187 | 43.15 | 139228.09 |
| CB188 | 22.17 | 71540.53 |
| CB189 | 14.43 | 46547.07 |
| CB190 | 12.85 | 41462.53 |
| CB191 | 11.88 | 38319.12 |
| CB192 | 8.6 | 27754.03 |
| CB193 | 5.82 | 18772.98 |
| CB194 | 4.43 | 14292.97 |
| CB195 | 2.23 | 7195.47 |

TABLE 2-5
Summary of Chat Bases Investigated
during the OU4 Remedial Investigation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Base Identification | Area (acres) | Estimated Volume (CY) |
|---|---|---|
| CB147 | 4.54 | 14657.99 |
| CB197 | 1.48 | 4779.69 |
| CB198 | 81.96 | 264440.01 |
| CB199 | 12.44 | 40132.66 |
| CB200 | 5.25 | 16938.13 |
| CB201 | 21.95 | 70820.39 |
| CB202 | 9.81 | 31637.82 |
| CB203 | 7.68 | 24792.59 |
| CB204 | 3.38 | 10896.76 |
| CB205 | 2.33 | 7529.05 |
| CB206 | 17.99 | 58052.2 |
| CB207 | 12.02 | 38784.99 |
| CB208 | 5.27 | 16995.22 |
| CB209 | 1.35 | 4365.67 |
| CB210 | 1.16 | 3733.07 |
| CB211 | 0.95 | 3078.47 |
| CB212 | 0.8 | 2596.31 |
| CB213 | 2.39 | 7727.74 |
| CB214 | 6.53 | 21073.92 |
| CB215 | 1.9 | 6126.06 |
| CB216 | 1.42 | 4573.49 |
| CB217 | 1.41 | 4539.59 |
| CB218 | 1.14 | 3690.18 |
| CB219 | 1.02 | 3306.86 |
| CB220 | 0.87 | 2807.2 |

| Chat Base Identification | Area (acres) | Estimated Volume (CY) |
|---|---|---|
| CB196 | 2.17 | 7016.68 |
| CB221 | 0.62 | 2016.13 |
| CB222 | 0.05 | 167.99 |
| CB223 | 11.62 | 37491.05 |
| CB224 | 6.38 | 20590.73 |
| CB225 | 4.19 | 13528.22 |
| CB226 | 3.05 | 9845.16 |
| CB227 | 5.44 | 17561.96 |
| CB228 | 3.13 | 10100.5 |
| CB229 | 1.75 | 5658.17 |
| CB230 | 2.74 | 8838.84 |
| CB231 | 2.59 | 8370.78 |
| CB232 | 2.53 | 8168.56 |
| CB233 | 0.82 | 2641.05 |
| CB234 | 0.49 | 1565.73 |
| CB235 | 0.41 | 1312.61 |
| CB236 | 0.05 | 172.06 |
| CB237 | 1.11 | 3568.9 |
| CB238 | 0.85 | 2753.03 |
| CB239 | 0.6 | 1937.49 |
| CB240 | 0.3 | 975.79 |
| CB241 | 0.4 | 1290.43 |
| CB242 | 0.4 | 1285.14 |
| CB243 | 0.33 | 1058.5 |
| **Total** | 2079.26 | 6709042.5 |

Notes:
Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).
CY - cubic yard

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TABLE 2-6
Chat Base Sampling Summary
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Base Name | Total Number of Samples | Number of Samples Colllected for pH, Grain Size, Bulk Density Analysis | Number of Samples Collected for Moisture Content and Metal Concentration Analysis | Field Duplicates |
|---|---|---|---|---|
| Pioneer | 4 | 0 | 4 | - |
| Blue Goose | 4 | 0 | 4 | - |
| Lawyers | 4 | 0 | 4 | - |
| St. Joe | 1 | 0 | 1 | - |
| Kenoyer | 6 | 1 | 5 | 1 |
| Gordon | 5 | 1 | 4 | - |
| Wilson | 1 | 1 | 0 | - |
| Tam-ah-hah | 1 | 1 | 0 | - |
| Subtotal | 26 | 4 | 22 | 1 |

**Notes:**

Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).

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TABLE 2-7
Chat Base Data Summary (pH, Grain Size Distribution, Bulk Density)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Chat Pile Name | Accumulation Identification | Location Identification | Dry Bulk Density ($lbs/ft^3$) | pH | Size Distribution (dry weight %)[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | > 3/8 inch | > #4 | > #40 | < #40 |
| Wilson | CP007 | S137 | 90.20 | 8.67 | 0.00 | 1.89 | 69.97 | 28.14 |
| Tam-ah-hah | CP008 | S114 | 85.20 | 7.11 | 0.17 | 30.62 | 62.06 | 7.15 |
| Gordon | CP026 | S104 | 87.90 | 7.70 | 0.00 | 23.87 | 69.03 | 7.10 |
| Kenoyer | CP034 A | S118 | 79.90 | 7.63 | 0.00 | 33.10 | 57.47 | 9.43 |

**Notes:**
Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).
[a]No. 4 mesh = 0.187 inch; #40 mesh = 0.0165 inch
$lbs/ft^3$ - pounds per cubic foot

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TABLE 2-8

Summary of Remedial Investigation Cadmium, Lead, and Zinc Analytical Results for Chat Bases

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| Bulk Chat | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cd (mg/kg) | | | Pb (mg/kg) | | | Zn (mg/kg) | | |
| **Remediation Goal (mg/kg)** | | **10** | | | **500** | | | **1,100** | | |
| **Chat Pile** | **n** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** |
| Blue Goose | 4 | 85 | 151 | 108 | 900 | 2490 | 1613 | 16700 | 29900 | 24500 |
| Gordon | 4 | 98 | 143 | 119 | 760 | 3020 | 1833 | 23500 | 33600 | 28325 |
| Kenoyer | 5 | 87 | 107 | 100 | 650 | 2430 | 1592 | 24200 | 30900 | 27400 |
| Lawyers | 4 | 51 | 78 | 61 | 1690 | 2290 | 1885 | 9520 | 16500 | 12730 |
| Pioneer | 4 | 83 | 123 | 98 | 2260 | 2680 | 2500 | 19100 | 25300 | 22025 |
| St. Joe | 1 | NA | NA | 76 | NA | NA | 1710 | NA | NA | 19900 |
| **Overall** | **22** | **51** | **151** | **96** | **650** | **3020** | **1863** | **9520** | **33600** | **23055** |

**Notes:**

Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).

mg/kg - milligrams per kilogram

n - number of chat base samples collected

Cd - cadmium

Pb - lead

Zn - zinc

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TABLE 2-9
Summary of Tailing Ponds Investigated during the OU4 Remedial Investigation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Fine Tailings Pond | Estimated Area (Acres) | Estimated Volume (CY) | Estimated Average Thickness (ft) | Number of Samples | Flotation Tailings | Surface Samples | Washed Fines |
|---|---|---|---|---|---|---|---|
| Atlas | 35.64 | 436,182 | 7.59 | 13 | 5 | 1 | 7 |
| Bird Dog | 115.96 | 674,188 | 3.6 | 19 | 6 | 3 | 10 |
| Blue Goose | 26.63 | 235,741 | 5.49 | 19 | 8 | 1 | 10 |
| Central Mill | 168.59 | 3,555,533 | 13.07 | 17 | 5 | 1 | 11 |
| John Beaver | 10.09 | 96,665 | 5.94 | 18 | 7 | 1 | 10 |
| Lawyers | 37.57 | 201,477 | 3.32 | 15 | 4 | 1 | 10 |
| Ottawa | 21.53 | 266,691 | 7.68 | 18 | 5 | 2 | 11 |
| Pioneer | 27.6 | 259,306 | 5.82 | 16 | 5 | 1 | 10 |
| Semple | 30.45 | 400,931 | 8.16 | 16 | 4 | 1 | 11 |
| Skelton | 14.07 | 99,194 | 4.37 | 18 | 6 | 1 | 11 |
| | | | **Subtotals** | **169** | **55** | **13** | **101** |

**Notes:**
Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).
ft - feet
CY - cubic yard

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TABLE 2-10

Summary of Remedial Investigation Cadmium, Lead, and Zinc Analytical Results for Fine Tailing Ponds

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| WASHED FINES | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cadmium (mg/kg) | | | Lead (mg/kg) | | | Zinc (mg/kg) | | |
| **Remediation Goal (mg/kg)** | | 10 | | | 500 | | | 1,100 | | |
| **Fine Tailings Pond** | **n** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** |
| Atlas | 7 | 59 | 150 | 93 | 633 | 2210 | 1541 | 11500 | 36300 | 20543 |
| Bird Dog | 10 | 22 | 190 | 95 | 1060 | 26600 | 8992 | 3550 | 29000 | 16010 |
| Blue Goose | 10 | 64 | 190 | 96 | 1030 | 3890 | 2430 | 11800 | 44500 | 20820 |
| Central Mill | 11 | 10 | 36 | 22 | 399 | 2380 | 1152 | 1810 | 7050 | 4340 |
| John Beaver | 10 | 67 | 166 | 134 | 2740 | 6730 | 5079 | 14100 | 42400 | 29860 |
| Lawyers | 10 | 11 | 49 | 23 | 1300 | 4830 | 2605 | 1730 | 7730 | 3916 |
| Ottawa | 11 | 112 | 320 | 171 | 5240 | 14700 | 7586 | 21000 | 70000 | 32809 |
| Pioneer | 10 | 60 | 159 | 84 | 2190 | 6120 | 4048 | 9690 | 47100 | 16999 |
| Semple | 11 | 22 | 60 | 37 | 220 | 1900 | 882 | 3630 | 10100 | 5999 |
| Skelton | 11 | 35 | 98 | 50 | 750 | 2520 | 1938 | 5980 | 26800 | 10713 |
| **All Washed Fines** | **101** | **10** | **320** | **80** | **220** | **26600** | **3658** | **1730** | **70000** | **15964** |

| FLOTATION TAILINGS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cadmium (mg/kg) | | | Lead (mg/kg) | | | Zinc (mg/kg) | | |
| **Remediation Goal (mg/kg)** | | 10 | | | 500 | | | 1,100 | | |
| **Fine Tailings Pond** | **n** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** |
| Atlas | 5 | 97 | 150 | 119 | 1380 | 4140 | 2832 | 24300 | 30100 | 26620 |
| Bird Dog | 6 | 55 | 174 | 118 | 2750 | 17800 | 8982 | 8270 | 29100 | 19228 |
| Blue Goose | 8 | 135 | 236 | 167 | 2840 | 9850 | 5441 | 25200 | 48000 | 37100 |
| Central Mill | 5 | 27 | 35 | 30 | 1130 | 2300 | 1762 | 4690 | 6350 | 5290 |
| John Beaver | 7 | 80 | 189 | 138 | 4720 | 8470 | 6660 | 27700 | 35700 | 31329 |
| Lawyers | 4 | 26 | 58 | 48 | 3630 | 6080 | 4290 | 4820 | 12200 | 8350 |
| Ottawa | 5 | 184 | 450 | 292 | 9170 | 17800 | 12874 | 46300 | 103000 | 68920 |
| Pioneer | 5 | 104 | 128 | 120 | 5540 | 7130 | 6074 | 21100 | 29200 | 24240 |
| Semple | 4 | 79 | 138 | 107 | 2820 | 3560 | 3115 | 14100 | 33700 | 23800 |
| Skelton | 6 | 79 | 225 | 148 | 1840 | 5530 | 3630 | 27500 | 60800 | 42650 |
| **All Flotation Tailings** | **55** | **26** | **450** | **133** | **1130** | **17800** | **5694** | **4690** | **103000** | **29842** |

**Notes:**

Data obtained from Draft Remedial Investigation Report for Operable Unit 4 (AATA, 2005).

mg/kg - milligrams per kilogram

n - number of samples

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TABLE 3-1
Hydraulic Properties of Hydrogeologic Units Present at the Tar Creek Superfund Site
as Provided from Published Sources
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Hydrogeologic Unit | | Hydraulic Properties | | | | |
|---|---|---|---|---|---|---|
| | | **Hydraulic Conductivity (cm/s)** | **Transmissivity ($ft^2/d$)** | **Storage Coefficient** | **Porosity** | **Well Yields (gpm)** |
| Boone Aquifer | | $7.8x10^{-3}$ | Less than 100 to greater than 1,000 | $2x10^{-4}$ | 5.2% avg | Less than 2 to greater than 2,000, avg 10 - 20 |
| Roubidoux Aquifer | Cotter and Jefferson City Dolomites | $3.7x10^{-7}$ to $9.6x10^{-9}$ | 70 - 940 | $3x10^{-4}$ | 10.3% avg | 100 to greater than 1,000 |
| | Roubidoux Formation | | 14 - 27,000, 400 - 700 avg | $1x10^{-6}$ to $9x10^{-4}$ | | |
| | Gasconade Dolomite | | 30 - 30,000 | $7x10^{-4}$ | | |
| | Eminence Dolomite | | 13 - 20,000 | $9x10^{-4}$ | | |

**Sources for Information:**
Reed et al., 1955
OWRB, 1983e
Imes and Emmett, 1994
Christenson, 1995
Christenson et al., 1990
Osborn, 2001
Playton, et al., 1980
Spruill, 1987

**Notes:**
Values for hydraulic properties vary in the literature. Ranges of values from reports are included in table.
cm/s - centimeters per second
$ft^2/d$ - square feet per day
gpm - gallons per minute

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TABLE 6-1
Operable Unit 4 Monitoring Network
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Northing | Easting | Surveyed Reference Elevation (ft amsl) | Total Depth (ft BTOC) | Screened Interval (ft bgs) | Depth of Mining Interval (ft bgs) | Depth of Well Casing (ft bgs) | Camera Survey Performed |
|---|---|---|---|---|---|---|---|---|---|
| BMW01 | Boone Formation | 741662.90 | 2894195.80 | 846.69 | 226.10 | 205 - 225 | NA | 205 | No |
| BMW02 | Boone Formation | 741480.70 | 2894419.38 | 844.52 | 212.00 | 191 - 211 | NA | 191 | No |
| BMW04 | Chester Group | 741439.05 | 2894904.76 | 853.56 | 131.25 | 111 - 131 | NA | 111 | No |
| BMW05 | Boone Formation | 733840.58 | 2890330.08 | 812.75 | 200.22 | 187-197 | NA | 187 | No |
| BMW06 | Boone Formation | 725577.90 | 2884129.13 | 831.87 | 328.00 | 295 - 325 | NA | 295 | No |
| BMW07 | Boone Formation | 726862.04 | 2891194.72 | 806.41 | 133.25 | 110 - 130 | NA | 110 | No |
| BMW08 | Boone Formation | 726851.57 | 2891216.33 | 806.99 | 104.17 | 81 - 101 | NA | 81 | No |
| BMW09 | Boone Formation | 726843.11 | 2891233.03 | 807.01 | 151.80 | 129 - 149 | NA | 129 | No |
| BMW10 | Boone Formation | 731333.27 | 2883486.24 | 840.07 | 266.15 | 233 - 263 | NA | 233 | No |
| BMW11 | Boone Formation | 727875.21 | 2890094.83 | 805.04 | 105.80 | 80 - 100 | NA | 80 | No |
| BMW12 | Boone Formation | 727866.40 | 2890082.15 | 805.18 | 159.00 | 134 - 154 | NA | 134 | No |
| BMW13 | Boone Formation | 733758.62 | 2908706.23 | 855.03 | 198.00 | 175 - 195 | NA | 175 | No |
| BMW14 | Boone Formation | 722888.62 | 2897532.07 | 846.75 | 164.27 | 130 - 160 | NA | 130 | No |
| BMW15 | Boone Formation | 743318.01 | 2915109.21 | 841.75 | 262.56 | 220 - 260 | NA | 220 | No |
| BW01 | Boone Formation | 740002.40 | 2926791.93 | 841.41 | 131.08 | NA | NA | 8 | Yes |
| BW02 | Boone Formation | 714814.93 | 2902230.58 | 852.46 | 272.70 | NA | NA | 46.5 | Yes |
| BW04 | Boone Formation | 716288.92 | 2862370.56 | 791.70 | 461.80 | NA | NA | 250+[1] | Yes |

TABLE 6-1
Operable Unit 4 Monitoring Network
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Northing | Easting | Surveyed Reference Elevation (ft amsl) | Total Depth (ft BTOC) | Screened Interval (ft bgs) | Depth of Mining Interval (ft bgs) | Depth of Well Casing (ft bgs) | Camera Survey Performed |
|---|---|---|---|---|---|---|---|---|---|
| BW05 | Shallow | 737013.16 | 2856419.83 | 818.54 | 127.80 | NA | NA | 14 | Yes |
| BW06 | Boone Formation | 736759.60 | 2899446.96 | 828.02 | 120.00 | NA | NA | 39 | Yes |
| BW07 | Boone Formation | 737612.70 | 2875848.17 | 821.13 | 123.60 | NA | NA | 11.5 | Yes |
| BW08 | Boone Formation | 732541.73 | 2867708.80 | 831.13 | ~500[2] | NA | NA | NM | No |
| BW09 | Boone Formation | 734579.68 | 2860004.30 | 800.78 | 325.60 | NA | NA | 11 - 21[3] | Yes |
| BW10 | Shallow | 731412.90 | 2850389.65 | 782.50 | 61.50 | NA | NA | NM | No |
| BW11 | Boone Formation | 731651.08 | 2847046.90 | 793.51 | 369.25 | NA | NA | 73.5 | Yes |
| BW12 | Boone Formation | 721871.90 | 2865674.03 | 811.87 | 137.80 | NA | NA | 23 | Yes |
| BW13 | Boone Formation | 722974.60 | 2867606.70 | 808.23 | 319.10 | NA | NA | 56 | Yes |
| BW14 | Boone Formation | 741230.20 | 2921129.70 | 841.79 | 248.40 | NA | NA | 20 | Yes |
| BW15 | Boone Formation | 739484.80 | 2887936.02 | 827.93 | 211.60 | NA | NA | 48 | Yes |
| BW16 | Boone Formation | 731340.75 | 2899884.40 | 839.04 | 157.00 | NA | NA | 25 | No |
| BW17 | Boone Formation | 722319.41 | 2869704.72 | 799.59 | 130.50 | NA | NA | 8 | Yes |
| CP013-MW1 | Chat Pile | 741437.65 | 2894915.54 | 854.05 | 25.85 | 13 - 23 | NA | 13 | No |
| CP013-MW2 | Chat Pile | 741776.70 | 2895207.42 | 861.03 | 28.93 | 16.5 - 26.5 | NA | 16.5 | No |
| CP013-MW3 | Chat Pile | 742613.75 | 2896137.82 | 852.66 | 14.45 | 6 - 11 | NA | 6 | No |
| CP013-MW4 | Chat Pile | 742561.02 | 2894407.53 | 850.54 | 10.19 | 3 - 8 | NA | 3 | No |
| CP013-MW5 | Chat Pile | 741682.17 | 2894198.04 | 847.08 | 13.47 | 5 - 10 | NA | 5 | No |
| FT059-MW1 | Tailings Pond | 726953.74 | 2888815.89 | 829.02 | 23.00 | 15 - 20 | NA | 15 | No |
| FT059-MW2 | Tailings Pond | 727328.44 | 2889374.29 | 822.30 | 21.25 | 13 - 18 | NA | 13 | No |
| FT059-MW3 | Tailings Pond | 726346.82 | 2889223.56 | 821.69 | 21.20 | 13 - 18 | NA | 13 | No |
| DEQ1W | Mine Pool | 717282.00 | 2879364.65 | 809.18 | 88.53 | 76 - 86 | 77 - 87 | 86 | No |
| EB1 | Mine Pool | 727855.70 | 2893984.54 | 821.97 | 90.6 [4] | NA | 116 - 137.5 | 20 | No |

TABLE 6-1
Operable Unit 4 Monitoring Network
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Northing | Easting | Surveyed Reference Elevation (ft amsl) | Total Depth (ft BTOC) | Screened Interval (ft bgs) | Depth of Mining Interval (ft bgs) | Depth of Well Casing (ft bgs) | Camera Survey Performed |
|---|---|---|---|---|---|---|---|---|---|
| EB3 | Mine Pool | 727592.30 | 2893527.37 | 823.39 | 91 [4] | NA | 132.5 - 156 | 17.5 | No |
| EB4 | Mine Pool | 727709.30 | 2893546.59 | 822.96 | 143.85 [4] | NA | 148 - 159 | 16.5 | No |
| EB5 | Mine Pool | 727520.50 | 2893438.30 | 822.79 | 151.75 | NA | 128 - 150 | 14 | No |
| FCB1 | Mine Pool | 727899.70 | 2895319.05 | 816.67 | 97.80 | NA | 95 - 109 | 38.8 | No |
| FCB2 | Mine Pool | 727822.60 | 2895271.97 | 815.21 | 124.55 | NA | 108 - 124 | NM | No |
| FCB3 | Mine Pool | 727922.20 | 2895298.91 | 816.39 | 81.75 | NA | 75 - 124 | NM | No |
| LMB2 | Mine Pool | 741650.50 | 2891472.82 | 856.02 | 278.62 | NA | 213 - 276 | 165 | No |
| LMB3 | Mine Pool | 741648.20 | 2891659.31 | 850.83 | 258.78 | NA | 252 - 258 | 71.3 | No |
| MD2 | Mine Pool | 723752.80 | 2912440.20 | 817.50 | 72.70 | NA | 48 - 66.5 | ~8 | Yes |
| MD20 | Mine Pool | 723380.40 | 2912610.70 | 813.90 | 69.12 | NA | NM | NM | No |
| MD3 | Mine Pool | 723792.90 | 2912531.60 | 815.80 | 67.55 | NA | NM | NM | No |
| MD4 | Mine Pool | 722828.30 | 2912660.20 | 813.62 | 61.20 | NA | ~57 - 68[5] | NM | No |
| MD5 | Boone Formation | 722817.30 | 2912815.60 | 810.26 | 30.16 | NA | NA | NM | No |
| MD7 | Shallow | 723147.40 | 2913038.50 | 806.09 | NM | NA | NA | NM | No |
| MMB3 | Mine Pool | 741819.50 | 2895211.40 | 860.96 | NM | NA | 213 - 221 | 104.3 | No |
| MP02 | Mine Pool | 728140.25 | 2886026.12 | 831.49 | 191.31 [4] | NA | ~315-322[5] | 106.5 | Yes |
| MP03 | Mine Pool | 735555.90 | 2889035.00 | 817.47 | 142.48 [4] | NA | ~169-183[5] | NM | Yes |
| MP04 | Mine Pool | 727861.57 | 2890547.68 | 805.59 | 219.04 | NA | 140 - 212 | 32.7 | Yes |
| MP05 | Mine Pool | 741325.64 | 2905364.13 | 848.81 | 162.45 | NA | 130 - 162.5 | 5 | Yes |
| MP06 | Mine Pool | 730510.46 | 2882043.62 | 834.12 | 282.70 | NA | ~240-278[5] | NM | No |
| MP14 | Mine Pool | 733744.41 | 2894406.87 | 807.78 | 274.80 | NA | NM | NM | No |
| MP17 | Mine Pool | 731387.20 | 2899913.33 | 839.60 | 191.40 | NA | 121.5 - 192 | 121.5 | Yes |
| MP19 | Mine Pool | 734955.55 | 2898443.59 | 828.68 | 138 [4] | NA | NM | NM | Yes |
| MP20 | Mine Pool | 740040.25 | 2906484.26 | 837.12 | 151.78 | NA | 127 - 151.5 | 120 | Yes |
| OCC1 | Mine Pool | 718550.85 | 2880309.76 | 819.98 | 270.08 | NA | 247 - 267 | NM | No |
| OCC2 | Mine Pool | 718475.80 | 2880182.73 | 817.00 | 88.65 [5] | NA | 97 - 134 | 69 | No |
| OCC3 | Mine Pool | 717343.10 | 2878878.23 | 813.97 | 183.83 | NA | 153 - 185 | 48 | No |
| OCC4 | Mine Pool | 717541.15 | 2878732.27 | 812.85 | 180.49 | NA | 165 - 193 | 48 | No |
| OCC5 | Mine Pool | 717687.80 | 2878874.21 | 814.47 | 208.55 | NA | 172 - 210 | 48 | No |
| RHMW2 | Mine Pool | 716022.60 | 2881428.92 | 802.44 | 93.48 | 80 - 100 | NM[6] | 80 | No |
| RMB1A | Mine Pool | 727325.10 | 2892161.85 | 823.56 | Blocked 25.00 | NA | 127 - 147 | 19.5 | No |
| RMB2 | Mine Pool | 727253.80 | 2892080.44 | 821.00 | 141.90 | NA | 138 - 157 | 21.5 | No |

TABLE 6-1
Operable Unit 4 Monitoring Network
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Northing | Easting | Surveyed Reference Elevation (ft amsl) | Total Depth (ft BTOC) | Screened Interval (ft bgs) | Depth of Mining Interval (ft bgs) | Depth of Well Casing (ft bgs) | Camera Survey Performed |
|---|---|---|---|---|---|---|---|---|---|
| RMB3 | Mine Pool | 727211.55 | 2892104.78 | 822.04 | 150.30 | NA | 136 - 165.5 | 22 | No |
| RMB4 | Mine Pool | 727329.50 | 2892212.67 | 823.21 | 135.00 | NA | 130.5 - 152.5 | NM | No |
| RMB5 | Mine Pool | 727335.70 | 2892301.07 | 825.91 | 97.6 [4] | NA | 141.5 - 161.5 | NM | No |
| SMB3 | Mine Pool | 741376.70 | 2894545.09 | 844.23 | 193.00 | NA | 189 - 212 | 98 | No |
| SMB5 | Mine Pool | 741525.80 | 2894617.60 | 846.69 | 204.00 | NA | 190 - 208 | 102 | No |
| SMB6 | Mine Pool | 741489.35 | 2894505.50 | 845.91 | 197.00 | NA | 188 - 211 | 102 | No |
| SMB7 | Mine Pool | 741539.57 | 2894306.50 | 845.22 | 223.30 | NA | 203 - 223 | 150 | No |
| SMB8 | Mine Pool | 742050.55 | 2894188.98 | 846.51 | 291.50 | NA | 283 - 291.5 | 100 | No |
| SMB9 | Mine Pool | 741681.43 | 2894382.23 | 845.14 | 205.54 | NA | 194 - 216 | 100 | No |
| TMB1 | Mine Pool | 736407.95 | 2901977.87 | 839.35 | 206.95 | NA | 210 - 239 | 75 | No |
| TMB2 | Mine Pool | 736410.70 | 2901917.80 | 840.41 | 222.59 | NA | 213 - 231 | 70 | No |
| TMB3 | Mine Pool | 736387.15 | 2901785.04 | 841.76 | 218.54 | NA | 204 - 235 | 62 | No |

**Notes:**

amsl - above mean sea level
bgs - below ground surface
BTOC - below top of casing
ft - feet
NA - not applicable
NM - not measured
1 - Casing encountered to depth attainable (250 ft) by the downhole camera.
2 - Pump still present in well, and total depth cannot be measured. Total depth listed is what was reported by the well owner.
3 - Cloudy conditions in well prevented exact determination of the casing depth.
4 - Based on available information, it appears the borehole has collapsed or become blocked.
5 - Mining interval depth based on information provided on the mine map.
6 - Location is completed in an old mine shaft.

TABLE 6-2
Monitoring Well Construction Details
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Date Installed | Surveyed Reference Elevation | Top of Screen | Bottom of Screen | Well Depth | Well Diameter |
|---|---|---|---|---|---|---|---|
| | | | (ft amsl) | (ft bgs) | (ft bgs) | (ft btoc) | (in.) |
| BMW01 | Boone Formation | 6/18/2008 | 846.69 | 202.50 | 222.50 | 226.10 | 4 |
| BMW02 | Boone Formation | 6/16/2008 | 844.52 | 189.50 | 209.50 | 212.00 | 4 |
| BMW04 | Chester Group | 6/19/2008 | 853.56 | 109.00 | 129.00 | 131.25 | 4 |
| BMW05 | Boone Formation | 11/1/2008 | 812.75 | 187.00 | 197.00 | 199.82 | 4 |
| BMW06 | Boone Formation | 3/27/2009 | 831.87 | 295.00 | 325.00 | 328.00 | 4 |
| BMW07 | Boone Formation | 4/8/2009 | 806.41 | 110.00 | 130.00 | 133.25 | 4 |
| BMW08 | Boone Formation | 4/8/2009 | 806.99 | 80.00 | 100.00 | 104.17 | 4 |
| BMW09 | Boone Formation | 4/8/2009 | 807.01 | 129.10 | 149.10 | 151.80 | 4 |
| BMW10 | Boone Formation | 3/27/2009 | 840.07 | 233.00 | 263.00 | 266.15 | 4 |
| BMW11 | Boone Formation | 4/16/2009 | 805.04 | 80.00 | 100.00 | 105.80 | 4 |
| BMW12 | Boone Formation | 4/16/2009 | 805.18 | 134.00 | 154.00 | 159.00 | 8 |
| BMW13 | Boone Formation | 4/29/2009 | 855.03 | 175.00 | 195.00 | 198.00 | 6 |
| BMW14 | Boone Formation | 4/23/2009 | 846.75 | 130.00 | 160.00 | 164.27 | 4 |
| BMW15 | Boone Formation | 4/30/2009 | 841.75 | 220.00 | 260.00 | 262.56 | 4 |
| CP013-MW1 | Chat Pile | 6/23/2008 | 854.05 | 13.00 | 23.00 | 25.85 | 2 |
| CP013-MW2 | Chat Pile | 6/23/2008 | 861.03 | 16.00 | 26.00 | 28.93 | 2 |
| CP013-MW3 | Chat Pile | 4/21/2009 | 852.66 | 6.00 | 11.00 | 14.45 | 2 |
| CP013-MW4 | Chat Pile | 4/21/2009 | 850.54 | 3.00 | 8.00 | 10.19 | 2 |
| CP013-MW5 | Chat Pile | 4/21/2009 | 847.08 | 5.00 | 10.00 | 13.47 | 2 |
| FT059-MW1 | Fine Tailings Pond | 4/28/2009 | 829.02 | 15.00 | 20.00 | 23.00 | 2 |
| FT059-MW2 | Fine Tailings Pond | 4/28/2009 | 822.30 | 13.00 | 18.00 | 21.25 | 2 |
| FT059-MW3 | Fine Tailings Pond | 4/28/2009 | 821.69 | 13.00 | 18.00 | 21.20 | 2 |

**Notes:**
ft amsl - feet above mean sea level
ft bgs - feet below ground surface
ft BTOC - feet below top of casing
in. - inches
All monitoring wells constructed of polyvinyl chloride (PVC)

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TABLE 6-3
Manual Water Level Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Surveyed Reference Elevation | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (ft amsl) | 7/15/2008 | | 8/26/2008 | | 9/22/2008 | | 10/16/2008 | | 11/21/2008 | | 1/21/2009 | | 2/9/2009 | | 3/17/2009 | |
| BMW01 | 846.69 | 45.21 | 801.48 | 45.87 | 800.82 | 44.70 | 801.99 | 45.95 | 800.74 | 45.15 | 801.54 | 45.85 | 800.84 | 46.36 | 800.33 | 45.75 | 800.94 |
| BMW02 | 844.52 | 43.32 | 801.20 | 43.75 | 800.77 | 42.62 | 801.90 | 43.80 | 800.72 | 42.98 | 801.54 | 43.65 | 800.87 | 44.16 | 800.36 | 43.56 | 800.96 |
| BMW03 | 846.55 | 8.88 | 837.67 | 9.98 | 836.57 | 10.63 | 835.92 | 11.15 | 835.40 | 11.92 | 834.63 | 13.09 | 833.46 | 13.53 | 833.02 | 14.20 | 832.35 |
| BMW04 | 853.56 | 51.12 | 802.44 | 51.78 | 801.78 | 50.78 | 802.78 | 52.00 | 801.56 | 51.13 | 802.43 | 51.67 | 801.89 | 52.18 | 801.38 | 51.67 | 801.89 |
| BMW05 | 812.75 | NM | NA | NM | NA | NM | NA | NM | NA | 11.14 | NA | 11.94 | 800.81 | 12.43 | 800.32 | 11.83 | 800.92 |
| BMW06 | 831.87 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW07 | 806.41 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW08 | 806.99 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW09 | 807.01 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW10 | 840.07 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW11 | 805.04 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW12 | 805.18 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW13 | 855.03 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW14 | 846.75 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BMW15 | 841.75 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BW01 | 841.41 | 13.61 | 827.80 | 15.18 | 826.23 | 14.81 | 826.60 | 15.50 | 825.91 | 15.86 | 825.55 | 15.60 | 825.81 | 16.51 | 824.90 | 15.51 | 825.90 |
| BW02 | 852.46 | 39.97 | 812.49 | 41.68 | 810.78 | 41.50 | 810.96 | 42.10 | 810.36 | 42.32 | 810.14 | 41.67 | 810.79 | 42.01 | 810.45 | 41.72 | 810.74 |
| BW04 | 791.70 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | 81.70 | 710.00 | 81.31 | 710.39 | 79.76 | 711.94 |
| BW05 | 818.54 | NM | NA | 14.86 | 803.68 | 14.46 | 804.08 | 14.80 | 803.74 | 15.12 | 803.42 | 14.96 | 803.58 | 15.37 | 803.17 | 15.22 | 803.32 |
| BW06 | 828.02 | 26.28 | 801.74 | 27.06 | 800.96 | 25.86 | 802.16 | 27.10 | 800.92 | NM | NA | 26.99 | 801.03 | 27.51 | 800.51 | 26.91 | 801.11 |
| BW07 | 821.13 | 18.35 | 802.78 | 18.27 | 802.86 | 17.43 | 803.70 | 18.52 | 802.61 | 17.27 | 803.86 | 16.35 | 804.78 | 16.27 | 804.86 | 19.83 | 801.30 |
| BW08 | 831.13 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NA | NA | NA | NA |
| BW09 | 800.78 | NM | NA | NM | NA | NM | NA | NM | NA | 10.30 | 790.48 | 10.35 | 790.43 | 10.59 | 790.19 | 10.94 | 789.84 |
| BW10 | 782.50 | 8.30 | 774.20 | 9.29 | 773.21 | 8.65 | 773.85 | 9.55 | 772.95 | 9.04 | 773.46 | 8.75 | 773.75 | 8.91 | 773.59 | 8.64 | 773.86 |
| BW11 | 793.51 | NM | NA | NM | NA | NM | NA | NM | NA | 14.79 | 778.72 | 14.57 | 778.94 | 14.97 | 778.54 | 14.87 | 778.64 |
| BW12 | 811.87 | 25.16 | 786.71 | 25.30 | 786.57 | 25.14 | 786.73 | 25.10 | 786.77 | 24.96 | 786.91 | 23.49 | 788.38 | 24.07 | 787.80 | 24.49 | 787.38 |
| BW13 | 808.23 | 58.71 | 749.52 | 58.60 | 749.63 | 58.71 | 749.52 | 58.70 | 749.53 | 58.80 | 749.43 | 58.82 | 749.41 | 59.13 | 749.10 | 52.97 | 755.26 |
| BW14 | 841.79 | 20.50 | 821.29 | 26.13 | 815.66 | 25.10 | 816.69 | 26.60 | 815.19 | 26.75 | 815.04 | 26.11 | 815.68 | 27.27 | 814.52 | 25.37 | 816.42 |
| BW15 | 827.93 | 26.68 | 801.25 | 27.40 | 800.53 | 26.27 | 801.66 | 27.42 | 800.51 | 26.60 | 801.33 | 27.37 | 800.56 | 27.88 | 800.05 | 27.26 | 800.67 |
| BW16 | 839.04 | 37.11 | 801.93 | 37.94 | 801.10 | 36.70 | 802.34 | 37.95 | 801.09 | 37.17 | 801.87 | 37.88 | 801.16 | 38.37 | 800.67 | 37.77 | 801.27 |
| BW17 | 799.59 | NM | NA | NM | NA | NM | NA | NM | NA | 8.76 | 790.83 | 8.48 | 791.11 | 8.32 | 791.27 | 8.63 | 790.96 |
| CP013-MW1 | 854.05 | 15.68 | 838.37 | 15.83 | 838.22 | 15.74 | 838.31 | 15.90 | 838.15 | 15.99 | 838.06 | 16.12 | 837.93 | 16.24 | 837.81 | 16.24 | 837.81 |
| CP013-MW2 | 861.03 | 20.82 | 840.21 | 21.28 | 839.75 | 21.10 | 839.93 | 21.40 | 839.63 | 21.55 | 839.48 | 21.88 | 839.15 | 21.11 | 839.92 | 22.13 | 838.90 |
| CP013-MW3 | 852.66 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| CP013-MW4 | 850.54 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| CP013-MW5 | 847.08 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| DEQ1W | 809.18 | 10.30 | 798.88 | 10.76 | 798.42 | 10.06 | 799.12 | 10.97 | 798.21 | 10.31 | 798.87 | 10.78 | 798.40 | 11.02 | 798.16 | 10.77 | 798.41 |
| EB1 | 821.97 | 19.36 | 802.61 | 21.02 | 800.95 | 19.95 | 802.02 | 21.15 | 800.82 | 20.28 | 801.69 | 21.08 | 800.89 | 21.59 | 800.38 | 21.00 | 800.97 |
| EB3 | 823.39 | 20.13 | 803.26 | 22.44 | 800.95 | 21.35 | 802.04 | 22.52 | 800.87 | 21.71 | 801.68 | 22.50 | 800.89 | 23.03 | 800.36 | 22.44 | 800.95 |
| EB4 | 822.96 | NM | NA | 21.98 | 800.98 | 20.92 | 802.04 | 22.05 | 800.91 | 21.22 | 801.74 | 22.00 | 800.96 | 22.58 | 800.38 | 21.98 | 800.98 |
| EB5 | 822.79 | 21.31 | 801.48 | 21.90 | 800.89 | 20.80 | 801.99 | 21.95 | 800.84 | 21.11 | 801.68 | 21.86 | 800.93 | 22.39 | 800.40 | 21.81 | 800.98 |
| FCB1 | 816.67 | 14.87 | 801.80 | 15.68 | 800.99 | 14.54 | 802.13 | 15.73 | 800.94 | 14.88 | 801.79 | 15.67 | 801.00 | 16.15 | 800.52 | 15.58 | 801.09 |
| FCB2 | 815.21 | 13.33 | 801.88 | 14.13 | 801.08 | 13.03 | 802.18 | 14.19 | 801.02 | 13.32 | 801.89 | 14.13 | 801.08 | 14.60 | 800.61 | 14.04 | 801.17 |
| FCB3 | 816.39 | 14.75 | 801.64 | 15.34 | 801.05 | 14.22 | 802.17 | 15.40 | 800.99 | 14.55 | 801.84 | 15.34 | 801.05 | 15.81 | 800.58 | 15.25 | 801.14 |
| FT059-MW01 | 829.02 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| FT059-MW02 | 822.30 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| FT059-MW03 | 821.69 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| LMB2 | 856.02 | 54.44 | 801.58 | 55.72 | 800.30 | 54.05 | 801.97 | 55.21 | 800.81 | 54.48 | 801.54 | 55.15 | 800.87 | 55.71 | 800.31 | 55.12 | 800.90 |
| LMB3 | 850.83 | 49.24 | 801.59 | 49.99 | 800.84 | 48.82 | 802.01 | 50.00 | 800.83 | 49.21 | 801.62 | 50.00 | 800.83 | 50.51 | 800.32 | 49.91 | 800.92 |
| MD2 | 817.50 | 8.02 | 809.48 | 10.40 | 807.10 | 8.55 | 808.95 | 10.30 | 807.20 | 9.98 | 807.52 | 9.02 | 808.48 | 10.05 | 807.45 | 8.96 | 808.54 |
| MD20 | 813.90 | 4.50 | 809.40 | 6.81 | 807.09 | 5.00 | 808.90 | 8.70 | 805.20 | 6.42 | 807.48 | 5.55 | 808.35 | 6.28 | 807.62 | 5.15 | 808.75 |
| MD3 | 815.80 | NM | NA | 8.75 | 807.05 | 6.94 | 808.86 | 8.60 | 807.20 | 8.34 | 807.46 | 7.62 | 808.18 | 8.36 | 807.44 | 7.22 | 808.58 |
| MD4 | 813.62 | 4.19 | 809.43 | 6.56 | 807.06 | 4.73 | 808.89 | 6.50 | 807.12 | 6.13 | 807.49 | 5.41 | 808.21 | 6.16 | 807.46 | 5.01 | 808.61 |

TABLE 6-3
Manual Water Level Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Surveyed Reference Elevation | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (ft amsl) | 7/15/2008 | | 8/26/2008 | | 9/22/2008 | | 10/16/2008 | | 11/21/2008 | | 1/21/2009 | | 2/9/2009 | | 3/17/2009 | |
| MD5 | 810.26 | NM | NA | 3.22 | 807.04 | 1.42 | 808.84 | 3.10 | 807.16 | 2.80 | 807.46 | 2.05 | 808.21 | 2.80 | 807.46 | 1.61 | 808.65 |
| MD7 | 806.09 | NM | NA | 1.81 | 804.28 | 1.80 | 804.29 | 1.80 | 804.29 | 1.82 | 804.27 | 1.80 | 804.29 | 1.81 | 804.28 | 1.80 | 804.29 |
| MMB3 | 860.96 | 59.99 | 800.97 | 60.61 | 800.35 | 41.45 | 819.51 | 60.70 | 800.26 | 59.90 | 801.06 | 60.54 | 800.42 | 61.12 | 799.84 | 60.49 | 800.47 |
| MP02 | 831.49 | 24.74 | 806.75 | 26.62 | 804.87 | 29.10 | 802.39 | 30.25 | 801.24 | 29.41 | 802.08 | 30.08 | 801.41 | 30.68 | 800.81 | 30.08 | 801.41 |
| MP03 | 817.47 | 15.70 | 801.77 | 16.38 | 801.09 | 15.32 | 802.15 | 16.50 | 800.97 | 15.63 | 801.84 | 16.31 | 801.16 | 16.85 | 800.62 | 16.32 | 801.15 |
| MP04 | 805.59 | 0.44 | 805.15 | 0.83 | 804.76 | 3.77 | 801.82 | 4.90 | 800.69 | 4.04 | 801.55 | 4.85 | 800.74 | 5.30 | 800.29 | 4.78 | 800.81 |
| MP05 | 848.81 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| MP06 | 834.12 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| MP14 | 807.78 | NM | NA | NM | NA | NM | NA | 6.65 | 801.13 | 5.48 | 802.30 | 6.18 | 801.60 | 6.84 | 800.94 | 6.16 | 801.62 |
| MP17 | 839.60 | 35.80 | 803.80 | 38.41 | 801.19 | 37.22 | 802.38 | 38.52 | 801.08 | 37.71 | 801.89 | 38.35 | 801.25 | 38.92 | 800.68 | 38.32 | 801.28 |
| MP19 | 828.68 | NM | NA | 28.80 | 799.88 | 26.68 | 802.00 | 27.85 | 800.83 | 27.04 | 801.64 | 27.76 | 800.92 | 28.22 | 800.46 | 27.67 | 801.01 |
| MP20 | 837.12 | 27.80 | 809.32 | 32.57 | 804.55 | 29.71 | 807.41 | 32.80 | 804.32 | 33.85 | 803.27 | 33.91 | 803.21 | 35.38 | 801.74 | 32.52 | 804.60 |
| OCC1 | 819.98 | NM | NA | 5.15 | 814.83 | 5.22 | 814.76 | 4.85 | 815.13 | 5.24 | 814.74 | 5.43 | 814.55 | 5.35 | 814.63 | 5.44 | 814.54 |
| OCC2 | 817.00 | 18.22 | 798.78 | 18.72 | 798.28 | 17.95 | 799.05 | 18.82 | 798.18 | 18.15 | 798.85 | 18.67 | 798.33 | 18.88 | 798.12 | 18.64 | 798.36 |
| OCC3 | 813.97 | 15.21 | 798.76 | 15.69 | 798.28 | 14.99 | 798.98 | 15.85 | 798.12 | 15.20 | 798.77 | 15.68 | 798.29 | 15.93 | 798.04 | 15.65 | 798.32 |
| OCC4 | 812.85 | 14.02 | 798.83 | 14.59 | 798.26 | 13.81 | 799.04 | 14.72 | 798.13 | 14.08 | 798.77 | 14.58 | 798.27 | 14.81 | 798.04 | 14.56 | 798.29 |
| OCC5 | 814.47 | 15.65 | 798.82 | 16.11 | 798.36 | 15.41 | 799.06 | 16.50 | 797.97 | 15.61 | 798.86 | 16.12 | 798.35 | 16.34 | 798.13 | 16.07 | 798.40 |
| RHMW2 | 802.44 | 4.15 | 798.29 | 4.55 | 797.89 | 3.86 | 798.58 | 4.69 | 797.75 | 4.02 | 798.42 | 4.54 | 797.90 | 4.76 | 797.68 | 4.52 | 797.92 |
| RMB1A | 823.56 | 13.64 | 809.92 | 13.31 | 810.25 | 11.36 | 812.20 | NM | NA | 11.90 | 811.66 | 20.01 | 803.55 | 22.26 | 801.30 | 21.52 | 802.04 |
| RMB2 | 821.00 | 19.23 | 801.77 | 20.01 | 800.99 | 18.90 | 802.10 | NM | NA | 19.20 | 801.80 | 20.00 | 801.00 | 20.50 | 800.50 | 19.91 | 801.09 |
| RMB3 | 822.04 | 20.30 | 801.74 | 21.09 | 800.95 | 19.98 | 802.06 | NM | NA | 20.31 | 801.73 | 21.09 | 800.95 | 21.60 | 800.44 | 21.00 | 801.04 |
| RMB4 | 823.21 | 22.05 | 801.16 | 22.75 | 800.46 | 21.70 | 801.51 | NM | NA | 22.03 | 801.18 | 22.80 | 800.41 | 22.72 | 800.49 | 22.20 | 801.01 |
| RMB5 | 825.91 | 24.05 | 801.86 | 24.74 | 801.17 | 23.09 | 802.82 | NM | NA | 23.37 | 802.54 | 24.34 | 801.57 | 24.78 | 801.13 | 24.51 | 801.40 |
| SMB1 | 843.13 | 20.20 | 822.93 | NM | NA | 19.20 | 823.93 | 18.90 | 824.23 | 18.90 | 824.23 | 18.63 | 824.50 | 18.05 | 825.08 | 18.51 | 824.62 |
| SMB3 | 844.23 | 42.60 | 801.63 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NA | NA |
| SMB5 | 846.69 | 45.20 | 801.49 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | 28.58 | NA |
| SMB6 | 845.91 | 44.47 | 801.44 | 45.16 | 800.75 | 44.00 | 801.91 | 43.75 | 802.16 | 44.35 | 801.56 | 45.06 | 800.85 | 45.51 | 800.40 | 44.89 | 801.02 |
| SMB7[a] | 845.22 | 41.77 | 803.45 | 42.45 | 802.77 | 41.31 | 803.91 | NM | NA | 43.69 | 801.53 | 44.40 | 800.82 | 44.92 | 800.30 | 44.32 | 800.90 |
| SMB8 | 846.51 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| SMB9 | 845.14 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| TMB1 | 839.35 | 37.66 | 801.69 | 38.46 | 800.89 | 37.31 | 802.04 | 38.50 | 800.85 | 37.70 | 801.65 | 38.40 | 800.95 | 38.92 | 800.43 | 38.42 | 800.93 |
| TMB2 | 840.41 | 38.63 | 801.78 | 39.40 | 801.01 | 38.27 | 802.14 | 39.45 | 800.96 | 38.65 | 801.76 | 39.38 | 801.03 | 39.87 | 800.54 | 39.33 | 801.08 |
| TMB3 | 841.76 | 40.21 | 801.55 | 40.98 | 800.78 | 39.83 | 801.93 | 41.03 | 800.73 | 40.21 | 801.55 | 40.91 | 800.85 | 41.43 | 800.33 | 40.88 | 800.88 |

**Notes:**
[a]SMB7 - Bingham installed the drop pipe and surface completion on SMB7 in October 2008. The injection boring was resurveyed, resulting in a new reference elevation for water levels collected after October 2008.
amsl - above mean sea level
bgs - below ground surface
BTOC - below top of casing
ft- feet
NA - not applicable
NM - not measured

TABLE 6-3
Manual Water Level Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Surveyed Reference Elevation | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (ft amsl) | 4/22/2009 | | 5/11/2009 | | 6/19/2009 | | 7/27/2009 | | 8/31/2009 | | 10/5/2009 | | 11/23/2009 | | 1/14/2010 | |
| BMW01 | 846.69 | 44.51 | 802.18 | 44.48 | 802.21 | 44.87 | 801.82 | 46.56 | 800.13 | 45.95 | 800.74 | 45.16 | 801.53 | 44.98 | 801.71 | 44.65 | 802.04 |
| BMW02 | 844.52 | 42.23 | 802.29 | 42.46 | 802.06 | 42.67 | 801.85 | 44.41 | 800.11 | 43.90 | 800.62 | 42.93 | 801.59 | 42.85 | 801.67 | 42.49 | 802.03 |
| BMW03 | 846.55 | 14.86 | 831.69 | 15.21 | 831.34 | NM | NA | 17.25 | 829.30 | 18.00 | 828.55 | 18.62 | 827.93 | 19.48 | 827.07 | 20.39 | 826.16 |
| BMW04 | 853.56 | 50.55 | 803.01 | 50.64 | 802.92 | 51.68 | 801.88 | 53.36 | 800.20 | NM | NA | 51.91 | 801.65 | 51.72 | 801.84 | 50.62 | 802.94 |
| BMW05 | 812.75 | 10.58 | 802.17 | 10.57 | 802.18 | 10.85 | 801.90 | 12.47 | 800.28 | 11.65 | 801.10 | 11.11 | 801.64 | 10.81 | 801.94 | 10.46 | 802.29 |
| BMW06 | 831.87 | NM | NA | 104.98 | 726.89 | 21.88 | 809.99 | 23.41 | 808.46 | 21.92 | 809.95 | 21.54 | 810.33 | 21.48 | 810.39 | 21.61 | 810.26 |
| BMW07 | 806.41 | 4.28 | 802.13 | 4.99 | 801.42 | 4.47 | 801.94 | 6.01 | 800.40 | 5.64 | 800.77 | 4.69 | 801.72 | 4.48 | 801.93 | 4.29 | 802.12 |
| BMW08 | 806.99 | 4.66 | 802.33 | 21.29 | 785.70 | 4.97 | 802.02 | 6.41 | 800.58 | 5.96 | 801.03 | 5.09 | 801.90 | 4.88 | 802.11 | 4.84 | 802.15 |
| BMW09 | 807.01 | 4.99 | 802.02 | 4.22 | 802.79 | NM | NA | 6.77 | 800.24 | 6.37 | 800.64 | 5.42 | 801.59 | 5.17 | 801.84 | 4.95 | 802.06 |
| BMW10 | 840.07 | 249.75 | 590.32 | 237.05 | 603.02 | 199.85 | 640.22 | 166.24 | 673.83 | 142.81 | 697.26 | 122.52 | 717.55 | 100.29 | 739.78 | 82.96 | 757.11 |
| BMW11 | 805.04 | 2.93 | 802.11 | 2.94 | 802.10 | 3.20 | 801.84 | 4.78 | 800.26 | 4.40 | 800.64 | 3.45 | 801.59 | 3.16 | 801.88 | 3.01 | 802.03 |
| BMW12 | 805.18 | 3.12 | 802.06 | 3.11 | 802.07 | 3.37 | 801.81 | 4.98 | 800.20 | 4.52 | 800.66 | 3.63 | 801.55 | 3.33 | 801.85 | 3.13 | 802.05 |
| BMW13 | 855.03 | 23.71 | 831.32 | 20.10 | 834.93 | 22.34 | 832.69 | 24.31 | 830.72 | 26.29 | 828.74 | 25.54 | 829.49 | 23.72 | 831.31 | 23.58 | 831.45 |
| BMW14 | 846.75 | 146.96 | 699.79 | 73.64 | 773.11 | 42.39 | 804.36 | 43.22 | 803.53 | 43.48 | 803.27 | 42.68 | 804.07 | 42.41 | 804.34 | 40.84 | 805.91 |
| BMW15 | 841.75 | NM | NA | 26.59 | 815.16 | 15.58 | 826.17 | 19.44 | 822.31 | 22.56 | 819.19 | 18.96 | 822.79 | 15.41 | 826.34 | 16.89 | 824.86 |
| BW01 | 841.41 | 15.10 | 826.31 | 12.42 | 828.99 | 14.71 | 826.70 | 15.89 | 825.52 | 16.32 | 825.09 | 14.03 | 827.38 | 13.82 | 827.59 | 13.27 | 828.14 |
| BW02 | 852.46 | 41.01 | 811.45 | 38.63 | 813.83 | 40.32 | 812.14 | 41.7 | 810.76 | 41.07 | 811.39 | 41.31 | 811.15 | 40.01 | 812.45 | 40.10 | 812.36 |
| BW04 | 791.70 | 78.19 | 713.51 | 77.67 | 714.03 | 76.80 | 714.90 | 75.82 | 715.88 | 75.19 | 716.51 | 73.63 | 718.07 | 71.76 | 719.94 | 72.04 | 719.66 |
| BW05 | 818.54 | 14.61 | 803.93 | 14.11 | 804.43 | 14.55 | 803.99 | 15.51 | 803.03 | 16.38 | 802.16 | 16.63 | 801.91 | 15.63 | 802.91 | 15.12 | 803.42 |
| BW06 | 828.02 | 25.65 | 802.37 | 25.65 | 802.37 | 25.98 | 802.04 | 27.56 | 800.46 | 27.04 | 800.98 | 26.18 | 801.84 | 25.89 | 802.13 | 25.52 | 802.50 |
| BW07 | 821.13 | 17.12 | 804.01 | 15.19 | 805.94 | 15.88 | 805.25 | 16.72 | 804.41 | 17.91 | 803.22 | 18.73 | 802.40 | 15.39 | 805.74 | 15.22 | 805.91 |
| BW08 | 831.13 | NA | NA | NA | NA | 151.54 | 679.59 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA |
| BW09 | 800.78 | 10.08 | 790.70 | 9.37 | 791.41 | 10.85 | 789.93 | 12.6 | 788.18 | 12.81 | 787.97 | 11.46 | 789.32 | 10.28 | 790.50 | 10.07 | 790.71 |
| BW10 | 782.50 | 7.08 | 775.42 | 6.35 | 776.15 | NM | NA | NM | NA | NM | NA | NM | NA | NM | NA | NA | NA |
| BW11 | 793.51 | 13.62 | 779.89 | 13.06 | 780.45 | 14.51 | 779.00 | 16.01 | 777.50 | 16.78 | 776.73 | 16.21 | 777.30 | 14.95 | 778.56 | 14.33 | 779.18 |
| BW12 | 811.87 | 24.48 | 787.39 | 24.35 | 787.52 | 24.46 | 787.41 | 24.61 | 787.26 | 24.94 | 786.93 | 24.61 | 787.26 | 24.47 | 787.40 | 24.52 | 787.35 |
| BW13 | 808.23 | 58.80 | 749.43 | 59.24 | 748.99 | 59.37 | 748.86 | 59.74 | 748.49 | 59.85 | 748.38 | 59.58 | 748.65 | 59.64 | 748.59 | 59.58 | 748.65 |
| BW14 | 841.79 | 23.18 | 818.61 | 19.12 | 822.67 | 21.75 | 820.04 | 27.17 | 814.62 | 29.95 | 811.84 | 25.56 | 816.23 | 11.73 | 830.06 | 25.05 | 816.74 |
| BW15 | 827.93 | 26.02 | 801.91 | 26.00 | 801.93 | 26.33 | 801.60 | 27.91 | 800.02 | 27.50 | 800.43 | 26.56 | 801.37 | 26.24 | 801.69 | 26.10 | 801.83 |
| BW16 | 839.04 | 36.41 | 802.63 | 36.21 | 802.83 | 26.55 | 812.49 | 38.44 | 800.60 | 38.00 | 801.04 | 37.06 | 801.98 | 36.74 | 802.30 | 36.31 | 802.73 |
| BW17 | 799.59 | 7.56 | 792.03 | 7.35 | 792.24 | 7.72 | 791.87 | 9.33 | 790.26 | 9.70 | 789.89 | 9.01 | 790.58 | 8.08 | 791.51 | 7.58 | 792.01 |
| CP013-MW1 | 854.05 | 16.05 | 838.00 | 15.80 | 838.25 | 15.77 | 838.28 | 15.96 | 838.09 | 16.03 | 838.02 | 15.86 | 838.19 | 15.85 | 838.20 | 16.01 | 838.04 |
| CP013-MW2 | 861.03 | 21.90 | 839.13 | 21.44 | 839.59 | 21.25 | 839.78 | 21.54 | 839.49 | 21.65 | 839.38 | 20.17 | 840.86 | 21.32 | 839.71 | 21.77 | 839.26 |
| CP013-MW3 | 852.66 | NM | NA | 10.58 | 842.08 | 10.70 | 841.96 | 11.21 | 841.45 | 11.23 | 841.43 | 10.97 | 841.69 | 10.89 | 841.77 | 11.40 | 841.26 |
| CP013-MW4 | 850.54 | NM | NA | 5.84 | 844.70 | 6.37 | 844.17 | 7.14 | 843.40 | 7.36 | 843.18 | 6.62 | 843.92 | 6.93 | 843.61 | 7.27 | 843.27 |
| CP013-MW5 | 847.08 | NM | NA | 8.08 | 839.00 | 8.16 | 838.92 | 8.4 | 838.68 | 8.54 | 838.54 | 8.34 | 838.74 | 8.31 | 838.77 | 8.21 | 838.87 |
| DEQ1W | 809.18 | 9.63 | 799.55 | 9.40 | 799.78 | 9.88 | 799.30 | 11.11 | 798.07 | 11.12 | 798.06 | 10.25 | 798.93 | 10.06 | 799.12 | 9.82 | 799.36 |
| EB1 | 821.97 | 19.17 | 802.80 | 19.70 | 802.27 | 20.04 | 801.93 | 21.63 | 800.34 | 21.25 | 800.72 | 20.25 | 801.72 | 19.95 | 802.02 | 19.77 | 802.20 |
| EB3 | 823.39 | 21.15 | 802.24 | 21.17 | 802.22 | 19.31 | 804.08 | 23.06 | 800.33 | 22.54 | 800.85 | 21.67 | 801.72 | 21.37 | 802.02 | 21.21 | 802.18 |
| EB4 | 822.96 | 20.74 | 802.22 | 20.70 | 802.26 | 20.99 | 801.97 | 22.59 | 800.37 | 17.75 | 805.21 | 21.21 | 801.75 | 20.99 | 801.97 | 20.75 | 802.21 |
| EB5 | 822.79 | 20.50 | 802.29 | 20.51 | 802.28 | 20.84 | 801.95 | 22.42 | 800.37 | 21.92 | 800.87 | 21.05 | 801.74 | 20.82 | 801.97 | 20.60 | 802.19 |
| FCB1 | 816.67 | 14.30 | 802.37 | 14.30 | 802.37 | 14.61 | 802.06 | 16.19 | 800.48 | 15.82 | 800.85 | 14.81 | 801.86 | 14.49 | 802.18 | 14.36 | 802.31 |
| FCB2 | 815.21 | 12.77 | 802.44 | 12.75 | 802.46 | 13.07 | 802.14 | 14.64 | 800.57 | 14.27 | 800.94 | 13.29 | 801.92 | 12.99 | 802.22 | 12.84 | 802.37 |
| FCB3 | 816.39 | 13.97 | 802.42 | 13.95 | 802.44 | 14.28 | 802.11 | 15.85 | 800.54 | 15.48 | 800.91 | 14.50 | 801.89 | 14.19 | 802.20 | 14.03 | 802.36 |
| FT059-MW01 | 829.02 | NM | NA | 3.98 | 825.04 | 5.10 | 823.92 | 6.53 | 822.49 | 6.48 | 822.54 | 4.93 | 824.09 | 3.98 | 825.04 | 3.44 | 825.58 |
| FT059-MW02 | 822.30 | NM | NA | 7.71 | NA | 6.80 | 815.50 | 8.2 | 814.10 | 8.35 | 813.95 | 6.20 | 816.10 | 5.73 | 816.57 | 5.47 | 816.83 |
| FT059-MW03 | 821.69 | NM | NA | 4.53 | NA | 4.25 | 817.44 | 5.2 | 816.49 | 5.40 | 816.29 | 4.42 | 817.27 | 3.85 | 817.84 | 3.50 | 818.19 |
| LMB2 | 856.02 | 53.88 | 802.14 | 53.86 | 802.16 | 54.16 | 801.86 | 55.81 | 800.21 | 55.22 | 800.80 | 54.43 | 801.59 | 54.11 | 801.91 | 53.99 | 802.03 |
| LMB3 | 850.83 | 48.66 | 802.17 | 48.62 | 802.21 | 48.91 | 801.92 | 50.54 | 800.29 | 50.05 | 800.78 | 49.14 | 801.69 | 48.87 | 801.96 | 48.76 | 802.07 |
| MD2 | 817.50 | 6.78 | 810.72 | 3.80 | 813.70 | 7.70 | 809.80 | 10.23 | 807.27 | 10.75 | 806.75 | 7.32 | 810.18 | 7.82 | 809.68 | 7.99 | 809.51 |
| MD20 | 813.90 | 3.00 | 810.90 | 0.22 | 813.68 | 3.91 | 809.99 | 6.43 | 807.47 | 6.84 | 807.06 | 4.50 | 809.40 | 4 | 809.90 | 4.15 | 809.75 |
| MD3 | 815.80 | 5.07 | 810.73 | 2.08 | 813.72 | 5.99 | 809.81 | 8.5 | 807.30 | 8.98 | 806.82 | 6.58 | 809.22 | 6.09 | 809.71 | 6.25 | 809.55 |
| MD4 | 813.62 | 2.84 | 810.78 | NM | NA | 3.77 | 809.85 | 6.31 | 807.31 | 6.77 | 806.85 | 4.33 | 809.29 | 3.87 | 809.75 | 4.04 | 809.58 |

TABLE 6-3
Manual Water Level Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Surveyed Reference Elevation | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) | Water Level (ft BTOC) | Water Level Elevation (ft amsl) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (ft amsl) | 4/22/2009 | | 5/11/2009 | | 6/19/2009 | | 7/27/2009 | | 8/31/2009 | | 10/5/2009 | | 11/23/2009 | | 1/14/2010 | |
| MD5 | 810.26 | NA | NA | NM | NA | 1.22 | 809.04 | 2.93 | 807.33 | 3.44 | 806.82 | NM | NA | NM | NA | NM | NA |
| MD7 | 806.09 | NA | NA | NM | NA | 1.81 | 804.28 | 1.85 | 804.24 | 1.94 | 804.15 | NM | NA | NM | NA | NM | NA |
| MMB3 | 860.96 | 59.26 | 801.70 | 59.45 | 801.51 | 61.67 | 799.29 | 63.61 | 797.35 | 62.44 | 798.52 | 60.93 | 800.03 | 64.69 | 796.27 | 60.37 | 800.59 |
| MP02 | 831.49 | 28.82 | 802.67 | 28.81 | 802.68 | 29.15 | 802.34 | 30.71 | 800.78 | 30.32 | 801.17 | 29.34 | 802.15 | 29.05 | 802.44 | 28.80 | 802.69 |
| MP03 | 817.47 | 15.04 | 802.43 | 15.05 | 802.42 | 15.41 | 802.06 | 16.98 | 800.49 | 16.45 | 801.02 | 15.62 | 801.85 | 15.27 | 802.20 | 14.92 | 802.55 |
| MP04 | 805.59 | 3.44 | 802.15 | 3.46 | 802.13 | 3.45 | 802.14 | 5.37 | 800.22 | 4.86 | 800.73 | 3.88 | 801.71 | 7.04 | 798.55 | 3.48 | 802.11 |
| MP05 | 848.81 | NM | NA | NM | NA | 40.80 | 808.01 | 46.01 | 802.80 | 48.21 | 800.60 | 42.83 | 805.98 | 40.78 | 808.03 | 42.76 | 806.05 |
| MP06 | 834.12 | NM | NA | NM | NA | 31.67 | 802.45 | 33.27 | 800.85 | 32.78 | 801.34 | 31.91 | 802.21 | 31.65 | 802.47 | 31.01 | 803.11 |
| MP14 | 807.78 | 4.90 | 802.88 | 4.91 | 802.87 | 5.19 | 802.59 | 6.78 | 801.00 | 6.27 | 801.51 | 5.41 | 802.37 | 5.12 | 802.66 | 4.80 | 802.98 |
| MP17 | 839.60 | 36.94 | 802.66 | 36.72 | 802.88 | 28.88 | 810.72 | 39.97 | 799.63 | 36.57 | 803.03 | 37.58 | 802.02 | 37.27 | 802.33 | 35.89 | 803.71 |
| MP19 | 828.68 | 26.41 | 802.27 | 29.59 | 799.09 | 26.71 | 801.97 | 28.31 | 800.37 | 27.86 | 800.82 | 26.93 | 801.75 | 26.64 | 802.04 | 26.27 | 802.41 |
| MP20 | 837.12 | 28.33 | 808.79 | 17.19 | 819.93 | 28.18 | 808.94 | 33.81 | 803.31 | 36.50 | 800.62 | 30.42 | 806.70 | 28.16 | 808.96 | NM | NA |
| OCC1 | 819.98 | 4.59 | 815.39 | 4.72 | 815.26 | NM | NA | NM | NA | NM | NA | NM | NA | 5.38 | 814.60 | 4.04 | 815.94 |
| OCC2 | 817.00 | 17.58 | 799.42 | 17.39 | 799.61 | 17.85 | 799.15 | 18.98 | 798.02 | 18.92 | 798.08 | 18.11 | 798.89 | 17.94 | 799.06 | 17.71 | 799.29 |
| OCC3 | 813.97 | 14.52 | 799.45 | 14.28 | 799.69 | 14.81 | 799.16 | 16.05 | 797.92 | 16.08 | 797.89 | 14.38 | 799.59 | 14.17 | 799.80 | 13.94 | 800.03 |
| OCC4 | 812.85 | 13.37 | 799.48 | 13.12 | 799.73 | 13.64 | 799.21 | 14.87 | 797.98 | 14.92 | 797.93 | 14.05 | 798.80 | 13.83 | 799.02 | 13.60 | 799.25 |
| OCC5 | 814.47 | 14.63 | 799.84 | 15.71 | 798.76 | 15.21 | 799.26 | 16.43 | 798.04 | 16.39 | 798.08 | 15.59 | 798.88 | 15.39 | 799.08 | 15.16 | 799.31 |
| RHMW2 | 802.44 | 3.52 | 798.92 | 3.34 | 799.10 | 3.77 | 798.67 | 4.85 | 797.59 | 4.83 | 797.61 | 4.00 | 798.44 | 3.71 | 798.73 | 3.63 | 798.81 |
| RMB1A | 823.56 | 19.23 | 804.33 | 13.83 | 809.73 | NM | NA | NM | NA | NM | NA | NM | NA | 11.38 | 812.18 | 11.02 | 812.54 |
| RMB2 | 821.00 | 18.62 | 802.38 | 18.64 | 802.36 | 18.92 | 802.08 | 20.53 | 800.47 | 20.15 | 800.85 | 19.17 | 801.83 | 18.87 | 802.13 | NM | NA |
| RMB3 | 822.04 | 19.73 | 802.31 | 19.74 | 802.30 | 20.02 | 802.02 | 21.62 | 800.42 | 21.11 | 800.93 | 20.26 | 801.78 | 19.97 | 802.07 | 19.76 | 802.28 |
| RMB4 | 823.21 | 21.45 | 801.76 | 21.46 | 801.75 | 21.74 | 801.47 | 23.34 | 799.87 | 22.95 | 800.26 | 21.97 | 801.24 | 21.67 | 801.54 | 21.49 | 801.72 |
| RMB5 | 825.91 | 21.82 | 804.09 | 20.88 | 805.03 | 22.99 | 802.92 | 25.27 | 800.64 | 24.98 | 800.93 | 23.58 | 802.33 | 22.69 | 803.22 | 16.60 | 809.31 |
| SMB1 | 843.13 | 18.53 | 824.60 | 19.54 | 823.59 | NM | NA | NM | NA | 18.49 | 824.64 | 17.87 | 825.26 | 17.71 | 825.42 | 18.33 | 824.80 |
| SMB3 | 844.23 | NM | NA | NM | NA | NM | NA | 44.39 | 799.84 | NM | NA | 40.76 | 803.47 | 40.3 | 803.93 | 39.51 | 804.72 |
| SMB5 | 846.69 | NM | NA | NM | NA | NM | NA | 47.97 | 798.72 | NM | NA | 47.11 | 799.58 | 44.02 | 802.67 | 45.22 | 801.47 |
| SMB6 | 845.91 | 43.39 | 802.52 | 43.45 | 802.46 | 42.59 | 803.32 | 44.94 | 800.97 | 44.87 | 801.04 | 44.24 | 801.67 | 47.06 | 798.85 | 46.16 | 799.75 |
| SMB7[a] | 845.22 | 43.08 | 802.14 | 43.06 | 802.16 | 43.35 | 801.87 | 44.99 | 800.23 | 44.52 | 800.70 | 43.61 | 801.61 | 43.31 | 801.91 | 42.95 | 802.27 |
| SMB8 | 846.51 | NM | NA | NM | NA | 44.48 | 802.03 | 46.11 | 800.40 | NM | NA | 44.78 | 801.73 | 44.47 | 802.04 | 44.35 | 802.16 |
| SMB9 | 845.14 | NM | NA | NM | NA | 42.97 | 802.17 | 44.91 | 800.23 | 44.45 | 800.69 | 43.62 | 801.52 | 43.18 | 801.96 | 42.70 | 802.44 |
| TMB1 | 839.35 | 37.07 | 802.28 | 37.06 | 802.29 | 37.38 | 801.97 | 38.89 | 800.46 | 38.56 | 800.79 | 37.56 | 801.79 | 37.27 | 802.08 | 36.84 | 802.51 |
| TMB2 | 840.41 | 38.03 | 802.38 | 38.02 | 802.39 | 38.32 | 802.09 | 39.94 | 800.47 | 39.54 | 800.87 | 38.55 | 801.86 | 38.27 | 802.14 | 37.86 | 802.55 |
| TMB3 | 841.76 | 39.58 | 802.18 | 39.56 | 802.20 | 39.87 | 801.89 | 41.51 | 800.25 | 41.09 | 800.67 | 40.10 | 801.66 | 39.82 | 801.94 | 39.41 | 802.35 |

**Notes:**
[a]SMB7 - Bingham installed the drop pipe and surface completion on SMB7 in October 2008. The injection boring was resurveyed, resulting in a new reference elevation for water levels collected after October 2008.
amsl - above mean sea level
bgs - below ground surface
BTOC - below top of casing
ft- feet
NA - not applicable
NM - not measured

TABLE 6-4
Transducer Monitoring Network
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Well ID | Date Installed | Pressure Transducer ID No. | Logging Interval (Minutes) | Reference Elevation (ft amsl) | Altitude Setting (ft amsl) | Pressure Transducer Depth | |
|---|---|---|---|---|---|---|---|
| | | | | | | (ft BTOC) | (ft amsl) |
| BW01 | 11/20/2008 | 0031035960 | 10 | 841.41 | 795 | 30 | 811.41 |
| BW02 | 11/20/2008 | 0031035933 | 10 | 852.46 | 801 | 52 | 800.46 |
| BW05 | 11/20/2008 | 0031035937 | 10 | 818.54 | 770 | 25 | 793.54 |
| BW06 | 11/18/2008 | 0031035902 | 10 | 828.02 | 795 | 33 | 795.02 |
| BW07 | 11/20/2008 | 0031035962 | 10 | 821.13 | 794 | 27 | 794.13 |
| BW11 | 11/20/2008 | 0031035936 | 10 | 793.51 | 800 | 25 | 768.51 |
| BW12 | 11/20/2008 | 0031035906 | 10 | 811.87 | 777 | 35 | 776.87 |
| BW15 | 11/19/2008 | 0031035942 | 10 | 827.93 | 795 | 33 | 794.93 |
| BW16 | 11/20/2008 | 0031035904 | 10 | 839.04 | 795 | 44 | 795.04 |
| BMW01[a] | 12/9/2008 | 0031035963 | 10 | 846.66 | 795 | 52 | 794.66 |
| Barologger | 11/18/2008 | 0011035479 | 10 | 846.66 | 816 | 31 | 815.66 |
| BMW05 | 11/19/2008 | 0041036063 | 10 | 812.75 | 791 | 21 | 791.75 |
| EB3 | 11/18/2008 | 0031035907 | 10 | 821.97 | 795 | 27 | 794.97 |
| FCB3 | 11/18/2008 | 0031035911 | 10 | 816.39 | 795 | 21 | 795.39 |
| LMB3 | 11/18/2008 | 0031035946 | 10 | 850.83 | 795 | 56 | 794.83 |
| MD2 | 11/19/2008 | 0031035948 | 10 | 817.5 | 793 | 20 | 797.50 |
| MD4 | 11/19/2008 | 0031035943 | 10 | 813.62 | 797 | 17 | 796.62 |
| MD20 | 11/19/2008 | 0031035938 | 10 | 813.90 | 797 | 17 | 796.90 |
| MMB3 | 11/19/2008 | 0031035969 | 10 | 861.16 | 795 | 66 | 795.16 |
| MP02 | 11/18/2008 | 0031035932 | 10 | 831.49 | 795 | 36 | 795.49 |
| MP03 | 11/20/2008 | 0031035939 | 10 | 817.47 | 795 | 22 | 795.47 |
| MP04 | 11/19/2008 | 0031035899 | 10 | 805.59 | 793 | 12 | 793.59 |
| MP14 | 11/20/2008 | 0031035949 | 10 | 807.78 | 791 | 16 | 791.78 |
| MP19 | 11/18/2008 | 0031035968 | 10 | 828.68 | 795 | 34 | 794.68 |
| MP20 | 11/20/2008 | 0031035904 | 10 | 837.12 | 795 | 42 | 795.12 |
| OCC4 | 11/19/2008 | 0031035897 | 10 | 812.85 | 789 | 24 | 788.85 |
| RHMW2 | 11/19/2008 | 0031035944 | 10 | 802.44 | 788 | 14 | 788.44 |
| RMB4 | 11/18/2008 | 0031035947 | 10 | 823.21 | 795 | 29 | 794.21 |
| SMB6 | 11/18/2008 | 0031035941 | 10 | 845.91 | 795 | 51 | 794.91 |
| TMB2 | 11/18/2008 | 0031035940 | 10 | 840.41 | 795 | 45 | 795.41 |
| CP013-MW2 | 11/19/2008 | 0031035896 | 10 | 861.03 | 835 | 26 | 835.03 |

**Notes:**
[a]pressure transducer installed on 12/9/08 due to repair.
Barologger installed in BMW01 to collect barometric data for pressure correction of water levels.
amsl - above mean sea level
BTOC - below top of casing (reference elevation)
ft - feet

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TABLE 6-5
Stream Gage and Weather Stations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| ID | Alternative ID | Latitude | Longitude |
|---|---|---|---|
| USGS Stream Gage Stations | | | |
| SR-2 | 7188000 | 36.93451148 | -94.74717111 |
| SR-1 | 7187600 | 37.023611 | -94.720833 |
| TC-2 | 7185095 | 36.90006955 | -94.8682878 |
| TC-1 | 7185090 | 36.94367955 | -94.8532862 |
| NR-2 | 7185080 | 36.86479264 | -94.8788446 |
| NR-1 | 7185000 | 36.92868144 | -94.9574574 |
| NOAA Weather Stations | | | |
| KS-1 | Columbus | 37.18 | -94.84 |
| KS-2 | Parsons 2NW | 37.37 | -95.29 |
| KS-3 | Oswego | 37.17 | -95.10 |
| KS-4 | Altamont | 37.19 | -95.29 |
| KS-5 | Mound Valley 3 WSW | 37.19 | -95.45 |
| KS-6 | Bartlett | 37.05 | -95.21 |
| MO-1 | Waco | 37.29 | -94.60 |
| MO-2 | Carthage 5S | 37.18 | -94.30 |
| MO-3 | Joplin Rgnl AP | 37.15 | -94.50 |
| MO-4 | Diamond 2W | 36.99 | -94.35 |
| MO-5 | Seneca | 36.83 | -94.62 |
| Mesonet Weather Stations | | | |
| OK-1 | Miami | 36.88832 | -94.84457 |
| OK-2 | Vinita | 36.77536 | -95.22094 |

**Notes:**
ID - identification
USGS - U.S. Geological Survey
NOAA - National Oceanic and Atmospheric Administration

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TABLE 6-6
Survey Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Alternate ID | Type | Northing | Easting | Reference Point Elevation (ft amsl) |
|---|---|---|---|---|---|
| Control Point 1 | CP1 | Survey Control Monument | 732367.70 | 2867961.80 | 831.95 |
| Control Point 2 | CP2 | Survey Control Monument | 733610.80 | 2904720.30 | 843.80 |
| Control Point 3 | CP3 | Survey Control Monument | 721819.70 | 2868221.40 | 804.22 |
| Control Point 4 | CP4 | Survey Control Monument | 723144.70 | 2907516.50 | 845.85 |
| BMW01 | BMW01 | Constructed Monitor Well | 741662.90 | 2894195.80 | 846.69 |
| BMW02 | BMW02 | Constructed Monitor Well | 741480.70 | 2894419.38 | 844.52 |
| BMW03 | BMW03 | Constructed Piezometer | 741458.90 | 2894694.31 | 846.55 |
| BMW04 | BMW04 | Constructed Monitor Well | 741439.05 | 2894904.76 | 853.56 |
| BMW05 | BMW05 | Constructed Monitor Well | 733840.58 | 2890330.08 | 812.75 |
| BMW06 | BMW06 | Constructed Monitor Well | 725577.90 | 2884129.13 | 831.87 |
| BMW07 | BMW07 | Constructed Monitor Well | 726862.04 | 2891194.72 | 806.41 |
| BMW08 | BMW08 | Constructed Monitor Well | 726851.57 | 2891216.33 | 806.99 |
| BMW09 | BMW09 | Constructed Monitor Well | 726843.11 | 2891233.03 | 807.01 |
| BMW10 | BMW10 | Constructed Monitor Well | 731333.27 | 2883486.24 | 840.07 |
| BMW11 | BMW11 | Constructed Monitor Well | 727875.21 | 2890094.83 | 805.04 |
| BMW12 | BMW12 | Constructed Monitor Well | 727866.40 | 2890082.15 | 805.18 |
| BMW13 | BMW13 | Constructed Monitor Well | 733758.62 | 2908706.23 | 855.03 |
| BMW14 | BMW14 | Constructed Monitor Well | 722888.62 | 2897532.07 | 846.75 |
| BMW15 | BMW15 | Constructed Monitor Well | 743318.01 | 2915109.21 | 841.75 |
| BW01 | KEH1 | Open Borehole Well with Surface Casing | 740002.40 | 2926791.93 | 841.41 |
| BW02 | 78 | Open Borehole Well with Surface Casing | 714814.93 | 2902230.58 | 852.46 |
| BW04 | Moore | Open Borehole Well with Surface Casing | 716288.92 | 2862370.56 | 791.70 |
| BW05 | USGS Model 28 | Open Borehole Well with Surface Casing | 737013.16 | 2856419.83 | 818.54 |
| BW06 | Turner | Open Borehole Well with Surface Casing | 736759.60 | 2899446.96 | 828.02 |
| BW07 | 178 | Cased Exploratory Boring | 737612.70 | 2875848.17 | 821.13 |
| BW08 | 140 | Open Borehole Well with Surface Casing | 732541.73 | 2867708.80 | 831.13 |
| BW09 | Miller | Open Borehole Well with Surface Casing | 734579.68 | 2860004.30 | 800.78 |
| BW10 | Furnas 1 | Open Borehole Well with Surface Casing | 731412.90 | 2850389.65 | 782.50 |
| BW11 | Patterson | Open Borehole Well with Surface Casing | 731651.08 | 2847046.90 | 793.51 |
| BW12 | McMain 1 | Open Borehole Well with Surface Casing | 721871.90 | 2865674.03 | 811.87 |
| BW13 | McMain 2 | Open Borehole Well with Surface Casing | 722974.60 | 2867606.70 | 808.23 |
| BW14 | Jackson | Cased Exploratory Boring | 741230.20 | 2921129.70 | 841.79 |
| BW15 | Gordon | Cased Exploratory Boring | 739484.80 | 2887936.02 | 827.93 |
| BW16 | JT South | Cased Exploratory Boring | 731340.75 | 2899884.40 | 839.04 |

TABLE 6-6
Survey Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Alternate ID | Type | Northing | Easting | Reference Point Elevation (ft amsl) |
|---|---|---|---|---|---|
| BW17 | Stoops | Open Borehole Well with Surface Casing | 722319.41 | 2869704.72 | 799.59 |
| CP013-MW1 | CP013-MW1 | Constructed Monitor Well | 741437.65 | 2894915.54 | 854.05 |
| CP013-MW2 | CP013-MW2 | Constructed Monitor Well | 741776.70 | 2895207.42 | 861.03 |
| CP013-MW3 | CP013-MW3 | Constructed Monitor Well | 742613.75 | 2896137.82 | 852.66 |
| CP013-MW4 | CP013-MW4 | Constructed Monitor Well | 742561.02 | 2894407.53 | 850.54 |
| CP013-MW5 | CP013-MW5 | Constructed Monitor Well | 741682.17 | 2894198.04 | 847.08 |
| DEQ1W | DEQ1W | Constructed Monitor Well | 717282.00 | 2879364.65 | 809.18 |
| EB1 | EB1 | Pilot Study Mine Pool Boring | 727855.70 | 2893984.54 | 821.97 |
| EB3 | EB3 | Pilot Study Mine Pool Boring | 727592.30 | 2893527.37 | 823.39 |
| EB4 | EB4 | Pilot Study Mine Pool Boring | 727709.30 | 2893546.59 | 822.96 |
| EB5 | EB5 | Pilot Study Mine Pool Boring | 727520.50 | 2893438.30 | 822.79 |
| FCB1 | FCB1 | Pilot Study Mine Pool Boring | 727899.70 | 2895319.05 | 816.67 |
| FCB2 | FCB2 | Pilot Study Mine Pool Boring | 727822.60 | 2895271.97 | 815.21 |
| FCB3 | FCB3 | Pilot Study Mine Pool Boring | 727922.20 | 2895298.91 | 816.39 |
| FT059-MW1 | FT059-MW1 | Constructed Monitor Well | 726953.74 | 2888815.89 | 829.02 |
| FT059-MW2 | FT059-MW2 | Constructed Monitor Well | 727328.44 | 2889374.29 | 822.30 |
| FT059-MW3 | FT059-MW3 | Constructed Monitor Well | 726346.82 | 2889223.56 | 821.69 |
| LMB1 | LMB1 | Pilot Study Mine Pool Boring | 741566.30 | 2891447.47 | 852.71 |
| LMB2 | LMB2 | Pilot Study Mine Pool Boring | 741650.50 | 2891472.82 | 856.02 |
| LMB3 | LMB3 | Pilot Study Mine Pool Boring | 741648.20 | 2891659.31 | 850.83 |
| MD2 | MD2 | Air Vent | 723752.80 | 2912440.20 | 817.50 |
| MD3 | MD3 | Air Vent | 723792.90 | 2912531.60 | 815.80 |
| MD4 | MD4 | Air Vent | 722828.30 | 2912660.20 | 813.62 |
| MD5 | MD5 | Cased Exploratory Boring | 722817.30 | 2912815.60 | 810.26 |
| MD7 | MD7 | Cased Exploratory Boring | 723147.40 | 2913038.50 | 806.09 |
| MD20 | MD20 | Air Vent | 723380.40 | 2912610.70 | 813.90 |
| MMB1 | MMB1 | Pilot Study Mine Pool Boring | 741935.10 | 2895248.61 | 860.55 |
| MMB2 | MMB2 | Pilot Study Mine Pool Boring | 741943.70 | 2895254.78 | 860.04 |
| MMB3 | MMB3 | Pilot Study Mine Pool Boring | 741819.50 | 2895211.40 | 860.96 |
| MMB4 | MMB4 | Pilot Study Mine Pool Boring | 741831.05 | 2895214.37 | 861.16 |
| MMB6 | MMB6 | Pilot Study Mine Pool Boring | 741817.05 | 2895219.00 | 861.80 |

TABLE 6-6
Survey Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Alternate ID | Type | Northing | Easting | Reference Point Elevation (ft amsl) |
|---|---|---|---|---|---|
| MP02 | Blue Goose | Air Vent | 728140.25 | 2886026.12 | 831.49 |
| MP03 | Kenoyer | Air Vent | 735555.90 | 2889035.00 | 817.47 |
| MP04 | Douthat Air Vent | Air Vent | 727861.57 | 2890547.68 | 805.59 |
| MP05 | Green | Air Vent | 741325.64 | 2905364.13 | 848.81 |
| MP06 | Thomas | Air Vent | 730510.46 | 2882043.62 | 834.12 |
| MP14 | Lytle/Sam | Air Vent | 733744.41 | 2894406.87 | 807.78 |
| MP17 | JT North | Air Vent | 731387.20 | 2899913.33 | 839.60 |
| MP19 | Royal #2 | Air Vent | 734955.55 | 2898443.59 | 828.68 |
| MP20 | Green | Air Vent | 740040.25 | 2906484.26 | 837.12 |
| OCC1 | OCC1 | Pilot Study Mine Pool Boring | 718550.85 | 2880309.76 | 819.98 |
| OCC2 | OCC2 | Pilot Study Mine Pool Boring | 718475.80 | 2880182.73 | 817.00 |
| OCC3 | OCC3 | Pilot Study Mine Pool Boring | 717343.10 | 2878878.23 | 813.97 |
| OCC4 | OCC4 | Pilot Study Mine Pool Boring | 717541.15 | 2878732.27 | 812.85 |
| OCC5 | OCC5 | Pilot Study Mine Pool Boring | 717687.80 | 2878874.21 | 814.47 |
| RMB1A | RMB1A | Pilot Study Mine Pool Boring | 727325.10 | 2892161.85 | 823.56 |
| RMB2 | RMB2 | Pilot Study Mine Pool Boring | 727253.80 | 2892080.44 | 821.00 |
| RMB3 | RMB3 | Pilot Study Mine Pool Boring | 727211.55 | 2892104.78 | 822.04 |
| RMB4 | RMB4 | Pilot Study Mine Pool Boring | 727329.50 | 2892212.67 | 823.21 |
| RMB5 | RMB5 | Pilot Study Mine Pool Boring | 727335.70 | 2892301.07 | 825.91 |
| RHMW2 | RHMW2 | Constructed Monitor Well | 716022.60 | 2881428.92 | 802.44 |
| SMB1 | SMB1 | Pilot Study Mine Pool Boring | 741381.05 | 2894580.82 | 843.13 |
| SMB2 | SMB2 | Pilot Study Mine Pool Boring | 741314.75 | 2894632.82 | 840.74 |
| SMB3 | SMB3 | Pilot Study Mine Pool Boring | 741376.70 | 2894545.09 | 844.23 |
| SMB4 | SMB4 | Pilot Study Mine Pool Boring | 741258.30 | 2894683.65 | 839.28 |
| SMB5 | SMB5 | Pilot Study Mine Pool Boring | 741525.80 | 2894617.60 | 846.69 |
| SMB6 | SMB6 | Pilot Study Mine Pool Boring | 741489.35 | 2894505.50 | 845.91 |
| SMB7 | SMB7 | Pilot Study Mine Pool Boring | 741539.57 | 2894306.50 | 845.22 |
| SMB8 | SMB8 | Pilot Study Mine Pool Boring | 742050.55 | 2894188.98 | 846.51 |
| SMB9 | SMB9 | Pilot Study Mine Pool Boring | 741681.43 | 2894382.23 | 845.14 |

TABLE 6-6
Survey Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Alternate ID | Type | Northing | Easting | Reference Point Elevation (ft amsl) |
|---|---|---|---|---|---|
| TMB1 | TMB1 | Pilot Study Mine Pool Boring | 736407.95 | 2901977.87 | 839.35 |
| TMB2 | TMB2 | Pilot Study Mine Pool Boring | 736410.70 | 2901917.80 | 840.41 |
| TMB3 | TMB3 | Pilot Study Mine Pool Boring | 736387.15 | 2901785.04 | 841.76 |
| Picher No. 5 | Picher No. 5 | Municipal Supply Well | 730606.46 | 2893993.70 | 818.99 |
| Picher No. 7 | Picher No. 7 | Municipal Supply Well | 733780.23 | 2890352.45 | 814.15 |
| GS-1 | USGS Well | Open Borehole Well with Surface Casing | 722851.48 | 2903291.64 | 835.20 |
| Powerhouse-C | C Pipe | Constructed Monitor Well | 732624.95 | 2883389.99 | 841.52 |
| Powerhouse-R | R Pipe | Constructed Monitor Well | 732625.13 | 2883389.57 | 841.21 |

**Notes:**
amsl - above mean sea level
ft - feet
All survey coordinates are Oklahoma State Plane Coordinate System, North Zone 3501
Horizontal coordinate datum is North American Datum of 1983 (NAD83)
Vertical coordinate datum is North American Vertical Datum of 1988 (NAVD88)

TABLE 6-7
Groundwater and Mine Water Sampling Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Total Depth (ft bgs) | Top of Screen (ft bgs) | Bottom of Screen (ft bgs) | Mine Roof Depth (ft bgs) |
|---|---|---|---|---|---|
| **Quarterly Sampling Program** | | | | | |
| BMW05 | Boone Formation | 197 | 187 | 197 | NA |
| BMW06 | Boone Formation | 328 | 295 | 325 | NA |
| BMW07 | Boone Formation | 133.25 | 110 | 130 | NA |
| BMW08 | Boone Formation | 104.17 | 81 | 101 | NA |
| BMW09 | Boone Formation | 151.8 | 129 | 149 | NA |
| BMW10 | Boone Formation | 266.15 | 233 | 263 | NA |
| BMW11 | Boone Formation | 105.8 | 80 | 100 | NA |
| BMW12 | Boone Formation | 159 | 134 | 154 | NA |
| BMW13 | Boone Formation | 198 | 175 | 195 | NA |
| BMW14 | Boone Formation | 164.27 | 130 | 160 | NA |
| BMW15 | Boone Formation | 262.56 | 220 | 260 | NA |
| BW02 | Boone Formation | 271.43 | NA | NA | NA |
| BW06 | Boone Formation | 119.95 | NA | NA | NA |
| BW07 | Boone Formation | 122.35 | NA | NA | NA |
| BW11 | Boone Formation | 367.68 | NA | NA | NA |
| BW13 | Boone Formation | 319.1 | NA | NA | NA |
| BW14 | Boone Formation | 248.4 | NA | NA | NA |
| BW15 | Boone Formation | 211.04 | NA | NA | NA |
| BW16 | Boone Formation | 156.35 | NA | NA | NA |
| FCB2 | Mine Pool | 123.89 | NA | NA | 108 |
| FCB3 | Mine Pool | 81.5 | NA | NA | 75 |
| LMB3 | Mine Pool | 258 | NA | NA | 252 |
| MD2 | Mine Pool | 66.59 | NA | NA | 48 |
| MP04 | Mine Pool | 211.71 | NA | NA | 140 |
| MP17 | Mine Pool | 190.86 | NA | NA | 122 |
| MP20 | Mine Pool | 151.58 | NA | NA | 127 |
| OCC3 | Mine Pool | 180.54 | NA | NA | 153 |
| RMB3 | Mine Pool | 149.47 | NA | NA | 136 |
| TMB3 | Mine Pool | 218.15 | NA | NA | 204 |
| FT059-MW1 | Central Mill Tailings Pond | 23 | 15 | 20 | NA |
| FT059-MW2 | Central Mill Tailings Pond | 21.25 | 13 | 18 | NA |
| FT059-MW3 | Central Mill Tailings Pond | 21.2 | 13 | 18 | NA |

TABLE 6-7
Groundwater and Mine Water Sampling Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Station ID | Completed In | Total Depth (ft bgs) | Top of Screen (ft bgs) | Bottom of Screen (ft bgs) | Mine Roof Depth (ft bgs) |
|---|---|---|---|---|---|
| Sooner Chat Pile Pilot Study Quarterly Sampling Program | | | | | |
| BMW01 | Boone Formation | 223 | 202.5 | 222.5 | NA |
| BMW02 | Boone Formation | 210 | 189.5 | 209.5 | NA |
| BMW04 | Chester Group | 129 | 109 | 129 | NA |
| Sandscrew | Sooner #1 Sand Screw | NA | NA | NA | NA |
| SMB3 | Mine Pool Injection Point | 212 | NA | NA | 189 |
| SMB5 | Mine Pool Injection Point | 208 | NA | NA | 190 |
| SMB6 | Mine Pool Injection Point | 211 | NA | NA | 188 |
| SMB7 | Mine Pool Injection Point | 223 | NA | NA | 203 |
| MMB2 | Mine Pool Extraction Well | 232.9 | NA | NA | 214 |
| CP013-MW1 | Sooner Chat Pile | 23 | 13 | 23 | NA |
| CP013-MW2 | Sooner Chat Pile | 26.5 | 16 | 26 | NA |
| CP013-MW3 | Sooner Chat Pile | 14.45 | 6 | 11 | NA |
| CP013-MW4 | Sooner Chat Pile | 10.19 | 3 | 8 | NA |
| CP013-MW5 | Sooner Chat Pile | 13.47 | 5 | 10 | NA |

**Notes:**
bgs - below ground surface
ft - feet
NA - not applicable
Wells with screen interval sampled at center of screen.
Mine pool borings sampled 1 to 5 feet above total depth.

TABLE 7-1
Groundwater Field Parameters in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Sample Date | Well ID | Pump Set Depth (ft BTOC) | pH | TEMP (°C) | DO (mg/L) | DO (mg/L) (Chemetrics Kit) | Turbidity (NTU) | ORP (mV) | Cond (µS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 7/15/2008 | BMW01 | 216 | 6.94 | 18.65 | 1.73 | 0.50 | 197.0 | -129.0 | 8340 |
| 7/15/2008 | BMW02 | 200 | 6.16 | 18.28 | 1.18 | 0.35 | 863.0 | -106.0 | 7430 |
| 10/20/2008 | BMW01 | 216 | 6.69 | 17.55 | 0.37 | 0.25 | 74.1 | -169.0 | 1510 |
| 10/22/2008 | BMW02 | 200 | 6.58 | 17.49 | 0.27 | 0.10 | 107.0 | -145.0 | 2800 |
| 2/5/2009 | BMW01 | 216 | 7.02 | 17.16 | 0.73 | 0.20 | -10.1 | -78.0 | 2476 |
| 2/5/2009 | BMW02 | 200 | 6.84 | 17.54 | 0.27 | 0.05 | -0.9 | -90.6 | 2438 |
| 4/15/2009 | BMW01 | 198 | 7.63 | 17.15 | -0.04 | NR | -0.1 | -112.2 | 2872 |
| 4/15/2009 | BMW02 | 200 | 7.12 | 17.80 | -0.20 | NR | 10.0 | -126.7 | 2860 |
| 4/21/2009 | BMW05 | 192 | 6.93 | 16.26 | -0.74 | 0.10 | -0.3 | -112.8 | 2750 |
| 4/21/2009 | BMW11 | 90 | 5.89 | 15.68 | 0.29 | 0.30 | 3.4 | 5.5 | 2409 |
| 4/20/2009 | BMW12 | 144 | 5.89 | 18.27 | 2.89 | 0.05 | 41.5 | -66.8 | 2845 |
| 5/5/2009 | BMW13 | 185 | 7.01 | 11.43 | 0.00 | 0.30 | 11.0 | -17.0 | 1470 |
| 4/16/2009 | BW02 | 267 | 7.26 | 15.33 | -3.05 | -- | 0.5 | -321.5 | 922 |
| 4/20/2009 | BW06 | 115 | 5.87 | 16.14 | 3.11 | 0.10 | 18.3 | 21.9 | 3041 |
| 4/21/2009 | BW07 | 119 | 6.20 | 15.78 | -0.06 | -- | 15.4 | 68.9 | 3399 |
| 4/20/2009 | BW11 | 265 | 6.54 | 20.60 | -0.59 | -- | 1.8 | -192.4 | 2145 |
| 4/22/2009 | BW13 | 314 | 8.58 | 15.89 | -0.41 | -- | 0.1 | 37.8 | 844 |
| 4/16/2009 | BW14 | 243 | 7.74 | 15.32 | -0.05 | -- | -0.3 | -38.9 | 824 |
| 4/20/2009 | BW15 | 207 | 6.63 | 17.59 | -0.64 | 0.01 | 5.1 | -98.1 | 4224 |
| 4/15/2009 | BW16 | 152 | 6.65 | 15.42 | 8.72 | 0.20 | -1.2 | -139.4 | 551 |
| 8/3/2009 | BMW07 | -- | 6.86 | 17.49 | 0.34 | 0.00 | 8.9 | -128.2 | 1456 |
| 8/3/2009 | BMW08 | -- | 7.76 | 20.41 | 0.24 | 0.05 | -2.5 | -263.5 | 550 |
| 8/3/2009 | BMW09 | -- | 5.98 | 17.97 | 0.47 | 0.00 | 9.2 | -57.0 | 2068 |
| 8/4/2009 | BMW11 | -- | 5.75 | 17.86 | 0.41 | 0.00 | 4.3 | -68.4 | 2324 |
| 7/29/2009 | BMW13 | -- | 7.03 | 15.65 | 1.19 | 0.10 | -2.6 | -71.0 | 1194 |
| 7/29/2009 | BW06 | -- | 5.59 | 16.53 | 1.19 | 0.10 | 135.0 | 19.0 | 2460 |
| 8/5/2009 | BW07 | -- | 6.25 | 15.44 | 0.99 | 0.90 | 550.9 | 87.7 | 3059 |
| 7/30/2009 | BW16 | -- | 6.91 | 15.51 | 0.60 | 0.00 | -6.8 | 53.7 | 476 |

TABLE 7-1
Groundwater Field Parameters in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Sample Date | Well ID | Pump Set Depth (ft BTOC) | pH | TEMP (°C) | DO (mg/L) | DO (mg/L) (Chemetrics Kit) | Turbidity (NTU) | ORP (mV) | Cond (µS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 10/5/2009 | BMW01 | 198 | 6.58 | 17.10 | 0.17 | 0.25 | 0.1 | -40.2 | 2970 |
| 10/7/2009 | BMW02 | 200 | 6.40 | 17.84 | 0.29 | 0.05 | 0.9 | -105.7 | 2932 |
| 10/8/2009 | BMW05 | 189 | 7.08 | 16.23 | 0.00 | 0.00 | 4.0 | -118.3 | 2497 |
| 10/13/2009 | BMW06 | 270 | 10.34 | 16.58 | 0.29 | 0.00 | 4.1 | -43.1 | 2277 |
| 10/13/2009 | BMW07 | 120 | 6.56 | 16.02 | 0.00 | 0.00 | 17.6 | -41.4 | 2307 |
| 10/13/2009 | BMW08 | 90 | 7.97 | 15.51 | 0.00 | 0.00 | 1.3 | -276.9 | 566 |
| 10/8/2009 | BMW09 | 139 | 6.23 | 16.16 | 0.00 | 0.00 | 1.9 | -41.1 | 2155 |
| 10/13/2009 | BMW11 | 90 | 5.80 | 15.73 | 0.00 | 0.00 | 55.2 | -72.5 | 2349 |
| 10/13/2009 | BMW12 | 144 | 5.90 | 16.12 | 0.00 | 0.00 | 50.4 | -77.6 | 2442 |
| 10/6/2009 | BMW13 | 185 | 7.24 | 15.55 | 0.42 | 0.00 | 0.0 | -63.8 | 1302 |
| 10/8/2009 | BMW14 | 145 | 11.98 | 16.45 | 0.43 | 0.00 | 4.9 | 266.1 | 1430 |
| 10/13/2009 | BMW15 | 240 | 7.64 | 15.21 | 5.18 | 4.00 | 19.2 | 115.4 | 1027 |
| 10/7/2009 | BW02 | 262 | 6.82 | 19.40 | 0.15 | 0.00 | 11.2 | -329.8 | 942 |
| 10/7/2009 | BW06 | 110 | 5.73 | 15.95 | 0.61 | 2.00 | 12.1 | 3.7 | 2545 |
| 10/14/2009 | BW07 | 113 | 6.12 | 15.86 | 0.55 | 1.00 | 13.9 | 108.9 | 4144 |
| 10/12/2009 | BW11 | 274 | 6.48 | 16.08 | 0.31 | 0.00 | 41.4 | -316.7 | 2220 |
| 10/7/2009 | BW13 | 280 | 7.81 | 19.20 | 0.36 | 1.00 | 0.0 | 113.9 | 907 |
| 10/13/2009 | BW14 | 238 | 7.07 | 14.99 | 0.46 | 1.00 | 1.7 | -70.2 | 846 |
| 10/13/2009 | BW15 | 201 | 6.54 | 16.92 | 0.34 | 1.00 | 17.1 | -121.0 | 4112 |
| 10/7/2009 | BW16 | 152 | 7.00 | 15.96 | 2.00 | 2.00 | 0.0 | 18.1 | 472 |

**Notes:**
DO - dissolved oxygen
DTW - depth to water
ORP - oxidation reduction potential
ft BTOC - feet below top of casing
mg/L - milligrams per liter
mV - millivolts
µS/cm - microsiemens per centimeter
°C - degrees celsius
NTU - nephelometric turbidity unit

TABLE 7-2

Mine Water Field Parameters in Mine Pool Locations

*Tar Creek Superfund Site. Operable Unit 4*

*Ottawa County, Oklahoma*

| Sample Date | Well ID | Pump Set Depth (ft BTOC) | pH | TEMP (°C) | DO (mg/L) | DO (mg/L) (Chemetrics Kit) | Turbidity (NTU) | ORP (mV) | Cond (µS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 2/27/2007 | FCB2 | 116 | 6.03 | 19.11 | 0.186 | -- | -- | -211 | 2342 |
| 2/27/2007 | FCB3 | 80 | 6.42 | 21.35 | 0.275 | -- | 48.5 | -180 | 338 |
| 2/28/2007 | LMB2 | 220 | 6.12 | 20.17 | 0.93 | -- | 20.7 | -94 | 2898 |
| 3/1/2007 | RMB3 | 145 | 6.12 | 7.95 | 8.3 | -- | 51.8 | -6 | 2345 |
| 3/1/2007 | RMB4 | 125 | 6.13 | 6.97 | 2.2 | -- | 8.9 | -120 | 2276 |
| 2/28/2007 | TMB3 | 215 | 6.31 | 19.62 | 1.4 | -- | 17.7 | -17 | 2590 |
| 7/11/2007 | SMB2 | 205 | 6.34 | 16.83 | 0.02 | -- | -- | -196 | 1714 |
| 10/22/2007 | FCB2 | 118 | 6.25 | 15.78 | 0.435 | -- | 2.4 | -78 | 2118 |
| 10/22/2007 | FCB3 | 82 | 6.82 | 16.11 | 0.066 | -- | 1.1 | -156 | 258 |
| 10/24/2007 | LMB2 | 227 | 6.1 | 16.87 | 19.4 | -- | 20 | 34 | 2792 |
| 10/23/2007 | RMB3 | 149 | 7.07 | 15.9 | 0.04 | -- | 23.6 | -113 | 2160 |
| 10/23/2007 | RMB4 | 134 | 7.07 | 15.93 | 0.18 | -- | 3.1 | -97 | 2134 |
| 10/24/2007 | SMB2 | 199 | 6.44 | 17.22 | 15 | -- | 11.7 | 234 | 2464 |
| 10/23/2007 | TMB2 | 222 | 7.2 | 16.76 | 0.06 | -- | 266.6 | -123 | 2555 |
| 10/27/2007 | TMB3 | 219 | 7.38 | 17.04 | 0.03 | -- | 19.3 | -117 | 2582 |
| 4/23/2008 | FCB2 | 123 | 6.64 | 15.58 | -- | -- | 3.1 | 53 | 1944 |
| 4/23/2008 | FCB3 | 71 | 7.14 | 16.18 | -- | -- | 1.8 | -122 | 249 |
| 4/22/2008 | LMB2 | 219 | 6.38 | 16.68 | -- | -- | 11.7 | -184 | 2773 |
| 4/24/2008 | RMB3 | 144 | 6.59 | 15.6 | -- | -- | 1.5 | 58 | 2046 |
| 4/24/2008 | RMB4 | 133 | 6.83 | 15.62 | -- | -- | 4.1 | 137 | 2042 |
| 4/21/2008 | SMB6 | 190 | 6.46 | 16.36 | -- | -- | 917.2 | 269 | 1290 |
| 4/22/2008 | TMB2 | 218 | 6.67 | 16.6 | -- | -- | 84.2 | -182 | 2611 |
| 4/23/2008 | TMB3 | 210 | 6.67 | 16.34 | -- | -- | 4.6 | 36 | 2136 |
| 7/16/2008 | SMB-3 | 192.0 | 7.44 | 19.49 | 9.55 | 8.0 | 532 | 138 | 9070 |
| 7/16/2008 | SMB-5 | 199.0 | 6.52 | 20.84 | 15.44 | 11.0 | 600 | 79 | 7710 |
| 7/16/2008 | SMB-6 | 192.0 | 6.43 | 20.56 | 13.92 | 9.0 | 250 | 82 | 7980 |
| 7/16/2008 | SMB-7 | 218.3 | 5.63 | 18.07 | 3.26 | 1.5 | 190 | -39 | 8790 |

TABLE 7-2

Mine Water Field Parameters in Mine Pool Locations

*Tar Creek Superfund Site. Operable Unit 4*

*Ottawa County, Oklahoma*

| Sample Date | Well ID | Pump Set Depth (ft BTOC) | pH | TEMP (°C) | DO (mg/L) | DO (mg/L) (Chemetrics Kit) | Turbidity (NTU) | ORP (mV) | Cond (µS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 10/28/2008 | FCB2 | 120.0 | 6.10 | 16.01 | 0.37 | 0.10 | 10.0 | -33 | 2318 |
| 10/28/2008 | FCB3 | 81.0 | 6.58 | 16.32 | 0.38 | 0.30 | 96.8 | -97 | 336 |
| 10/28/2008 | LMB2 | 275.0 | 6.07 | 17.06 | 0.52 | 0.20 | 174.0 | -51 | 3312 |
| 10/29/2008 | RMB3 | 142.0 | 5.95 | 16.02 | 0.48 | -- | 10.0 | -13 | 2499 |
| 10/29/2008 | RMB4 | 132.0 | 6.18 | 16.03 | 0.77 | -- | 9.0 | -3 | 2305 |
| 10/20/2008 | SMB-3 | 192.0 | 7.92 | 18.33 | 18.59 | 8.00 | 0.0 | 117 | 1450 |
| 10/21/2008 | SMB-5 | 196.0 | 7.25 | 18.27 | 15.50 | 9.00 | 0.3 | 118 | 2800 |
| 10/21/2008 | SMB-6 | 195.0 | 7.74 | 18.09 | 2.75 | 2.00 | 0.0 | 95 | 2560 |
| 10/21/2008 | SMB-7 | 220.0 | 4.55 | 17.33 | 1.97 | 2.00 | 78.2 | 233 | 2840 |
| 10/27/2008 | TMB2 | 221.0 | 6.40 | 16.81 | 0.41 | 0.15 | 48.7 | -48 | 3402 |
| 10/23/2008 | TMB3 | 215.0 | 5.97 | 16.34 | 0.37 | 0.15 | 126.0 | -51 | 3139 |
| 2/3/2009 | SMB-3 | 192.0 | 7.44 | 15.82 | 9.52 | 8.00 | 1400.0 | 123 | 2395 |
| 2/3/2009 | SMB-5 | 193.5 | 7.48 | 16.91 | 11.56 | -- | 273.5 | 83.6 | 2306 |
| 2/4/2009 | SMB-6 | 195.0 | 6.78 | 16.98 | 0.87 | 0.30 | 301.9 | 23.1 | 2809 |
| 2/4/2009 | SMB-7 | 220.0 | 6.44 | 16.99 | 1.44 | 1.50 | 30.1 | 103.6 | 2887 |
| 4/16/2009 | FCB2 | 119.0 | 6.04 | 15.19 | 1.61 | 0.10 | 7.0 | -27.5 | 1969 |
| 4/16/2009 | FCB3 | 76.5 | 6.60 | 15.68 | 1.81 | 0.10 | 0.5 | -141.5 | 229 |
| 4/20/2009 | LMB2 | 253.0 | 5.18 | 15.76 | -0.54 | 0.10 | 0.8 | -4 | 2998 |
| 4/15/2009 | MD2 | 62.0 | 6.51 | 15.26 | 8.75 | 0.10 | -3.3 | -60.6 | 798 |
| 4/21/2009 | MP04 | 207.0 | 5.06 | 15.50 | -0.60 | 0.00 | 3.5 | -6.6 | 3483 |
| 4/15/2009 | MP17 | 269.0 | 6.61 | 17.88 | 9.51 | -- | 4.1 | 39.9 | 535 |
| 4/22/2009 | MP20 | 147.0 | 6.74 | 16.14 | 0.37 | 0.50 | 0.6 | -10.4 | 2741 |
| 4/16/2009 | RMB3 | 145.0 | 5.95 | 16.38 | 3.09 | 0.30 | -2.0 | -27.6 | 2150 |
| 4/14/2009 | SMB-3 | 192.0 | 7.66 | 17.29 | 8.86 | 8.00 | 2.2 | 60.8 | 3031 |
| 4/15/2009 | SMB-5 | 192.0 | 6.96 | 16.76 | 11.19 | 8.00 | 98.2 | 179.4 | 2715 |
| 4/15/2009 | SMB-6 | 190.0 | 7.11 | 17.17 | 1.02 | 1.00 | 98.5 | 29.2 | 2911 |
| 4/15/2009 | SMB-7 | 220.0 | 6.48 | 16.99 | 2.64 | 1.00 | 5.7 | 20 | 3045 |
| 4/16/2009 | TMB3 | 213.0 | 6.11 | 16.69 | 0.06 | 0.06 | 10.0 | -34.7 | 2850 |

TABLE 7-2

Mine Water Field Parameters in Mine Pool Locations

*Tar Creek Superfund Site. Operable Unit 4*

*Ottawa County, Oklahoma*

| Sample Date | Well ID | Pump Set Depth (ft BTOC) | pH | TEMP (°C) | DO (mg/L) | DO (mg/L) (Chemetrics Kit) | Turbidity (NTU) | ORP (mV) | Cond (µS/cm) |
|---|---|---|---|---|---|---|---|---|---|
| 7/30/2009 | FCB3 | 76.5 | 6.59 | 16.46 | 0.59 | 0.40 | -7.2 | -99.3 | 243 |
| 8/4/2009 | MD2 | -- | 6.54 | 16.02 | 0.74 | 0.30 | 0.3 | -60.1 | 660 |
| 8/5/2009 | MP06 | -- | 9.87 | 18.41 | 0.56 | 0.00 | 300.6 | -185.8 | 852 |
| 7/30/2009 | MP17 | -- | 6.94 | 15.56 | 0.44 | 0.50 | 18.0 | 7.2 | 472 |
| 7/29/2009 | MP20 | 146.0 | 6.33 | 16.16 | 0.87 | 0.00 | 28.0 | -87 | 2245 |
| 10/12/2009 | FCB2 | 123 | 6.15 | 15.83 | 0.18 | 0 | -1.2 | -26 | 1726 |
| 10/12/2009 | FCB3 | 76.5 | 6.64 | 16.05 | 0.51 | 0.00 | 0.4 | -71.7 | 221 |
| 10/8/2009 | LMB2 | 273.0 | 6.08 | 16.79 | 0.53 | 0.00 | 188.5 | -39.8 | 2884 |
| 10/15/2009 | MD2 | 62.0 | 6.53 | 15.60 | 0.00 | 0.00 | 7.4 | -56.8 | 812 |
| 10/12/2009 | MP05 | 158.0 | 6.20 | 15.76 | 0.16 | 0.00 | 29.5 | -59.5 | 2832 |
| 10/12/2009 | MP06 | 260.0 | 7.98 | 16.07 | 0.24 | 0.00 | 287.2 | -344.4 | 2398 |
| 10/7/2009 | MP17 | 185.9 | 6.93 | 16.16 | 0.51 | 0.00 | 1.8 | -11.9 | 512 |
| 10/6/2009 | MP20 | 146.0 | 6.70 | 15.64 | 0.47 | 0.00 | 91.3 | 112.9 | 2465 |
| 10/14/2009 | RMB3 | 145.0 | 5.88 | 16.04 | 0.56 | 0.00 | 8.4 | -42.6 | 2243 |
| 10/6/2009 | SMB-3 | 207.0 | 7.75 | 18.13 | 9.92 | 9.00 | 303.0 | 237.8 | 2867 |
| 10/5/2009 | SMB-5 | 203.0 | 7.83 | 18.94 | 9.17 | 9.00 | 159.2 | 198.6 | 2524 |
| 10/7/2009 | SMB-6 | 170.7 | 6.54 | 18.24 | 2.10 | 0.30 | 1271.7 | 58.7 | 2859 |
| 10/6/2009 | SMB-7 | 218.0 | 6.33 | 17.55 | 8.66 | 3.00 | 164.2 | 117.8 | 2891 |
| 10/6/2009 | SMB-8 | 286.5 | 5.97 | 17.03 | 0.70 | 0.10 | 53.5 | -118.6 | 3907 |
| 10/6/2009 | SMB-9 | 193.0 | 6.71 | 17.67 | 2.32 | 0.20 | 10.8 | 53.4 | 2919 |
| 10/12/2009 | TMB3 | 213.0 | 6.32 | 16.86 | 0.82 | 0.00 | 9.8 | -43 | 2681 |

**Notes:**

DO - dissolved oxygen

DTW - depth to water

ORP - oxidation reduction potential

ft BTOC - feet below top of casing

mg/L - milligrams per liter

mV - millivolts

µS/cm - microsiemens per centimeter

°C - degrees celsius

NTU - nephelometric turbidity unit

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TABLE 7-3
Groundwater Field Parameters in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | Cond. | Temp. | pH | D.O. | Alk (Field) |
|---|---|---|---|---|---|
| | (Field) | (Field) | (Field) | (Field) | CaCO3 |
| Unit | µS/cm | °C | | mg/l | mg/l |
| **Cardin #1** | | | | | |
| 4/21/2008 | 467 | 20.85 | 7.2 | 1.35 | 126 |
| 10/23/2007 | 442 | 19.05 | 7.33 | 0.9 | 132 |
| 5/8/2007 | 384 | 18.85 | 7.56 | 1.12 | 125 |
| 11/8/2006 | 634 | 21.79 | 7.2 | 1.32 | 160 |
| 4/11/2006 | 368 | 18.8 | 7.28 | 5.32 | 111 |
| 10/17/2005 | 487 | 19.2 | 7.8 | 0.9 | 127 |
| 4/25/2005 | 510 | 18.3 | 7.56 | 1.58 | 177 |
| 10/12/2004 | 498 | 18.3 | 7.62 | 1.82 | 199 |
| 4/27/2004 | 334 | 19.6 | 7.43 | 3.48 | 150 |
| 11/6/2003 | 595 | 17.6 | 6.47 | - | 145 |
| Averages | 472 | 19.23 | 7.35 | 1.98 | 145 |
| **Commerce #3 - (Plugged - 2004)** | | | | | |
| 11/6/1997 | 600 | 18 | 7.14 | - | - |
| 7/23/1997 | 700 | 22 | 6.98 | - | - |
| 4/17/1997 | 675 | 19 | 6.89 | - | - |
| 1/10/1997 | 700 | 15 | 6.71 | - | - |
| 12/11/1996 | 800 | 19.5 | 7.04 | - | - |
| 10/14/1996 | 840 | 21 | 7.55 | - | - |
| Averages | 719 | 19.1 | 7.05 | - | - |
| **Commerce #4** | | | | | |
| 4/22/2008 | 727 | 20.41 | 7.2 | 4.22 | 146 |
| 10/23/2007 | 676 | 18.32 | 7.35 | 2.47 | 131 |
| 5/8/2007 | 710 | 20.03 | 7.37 | 3.6 | 136 |
| 11/8/2006 | 769 | 20.92 | 7.11 | 4.41 | 162 |
| 4/11/2006 | 412 | 20.1 | 8.41 | 3.54 | 164 |
| 10/18/2005 | 356 | 19.4 | 7.95 | 0.6 | 117 |
| 4/26/2005 | 577 | 19.4 | 7.7 | 1.8 | - |
| 10/12/2004 | 614 | 19 | 7.47 | 1.61 | 183 |
| 4/27/2004 | 403 | 18.7 | 7.75 | 3.39 | 218 |
| 11/6/2003 | 615 | 17.9 | 6.42 | - | 153 |
| Averages | 586 | 19.4 | 7.47 | 2.85 | 157 |
| **Commerce #5** | | | | | |
| 4/22/2008 | 279 | 20.65 | 7.47 | 1.11 | 109 |
| 10/23/2007 | 283 | 18.58 | 7.65 | 0.78 | 109 |
| 5/8/2007 | 308 | 20.04 | 7.74 | 1.49 | 103 |
| 11/8/2006 | 313 | 21.2 | 7.74 | 2.12 | 115 |
| 4/11/2006 | 301 | 19.9 | 8.57 | 1.44 | 107 |
| 10/18/2005 | 269 | 20.4 | 7.81 | 0.1 | 145 |
| 4/26/2005 | 268 | 18.4 | 8.17 | 5.18 | - |
| 10/12/2004 | 260 | 17.9 | 8.64 | 5.65 | 152 |
| 4/27/2004 | 252 | 18.9 | 7.82 | 5.75 | 158 |
| 11/6/2003 | 294 | 17.7 | 7.29 | - | 108 |
| 4/18/2002 | 294 | 20.6 | 7.5 | - | - |

TABLE 7-3
Groundwater Field Parameters in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | **Cond.** | **Temp.** | **pH** | **D.O.** | **Alk (Field)** |
|---|---|---|---|---|---|
| | (Field) | (Field) | (Field) | (Field) | CaCO3 |
| Unit | µS/cm | °C | | mg/l | mg/l |
| 12/13/2001 | 282 | 17.7 | 7.48 | - | - |
| 3/9/2001 | 296 | 15.6 | 7.75 | - | - |
| 10/13/2000 | 333 | 20.5 | 7.68 | - | - |
| 10/13/2000 | 333 | 20.5 | 7.68 | - | - |
| Averages | 291 | 19.24 | 7.80 | 2.62 | 123 |
| **Ontario (Fernandez) Well** | | | | | |
| 4/21/2008 | 407 | 20.26 | 7.2 | 1.57 | 120 |
| 10/23/2007 | 997 | 16.23 | 6.92 | 1.21 | 181 |
| 5/7/2007 | 951 | 18.38 | 6.81 | 1.75 | 206 |
| 11/8/2006 | 378 | 18.8 | 7.3 | 1.06 | 132 |
| 4/10/2006 | 239 | 17.8 | 6.69 | 1.43 | 153 |
| 10/17/2005 | 404 | 17.1 | 7.59 | 2.5 | 155 |
| 4/25/2005 | 402 | 15.8 | 7.27 | 1.4 | 180 |
| 1/28/2005 | 756 | 12.1 | 7.03 | 2.63 | - |
| 10/11/2004 | 445 | 15.4 | 7.41 | 2.09 | 128 |
| 4/29/2004 | 427 | 17.3 | 7.5 | 2.27 | 134 |
| 12/19/2003 | 415 | 14.8 | 6.64 | - | 125 |
| 11/4/2003 | 252 | 17.1 | 7.83 | - | 115 |
| 10/6/2003 | 257 | 18.3 | 7.08 | - | 130 |
| 7/30/2003 | 370 | 18.2 | 8.19 | - | - |
| Averages | 479 | 16.97 | 7.25 | 1.79 | 147 |
| **Miami #1** | | | | | |
| 4/27/2004 | 413 | 19.6 | 8.27 | 3.3 | 120 |
| 11/4/2003 | 500 | 15.7 | 7.15 | - | - |
| Averages | 457 | 17.7 | 7.71 | 3.3 | 120 |
| **Miami #3** | | | | | |
| 4/22/2008 | 537 | 20.06 | 7.22 | 0.66 | 107 |
| 10/23/2007 | 533 | 16.94 | 7.28 | 1.47 | 114 |
| 5/8/2007 | 523 | 19.5 | 7.35 | 0.49 | 108 |
| 11/8/2006 | 538 | 18.56 | 7.52 | 1.51 | 116 |
| 4/11/2006 | 547 | 20.1 | 8.51 | 2.14 | 155 |
| 10/18/2005 | 492 | 19.3 | 7.7 | 0.7 | 125 |
| 4/26/2005 | 527 | 18.8 | 7.77 | 1.47 | - |
| 10/12/2004 | 506 | 16.5 | 8 | 1.65 | 102 |
| Averages | 525 | 18.72 | 7.67 | 1.26 | 118 |
| **Miami #11** | | | | | |
| 5/8/2007 | 345 | 19.1 | 7.73 | 1.3 | 104 |
| 11/8/2006 | 353 | 19.4 | 7.74 | 1.24 | 111 |
| Averages | 349 | 19.3 | 7.74 | 1.27 | 108 |
| **Picher #2 - (Plugged - 2004)** | | | | | |
| 8/12/1999 | 620 | 23.7 | 7.2 | - | - |
| 11/6/1997 | 305 | 16 | 7.31 | - | - |
| 7/15/1997 | 455 | 23 | 6.95 | - | - |

TABLE 7-3
Groundwater Field Parameters in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | Cond. | Temp. | pH | D.O. | Alk (Field) |
|---|---|---|---|---|---|
| | (Field) | (Field) | (Field) | (Field) | CaCO3 |
| Unit | µS/cm | °C | | mg/l | mg/l |
| 4/9/1997 | 625 | 18 | 7.08 | - | - |
| 10/25/1996 | 500 | 19.5 | 7.38 | - | - |
| 10/1/1996 | 490 | 20 | 6.87 | - | - |
| Averages | 499 | 20.0 | 7.13 | - | - |
| **Picher #3 - (Plugged - 2004)** | | | | | |
| 11/6/1997 | 600 | 21 | 7.01 | - | - |
| 7/15/1997 | 850 | 23 | 6.89 | - | - |
| 6/6/1997 | 975 | 22 | 6.92 | - | - |
| 9/23/1996 | 800 | 17 | 6.7 | - | - |
| Averages | 806 | 21 | 6.88 | - | - |
| **Picher #4 - (Plugged - 2004)** | | | | | |
| 12/11/1997 | 630 | 17.5 | 6.92 | - | - |
| 9/16/1997 | 700 | 22 | 6.89 | - | - |
| 8/28/1997 | 715 | 23 | 6.9 | - | - |
| 4/9/1997 | 700 | 19 | 6.82 | - | - |
| 10/8/1996 | 725 | 22 | 6.88 | - | - |
| 9/16/1996 | 1120 | 20 | 7.03 | - | - |
| Averages | 765 | 20.6 | 6.91 | - | - |
| **Picher #5** | | | | | |
| 4/22/2008 | 604 | 21.67 | 7.26 | 2.35 | 135 |
| 10/23/2007 | 605 | 19.25 | 7.17 | 2.5 | 137 |
| 5/8/2007 | 442 | 20.03 | 7.59 | 1.56 | 119 |
| 11/8/2006 | 635 | 21.46 | 7.23 | 0.88 | 139 |
| 4/11/2006 | 483 | 23.9 | 8.51 | 2.68 | 157 |
| 10/17/2005 | 544 | 21.8 | 7.81 | 0.3 | 124 |
| 4/25/2005 | 581 | 18.5 | 7.56 | 2.91 | 132 |
| 10/12/2004 | 569 | 18.3 | 7.68 | 2.33 | 122 |
| 4/27/2004 | 536 | 20.7 | 7.33 | 3.19 | 142 |
| 11/5/2003 | 590 | 14 | 6.52 | - | - |
| 4/18/2002 | 591 | 19.9 | 7.11 | - | - |
| 12/13/2001 | 527 | 15.4 | 7.21 | - | - |
| 3/9/2001 | 580 | 19.1 | 7.22 | - | - |
| 10/11/2000 | 571 | 20.2 | 7.15 | - | - |
| 2/25/2000 | 621 | 20.2 | 7.07 | - | - |
| 8/12/1999 | 550 | 23 | 7.45 | - | - |
| 7/22/1999 | 490 | 19.5 | 7.05 | - | - |
| 3/25/1999 | 440 | 15 | 7.04 | - | - |
| 12/15/1998 | 380 | 20 | 7.18 | - | - |
| 8/25/1998 | 480 | 21 | 7.06 | - | - |
| 7/31/1998 | 485 | 21.5 | 6.85 | - | - |
| 3/20/1998 | 325 | 15 | 7.06 | - | - |
| 12/4/1997 | 400 | 18 | 7.17 | - | - |
| 9/16/1997 | 550 | 22 | 6.94 | - | - |
| 8/15/1997 | 550 | 22 | 7.3 | - | - |

TABLE 7-3
Groundwater Field Parameters in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | **Cond.** | **Temp.** | **pH** | **D.O.** | **Alk (Field)** |
|---|---|---|---|---|---|
| | (Field) | (Field) | (Field) | (Field) | CaCO3 |
| Unit | µS/cm | °C | | mg/l | mg/l |
| 7/30/1997 | 470 | 22 | 7.04 | - | - |
| Averages | 523 | 19.75 | 7.25 | 2.08 | 134 |
| **Picher #6** | | | | | |
| 4/21/2008 | 662 | 21.89 | 7.1 | 4.24 | 136 |
| 10/22/2007 | 619 | 16.4 | 7.25 | 4.05 | 143 |
| 5/7/2007 | 616 | 20.06 | 7.22 | 1.97 | 138 |
| 11/7/2006 | 602 | 21.4 | 6.94 | 4.17 | 141 |
| 4/10/2006 | 511 | 20.3 | 8.11 | 2.62 | 134 |
| 10/27/2005 | 453 | 17.8 | 7.73 | 3.79 | 125 |
| 4/25/2005 | 510 | 18.6 | 7.77 | 3.24 | - |
| 10/11/2004 | 553 | 19.1 | 7.44 | 2.06 | 193 |
| 4/27/2004 | 555 | 20.9 | 7.26 | 4.92 | 157 |
| 12/9/2003 | 537 | 18.2 | 6.83 | - | 135 |
| 4/18/2002 | 565 | 20.3 | 7.24 | - | - |
| 12/13/2001 | 569 | 18.9 | 7.13 | - | - |
| 2/26/2001 | 863 | 19.1 | 7.08 | - | - |
| 10/17/2000 | 900 | 20.5 | 6.94 | - | - |
| 10/12/2000 | 980 | 23 | 7.05 | - | - |
| Averages | 633 | 19.76 | 7.27 | 3.45 | 145 |
| **Picher #7** | | | | | |
| 4/21/2008 | 779 | 22.21 | 7.09 | 1.92 | 155 |
| 10/22/2007 | 700 | 16.05 | 7.3 | 1.38 | 151 |
| 5/8/2007 | 647 | 19.65 | 7.41 | 1.14 | 148 |
| 11/7/2006 | 652 | 19.81 | 7.04 | 2.04 | 153 |
| 4/11/2006 | 482 | 19.6 | 8.2 | 1.43 | 117 |
| 10/17/2005 | 527 | 20.4 | 7.82 | 0.2 | 179 |
| 4/25/2005 | 524 | 18.3 | 7.71 | 1.87 | 174 |
| 10/12/2004 | 483 | 17.9 | 7.83 | 1.31 | 129 |
| 4/27/2004 | 480 | 20.2 | 7.5 | 4.35 | 105 |
| 11/5/2003 | 563 | 14.7 | 6.89 | - | - |
| 4/19/2002 | 525 | 20.2 | 7.38 | - | - |
| 12/13/2001 | 455 | 16.9 | 7.6 | - | - |
| 3/9/2001 | 546 | 17.7 | 7.48 | - | - |
| 10/17/2000 | 453 | 16.9 | 7.25 | - | - |
| 10/13/2000 | 495 | 21.7 | 7.59 | - | - |
| Averages | 554 | 18.81 | 7.47 | 1.74 | 146 |
| **Quapaw #2** | | | | | |
| 11/6/1997 | 875 | 17 | 6.91 | - | - |
| 7/17/1997 | 950 | 23.5 | 6.85 | - | - |
| 2/4/1997 | 700 | 16 | 7.13 | - | - |
| 10/14/1996 | 600 | 18.5 | 7.22 | - | - |
| Averages | 781 | 18.8 | 7.03 | - | - |
| **Quapaw #4** | | | | | |

TABLE 7-3
Groundwater Field Parameters in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | **Cond.** | **Temp.** | **pH** | **D.O.** | **Alk (Field)** |
|---|---|---|---|---|---|
| | (Field) | (Field) | (Field) | (Field) | CaCO3 |
| Unit | µS/cm | °C | | mg/l | mg/l |
| 4/22/2008 | 263 | 20.35 | 7.54 | 1.35 | 102 |
| 10/24/2007 | 280 | 17.87 | 7.4 | 1.46 | 109 |
| 5/9/2007 | 287 | 19.85 | 7.28 | 1.12 | 104 |
| 11/9/2006 | 276 | 19.12 | 7.39 | 0.52 | 118 |
| 4/12/2006 | 270 | 18.8 | 8.53 | 1.03 | 92 |
| 10/18/2005 | 258 | 19.9 | 7.96 | 1.58 | 96 |
| 4/26/2005 | 261 | 16.8 | 8.04 | 1.57 | - |
| 10/13/2004 | 242 | 17.4 | 7.86 | 1.43 | 124 |
| 4/28/2004 | 275 | 19.4 | 7.31 | 2.29 | 146 |
| 11/6/2003 | 249 | 17.7 | 7.03 | - | 107 |
| Averages | 266 | 18.72 | 7.63 | 1.37 | 111 |
| **Quapaw #5** | | | | | |
| 4/23/2008 | 1497 | 21.15 | 6.5 | 1.8 | 265 |
| 10/24/2007 | 1503 | 17.23 | 6.8 | 5.94 | 279 |
| 5/9/2007 | 1477 | 20.6 | 6.7 | 1.46 | 264 |
| 11/9/2006 | 1446 | 19.93 | 6.78 | 1.39 | 272 |
| 4/12/2006 | 1497 | 20.3 | 7.7 | 1.29 | 244 |
| 10/18/2005 | 1378 | 20.8 | 7.11 | 3.8 | 308 |
| 4/26/2005 | 1350 | 19.2 | 7.1 | 1.93 | - |
| 10/13/2004 | 1341 | 18.6 | 7.01 | 2.43 | 247 |
| 4/28/2004 | 1372 | 21.7 | 6.87 | 1.75 | 260 |
| 11/6/2003 | 1427 | 18.5 | 6.41 | - | 265 |
| 4/18/2002 | 1231 | 21 | 6.77 | - | - |
| 12/14/2001 | 1237 | 15.3 | 6.96 | - | - |
| 3/9/2001 | 1144 | 20.2 | 7 | - | - |
| 10/13/2000 | 1166 | 21.5 | 7.02 | - | - |
| Averages | 1362 | 19.72 | 6.91 | 2.42 | 267 |
| **RWD4 #3** | | | | | |
| 4/23/2008 | 297 | 21.47 | 7.05 | 0.98 | 107 |
| 10/24/2007 | 295 | 18.31 | 7.58 | 0.55 | 113 |
| 5/9/2007 | 298 | 19.75 | 7.52 | 0.93 | 125 |
| 11/9/2006 | 299 | 20.28 | 7.69 | 1.25 | 116 |
| 4/2/2006 | 309 | 19.4 | 7.98 | 0.86 | 99 |
| 10/18/2005 | 295 | 20.4 | 8.09 | 1.05 | 141 |
| 4/26/2005 | 282 | 18.4 | 8.01 | 1.91 | - |
| 10/13/2004 | 275 | 18.9 | 7.97 | 2.3 | 157 |
| 4/28/2004 | 273 | 19.9 | 7.42 | 3.34 | 124 |
| 11/7/2003 | 283 | 17.7 | 6.65 | - | 110 |
| Averages | 291 | 19.45 | 7.60 | 1.46 | 121 |
| **RWD7 #2** | | | | | |
| 5/9/2008 | 1169 | 22.5 | 7.37 | 3.55 | 148 |
| 10/24/2007 | 1189 | 20.2 | 7.72 | 0.39 | 142 |
| 5/9/2007 | 1181 | 22.4 | 7.62 | 1.41 | 143 |

TABLE 7-3
Groundwater Field Parameters in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | **Cond.** | **Temp.** | **pH** | **D.O.** | **Alk (Field)** |
|---|---|---|---|---|---|
| | (Field) | (Field) | (Field) | (Field) | CaCO3 |
| Unit | µS/cm | °C | | mg/l | mg/l |
| 11/9/2006 | 1446 | 19.9 | 6.78 | 1.39 | 270 |
| Averages | 1246 | 21.25 | 7.37 | 1.69 | 176 |

**Notes:**

Cond. Conductivity
Temp. Temperature
Alk Alkalinity
D.O. Dissolved Oxygen
CaCO3 Calcium carbonate
µS/cm microSiemens per centimeter
°C degrees Celsius
mg/L millgrams per liter

TABLE 7-4
General Chemistry Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BMW01** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 15-Jul-08 | | 20-Oct-08 | | 5-Feb-09 | | 15-Apr-09 | | 28-Jul-09 | | 5-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **269** | = | **288** | = | **300** | = | **290** | = | **280** | = | **275** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **269** | = | **288** | = | **300** | = | **290** | = | **280** | = | **275** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | = | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **6** | = | **5** | = | **6** | = | **5** | = | **7** | = | **12** | = |
| Fluoride | 4[a] / 2[b] | mg/L | 0.5 | U | **0.35** | = | **0.28** | = | 0.25 | U | 0.25 | U | 0.5 | U |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,757** | = | 0 | U | **1,723** | = | **1,633** | = | **1,776** | = | **1,620** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | 0.24 | = | **0.28** | = | 0.25 | = | **0.34** | = | **0.24** | = | **0.28** | = |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.04** | = | **0.03** | = |
| Sulfate (as $SO_4$) | 250[b] | mg/L | **1,590** | = | **1,540** | = | **1,600** | = | **1,490** | = | **1,590** | = | **1,520** | = |
| Sulfide | NA | mg/L | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,680** | = | **2,440** | = | **2,520** | = | **2,390** | = | **2,360** | = | **2,160** | = |
| Calcium (Dissolved) | NA | mg/L | **399** | = | **382** | = | **400** | = | **409** | = | **351** | = | **434** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **2.19** | = | **4.42** | = | **8** | = | **7.6** | = | **8.21** | = | **10.8** | = |
| Magnesium (Dissolved) | NA | mg/L | **168** | = | **162** | = | **149** | = | **148** | = | **133** | = | **153** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **2.45** | = | **3.42** | = | **5.86** | = | **5.43** | = | **6.04** | = | **6.75** | = |
| Potassium (Dissolved) | NA | mg/L | **13.5** | = | **23.2** | = | **9.75** | = | **34.4** | = | **6.46** | = | **11** | = |
| Sodium (Dissolved) | NA | mg/L | **109** | = | **103** | = | **86** | = | **107** | = | **67.5** | = | **82.2** | = |

| | | **Well ID:** | **BMW02** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 15-Jul-08 | | 15-Jul-08 | | 22-Oct-08 | | 22-Oct-08 | | 5-Feb-09 | | 5-Feb-09 | | 15-Apr-09 | | 15-Apr-09 | | 29-Jul-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **198** | = | **198** | = | **164** | = | **167** | = | **137** | = | **136** | = | **118** | = | **118** | = | **130** | = | **162** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **198** | = | **198** | = | **164** | = | **167** | = | **137** | = | **136** | = | **118** | = | **118** | = | **130** | = | **162** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **11** | = | **11** | = | **12** | = | **12** | = | **22** | = | **25** | = | **34** | = | **33** | = | **37** | = | **42** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **1.57** | = | **1.6** | = | **1.88** | = | **1.78** | = | **1.71** | = | **2.54** | = | **2.81** | = | **2.74** | = | **1.92** | = | **2.29** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,807** | = | **1,742** | = | **141** | = | **158** | = | **1,726** | = | **1,786** | = | **1,788** | = | **1,761** | = | **1,752** | = | **1,737** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.14** | = | **0.14** | = | **0.19** | = | **0.19** | = | **0.17** | = | **0.18** | = | **0.18** | = | **0.17** | = | **0.22** | = | **0.15** | = |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | **0.03** | = | **0.03** | = | -- | -- | -- | -- | **0.02** | = | **0.04** | = | 0.02 | U | **0.02** | = | **0.06** | = | **0.05** | = |
| Sulfate (as $SO_4$) | 250[b] | mg/L | **1,550** | = | **1,600** | = | **1,560** | = | **1,550** | = | **361** | = | **1,660** | = | **1,600** | = | **1,580** | = | **1,590** | = | **1,500** | = |
| Sulfide | NA | mg/L | **0.02** | J | **0.02** | = | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | **0.01** | = | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,680** | = | **2,620** | = | **2,470** | = | **2,280** | = | **2,600** | = | **2,640** | = | **2,550** | = | **2,740** | = | **2,020** | = | **2,440** | = |
| Calcium (Dissolved) | NA | mg/L | **569** | = | **590** | = | **616** | = | **598** | = | **562** | = | **560** | = | **594** | = | **602** | = | **517** | = | **550** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **21.6** | = | **22.2** | = | **31.2** | = | **30.4** | = | **30.7** | = | **31.2** | = | **33.1** | = | **35.1** | = | **21.8** | = | **22.3** | = |
| Magnesium (Dissolved) | NA | mg/L | **65.9** | = | **68.5** | = | **57.3** | = | **56.3** | = | **53.8** | = | **53.4** | = | **58.8** | = | **62.8** | = | **56.7** | = | **57.6** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **5.54** | = | **5.75** | = | **3.09** | = | **2.96** | = | **2.50** | = | **2.46** | = | **3.09** | = | **3.22** | = | **1.84** | = | **1.66** | = |
| Potassium (Dissolved) | NA | mg/L | **5.96** | = | **6.32** | = | **31** | = | **29.5** | = | **8.83** | = | **8.66** | = | **6.79** | = | **7.57** | = | **15** | = | **4.59** | = |
| Sodium (Dissolved) | NA | mg/L | **45.0** | = | **46.8** | = | **55.3** | = | **53** | = | **43.9** | = | **43.8** | = | **46.8** | = | **53.4** | = | **56** | = | **49.4** | = |

**Notes:**

[a]MCL

[b]SMCL

$CaCO_3$ - calcium carbonate

Cl - chloride

N - nitrogen

$SO_4$ - sulfate

MCL - maximum contaminant level

SMCL - secondary maximum contaminant level

FD - field duplicate

NA - not applicable

All results in milligrams per liter (mg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-4
General Chemistry Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BMW05** | | | | | | **BMW06** | | | | **BMW07** | | | | **BMW08** | | | | | | **BMW09** | | | | **BMW11** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 21-Apr-09 | | 3-Aug-09 | | 8-Oct-09 | | 30-Jul-09 | | 13-Oct-09 | | 3-Aug-09 | | 13-Oct-09 | | 3-Aug-09 | | 3-Aug-09 | | 13-Oct-09 | | 3-Aug-09 | | 8-Oct-09 | | 21-Apr-09 | | 4-Aug-09 | | 13-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **192** | = | **162** | = | **182** | = | **160** | = | **92** | = | **246** | = | **172** | = | **242** | = | **242** | = | **254** | = | **94** | = | **91** | = | **70** | = | **31** | = | **24** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **192** | = | **162** | = | **182** | = | **160** | = | **32** | = | **246** | = | **172** | = | **242** | = | **242** | = | **254** | = | **94** | = | **91** | = | **70** | = | **31** | = | **24** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | **60** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | **30** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **10** | = | **11** | = | **11** | = | **48** | = | **46** | = | **8** | = | **11** | = | 5 | U | **5** | = | **5** | = | **11** | = | **11** | = | **11** | = | **11** | = | **14** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **1.49** | = | **1.77** | = | **1.49** | = | **0.43** | = | 0.5 | U | **1.04** | = | **3.29** | = | **0.92** | = | **1.19** | = | **1.49** | = | **2.75** | = | **2.56** | = | **0.99** | = | **2.08** | = | **2.26** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,744** | = | **1,776** | = | **2,228** | = | **428** | = | **340** | = | **948** | = | **1,832** | = | **208** | = | **224** | = | **185** | = | **1,556** | = | **1,988** | = | 0 | U | **1,320** | = | **3,145** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | **5.87** | = | **0.81** | = | **0.76** | = | **1.28** | = | **1.88** | = | **0.12** | = | **0.13** | = | **0.12** | = | **0.12** | = | **0.14** | = | **0.2** | = | **0.18** | = | **0.21** | = | **0.16** | = | **0.19** | = |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | **3.93** | = | **3.79** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.04 | U | 0.04 | U | **4.58** | = | **4.59** | = | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | **0.04** | = | **0.04** | = | **0.02** | **J** | **0.65** | = | **0.8** | = | **0.03** | = | **0.04** | = | 0.02 | U | 0.02 | U | 0.02 | U | **0.04** | = | **0.03** | = | **0.02** | = | **0.02** | = | **0.03** | = |
| Sulfate (as $SO_4$) | 250[b] | mg/L | **1,670** | = | **1,580** | = | **1,490** | = | **979** | = | **875** | = | **761** | = | **1,460** | = | **43** | **J** | **60** | **J** | **52** | = | **1,430** | = | **1,330** | = | **1,620** | = | **1,650** | = | **1,720** | = |
| Sulfide | NA | mg/L | **0.02** | = | 0.01 | U | 0.01 | U | **0.01** | = | 0.01 | U | **0.01** | = | **0.02** | = | **3.15** | = | **3.97** | = | **4.05** | = | 0.01 | U | **0.01** | = | 0.01 | U | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,550** | = | **2,280** | = | **2,300** | = | **1,710** | = | **1,280** | = | **1,420** | = | **2,080** | = | **394** | = | **344** | = | **398** | = | **2,060** | = | **2,090** | = | **2,490** | = | **2,210** | = | **2,320** | = |
| Calcium (Dissolved) | NA | mg/L | **603** | = | **568** | = | **595** | = | **80.8** | = | **189** | = | **321** | = | **473** | = | **49.7** | = | **50.6** | = | **47.9** | = | **556** | = | **552** | = | **549** | = | **566** | = | **546** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **32** | = | **273** | **J** | **315** | = | 0.025 | U | 0.025 | U | **10.9** | **J** | **30.3** | = | **0.0419** | **J** | **0.0443** | **J** | **0.0419** | = | **51.4** | **J** | **50.4** | = | **35.9** | = | **65.9** | = | **84.2** | = |
| Magnesium (Dissolved) | NA | mg/L | **66.1** | = | **547** | = | **599** | = | **38.9** | = | **26.4** | = | **38.6** | = | **33.7** | = | **19.8** | = | **20.2** | = | **18.9** | = | **40.3** | = | **39.9** | = | **49.1** | = | **45.1** | = | **49.4** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **1.41** | = | **1.04** | = | **1.29** | = | **0.0157** | = | 0.005 | U | **0.509** | **J** | **0.984** | = | **0.124** | **J** | **0.128** | **J** | **0.0749** | = | **1.05** | = | **0.99** | = | **16.2** | = | **7.27** | = | **2.48** | = |
| Potassium (Dissolved) | NA | mg/L | **9.98** | = | **14.3** | = | **12.3** | = | **28.8** | = | **34.3** | = | **14.3** | = | **2.53** | = | **9.89** | = | **9.98** | = | **10.6** | = | **2.41** | = | **2.31** | = | **6.03** | = | **3.94** | = | **3.98** | = |
| Sodium (Dissolved) | NA | mg/L | **41.4** | = | **47.9** | = | **46.8** | = | **309** | = | **338** | = | **55.3** | = | **73.3** | = | **56.7** | = | **57.5** | = | **46.5** | = | **25** | = | **23.2** | = | **80.2** | = | **35.8** | = | **32.8** | = |

**Notes:**

[a]MCL

[b]SMCL

$CaCO_3$ - calcium carbonate

Cl - chloride

N - nitrogen

$SO_4$ - sulfate

MCL - maximum contaminant level

SMCL - secondary maximum contaminant level

FD - field duplicate

NA - not applicable

All results in milligrams per liter (mg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-4
General Chemistry Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | Well ID: | BMW12 | | | | | | BMW13 | | | | | | BMW14 | | | | BMW15 | | | | BW02 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Date: | 20-Apr-09 | | 4-Aug-09 | | 13-Oct-09 | | 5-May-09 | | 29-Jul-09 | | 6-Oct-09 | | 3-Aug-09 | | 8-Oct-09 | | 5-Aug-09 | | 13-Oct-09 | | 16-Apr-09 | | 16-Apr-09 | | 29-Jul-09 | | 29-Jul-09 | | 7-Oct-09 | | 7-Oct-09 | |
| | | Type: | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | FD | | Normal | | FD | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **27** | = | **24** | = | **25** | = | **230** | = | **234** | = | **247** | = | **500** | = | **388** | = | **224** | = | **238** | = | **282** | = | **284** | = | **292** | = | **292** | = | **310** | = | **308** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **27** | = | **24** | = | **25** | = | **230** | = | **234** | = | **247** | = | 10 | U | **16** | = | **224** | = | **238** | = | **282** | = | **284** | = | **292** | = | **292** | = | **310** | = | **308** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **484** | = | **372** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | -- | -- | 10 | U | 10 | U | **258** | = | **186** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **10** | = | **11** | = | **11** | = | **6** | = | **6** | = | **6** | = | **17** | = | **20** | = | **11** | = | **8** | = | **22** | = | **21** | = | **28** | = | **28** | = | **25** | = | **23** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **0.92** | = | **1.14** | = | **1.74** | = | **0.39** | = | **0.3** | = | **0.33** | = | **0.95** | = | **1.12** | = | 0.25 | U | 0.25 | U | **0.28** | = | **0.27** | = | **0.31** | = | **0.29** | = | **0.27** | = | 0.25 | U |
| Hardness (as $CaCO_3$) | NA | mg/L | **44** | = | **1,564** | = | **1,744** | = | **411** | = | **548** | = | **500** | = | **80** | = | **320** | = | **244** | = | **392** | = | **440** | = | **420** | = | **428** | = | **444** | = | **680** | = | **462** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.19** | = | **0.19** | = | **0.21** | = | 0.05 | U | 0.05 | U | **0.08** | = | **1.48** | = | **1.51** | = | **0.1** | = | 0.05 | U | **0.09** | = | **0.1** | = | **0.09** | = | **0.09** | = | **0.07** | = | **0.06** | = |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **565** | = | 0.02 | U | 0.02 | U | **0.08** | = | **0.06** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.05 | = | 0.04 | U | 0.04 | U | 0.04 | U | **565** | = | 0.04 | U | 0.04 | U | **0.1** | = | **0.07** | = | 0.04 | U | 0.04 | U | 0.04 | U | **0.04** | = | 0.04 | U | **0.06** | = |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | **0.05** | = | **0.1** | = | **0.07** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.02** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.03** | = | **0.03** | = | **0.04** | = | **0.04** | = |
| Sulfate (as $SO_4$) | 250[b] | mg/L | **1,740** | = | **1,750** | = | **1,780** | = | **492** | = | **490** | = | **487** | = | **25** | = | **39** | = | **279** | = | **243** | = | **131** | = | **129** | = | **162** | = | **167** | = | **122** | = | **133** | = |
| Sulfide | NA | mg/L | 0.01 | U | **0.12** | = | **0.05** | = | 0.01 | U | **0.02** | = | **0.06** | = | 0.01 | U | **0.29** | = | 0.01 | U | 0.01 | U | **22.1** | = | **21** | = | **18.8** | = | **18.7** | = | **23.1** | = | **21.3** | = |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,360** | = | **2,610** | = | **2,350** | = | **924** | = | **1,050** | = | **924** | = | **660** | = | **528** | = | **632** | = | **622** | = | **532** | = | **546** | = | **570** | = | **538** | = | **584** | = | **562** | = |
| Calcium (Dissolved) | NA | mg/L | **562** | = | **0.562** | = | **548** | = | **172** | = | **162** | = | **181** | **J** | **13.6** | = | **8.16** | = | **123** | = | **143** | = | **170** | = | **165** | = | **145** | = | **147** | = | **157** | = | **155** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **82.8** | = | **0.141** | = | **107** | = | **0.0623** | = | **0.421** | **J** | **0.159** | = | 0.025 | U | 0.025 | U | 0.025 | U | 0.025 | U | **0.0911** | = | **0.0902** | = | **0.030** | = | **0.03** | = | **0.033** | = | **0.0386** | |
| Magnesium (Dissolved) | NA | mg/L | **54.4** | = | **0.0564** | = | **54.1** | = | **13.3** | = | **15.1** | = | **15.9** | = | **4.56** | = | **2.58** | = | **26.6** | = | **27.1** | = | **5.27** | = | **5.08** | = | **5.18** | = | **5.21** | = | **4.89** | = | **4.81** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **9.24** | = | **0.0032** | = | **1.48** | = | **1.19** | = | **1.76** | **J** | **2.23** | = | 0.005 | U | 0.005 | U | **0.0825** | = | **0.0538** | = | **0.0334** | = | **0.0324** | = | **0.0264** | = | **0.0267** | = | **0.0229** | = | **0.0218** | = |
| Potassium (Dissolved) | NA | mg/L | **5.15** | = | **0.0052** | = | **4.31** | = | **6.08** | = | **5.36** | = | **5.4** | = | **87.9** | = | **61.6** | = | **9.88** | = | **5.44** | = | 1 | U | 1 | U | 1 | U | 1 | U | 1 | U | 1 | U |
| Sodium (Dissolved) | NA | mg/L | **40.8** | = | **0.034** | = | **33.2** | = | **122** | = | **118** | = | **124** | = | **175** | = | **159** | = | **27.1** | = | **31.7** | = | **31.1** | = | **30** | = | **0.0307** | = | **31** | = | **27.3** | = | **27** | = |

**Notes:**

[a]MCL

[b]SMCL

$CaCO_3$ - calcium carbonate

Cl - chloride

N - nitrogen

$SO_4$ - sulfate

MCL - maximum contaminant level

SMCL - secondary maximum contaminant level

FD - field duplicate

NA - not applicable

All results in milligrams per liter (mg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-4
General Chemistry Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BW06** | | | | | | **BW07** | | | | | | | | **BW11** | | | | | | **BW13** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 20-Apr-09 | | 29-Jul-09 | | 7-Oct-09 | | 21-Apr-09 | | 21-Apr-09 | | 5-Aug-09 | | 14-Oct-09 | | 20-Apr-09 | | 30-Jul-09 | | 12-Oct-09 | | 22-Apr-09 | | 29-Jul-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **122** | = | **104** | = | **112** | = | **212** | = | **211** | = | **224** | = | **218** | = | **194** | = | **272** | = | **242** | = | **310** | = | **312** | = | **330** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **122** | = | **104** | = | **112** | = | **212** | = | **211** | = | **224** | = | **218** | = | **194** | = | **272** | = | **242** | = | **310** | = | **312** | = | **330** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **6** | = | **6** | = | 10 | U | **11** | = | **11** | = | **13** | = | **11** | = | **6** | = | **7** | = | **7** | = | **66** | = | **69** | = | **74** | = |
| Fluoride | 4[a] / 2[b] | mg/L | 0.25 | U | 0.25 | U | 0.5 | U | **0.31** | = | **0.33** | = | 0.25 | U | 0.5 | U | 0.25 | U | 0.25 | U | 0.5 | U | **2.22** | = | **2.31** | = | **2.48** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,723** | = | **1,844** | = | **2,048** | = | 0 | U | 0 | U | **1,364** | = | **2,925** | = | **2** | = | **908** | = | **755** | = | **40** | = | **60** | = | **360** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.38** | = | **0.21** | = | **0.31** | = | **0.1** | = | **0.1** | = | **0.11** | = | **0.11** | = | **0.67** | = | **0.53** | = | **0.63** | = | **0.51** | = | **0.52** | = | **0.52** | = |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | **0.06** | = | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | **0.04** | = | **0.07** | = | **0.07** | = | 0.02 | U | **0.02** | = | **0.02** | = | 0.02 | U | 0.02 | U | **0.03** | = | **0.04** | = | 0.02 | U | 0.02 | U | **0.02** | = |
| Sulfate (as $SO_4$) | 250[b] | mg/L | **1,840** | = | **1,820** | = | **1,740** | = | **2,430** | = | **2,410** | = | **2,710** | = | **2,350** | = | **1,020** | = | **1,020** | = | **982** | = | 5 | U | 5 | U | 5 | U |
| Sulfide | NA | mg/L | **0.51** | = | **0.64** | = | **0.15** | = | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | **0.72** | = | **12.1** | = | **11.8** | = | **0.04** | = | **0.03** | = | **0.17** | = |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,800** | = | **2,790** | = | **2,410** | = | **3,630** | = | **3,730** | = | **3,720** | = | **4,360** | = | **1,750** | = | **1,400** | = | **1,560** | = | **572** | = | **532** | = | **488** | = |
| Calcium (Dissolved) | NA | mg/L | **469** | = | **447** | = | **466** | = | **426** | = | **426** | = | **425** | = | **412** | = | **260** | = | **231** | = | **248** | = | **10.7** | = | **10.1** | = | **11.9** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **63.3** | = | **60** | = | **61** | = | **0.393** | = | **0.394** | = | **0.552** | J | **0.107** | = | **3.68** | = | **0.131** | = | **0.607** | = | **0.128** | = | **0.147** | = | **0.145** | = |
| Magnesium (Dissolved) | NA | mg/L | **124** | = | **107** | = | **113** | = | **286** | = | **287** | = | **305** | = | **289** | = | **70.1** | = | **66.4** | = | **67.8** | = | **3.43** | = | **3.12** | = | **3.4** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.763** | = | **0.669** | J | **0.713** | = | **12.8** | = | **12.9** | = | **13.7** | = | **13** | = | **5** | = | **4.15** | = | **4.55** | = | **0.0129** | = | **0.0167** | = | **0.0164** | = |
| Potassium (Dissolved) | NA | mg/L | **5.47** | = | **4.76** | = | **4.9** | = | **7.85** | = | **7.93** | = | **8.62** | = | **7.98** | = | **6.23** | = | **6.07** | = | **5.96** | = | **4.68** | = | **4.17** | = | **4.5** | = |
| Sodium (Dissolved) | NA | mg/L | **58.7** | = | **51.3** | = | **52.6** | = | **172** | = | **174** | = | **183** | = | **164** | = | **150** | = | **145** | = | **142** | = | **180** | = | **153** | = | **164** | = |

**Notes:**

[a]MCL

[b]SMCL

$CaCO_3$ - calcium carbonate

Cl - chloride

N - nitrogen

$SO_4$ - sulfate

MCL - maximum contaminant level

SMCL - secondary maximum contaminant level

FD - field duplicate

NA - not applicable

All results in milligrams per liter (mg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-4
General Chemistry Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BW14** | | | | | | | | | | **BW15** | | | | | | **BW16** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 16-Apr-09 | | 4-Aug-09 | | 4-Aug-09 | | 13-Oct-09 | | 13-Oct-09 | | 20-Apr-09 | | 3-Aug-09 | | 13-Oct-09 | | 15-Apr-09 | | 30-Jul-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | Normal | | FD | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **220** | = | **214** | = | **215** | = | **224** | = | **222** | = | **570** | = | **560** | = | **500** | = | **172** | = | **160** | = | **174** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **220** | = | **214** | = | **215** | = | **224** | = | **222** | = | **570** | = | **560** | = | **500** | = | **172** | = | **160** | = | **174** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | **29** | = | **27** | = | **28** | = | 5 | U | 5 | U | **5** | = |
| Fluoride | 4[a] / 2[b] | mg/L | 0.25 | U | 0.25 | U | 0.25 | U | 0.25 | U | 0.25 | U | **0.6** | = | **0.58** | = | **0.62** | = | **0.36** | = | **0.41** | = | **0.31** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **388** | = | **392** | = | **380** | = | **577** | = | **445** | = | **2,380** | = | **2,464** | = | **2,920** | = | **272** | = | **284** | = | **326** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | 0.05 | U | 0.05 | U | 0.05 | U | **0.05** | = | **0.05** | = | **3.04** | = | **1.79** | = | **0.76** | = | **0.16** | = | 0.05 | U | 0.05 | U |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.05** | = | **0.09** | = |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | **0.07** | = | **0.12** | = |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.05** | = | **0.05** | = | **0.05** | = | 0.02 | U | 0.02 | U | **0.02** | = |
| Sulfate (as $SO_4$) | 250[b] | mg/L | **182** | = | **197** | = | **203** | = | **173** | = | **177** | = | **2,330** | = | **1,990** | = | **2,060** | = | **99** | = | **122** | = | **87** | = |
| Sulfide | NA | mg/L | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | **2.81** | = | **0.2** | = | **0.2** | = | **0.07** | = | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **518** | = | **426** | = | **524** | = | **474** | = | **486** | = | **3,510** | = | **18,300** | = | **3,160** | = | **414** | = | **414** | = | **338** | = |
| Calcium (Dissolved) | NA | mg/L | **133** | = | **134** | = | **135** | = | **127** | = | **131** | = | **454** | = | **444** | = | **473** | = | **22.1** | = | **72.6** | = | **79.6** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **0.646** | = | **0.608** | = | **0.615** | = | **0.491** | = | **0.506** | = | **36.6** | = | **36.3** | = | **38.9** | = | **0.0993** | = | 0.025 | U | **0.105** | = |
| Magnesium (Dissolved) | NA | mg/L | **17.5** | = | **18** | = | **18** | = | **16.9** | = | **17.6** | = | **293** | = | **277** | = | **287** | = | **1.75** | = | **5.97** | = | **6.7** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.089** | = | **0.103** | = | **0.104** | = | **0.0853** | = | **0.0891** | = | **3.5** | = | **3.71** | = | **3.87** | = | **0.0278** | = | **0.0623** | J | **0.704** | = |
| Potassium (Dissolved) | NA | mg/L | **1.83** | = | **1.91** | = | **1.91** | = | **17.7** | = | **1.83** | = | **19.2** | = | **19.2** | = | **18.5** | = | 1 | U | **2.08** | = | **3.17** | = |
| Sodium (Dissolved) | NA | mg/L | **15.8** | = | **16.3** | = | **16.2** | = | **14.7** | = | **14.9** | = | **151** | = | **144** | = | **145** | = | **2.14** | = | **21.7** | = | **21.5** | = |

**Notes:**

[a]MCL

[b]SMCL

$CaCO_3$ - calcium carbonate

Cl - chloride

N - nitrogen

$SO_4$ - sulfate

MCL - maximum contaminant level

SMCL - secondary maximum contaminant level

FD - field duplicate

NA - not applicable

All results in milligrams per liter (mg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

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TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **FCB2** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 27-Feb-07 | | 22-Oct-07 | | 23-Apr-08 | | 28-Oct-08 | | 16-Apr-09 | | 30-Jul-09 | | 30-Jul-09 | | 12-Oct-09 | | 12-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | FD | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **40** | **=** | **58** | **=** | **65** | **=** | **76** | **=** | **70** | **=** | **72** | **=** | **72** | **=** | **68** | **=** | **66** | **=** |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **40** | **=** | **58** | **=** | **65** | **=** | **76** | **=** | **70** | **=** | **72** | **=** | **72** | **=** | **68** | **=** | **66** | **=** |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | 10 | U | 10 | U | **7** | **=** | **8** | **=** | **7** | **=** | **8** | **=** | **7** | **=** | **8** | **=** | **13** | **=** |
| Fluoride | 4[a] / 2[b] | mg/L | **3.24** | **=** | **2.76** | **=** | **2.84** | **=** | **2.84** | **=** | **2.71** | **=** | **3** | **=** | **3.03** | **=** | **2.75** | **=** | **2.89** | **=** |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,434** | **=** | **1,168** | **=** | **1,054** | **=** | **1,087** | **=** | **1,228** | **=** | **1,063** | **=** | **1,104** | **=** | **1,068** | **=** | **1,132** | **=** |
| Nitrogen, ammonia (as N) | NA | mg/L | ND | ND | ND | ND | ND | ND | **0.19** | **=** | **0.19** | **=** | **0.18** | **=** | **0.18** | **=** | **0.58** | **=** | **0.63** | **=** |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.04 | U | 0.02 | U | 0.02 | U | 0.02 | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | ND | ND | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | ND | ND | 0.02 | U | **0.03** | **=** | ND | ND | 0.02 | U | **0.03** | **=** | **0.02** | **=** | **0.02** | **=** | **0.02** | **=** |
| Sulfate (as SO4) | 250[b] | mg/L | **1,410** | **=** | **1,120** | **=** | **971** | **=** | **994** | **=** | **1,060** | **=** | **1,050** | **=** | **1,060** | **=** | **1,020** | **=** | **918** | **=** |
| Sulfide | NA | mg/L | ND | ND | ND | ND | ND | ND | 0.01 | U | 0.01 | U | **0.03** | **J** | **0.01** | **J** | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,210** | **=** | **1,790** | **=** | **1,560** | **=** | **1,600** | **=** | **1,620** | **=** | **1,610** | **=** | **1,450** | **=** | **1,590** | **=** | **1,490** | **=** |
| Calcium (Dissolved) | NA | mg/L | **506** | **=** | **506** | **=** | **392** | **=** | **458** | **=** | **446** | **=** | **342** | **=** | **356** | **=** | **402** | **=** | **401** | **=** |
| Iron (Dissolved) | 0.3[b] | mg/L | **40.7** | **=** | **40.3** | **=** | **33.4** | **=** | **36.6** | **=** | **35.5** | **=** | **28.2** | **=** | **29.9** | **=** | **31.7** | **=** | **31.5** | **=** |
| Magnesium (Dissolved) | NA | mg/L | **16.5** | **=** | **18.8** | **=** | **14.1** | **=** | **21.6** | **=** | **20.7** | **=** | **18.4** | **=** | **20.0** | **=** | **17.8** | **=** | **17.8** | **=** |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.534** | **=** | **0.586** | **=** | **0.432** | **=** | **0.589** | **=** | **0.546** | **=** | **0.468** | **J** | **0.503** | **J** | **0.482** | **=** | **0.480** | **=** |
| Potassium (Dissolved) | NA | mg/L | **1.62** | **=** | **2.58** | **=** | **2.47** | **=** | **2.11** | **=** | **2.00** | **=** | **1.86** | **=** | **2.04** | **=** | **1.92** | **=** | **1.88** | **=** |
| Sodium (Dissolved) | NA | mg/L | **15.5** | **=** | **20.6** | **=** | **20.4** | **=** | **19.0** | **=** | **17.3** | **=** | **14.5** | **=** | **16.0** | **=** | **15.9** | **=** | **15.8** | **=** |

| | | **Well ID:** | **FCB3** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 27-Feb-07 | | 22-Oct-07 | | 23-Apr-08 | | 28-Oct-08 | | 16-Apr-09 | | 30-Jul-09 | | 12-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **54** | **=** | **72** | **=** | **81** | **=** | **81** | **=** | **90** | **=** | **86** | **=** | **72** | **=** |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **54** | **=** | **72** | **=** | **81** | **=** | **81** | **=** | **90** | **=** | **86** | **=** | **72** | **=** |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **7** | **=** | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Fluoride | 4[a] / 2[b] | mg/L | **0.34** | **=** | **0.26** | **=** | **0.26** | **=** | **0.27** | **=** | **0.3** | **=** | **0.29** | **=** | 0.25 | U |
| Hardness (as $CaCO_3$) | NA | mg/L | **143** | **=** | **102** | **=** | **108** | **=** | **106** | **=** | **230** | **=** | **173** | **=** | **300** | **=** |
| Nitrogen, ammonia (as N) | NA | mg/L | ND | ND | ND | ND | ND | ND | **0.3** | **=** | **0.34** | **=** | **0.35** | **=** | **0.2** | **=** |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.04 | U | 0.02 | U | 0.02 | U | **0.05** | **=** | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | ND | ND | 0.04 | U | 0.04 | U | **0.05** | **=** | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | ND | ND | 0.02 | U | 0.02 | U | ND | ND | 0.02 | U | 0.04 | = | **0.02** | **=** |
| Sulfate (as SO4) | 250[b] | mg/L | **80** | **=** | **20** | **=** | **22** | **=** | **24** | **=** | **30** | **=** | **29** | **=** | **24** | **=** |
| Sulfide | NA | mg/L | ND | ND | ND | ND | ND | ND | **0.41** | **=** | **0.34** | **=** | **0.31** | **=** | **0.34** | **=** |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **246** | **=** | **177** | **=** | **190** | **=** | **185** | **=** | **208** | **=** | **217** | **=** | **178** | **=** |
| Calcium (Dissolved) | NA | mg/L | **44.2** | **=** | **33.4** | **=** | **38.4** | **=** | **41.2** | **=** | **41** | **=** | **36.7** | **=** | **30.2** | **=** |
| Iron (Dissolved) | 0.3[b] | mg/L | **2.66** | **=** | **5.39** | **=** | **7.67** | **=** | **6.09** | **=** | **6.73** | **=** | **5.86** | **J** | **4.9** | **=** |
| Magnesium (Dissolved) | NA | mg/L | **4.71** | **=** | **3.97** | **=** | **4.56** | **=** | **4.61** | **=** | **4.65** | **=** | **4.4** | **=** | **3.87** | **=** |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.165** | **=** | **0.211** | **=** | **0.237** | **=** | **0.220** | **=** | **0.233** | **=** | **0.204** | **J** | **0.191** | **=** |
| Potassium (Dissolved) | NA | mg/L | **3.12** | **=** | **5.74** | **=** | **5.24** | **=** | **4.34** | **=** | **4.13** | **=** | **3.85** | **=** | **4.00** | **=** |
| Sodium (Dissolved) | NA | mg/L | **5.87** | **=** | **4.37** | **=** | **5.49** | **=** | **5.19** | **=** | **4.91** | **=** | **4.78** | **=** | **3.49** | **=** |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data
All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration
Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **LMB2** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 28-Feb-07 | | 28-Feb-07 | | 24-Oct-07 | | 22-Apr-08 | | 28-Oct-08 | | 20-Apr-09 | | 5-Aug-09 | | 8-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **97** | **=** | **98** | **=** | **120** | **=** | **117** | **=** | **150** | **=** | **109** | **=** | **130** | **=** | **102** | **=** |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **97** | **=** | **98** | **=** | **120** | **=** | **117** | **=** | **150** | **=** | **109** | **=** | **130** | **=** | **102** | **=** |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **69** | **=** | **68** | **=** | **46** | **=** | **38** | **=** | **34** | **=** | **31** | **=** | **33** | **=** | **28** | **=** |
| Fluoride | 4[a] / 2[b] | mg/L | **2.99** | **=** | **2.89** | **=** | **2.83** | **=** | **2.81** | **=** | **2.93** | **=** | **2.49** | **=** | **2.93** | **=** | **2.81** | **=** |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,734** | **=** | **1,672** | **=** | **1,767** | **=** | **1,681** | **=** | **1,619** | **=** | **1,629** | **=** | **1,184** | **=** | **1,768** | **=** |
| Nitrogen, ammonia (as N) | NA | mg/L | ND | ND | ND | ND | ND | ND | ND | ND | **0.28** | **=** | **0.4** | **=** | **0.23** | **=** | **0.27** | **=** |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.04 | U | 0.04 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | ND | ND | ND | ND | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | ND | ND | ND | ND | **0.02** | **=** | **0.03** | **=** | ND | ND | **0.03** | **=** | **0.03** | **=** | **0.03** | **=** |
| Sulfate (as SO4) | 250[b] | mg/L | **1,740** | **=** | **1,780** | **=** | **1,630** | **=** | **1,600** | **=** | **1,550** | **=** | **1,630** | **=** | **1,580** | **=** | **1,500** | **=** |
| Sulfide | NA | mg/L | ND | ND | ND | ND | ND | ND | ND | ND | **0.02** | **=** | **0.02** | **=** | **0.02** | **=** | **0.20** | **=** |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,650** | **=** | **2,600** | **=** | **2,630** | **=** | **2,630** | **=** | **2,180** | **=** | **2,520** | **=** | **2,520** | **=** | **2,060** | **=** |
| Calcium (Dissolved) | NA | mg/L | **530** | **=** | **545** | **=** | **585** | **=** | **600** | **=** | **644** | **=** | **563** | **=** | **521** | **=** | **537** | **=** |
| Iron (Dissolved) | 0.3[b] | mg/L | **32.4** | **=** | **33.4** | **=** | **22.9** | **=** | **38.3** | **=** | **45.0** | **=** | **37.8** | **=** | **38.6** | **=** | **47.8** | **=** |
| Magnesium (Dissolved) | NA | mg/L | **59.7** | **=** | **61.5** | **=** | **64.9** | **=** | **64.9** | **=** | **65.2** | **=** | **57.7** | **=** | **57.2** | **=** | **61.9** | **=** |
| Manganese (Dissolved) | 0.05[b] | mg/L | **1.75** | **=** | **1.80** | **=** | **1.81** | **=** | **1.82** | **=** | **1.89** | **=** | **1.44** | **=** | **1.52** | **=** | **1.53** | **=** |
| Potassium (Dissolved) | NA | mg/L | **3.58** | **=** | **3.68** | **=** | **3.82** | **=** | **4.2** | **=** | **3.98** | **=** | **3.60** | **=** | **3.33** | **=** | **3.44** | **=** |
| Sodium (Dissolved) | NA | mg/L | **75.9** | **=** | **78.3** | **=** | **70.2** | **=** | **74.0** | **=** | **71.6** | **=** | **55.8** | **=** | **56.5** | **=** | **54.2** | **=** |

| | | **Well ID:** | **MD2** | | | | | | | | **MMB2** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 15-Apr-09 | | 4-Aug-09 | | 15-Oct-09 | | 15-Oct-09 | | 17-Jul-08 | | 23-Oct-08 | | 4-Feb-09 | | 14-Apr-09 | | 28-Jul-09 | | 6-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **182** | **=** | **182** | **=** | **187** | **=** | **186** | **=** | **140** | **=** | **157** | **=** | **168** | **=** | **164** | **=** | **154** | **=** | **154** | **=** |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **182** | **=** | **182** | **=** | **187** | **=** | **186** | **=** | **140** | **=** | **157** | **=** | **168** | **=** | **164** | **=** | **154** | **=** | **154** | **=** |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | -- | -- | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **6** | **=** | **6** | **=** | **6** | **=** | **6** | **=** | **37** | **=** | **41** | **=** | **58** | **=** | **52** | **=** | **36** | **=** | **38** | **=** |
| Fluoride | 4[a] / 2[b] | mg/L | **0.86** | **=** | **0.93** | **=** | **1.35** | **=** | **0.85** | **=** | ND | ND | **2.35** | **=** | **2.47** | **=** | **2.24** | **=** | **2.34** | **=** | **2.09** | **=** |
| Hardness (as $CaCO_3$) | NA | mg/L | **392** | **=** | **320** | **=** | **380** | **=** | **444** | **=** | **1,758** | **=** | **17** | **=** | **1,808** | **=** | **1,732** | **=** | **1,700** | **=** | **1,710** | **=** |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.08** | **=** | **0.07** | **=** | **0.09** | **=** | **0.09** | **=** | 0.05 | U | **0.1** | **=** | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | **0.07** | **=** | **0.02** | **=** | **0.02** | **=** | **0.19** | **=** | **0.11** | **=** | **0.15** | **=** | **0.11** | **=** | **0.39** | **=** | **0.71** | **=** |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | **0.09** | **=** | 0.04 | U | 0.04 | U | **0.20** | **=** | **0.12** | **=** | **0.16** | **=** | **0.12** | **=** | **0.41** | **=** | **0.73** | **=** |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | 0.02 | U | **0.03** | **=** | 0.02 | = | 0.02 | = | 0.02 | U | ND | ND | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Sulfate (as SO4) | 250[b] | mg/L | **205** | **=** | **210** | **=** | **195** | **=** | **203** | **=** | **1,540** | **=** | **1,570** | **=** | **1,670** | **=** | **1,590** | **=** | **1,590** | **=** | **1,530** | **=** |
| Sulfide | NA | mg/L | 0.01 | U | 0.01 | U | **0.01** | **=** | **0.01** | **=** | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **508** | **=** | **510** | **=** | **510** | **=** | **488** | **=** | **2,540** | **=** | **2,320** | **=** | **2,790** | **=** | **2,580** | **=** | **2,560** | **=** | **2,220** | **=** |
| Calcium (Dissolved) | NA | mg/L | **140** | **=** | **146** | **=** | **143** | **=** | **140** | **=** | **599** | **=** | **637** | **=** | **572** | **=** | **612** | **=** | **507** | **=** | **582** | **=** |
| Iron (Dissolved) | 0.3[b] | mg/L | **7.79** | **=** | **8.20** | **J** | **7.83** | **=** | **7.72** | **=** | **0.391** | **=** | **0.033** | **=** | **0.381** | **=** | 0.025 | U | **0.279** | **=** | 0.025 | U |
| Magnesium (Dissolved) | NA | mg/L | **8.14** | **=** | **8.54** | **=** | **8.34** | **=** | **8.25** | **=** | **45.8** | **=** | **57.4** | **=** | **58.0** | **=** | **59.6** | **=** | **50.6** | **=** | **55.4** | **=** |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.173** | **=** | **0.184** | **J** | **0.178** | **=** | **0.176** | **=** | **1.19** | **=** | **1.43** | **=** | **1.53** | **=** | **1.35** | **=** | **1.03** | **=** | **0.870** | **=** |
| Potassium (Dissolved) | NA | mg/L | **1.38** | **=** | **1.50** | **=** | **1.42** | **=** | **1.41** | **=** | **3.09** | **=** | **3.65** | **=** | **3.63** | **=** | **3.63** | **=** | **3.14** | **=** | **3.43** | **=** |
| Sodium (Dissolved) | NA | mg/L | **11.6** | **=** | **12.5** | **=** | **11.7** | **=** | **11.4** | **=** | **49.6** | **=** | **62.9** | **=** | **68.8** | **=** | **70.6** | **=** | **48.8** | **=** | **50.1** | **=** |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data
All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration
Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **MP04** | | | | | | **MP05** | | | | **MP06** | | | | **MP17** | | | | | | **MP20** | | | | | | **OCC3** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 21-Apr-09 | | 30-Jul-09 | | 14-Oct-09 | | 4-Aug-09 | | 12-Oct-09 | | 5-Aug-09 | | 12-Oct-09 | | 15-Apr-09 | | 30-Jul-09 | | 7-Oct-09 | | 22-Apr-09 | | 29-Jul-09 | | 6-Oct-09 | | 23-Apr-08 | | 27-Oct-08 | | 15-Apr-09 | | 5-Aug-09 | | 14-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **212** | = | **265** | = | **164** | = | **274** | = | **245** | = | **24** | = | **158** | = | **156** | = | **164** | = | **140** | = | **188** | = | **172** | = | **206** | = | **116** | = | **133** | = | **129** | = | **142** | = | **146** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **212** | = | **265** | = | **164** | = | **274** | = | **245** | = | **12** | = | **158** | = | **156** | = | **164** | = | **140** | = | **188** | = | **172** | = | **206** | = | **116** | = | **133** | = | **129** | = | **142** | = | **146** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **12** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **13** | = | **15** | = | **13** | = | **8** | = | **7** | = | **41** | = | **17** | = | 5 | U | 5 | U | 5 | U | **6** | = | **6** | = | 5 | U | **17** | = | **17** | = | **17** | = | **18** | = | **16** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **3.21** | = | **2.99** | = | **3.14** | = | **3.55** | = | **2.48** | = | **7.01** | = | **6.54** | = | **0.35** | = | **0.34** | = | **0.37** | = | **2.57** | = | **2.82** | = | **2.80** | = | **2.88** | = | **3.18** | = | **2.99** | = | **5.20** | = | **2.61** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | 0 | U | **680** | = | **3,205** | = | **1,332** | = | **2,900** | = | **260** | = | **2,304** | = | **264** | = | **244** | = | **364** | = | **1,603** | = | **1,676** | = | **1,760** | = | **1,795** | = | ND | ND | ND | ND | **976** | = | ND | ND |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.71** | = | **0.71** | = | **0.75** | = | **2.52** | = | **2.43** | = | **1.09** | = | **0.51** | = | 0.05 | U | 0.05 | U | 0.05 | U | **0.77** | = | **0.56** | = | **0.79** | = | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.03** | = | **0.03** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | ND | ND | ND | ND | ND | ND | ND | ND |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | **0.11** | = | **0.07** | = | 0.04 | U | 0.04 | U | **0.04** | = | 0.04 | U | 0.04 | U | **0.05** | = | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | ND | ND | **0.04** | **J** | ND | ND |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | **0.22** | = | **0.31** | = | **0.24** | = | **0.11** | = | **0.11** | = | **0.02** | = | **0.10** | = | 0.02 | U | **0.02** | = | **0.02** | = | 0.02 | U | **0.07** | = | **0.06** | = | **0.03** | = | ND | ND | 0.02 | U | ND | ND | ND | ND |
| Sulfate (as SO4) | 250[b] | mg/L | **2,540** | = | **2,400** | = | **2,320** | = | **2,080** | = | **1,820** | = | **416** | = | **1,580** | = | **106** | = | **117** | = | **118** | = | **1,500** | = | **1,490** | = | **1,490** | = | **1,740** | = | **1,640** | = | **1,700** | = | **1,830** | = | **1,600** | = |
| Sulfide | NA | mg/L | **0.03** | = | 0.01 | U | 0.01 | U | **0.14** | = | **0.04** | = | **0.02** | = | **2.45** | = | 0.01 | U | 0.01 | U | 0.01 | U | **0.02** | = | **0.01** | = | **0.02** | = | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **3,770** | = | **3,710** | = | **3,640** | = | **3,000** | = | **2,550** | = | **734** | = | **2,580** | = | **330** | = | **390** | = | **356** | = | **2,260** | = | **2,460** | = | **2,310** | = | **2,700** | = | **2,720** | = | **2,440** | = | **2,720** | = | **2,500** | = |
| Calcium (Dissolved) | NA | mg/L | **540** | = | **469** | = | **542** | = | **553** | = | **550** | = | **67.4** | = | **482** | = | **84.4** | = | **76.9** | = | **85.6** | = | **587** | = | **495** | = | **562** | = | **554** | = | **633** | = | **585** | = | **578** | = | **596** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **289** | = | **275** | = | **297** | = | **139** | = | **113** | = | .025 | U | **83.3** | = | .025 | U | **37.2** | = | **.139** | = | **40.0** | = | **26.4** | = | **42.0** | = | **17.6** | = | **23.1** | = | **23.7** | = | **25.6** | = | **27.5** | = |
| Magnesium (Dissolved) | NA | mg/L | **154** | = | **144** | = | **161** | = | **150** | = | **134** | = | **27.2** | = | **91.4** | = | **6.73** | = | **6.52** | = | **6.95** | = | **60.1** | = | **47.5** | = | **53.8** | = | **42.9** | = | **46.4** | = | **45.0** | = | **45.3** | = | **47.3** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **4.06** | = | **3.86** | = | **4.20** | = | **1.23** | = | **1.04** | = | **0.0094** | = | **1.43** | = | **0.23** | = | **0.0493** | = | **0.182** | = | **1.02** | = | **0.806** | **J** | **0.935** | = | **1.38** | = | **1.55** | = | **1.40** | = | **1.39** | = | **1.42** | = |
| Potassium (Dissolved) | NA | mg/L | **8.34** | = | **8.16** | = | **8.54** | = | **8.06** | = | **6.85** | = | **9.01** | = | **6.50** | = | **2.50** | = | **2.32** | = | **2.50** | = | **10.2** | = | **8.99** | = | **9.84** | = | **5.92** | = | **6.55** | = | **6.09** | = | **6.31** | = | **6.32** | = |
| Sodium (Dissolved) | NA | mg/L | **79.8** | = | **76.8** | = | **78.6** | = | **53.6** | = | **47.2** | = | **112** | = | **86.1** | = | **23.8** | = | **24.3** | = | **24.2** | = | **28.0** | = | **22.4** | = | **25.2** | = | **64.3** | = | **75.4** | = | **68.3** | = | **69.6** | = | **68.6** | = |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data

All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **RMB3** | | | | | | **RMB4** | | | | | | | | **SMB2** | | | | **SMB3** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 16-Apr-09 | | 4-Aug-09 | | 14-Oct-09 | | 1-Mar-07 | | 23-Oct-07 | | 24-Apr-08 | | 29-Oct-08 | | 11-Jul-07 | | 24-Oct-07 | | 16-Jul-08 | | 20-Oct-08 | | 3-Feb-09 | | 14-Apr-09 | | 27-Jul-09 | | 6-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **72** | = | **48** | = | **47** | = | **41** | = | **49** | = | **50** | = | **48** | = | **109** | = | **142** | = | **197** | = | **156** | = | **186** | = | **184** | = | **153** | = | **196** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **72** | = | **48** | = | **47** | = | **41** | = | **49** | = | **50** | = | **48** | = | **109** | = | **142** | = | **197** | = | **156** | = | **186** | = | **184** | = | **153** | = | **196** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | -- | -- | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **7** | = | **8** | = | **7** | = | **9** | = | 10 | U | **7** | = | **8** | = | 5 | U | 10 | U | **39** | = | **33** | = | **38** | = | **37** | = | **31** | = | **38** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **2.57** | = | **3.01** | = | **2.71** | = | **2.55** | = | **2.31** | = | **2.71** | = | **2.23** | = | **1.56** | = | **1.43** | = | **1.70** | = | **1.62** | = | **1.67** | = | **1.60** | = | **2.09** | = | **2.17** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,318** | = | **1,012** | = | **2,588** | = | **1,332** | = | **1,258** | = | **1,173** | = | **1,109** | = | **1,575** | = | **1,652** | = | **1,844** | = | **20** | = | **1,890** | = | **1,907** | = | **1,824** | = | **1,788** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.18** | = | **0.17** | = | **0.21** | = | ND | ND | ND | ND | ND | ND | **0.2** | = | ND | ND | ND | ND | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.04 | U | 0.02 | U | 0.02 | U | **0.02** | = | 0.02 | U | 0.02 | U | **0.22** | = | **0.29** | = | **0.24** | = | **0.23** | = | **0.12** | = | **0.09** | = |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.04 | U | 0.04 | U | ND | ND | 0.04 | U | 0.04 | U | **0.05** | = | 0.04 | U | 0.04 | U | **0.22** | = | **0.31** | = | **0.25** | = | **0.24** | = | **0.13** | J | **0.11** | = |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | 0.02 | U | 0.04 | = | 0.02 | U | ND | ND | 0.02 | U | **0.04** | = | ND | ND | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.02** | = |
| Sulfate (as SO4) | 250[b] | mg/L | **1,200** | = | **1,200** | = | **1,130** | = | **1,350** | = | **1,220** | = | **1,150** | = | **1,010** | = | **1,500** | = | **1,490** | = | **1,640** | = | **1,610** | = | **1,740** | = | **1,650** | = | **1,690** | = | **1,590** | = |
| Sulfide | NA | mg/L | 0.01 | U | **0.02** | = | 0.01 | U | ND | ND | ND | ND | ND | ND | 0.01 | U | ND | ND | ND | ND | **0.27** | = | 0.125 | U | 0.01 | U | 0.01 | U | 0.01 | U | **0.03** | = |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **1,680** | = | **1,750** | = | **1,660** | = | **2,190** | = | **1,930** | = | **1,850** | = | **1,570** | J | **2,310** | = | **2,490** | = | **2,580** | = | **2,460** | = | **2,640** | = | **2,820** | = | **2,760** | = | **2,340** | = |
| Calcium (Dissolved) | NA | mg/L | **500** | = | **479** | = | **463** | = | **473** | = | **470** | = | **439** | = | **419** | = | **625** | = | **581** | = | **613** | = | **662** | = | **545** | = | **573** | = | **501** | = | **568** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **38.6** | = | **41.0** | J | **38.9** | = | **39.7** | = | **34.9** | = | **39.7** | = | **29.6** | = | **11.9** | = | .025 | U | .025 | U | **.027** | = | .025 | U | .025 | U | .025 | U | .025 | U |
| Magnesium (Dissolved) | NA | mg/L | **23.0** | = | **19.9** | = | **22.2** | = | **23.8** | = | **31.5** | = | **21.7** | = | **26.5** | = | **35.3** | = | **33.8** | = | **46.0** | = | **88.7** | = | **93.1** | = | **95.4** | = | **61.8** | = | **53.4** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.617** | = | **0.588** | J | **0.587** | = | **0.715** | = | **0.758** | = | **0.599** | = | **0.68** | = | **1.83** | = | **1.42** | = | **0.934** | = | **1.62** | = | **1.68** | = | **1.32** | = | **0.584** | = | **0.79** | = |
| Potassium (Dissolved) | NA | mg/L | **1.92** | = | **2.02** | = | **2.03** | = | **1.75** | = | **2.48** | = | **2.05** | = | **2.25** | = | **2.81** | = | **2.54** | = | **3.05** | = | **7.17** | = | **7.89** | = | **7.62** | = | **4.26** | = | **3.18** | = |
| Sodium (Dissolved) | NA | mg/L | **16.8** | = | **18.0** | = | **15.8** | = | **14.9** | = | **20.2** | = | **16.3** | = | **18.0** | = | **22.7** | = | **22.3** | = | **50.4** | = | **75.8** | = | **76.6** | = | **74.0** | = | **48.1** | = | **47.6** | = |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data
All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration
Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | Well ID: | SMB5 | | | | | | | | | | | | SMB6 | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Date: | 16-Jul-08 | | 21-Oct-08 | | 3-Feb-09 | | 15-Apr-09 | | 27-Jul-09 | | 5-Oct-09 | | 21-Apr-08 | | 16-Jul-08 | | 16-Jul-08 | | 21-Oct-08 | | 21-Oct-08 | | 4-Feb-09 | | 4-Feb-09 | | 15-Apr-09 | | 15-Apr-09 | | 7-Oct-09 | |
| | | Type: | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **148** | = | **154** | = | **145** | = | **260** | = | **136** | = | **152** | = | **148** | = | **149** | = | **152** | = | **158** | = | **164** | = | **154** | = | **157** | = | **166** | = | **146** | = | **496** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **148** | = | **154** | = | **145** | = | **260** | = | **136** | = | **152** | = | **148** | = | **149** | = | **152** | = | **158** | = | **164** | = | **154** | = | **157** | = | **166** | = | **146** | = | **496** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **21** | = | **37** | = | **51** | = | **53** | = | **36** | = | **39** | = | **43** | = | **20** | = | **20** | = | **37** | = | **36** | = | **50** | = | **50** | = | **51** | = | **51** | = | **43** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **1.00** | = | **1.99** | = | **1.87** | = | **2.13** | = | **2.39** | = | **1.99** | = | **2.17** | = | **0.91** | = | **0.93** | = | **1.98** | = | **1.96** | = | **3.23** | = | **3.22** | = | **3.40** | = | **3.35** | = | **3.79** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,646** | = | **91** | = | **1,864** | = | **2,021** | = | **1,772** | = | **1,922** | = | **27** | = | **1,682** | = | **1,682** | = | **22** | = | **6** | = | **1,830** | = | **1,882** | = | **1,770** | = | **1,834** | = | **2,696** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | ND | ND | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U | **0.06** | = | **0.06** | = | 0.05 | U | 0.05 | U | 0.05 | U |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | **0.02** | = | **0.17** | = | **0.16** | = | **0.15** | = | **0.10** | = | **0.11** | = | **0.13** | = | **0.04** | = | **0.03** | = | **0.12** | = | **0.11** | = | **0.07** | = | **0.07** | = | **0.11** | = | **0.11** | = | **0.07** | = |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | **0.19** | = | **0.18** | = | **0.17** | = | **0.12** | J | **0.12** | = | **0.14** | = | **0.04** | = | 0.04 | U | **0.14** | = | **0.12** | = | **0.08** | = | **0.08** | = | **0.13** | = | **0.13** | = | **0.11** | = |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | **0.03** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.02** | = | 0.02 | U | **0.04** | = |
| Sulfate (as SO4) | 250[b] | mg/L | **1,500** | = | **1,590** | = | **1,560** | = | **1,590** | = | **1,600** | = | **1,580** | = | **1,530** | = | **1,490** | = | **1,470** | = | **1,580** | = | **1,580** | = | **1,660** | = | **1,660** | = | **1,600** | = | **1,590** | = | **1,550** | = |
| Sulfide | NA | mg/L | **0.64** | = | 0.125 | U | 0.01 | U | 0.01 | U | **0.02** | = | 0.01 | U | ND | ND | **0.65** | = | **0.68** | = | 0.125 | U | 0.125 | U | 0.01 | U | 0.01 | U | **0.01** | = | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,460** | = | **2,520** | = | **2,580** | = | **2,540** | = | **2,580** | = | **2,500** | = | **2,660** | = | **2,410** | = | **2,500** | = | **2,320** | = | **2,720** | = | **2,650** | = | **2,680** | = | **2,420** | = | **2,460** | = | **2,330** | = |
| Calcium (Dissolved) | NA | mg/L | **603** | = | **616** | = | **575** | = | **616** | = | **499** | = | **599** | = | **602** | = | **606** | = | **609** | = | **634** | = | **682** | = | **570** | = | **579** | = | **558** | = | **523** | = | **560** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **.065** | = | **.026** | = | **.035** | = | **35.4** | = | .025 | U | .025 | U | **.031** | = | .025 | U | .025 | U | **.037** | = | **.043** | = | **2.71** | = | **2.64** | = | **.447** | = | **.351** | = | **0.407** | = |
| Magnesium (Dissolved) | NA | mg/L | **34.5** | = | **51.3** | = | **49.5** | = | **56.9** | = | **47.2** | = | **54.9** | = | **54.4** | = | **34.2** | = | **34.0** | = | **51.5** | = | **54.6** | = | **53.7** | = | **53.9** | = | **55.2** | = | **48** | = | **54** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **1.01** | = | **1.35** | = | **1.10** | = | **1.13** | = | **0.896** | = | **0.777** | J | **1.88** | = | **1.08** | = | **1.07** | = | **2.15** | = | **2.30** | = | **1.09** | = | **1.09** | = | **0.506** | = | **0.439** | = | **0.882** | = |
| Potassium (Dissolved) | NA | mg/L | **2.48** | = | **3.33** | = | **3.32** | = | **3.45** | = | **2.94** | = | **3.48** | = | **3.73** | = | **2.51** | = | **2.45** | = | **3.91** | = | **4.20** | = | **3.16** | = | **3.21** | = | **2.84** | = | **2.40** | = | **2.62** | = |
| Sodium (Dissolved) | NA | mg/L | **27.2** | = | **54.6** | = | **59.1** | = | **65.3** | = | **42.7** | = | **50.5** | = | **62.5** | = | **26.7** | = | **26.7** | = | **52.0** | = | **55.9** | = | **57.2** | = | **58.6** | = | **58.6** | = | **48.5** | = | **45.3** | = |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data

All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **SMB7** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 16-Jul-08 | | 16-Jul-08 | | 21-Oct-08 | | 4-Feb-09 | | 15-Apr-09 | | 27-Jul-09 | | 6-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **108** | = | **108** | = | **137** | = | **158** | = | **158** | = | **150** | = | **155** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **108** | = | **108** | = | **137** | = | **158** | = | **158** | = | **150** | = | **155** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **41** | = | **41** | = | **45** | = | **64** | = | **54** | = | **45** | = | **46** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **3.00** | = | **2.83** | = | **2.63** | = | **2.58** | = | **2.40** | = | **2.35** | = | **2.26** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,706** | = | **1,662** | = | **1,604** | = | **1,771** | = | **1,678** | = | **1,780** | = | **1,920** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | **0.22** | = | **0.21** | = | **0.13** | = | 0.05 | U | 0.05 | U | 0.05 | U | 0.05 | U |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.02 | U | 0.02 | U | **0.04** | = | **0.14** | = | **0.1** | = | **0.11** | = | **0.08** | = |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | 0.04 | U | 0.04 | U | **0.06** | = | **0.16** | = | **0.11** | = | **0.12** | J | **0.10** | = |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | 0.02 | U | **0.02** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Sulfate (as SO4) | 250[b] | mg/L | **1,610** | = | **1,590** | = | **1,600** | = | **1,680** | = | **1,610** | = | **1,590** | = | **1,570** | = |
| Sulfide | NA | mg/L | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U | 0.01 | U |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,460** | = | **2,520** | = | **2,590** | = | **2,540** | = | **2,330** | = | **2,640** | = | **2,350** | = |
| Calcium (Dissolved) | NA | mg/L | **555** | = | **546** | = | **639** | = | **566** | = | **611** | = | **498** | = | **565** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **33.5** | = | **33.1** | = | **.075** | = | .025 | U | **1.94** | = | .025 | U | 0.025 | U |
| Magnesium (Dissolved) | NA | mg/L | **59.6** | = | **59.2** | = | **60.6** | = | **57.2** | = | **59.8** | = | **49.5** | = | **54.7** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **1.72** | = | **1.70** | = | **1.74** | = | **1.69** | = | **1.57** | = | **1.07** | = | **0.909** | = |
| Potassium (Dissolved) | NA | mg/L | **3.61** | = | **3.60** | = | **3.78** | = | **3.45** | = | **3.46** | = | **2.86** | = | **3.25** | = |
| Sodium (Dissolved) | NA | mg/L | **65.6** | = | **64.9** | = | **71.1** | = | **73.0** | = | **71.4** | = | **52** | = | **46.4** | = |

| | **Well ID:** | **SMB8** | | | | | | | | **SMB9** | | | | **TMB2** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Sample Date:** | 28-Jul-09 | | 28-Jul-09 | | 6-Oct-09 | | 6-Oct-09 | | 28-Jul-09 | | 6-Oct-09 | | 23-Oct-07 | | 23-Oct-07 | | 22-Apr-08 | | 22-Apr-08 | | 27-Oct-08 | |
| | **Type:** | Normal | | FD | | Normal | | FD | | Normal | | Normal | | Normal | | FD | | Normal | | FD | | Normal | |
| **Analyte** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | | | | | | | | |
| Alkalinity | mg/L | **274** | = | **254** | = | **348** | = | **326** | = | **189** | = | **326** | = | **122** | = | **123** | = | **136** | = | **138** | = | **158** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | mg/L | **274** | = | **254** | = | **348** | = | **326** | = | **189** | = | **326** | = | **122** | = | **123** | = | **136** | = | **138** | = | **158** | = |
| Alkalinity, carbonate (as $CaCO_3$) | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | mg/L | **19** | = | **18** | = | **25** | = | **34** | = | **42** | = | **45** | = | **12** | = | **12** | = | 5 | U | 5 | U | **15** | = |
| Fluoride | mg/L | **1.92** | = | **2.07** | = | **2.72** | = | **2.85** | = | **2.15** | = | **2.30** | = | **1.20** | = | **1.28** | = | **0.98** | = | **0.78** | = | **1.68** | = |
| Hardness (as $CaCO_3$) | mg/L | **2,480** | = | **2,311** | = | **2,480** | = | **2,500** | = | **1,992** | = | **2,280** | = | **1,568** | = | **1,616** | = | **1,012** | = | **1,334** | = | **1,730** | = |
| Nitrogen, ammonia (as N) | mg/L | **0.41** | = | **0.4** | = | **0.29** | = | **0.3** | = | 0.05 | U | 0.05 | U | ND | ND | ND | ND | ND | ND | ND | ND | **0.32** | = |
| Nitrogen, Nitrate (as N) | mg/L | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | **0.06** | = | **0.17** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | mg/L | **0.12** | J | **0.20** | J | **0.04** | = | 0.04 | U | 0.04 | U | **0.09** | = | **0.18** | = | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | mg/L | **0.20** | = | **0.19** | = | **0.23** | = | **0.17** | = | 0.02 | U | **0.03** | = | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | ND | ND |
| Sulfate (as SO4) | mg/L | **2,580** | = | **2,600** | = | **2,550** | = | **2,350** | = | **1,590** | = | **1,590** | = | **1,500** | = | **1,490** | = | **1,160** | = | **751** | = | **1,560** | = |
| Sulfide | mg/L | 0.01 | U | 0.01 | U | **0.13** | J | **0.09** | J | 0.01 | U | **0.06** | = | ND | ND | ND | ND | ND | ND | ND | ND | 0.025 | U |
| Total Dissolved Solids (residue, filterable) | mg/L | **4,100** | = | **4,050** | = | **4,110** | = | **3,860** | = | **2,680** | = | **2,360** | = | **2,430** | = | **2,500** | = | **1,920** | = | **1,340** | = | **2,620** | = |
| Calcium (Dissolved) | mg/L | **475** | = | **465** | = | **512** | = | **512** | = | **529** | = | **569** | = | **144** | = | **125** | = | **188** | = | **190** | = | **631** | = |
| Iron (Dissolved) | mg/L | **188** | = | **184** | = | **126** | = | **127** | = | .025 | U | .025 | U | **4.05** | = | **3.76** | = | **17.2** | = | **19.5** | = | **37.3** | = |
| Magnesium (Dissolved) | mg/L | **255** | = | **251** | = | **212** | = | **216** | = | **52.4** | = | **53.1** | = | **30.7** | = | **30.3** | = | **30.8** | = | **33.9** | = | **55.1** | = |
| Manganese (Dissolved) | mg/L | **2.37** | = | **2.30** | = | **1.40** | = | **1.42** | = | **1.13** | = | **0.698** | = | **0.293** | = | **0.254** | = | **0.352** | = | **0.345** | = | **1.4** | = |
| Potassium (Dissolved) | mg/L | **4.37** | = | **4.26** | = | **2.40** | = | **2.41** | = | **3.51** | = | **3.46** | = | **6.44** | = | **6.66** | = | **5.10** | = | **5.89** | = | **6.16** | J |
| Sodium (Dissolved) | mg/L | **80.3** | = | **79.2** | = | **75.2** | = | **76.1** | = | **59.9** | = | **54.9** | = | **32.4** | = | **32.2** | = | **32.9** | = | **37.9** | = | **31.9** | = |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data
All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration
Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-5
General Chemistry Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **TMB3** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 28-Feb-07 | | 24-Oct-07 | | 23-Apr-08 | | 23-Oct-08 | | 16-Apr-09 | | 4-Aug-09 | | 12-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***General Chemistry*** | | | | | | | | | | | | | | | | |
| Alkalinity | NA | mg/L | **156** | = | **128** | = | **132** | = | **133** | = | **194** | = | **126** | = | **138** | = |
| Alkalinity, bicarbonate (as $CaCO_3$) | NA | mg/L | **156** | = | **128** | = | **132** | = | **133** | = | **194** | = | **126** | = | **138** | = |
| Alkalinity, carbonate (as $CaCO_3$) | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Alkalinity, phenolphthalein | NA | mg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Chloride (as Cl) | 250[b] | mg/L | **14** | = | **13** | = | **8** | = | **10** | = | **10** | = | **9** | = | **7** | = |
| Fluoride | 4[a] / 2[b] | mg/L | **1.14** | = | **1.18** | = | **0.98** | = | **1.54** | = | **1.14** | = | **1.26** | = | **1.02** | = |
| Hardness (as $CaCO_3$) | NA | mg/L | **1,614** | = | **1,702** | = | **1,378** | = | **1,651** | = | **1,697** | = | **1,292** | = | **2,144** | = |
| Nitrogen, ammonia (as N) | NA | mg/L | ND | ND | ND | ND | ND | ND | **0.27** | = | **0.73** | = | **0.23** | = | **0.25** | = |
| Nitrogen, Nitrate (as N) | 10[a] | mg/L | 0.04 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U | 0.02 | U |
| Nitrogen, Nitrate-Nitrite | NA | mg/L | ND | ND | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U | 0.04 | U |
| Nitrogen, Nitrite (as N) | 1[a] | mg/L | ND | ND | 0.02 | U | **0.02** | = | ND | ND | **0.03** | = | **0.02** | = | **0.03** | = |
| Sulfate (as SO4) | 250[b] | mg/L | **1,570** | = | **1,480** | = | **1,390** | = | **1,510** | = | **1,570** | = | **1,590** | = | **1,510** | = |
| Sulfide | NA | mg/L | ND | ND | ND | ND | ND | ND | 0.01 | U | **0.14** | = | 0.01 | U | **0.01** | = |
| Total Dissolved Solids (residue, filterable) | 500[b] | mg/L | **2,470** | = | **2,490** | = | **2,320** | = | **2,460** | = | **2,370** | = | **2,300** | = | **2,260** | = |
| Calcium (Dissolved) | NA | mg/L | **545** | = | **569** | = | **606** | = | **640** | = | **621** | = | **599** | = | **557** | = |
| Iron (Dissolved) | 0.3[b] | mg/L | **6.94** | = | **18.9** | = | **21.3** | = | **33.8** | = | **32.1** | = | **29.8** | = | **16.6** | = |
| Magnesium (Dissolved) | NA | mg/L | **45.9** | = | **45.2** | = | **43.6** | = | **48.3** | = | **51.3** | = | **43.8** | = | **31.2** | = |
| Manganese (Dissolved) | 0.05[b] | mg/L | **0.916** | = | **1.11** | = | **1.13** | = | **1.41** | = | **1.73** | = | **1.29** | = | **1.12** | = |
| Potassium (Dissolved) | NA | mg/L | **4.27** | = | **4.82** | = | **5.02** | = | **5.87** | = | **5.50** | = | **5.80** | = | **3.58** | = |
| Sodium (Dissolved) | NA | mg/L | **26.1** | = | **24.3** | = | **23.2** | = | **26.6** | = | **26.3** | = | **24.7** | = | **15.4** | = |

**Notes:**
[a]MCL
[b]SMCL
$CaCO_3$ - Calcium Carbonate
Cl - Chloride
N - Nitrogen
SO4 - Sulfate
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
FD - field duplicate
NA - not applicable
ND - no data

All results in milligrams per liter (mg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

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TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| **Cardin #1** | | | | | | | | | | |
| 4/21/2008 | Totals | 132 | 13.7 | 78.2 | 242 | 205 | 46.6 | 21.3 | 11.7 | 2.6 |
| | Dissolved | - | - | - | - | - | 47.4 | 21.8 | 11.5 | 2.5 |
| 10/23/2007 | Totals | 132 | 11 | 56.5 | 216 | 189 | 40.7 | 18.6 | 10 | 2.3 |
| | Dissolved | - | - | - | - | - | 40.8 | 19 | 10 | 2.3 |
| 5/8/2007 | Totals | 123 | <10 | 28.2 | 167 | 157 | 38.7 | 18.4 | 11.1 | 2.7 |
| | Dissolved | - | - | - | - | - | 32.2 | 15.6 | 9.1 | 2.3 |
| 11/8/2006 | Totals | 147 | 28 | *156* | 375 | 293 | 64 | 29 | 15 | 3 |
| | Dissolved | - | - | - | - | - | 60 | 28 | 15 | 3 |
| 4/11/2006 | Totals | 137 | 13.5 | 78.8 | 238 | 201 | 43 | 20 | 11 | 3 |
| | Dissolved | - | - | - | - | - | 43 | 20 | 11 | 3 |
| 10/17/2005 | Totals | 144 | 20.8 | *107* | 308 | 262 | 60 | 27 | 13 | 3 |
| | Dissolved | - | - | - | - | - | 69 | 29 | 13 | 3 |
| 4/25/2005 | Totals | 144 | 21 | *111* | 347 | 260 | 59 | 27 | 14 | 3 |
| | Dissolved | - | - | - | - | - | 58 | 26 | 13 | 3 |
| 10/12/2004 | Totals | 140 | 20.4 | *107* | 333 | 250 | 59 | 27 | 14 | 3 |
| | Dissolved | - | - | - | - | - | 56 | 26 | 13 | 3 |
| 4/27/2004 | Totals | 138 | 14.5 | *93.3* | 319 | 231 | 50 | 24 | 12 | 3 |
| | Dissolved | - | - | - | - | - | 50 | 24 | 12 | 3 |
| 11/6/2003 | Totals | 149 | 27.1 | *134* | 388 | 281 | 61 | 30 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 61 | 30 | 17 | 3 |
| | Averages | 139 | 18 | *95* | 293 | 233 | 52 | 24 | 13 | 2.8 |
| **Commerce #3 - (Plugged - 2004)** | | | | | | | | | | |
| 11/6/1997 | Totals | 154 | 47.8 | 126.3 | 480 | 118 | 71 | 26 | 31 | 3 |
| | Dissolved | - | - | - | - | - | 72 | 26 | 32 | 4 |
| 7/23/1997 | Totals | 157 | 62 | 153.1 | 466 | 232 | 73 | 27 | 32 | < 2 |
| | Dissolved | - | - | - | - | - | 73 | 27 | 32 | < 2 |
| *4/17/1997 | Totals | 175 | 63.4 | 182.9 | 490 | 308 | 76 | 28 | 34 | 3 |
| | Dissolved | - | - | - | - | - | 80 | 30 | 37 | 3 |
| 4/17/1997 | Totals | 177 | 59.4 | 182.3 | 486 | 298 | 81 | 30 | 36 | 3 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 80 | 30 | 37 | 3 |
| 1/10/1997 | Totals | 146 | 62.43 | 139.5 | **510** | 336 | 84 | 32 | 41 | 5 |
| | Dissolved | - | - | - | - | - | 83 | 32 | 40 | 5 |
| 12/11/1996 | Totals | 165.17 | 75.62 | 221.8 | **665** | 400 | 109 | 39 | 47 | 6 |
| | Dissolved | - | - | - | - | - | 109 | 38 | 48 | 6 |
| 10/14/1996 | Totals | 147.46 | 115.56 | 90.7 | **527** | 328.35 | 75 | 29 | 65 | 6 |
| | Dissolved | - | - | - | - | - | 75 | 29 | 66 | 6 |
| | Averages | 160.23 | 69.46 | 156.7 | **518** | 289 | 82 | 30 | 41 | 4 |
| **Commerce #4** | | | | | | | | | | |
| 4/22/2008 | Totals | 152 | 78.5 | *113* | 432 | 256 | 61.3 | 25.8 | 46.1 | 3.2 |
| | Dissolved | - | - | - | - | - | 58.1 | 24.7 | 43.1 | 3 |
| 10/23/2007 | Totals | 134 | <10 | 61.9 | 219 | 186 | 42.9 | 19.1 | 18 | 2.6 |
| | Dissolved | - | - | - | - | - | 47.1 | 21.2 | 36.5 | 2.7 |
| 5/8/2007 | Totals | 148 | 75.3 | *125* | 432 | 291 | 71.9 | 30.9 | 43.1 | 3.4 |
| | Dissolved | - | - | - | - | - | 68.8 | 29.5 | 41.5 | 3.3 |
| 11/8/2006 | Totals | 159 | 48.7 | *161* | 448 | 307 | 74 | 28 | 31 | 4 |
| | Dissolved | - | - | - | - | - | 66 | 28 | 30 | 4 |
| 4/11/2006 | Totals | 161 | 56.5 | *166* | 437 | 311 | 70 | 29 | 36 | 4 |
| | Dissolved | - | - | - | - | - | 72 | 30 | 37 | 4 |
| 10/18/2005 | Totals | 135 | <10 | 66 | 250 | 189 | 44 | 19 | 9 | 3 |
| | Dissolved | - | - | - | - | - | 45 | 20 | 9 | 3 |
| 4/26/2005 | Totals | 135 | 60.5 | 76 | 342 | 214 | 49 | 22 | 34 | 3 |
| | Dissolved | - | - | - | - | - | 48 | 21 | 34 | 3 |
| 10/12/2004 | Totals | 148 | 43.5 | *126* | 403 | 270 | 65 | 27 | 29 | 3 |
| | Dissolved | - | - | - | - | - | 63 | 26 | 29 | 3 |
| 4/27/2004 | Totals | 144 | 59.5 | *107* | 409 | 252 | 54 | 24 | 35 | 3 |
| | Dissolved | - | - | - | - | - | 56 | 25 | 35 | 3 |
| 11/6/2003 | Totals | 150 | 37.9 | *119* | 383 | 260 | 61 | 26 | 28 | 3 |
| | Dissolved | - | - | - | - | - | 57 | 25 | 27 | 3 |
| | Averages | 147 | 48 | *112.1* | 376 | 254 | 59 | 25 | 32 | 3.2 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| **Commerce #5** | | | | | | | | | | |
| 4/22/2008 | Totals | 118 | 10.5 | 13.7 | 157 | 127 | 27.1 | 13 | 8.2 | 1.8 |
| | Dissolved | - | - | - | - | - | 27.3 | 13 | 8.1 | 1.8 |
| 10/23/2007 | Totals | 115 | 11.4 | 14.2 | 149 | 129 | 27.9 | 13.4 | 8.3 | 1.9 |
| | Dissolved | - | - | - | - | - | 25 | 12.3 | 7.6 | 1.7 |
| 5/8/2007 | Totals | 111 | 20 | 12.1 | 155 | 135 | 27.8 | 13.8 | 11.8 | 2 |
| | Dissolved | - | - | - | - | - | 27.4 | 13.8 | 12 | 2.1 |
| 11/8/2006 | Totals | 111 | 18 | 17.4 | 157 | 129 | 28 | 13 | 11 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 13 | 10 | 2 |
| 4/11/2006 | Totals | 115 | 15.3 | 14.6 | 138 | 124 | 26 | 13 | 10 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 13 | 10 | 2 |
| 10/18/2005 | Totals | 114 | 10.3 | 13.7 | 173 | 130 | 29 | 14 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 31 | 14 | 8 | 2 |
| 4/26/2005 | Totals | 115 | <10 | 13.9 | 150 | 121 | 28 | 13 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 13 | 8 | 2 |
| 10/12/2004 | Totals | 111 | <10 | 13 | 154 | 124 | 28 | 13 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 13 | 8 | 2 |
| 4/27/2004 | Totals | 111 | <10 | 11.8 | 158 | 122 | 25 | 13 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 25 | 13 | 8 | 2 |
| *4/27/2004 | Totals | 111 | <10 | 11.8 | 158 | 123 | 25 | 13 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 13 | 8 | 2 |
| 11/6/2003 | Totals | 112 | 15.6 | 12 | 155 | 127 | 26 | 13 | 11 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 13 | 11 | 2 |
| | Averages | 113 | 12.8 | 13.5 | 155 | 126 | 27 | 13 | 9 | 2 |
| 4/18/2002 | Totals | 109 | 15 | 11.6 | 149 | 128 | 28 | 14 | 11 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 14 | 10 | 2 |
| 12/13/2001 | Totals | 119 | 9.2 | 40.9 | 123 | 126 | 27 | 13 | 10 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 13 | 10 | 2 |
| 3/9/2001 | Totals | 118 | 13 | 12.4 | 165 | 125 | 28 | 14 | 10 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 14 | 10 | 2 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| 10/13/2000 | Totals | 112 | 15.7 | 10.3 | 174 | 129 | 28 | 14 | 12 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 14 | 11 | 2 |
| 10/13/2000 | Totals | 113 | 16.1 | 11 | 179 | 129 | - | - | 11 | - |
| | Dissolved | - | - | - | - | - | - | - | - | - |
| | Averages | 114.2 | 13.8 | 17.2 | 158 | 127 | 28 | 14 | 11 | 2 |
| **Ontario (Fernandez) Well** | | | | | | | | | | |
| 4/21/2008 | Totals | 135 | <10 | 62.2 | 207 | 185 | 41 | 20 | 6 | 1.9 |
| | Dissolved | - | - | - | - | - | 39 | 19 | 6 | 1.8 |
| 10/23/2007 | Totals | 181 | <10 | *111* | 324 | 273 | 112 | 52 | 16 | 4.2 |
| | Dissolved | - | - | - | - | - | 60 | 29 | 12 | 3.2 |
| 5/7/2007 | Totals | 216 | <10 | **285** | **679** | 522 | 113 | 54 | 15 | 3.9 |
| | Dissolved | - | - | - | - | - | 106 | 51 | 14 | 3.7 |
| 11/8/2006 | Totals | 126 | <10 | 57.2 | 206 | 184 | 41 | 18 | 6 | 2 |
| | Dissolved | - | - | - | - | - | 36 | 18 | 6 | 2 |
| 4/10/2006 | Totals | 155 | <10 | *130* | 306 | 262 | 25 | 13 | 5 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 14 | 5 | 2 |
| 10/17/2005 | Totals | 151 | <10 | *125* | 348 | 274 | 61 | 29 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 68 | 30 | 8 | 2 |
| 4/25/2005 | Totals | 136 | <10 | 72.5 | 241 | 199 | 44 | 21 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 43 | 21 | 7 | 2 |
| 1/28/2005 | Totals | 211 | <10 | **282** | **648** | 477 | - | - | 49 | 13 |
| 10/11/2004 | Totals | 138 | <10 | *92.4* | 284 | 219 | 57 | 27 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 56 | 26 | 8 | 2 |
| *10/11/2004 | Totals | 148 | <10 | *115* | 327 | 248 | 57 | 27 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 54 | 25 | 7 | 2 |
| 4/29/2004 | Totals | 128 | <10 | 56.3 | 233 | 185 | 43 | 22 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 15 | 6 | 2 |
| *4/29/2004 | Totals | 144 | <10 | *103* | 328 | 236 | 39 | 20 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 15 | 6 | 2 |
| 12/19/2003 | Totals | 147 | <10 | *85.5* | 274 | 213 | 46 | 23 | 8 | 2 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 46 | 24 | 8 | 2 |
| 11/4/2003 | Totals | 114 | <10 | 16.4 | 138 | 126 | 27 | 14 | 5 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 14 | 5 | 2 |
| 10/6/2003 | Totals | 98.9 | <10 | 14 | 148 | 124 | 26 | 14 | 5 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 14 | 5 | 2 |
| *10/6/2003 | Totals | 98.6 | <10 | 16.4 | 132 | 126 | 26 | 14 | 5 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 14 | 5 | 2 |
| 7/30/2003 | Dis Met | 145 | 11.1 | *126* | 368 | na | 60 | 29 | 8 | 2 |
| | Averages | 145.4 | 10.1 | *102.9* | 305 | 241 | 48 | 23 | 9 | 2.6 |
| **Miami #1** | | | | | | | | | | |
| 4/27/2004 | Totals | 112 | 78.8 | 12.6 | 265 | 133 | 29 | 14 | 47 | 3 |
| | Dissolved | - | - | - | - | - | 28 | 14 | 45 | 2 |
| 11/4/2003 | Totals | 117 | 83.6 | 12.4 | 262 | 133 | 30 | 15 | 50 | 3 |
| | Dissolved | - | - | - | - | - | 30 | 15 | 50 | 3 |
| *11/4/2003 | Totals | 116 | 84.5 | 12.5 | 264 | 135 | 29 | 14 | 49 | 3 |
| | Dissolved | - | - | - | - | - | 30 | 15 | 50 | 3 |
| | Averages | 115 | 82.3 | 12.5 | 264 | 134 | 29 | 15 | 49 | 3 |
| **Miami #3** | | | | | | | | | | |
| 4/22/2008 | Totals | 121 | 96.9 | 13.7 | 286 | 137 | 29.5 | 13.8 | 58.1 | 2.8 |
| | Dissolved | - | - | - | - | - | 29.1 | 13.7 | 56.3 | 2.8 |
| 10/23/2007 | Totals | 118 | 90.4 | 14.1 | 274 | 138 | 29.9 | 14 | 52.6 | 2.7 |
| | Dissolved | - | - | - | - | - | 27.9 | 13.4 | 50.6 | 2.7 |
| 5/8/2007 | Totals | 116 | 87.5 | 11.5 | 266 | 144 | 28.7 | 13.8 | 53.7 | 2.9 |
| | Dissolved | - | - | - | - | - | 28.6 | 13.9 | 52.1 | 2.8 |
| 11/8/2006 | Totals | 115 | 95.6 | 16.8 | 275 | 129 | 27 | 14 | 54 | 3 |
| | Dissolved | - | - | - | - | - | 27 | 13 | 52 | 3 |
| 4/11/2006 | Totals | 138 | 94.3 | 15.3 | 256 | 131 | 28 | 14 | 57 | 3 |
| | Dissolved | - | - | - | - | - | 29 | 14 | 57 | 3 |
| 10/18/2005 | Totals | 118 | 92.8 | 12.9 | 263 | 138 | 31 | 14 | 54 | 3 |
| | Dissolved | - | - | - | - | - | 31 | 14 | 55 | 3 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| *10/18/2005 | Totals | 118 | 91.6 | 13.7 | 258 | 138 | 32 | 14 | 54 | 3 |
| | Dissolved | - | - | - | - | - | 34 | 15 | 54 | 3 |
| 4/26/2005 | Totals | 116 | 96.8 | 14 | 282 | 131 | 30 | 14 | 56 | 3 |
| | Dissolved | - | - | - | - | - | 29 | 14 | 57 | 3 |
| *4/26/2005 | Totals | 117 | 97.4 | 15.4 | 283 | 130 | 29 | 14 | 56 | 3 |
| | Dissolved | - | - | - | - | - | 29 | 14 | 56 | 3 |
| 10/12/2004 | Totals | 114 | 97.2 | 13.4 | 293 | 134 | 30 | 14 | 57 | 3 |
| | Dissolved | - | - | - | - | - | 32 | 15 | 56 | 3 |
| *10/12/2004 | Totals | 114 | 95.7 | 13.6 | 291 | 132 | 28 | 13 | 54 | 3 |
| | Dissolved | - | - | - | - | - | 30 | 14 | 56 | 3 |
| | Averages | 119 | 94.2 | 14 | 275 | 135 | 29.5 | 14 | 55 | 2.9 |
| **Miami #11** | | | | | | | | | | |
| 5/8/2007 | Totals | 108 | 33.2 | 11.8 | 168 | 128 | 24.9 | 13 | 24.2 | 1.6 |
| | Dissolved | - | - | - | - | - | 24.7 | 12.9 | 23.5 | 1.6 |
| *5/8/2007 | Totals | 109 | 34.4 | 11.4 | 171 | 127 | 25.2 | 13 | 24.3 | 1.6 |
| | Dissolved | - | - | - | - | - | 25.1 | 13 | 23.2 | 1.6 |
| 11/8/2006 | Totals | 108 | 35.9 | 15.6 | 178 | 117 | 22 | 12 | 22 | 2 |
| | Dissolved | - | - | - | - | - | 22 | 12 | 22 | 2 |
| *11/8/2006 | Totals | 109 | 35.1 | 15.5 | 183 | 115 | 23 | 12 | 23 | 2 |
| | Dissolved | - | - | - | - | - | 23 | 12 | 23 | 2 |
| | Averages | 109 | 34.7 | 13.6 | 175 | 122 | 24 | 12 | 23 | 2 |
| **Picher #2 - (Plugged - 2004)** | | | | | | | | | | |
| 8/12/1999 | Totals | 191 | 8.5 | 182 | 100 | 322 | 79 | 33 | 17 | 2 |
| | Dissolved | - | - | - | - | - | 78 | 33 | 18 | 2 |
| 11/6/1997 | Totals | 128 | 12.6 | 44.3 | 252 | 177 | 40 | 17 | 11 | 2 |
| | Dissolved | - | - | - | - | - | 39 | 17 | 11 | 2 |
| 7/15/1997 | Totals | 125 | 23.2 | 121 | 300 | 240 | 53 | 22 | 13 | < 2 |
| | Dissolved | - | - | - | - | - | 53 | 22 | 12 | < 2 |
| 4/9/1997 | Totals | 145 | 25 | 200.4 | 490 | 188 | 88 | 35 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 86 | 35 | 17 | 3 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| 10/25/1996 | Totals | 127.76 | 19.91 | 121 | 366 | 278.6 | 62 | 27 | 14 | 4 |
| | Dissolved | - | - | - | - | - | 63 | 27 | 13 | 3 |
| 10/1/1996 | Totals | 145 | 13.93 | 151 | 369 | 266.66 | 61 | 27 | 14 | 4 |
| | Dissolved | - | - | - | - | - | 59 | 26 | 14 | 4 |
| | Averages | 143.35 | 17.84 | 133.7 | 302 | 241 | 64 | 27 | 14 | 3 |
| **Picher #3 - (Plugged - 2004)** | | | | | | | | | | |
| 11/6/1997 | Totals | 156 | 15.8 | 139 | 493 | 382 | 83 | 32 | 16 | 3 |
| | Dissolved | - | - | - | - | - | 82 | 31 | 16 | 2 |
| 7/15/1997 | Totals | 173 | 25.1 | **291.8** | **630** | 242 | 117 | 42 | 19 | <2 |
| | Dissolved | - | - | - | - | - | 114 | 41 | 19 | <2 |
| 6/6/1997 | Totals | 193 | 18 | 245.5 | **739** | 482 | 133 | 49 | 21 | 4 |
| | Dissolved | - | - | - | - | - | 131 | 48 | 21 | 4 |
| 9/23/1996 | Totals | 174.44 | 19.9 | 245.5 | **646** | 457.7 | 115 | 46 | 21 | 5 |
| | Dissolved | - | - | - | - | - | 110 | 44 | 20 | 5 |
| | Averages | 174 | 19.63 | 225.4 | **621** | 369 | 110 | 41 | 19 | 3 |
| **Picher #4 - (Plugged - 2004)** | | | | | | | | | | |
| 12/11/1997 | Totals | 145 | 33.2 | 181.6 | **508** | 339 | 85 | 35 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 81 | 34 | 17 | 2 |
| 9/16/1997 | Totals | 158 | 24.5 | 211.6 | 211 | 367 | 81 | 32 | 15 | 3 |
| | Dissolved | - | - | - | - | - | 81 | 32 | 15 | 3 |
| 8/28/1997 | Totals | 181 | 30.9 | 248.4 | **510** | 394 | 95 | 36 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 96 | 36 | 18 | 3 |
| 4/9/1997 | Totals | 147 | 32 | 223 | **543** | 222 | 98 | 38 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 99 | 38 | 17 | 3 |
| 10/8/1996 | Totals | 152.25 | 27.89 | 197.6 | **545** | 358.2 | 90 | 35 | 15 | 4 |
| | Dissolved | - | - | - | - | - | 90 | 35 | 15 | 4 |
| 9/16/1996 | Totals | 223 | 24.83 | **410** | **920.88** | 660 | 163 | 53 | 27 | 6 |
| | Dissolved | - | - | - | - | - | 171 | 53 | 25 | 5 |
| | Averages | 156.65 | 29.7 | 212.4 | 463 | 336 | 90 | 35 | 17 | 3 |
| **Picher #5** | | | | | | | | | | |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| 4/22/2008 | Totals | 142 | 26 | *135* | 383 | 264 | 59.5 | 27.5 | 17 | 2.8 |
| | Dissolved | - | - | - | - | - | 59.6 | 27.8 | 16.8 | 2.8 |
| 10/23/2007 | Totals | 136 | 30 | *119* | 332 | 265 | 57.4 | 26.5 | 17.9 | 2.9 |
| | Dissolved | - | - | - | - | - | 58.2 | 27.3 | 17.5 | 2.9 |
| *10/23/2007 | Totals | 136 | 28.9 | *122* | 356 | 268 | 57.9 | 26.8 | 17.6 | 2.9 |
| | Dissolved | - | - | - | - | - | 53.2 | 25 | 16.4 | 2.6 |
| 5/8/2007 | Totals | 121 | 38.9 | 57.2 | 256 | 194 | 40.9 | 20.1 | 25.8 | 2.8 |
| | Dissolved | - | - | - | - | - | 37.4 | 18.7 | 23.5 | 2.9 |
| 11/8/2006 | Totals | 137 | 27.4 | *141* | 373 | 282 | 64 | 28 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 58 | 27 | 17 | 3 |
| 4/11/2006 | Totals | 127 | 34.4 | 68.3 | 243 | 189 | 39 | 19 | 21 | 3 |
| | Dissolved | - | - | - | - | - | 41 | 20 | 21 | 3 |
| *4/11/2006 | Totals | 126 | 34.4 | 69.8 | 245 | 189 | 40 | 20 | 21 | 3 |
| | Dissolved | - | - | - | - | - | 42 | 20 | 21 | 3 |
| 10/17/2005 | Totals | 135 | 27.1 | *119* | 332 | 264 | 60 | 27 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 71 | 30 | 18 | 3 |
| *10/17/2005 | Totals | 135 | 28.3 | *118* | 307 | 265 | 61 | 27 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 73 | 30 | 18 | 3 |
| 4/25/2005 | Totals | 138 | 25.4 | *132* | 373 | 273 | 61 | 28 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 62 | 28 | 17 | 3 |
| 10/12/2004 | Totals | 136 | 26.4 | *140* | 398 | 279 | 63 | 29 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 62 | 28 | 17 | 3 |
| 4/27/2004 | Totals | 134 | 28.3 | *126* | 384 | 253 | 55 | 26 | 19 | 3 |
| | Dissolved | - | - | - | - | - | 55 | 27 | 18 | 3 |
| 11/5/2003 | Totals | 140 | 25.6 | *135* | 381 | 278 | 61 | 29 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 59 | 28 | 18 | 3 |
| | Averages | 134 | 29.3 | *114* | 336 | 251 | 56 | 26 | 19 | 3 |
| 4/18/2002 | Totals | 136 | 25 | *121* | 377 | 271 | 62 | 29 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 62 | 29 | 17 | 3 |
| 12/13/2001 | Totals | 134 | 35.6 | 94.8 | 429 | 216 | 49 | 24 | 23 | 3 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 49 | 24 | 23 | 3 |
| 3/9/2001 | Totals | 151 | 24.3 | *119* | 375 | 266 | 58 | 28 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 57 | 28 | 17 | 3 |
| 10/11/2000 | Totals | 134 | 24.3 | 101 | 366 | 280 | 55 | 27 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 56 | 27 | 17 | 3 |
| 2/25/2000 | Totals | 153 | 30 | 129 | 379 | 284 | 60 | 28 | 19 | 2 |
| | Dissolved | - | - | - | - | - | 59 | 28 | 18 | 3 |
| 8/12/1999 | Totals | 178 | 23.9 | *118* | 106 | 268 | 62 | 28 | 19 | 2 |
| | Dissolved | - | - | - | - | - | - | - | - | - |
| 7/22/1999* | Totals | 129 | 23.1 | *119* | 371 | 262 | 64 | 29 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 63 | 29 | 19 | 3 |
| 7/22/1999 | Totals | 135 | 24.5 | *120* | 370 | 262 | 64 | 29 | 22 | 3 |
| | Dissolved | - | - | - | - | - | 64 | 29 | 21 | 3 |
| 3/25/1999 | Totals | 125 | 30.4 | *107* | 342 | 292 | 55 | 26 | 19 | 2.7 |
| | Dissolved | - | - | - | - | - | 55 | 25 | 18 | 2.7 |
| 12/15/1998* | Totals | 123 | 34.9 | *33.8* | 245 | 182.2 | 40 | 19 | 20 | 2.7 |
| | Dissolved | - | - | - | - | - | 40 | 18 | 19 | 1.2 |
| 12/15/1998 | Totals | 117 | 36.5 | *34* | 273 | 191.7 | 40 | 19 | 19 | 1.3 |
| | Dissolved | - | - | - | - | - | 40 | 19 | 19 | 2 |
| 8/25/1998 | Totals | 108 | 37.1 | 60 | 345 | 236 | 55 | 25 | 19 | 3 |
| | Dissolved | - | - | - | - | - | 55 | 25 | 19 | 3 |
| 7/31/1998 | Totals | 185 | 31.7 | *38* | 352 | 260 | 57 | 27 | 19 | 3 |
| | Dissolved | - | - | - | - | - | 57 | 27 | 17 | 3 |
| 3/20/1998 | Totals | 109 | 59.7 | 29.9 | 42 | 180 | 39 | 18 | 19 | 3 |
| | Dissolved | - | - | - | - | - | 38 | 17 | 18 | 3 |
| 12/4/1997* | Totals | 128 | 34.7 | 13.1 | 269 | 214 | 49 | 21 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 48 | 22 | 18 | 3 |
| 12/4/1997 | Totals | 124 | 34.5 | *41.1* | 271 | 220 | 49 | 21 | 18 | 3 |
| | Dissolved | - | - | - | - | - | 48 | 21 | 17 | 3 |
| 9/16/1997 | Totals | 130 | 31.7 | *105.3* | 371 | 283 | 57 | 26 | 17 | 3 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 55 | 25 | 16 | 3 |
| 8/15/1997 | Totals | 131 | 44 | *117* | 375 | 248 | 60 | 27 | 17 | 3 |
| | Dissolved | - | - | - | - | - | 59 | 26 | 17 | 3 |
| 7/30/1997 | Totals | 137 | 52 | *82* | 310 | 248 | - | - | 17 | - |
| | Dissolved | - | - | - | - | - | - | - | - | - |
| | Averages | 135.11 | 33.57 | *83.3* | 314 | 245 | 54 | 25 | 18 | 3 |
| **Picher #6** | | | | | | | | | | |
| 4/21/2008 | Totals | 151 | <10 | *186* | 405 | 312 | 69 | 32.6 | 14.4 | 2.4 |
| | Dissolved | - | - | - | - | - | 68.6 | 32.9 | 14 | 2.4 |
| *4/21/2008 | Totals | 151 | <10 | *184* | 397 | 313 | 70.9 | 33.5 | 14.8 | 2.4 |
| | Dissolved | - | - | - | - | - | 70.3 | 33.4 | 14.3 | 2.4 |
| 10/22/2007 | Totals | 147 | 10.2 | *171* | 387 | 312 | 68.9 | 31.9 | 13.5 | 2.3 |
| | Dissolved | - | - | - | - | - | 66.7 | 31.8 | 13.5 | 2.3 |
| *10/22/2007 | Totals | 147 | 10.2 | *170* | 406 | 310 | 68.4 | 31.9 | 13.4 | 2.3 |
| | Dissolved | - | - | - | - | - | 66.5 | 31.5 | 13.4 | 2.3 |
| 5/7/2007 | Totals | 139 | <10 | *177* | 375 | 286 | 63.6 | 30.8 | 13.7 | 2.4 |
| | Dissolved | - | - | - | - | - | 63.7 | 30.8 | 14 | 2.4 |
| *5/7/2007 | Totals | 139 | <10 | *175* | 381 | 290 | 64 | 30.9 | 13.6 | 2.3 |
| | Dissolved | - | - | - | - | - | 63.4 | 30.4 | 13.8 | 2.3 |
| 11/7/2006 | Totals | 136 | <10 | *144* | 339 | 273 | 56 | 27 | 12 | 2 |
| | Dissolved | - | - | - | - | - | 55 | 27 | 12 | 2 |
| 4/10/2006 | Totals | 139 | 10 | *142* | 315 | 258 | 56 | 26 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 59 | 27 | 13 | 2 |
| *4/10/2006 | Totals | 138 | 10 | *143* | 316 | 258 | 54 | 25 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 57 | 26 | 13 | 2 |
| 10/27/2005 | Totals | 136 | 10 | *125* | 313 | 249 | 58 | 26 | 12 | 2 |
| | Dissolved | - | - | - | - | - | 59 | 26 | 12 | 2 |
| *10/27/2005 | Totals | 137 | 10 | *125* | 307 | 251 | 63 | 27 | 12 | 2 |
| | Dissolved | - | - | - | - | - | 59 | 26 | 12 | 2 |
| 4/25/2005 | Totals | 135 | <10 | *125* | 333 | 251 | 60 | 26 | 12 | 2 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 58 | 26 | 12 | 2 |
| *4/25/2005 | Totals | 134 | <10 | *126* | 336 | 251 | 61 | 26 | 12 | 2 |
| | Dissolved | - | - | - | - | - | 56 | 25 | 12 | 2 |
| 10/11/2004 | Totals | 147 | <10 | *170* | 417 | 303 | 71 | 30 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 71 | 30 | 13 | 2 |
| 4/27/2004 | Totals | 143 | <10 | *156* | 407 | 293 | 63 | 29 | 14 | 2 |
| | Dissolved | - | - | - | - | - | 62 | 29 | 13 | 2 |
| 12/9/2003 | Totals | 143 | <10 | *150* | 380 | 280 | 65 | 29 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 60 | 27 | 12 | 2 |
| *12/9/2003 | Totals | 142 | <10 | *150* | 381 | 277 | 64 | 29 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 61 | 27 | 12 | 2 |
| | Averages | 141 | 10 | *154.1* | 364 | 280 | 63 | 29 | 13 | 2 |
| 4/18/2002 | Totals | 142 | 7.1 | *86* | 364 | 280 | 63 | 27 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 65 | 27 | 12 | 2 |
| 12/13/2001 | Totals | 149 | 6.7 | *152* | 370 | 276 | 65 | 27 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 65 | 27 | 13 | 2 |
| 2/26/2001 | Totals | 191 | 8.8 | ***358*** | **623** | 483 | 111 | 42 | 16 | 3 |
| | Dissolved | - | - | - | - | - | 111 | 42 | 16 | 3 |
| 10/17/2000 | Totals | 207 | 6.7 | ***307*** | **836** | 874 | 153 | 57 | 17 | 3 |
| | Dissolved | - | - | NA | NA | NA | 152 | 57 | 17 | 3 |
| 10/12/2000 | Totals | 220 | 6.8 | ***294*** | **842** | 973 | - | - | 19 | - |
| | Dissolved | - | - | - | - | - | - | - | - | - |
| | Averages | 181.8 | 7.22 | *239.4* | **607** | 577 | 98 | 38 | 15 | 3 |
| **Picher #7** | | | | | | | | | | |
| 4/21/2008 | Totals | 165 | 11 | *240* | 490 | 393 | 85.3 | 41.9 | 12.5 | 3.1 |
| | Dissolved | - | - | - | - | - | 81 | 40.4 | 11.6 | 2.9 |
| 10/22/2007 | Totals | 155 | 12 | *194* | 447 | 347 | 73.4 | 35.8 | 11.7 | 2.8 |
| | Dissolved | - | - | - | - | - | 68.5 | 34.4 | 11.3 | 2.8 |
| 5/8/2007 | Totals | 146 | 11.8 | *198* | 405 | 307 | 67.5 | 34.3 | 12.2 | 2.9 |
| | Dissolved | - | - | - | - | - | 66.9 | 34.5 | 11.9 | 2.8 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| 11/7/2006 | Totals | 146 | 12.3 | *175* | 397 | 329 | 65 | 33 | 12 | 3 |
| | Dissolved | - | - | - | - | - | 60 | 31 | 11 | 3 |
| 4/11/2006 | Totals | 129 | 17.5 | *103* | 257 | 216 | 44 | 23 | 13 | 3 |
| | Dissolved | - | - | - | - | - | 47 | 23 | 13 | 3 |
| 10/17/2005 | Totals | 142 | 11.4 | *137* | 326 | 280 | 62 | 30 | 11 | 3 |
| | Dissolved | - | - | - | - | - | 72 | 32 | 11 | 3 |
| 4/25/2005 | Totals | 140 | 10.1 | *125* | 341 | 261 | 59 | 28 | 11 | 3 |
| | Dissolved | - | - | - | - | - | 56 | 28 | 11 | 3 |
| 10/12/2004 | Totals | 136 | 13.5 | *112* | 306 | 244 | 54 | 26 | 12 | 3 |
| | Dissolved | - | - | - | - | - | 55 | 27 | 12 | 3 |
| 4/27/2004 | Totals | 134 | 12.6 | *112* | 335 | 237 | 51 | 26 | 12 | 3 |
| | Dissolved | - | - | - | - | - | 49 | 26 | 12 | 3 |
| 11/5/2003 | Totals | 145 | <10 | *141* | 374 | 284 | 60 | 31 | 12 | 3 |
| | Dissolved | - | - | - | - | - | 59 | 31 | 12 | 3 |
| | Averages | 144 | 12.2 | *153.7* | 368 | 290 | 62 | 31 | 12 | 3 |
| 4/19/2002* | Totals | 132 | 14.2 | 91 | 338 | 255 | 54 | 28 | 13 | 3 |
| | Dissolved | - | - | - | - | - | 55 | 28 | 13 | 3 |
| 4/19/2002 | Totals | 132 | 14.1 | 112 | 332 | 255 | 54 | 27 | 13 | 3 |
| | Dissolved | - | - | - | - | - | 53 | 27 | 13 | 2 |
| 12/13/2001* | Totals | 131 | 15.8 | 93.7 | 253 | 203 | 47 | 23 | 14 | 3 |
| | Dissolved | - | - | - | - | - | 46 | 23 | 14 | 3 |
| 12/13/2001 | Totals | 131 | 18 | 93.3 | 241 | 211 | 45 | 23 | 14 | 3 |
| | Dissolved | - | - | - | - | - | 45 | 23 | 13 | 3 |
| 3/9/2001 | Totals | 174 | 14.6 | 121 | 351 | 257 | 55 | 28 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 54 | 28 | 13 | 2 |
| 10/17/2000* | Totals | 117 | 15.6 | 68.4 | 277 | 216 | 46 | 23 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 45 | 23 | 12 | 2 |
| 10/17/2000 | Totals | 120 | 15.7 | 71.1 | 282 | 215 | 45 | 22 | 13 | 2 |
| | Dissolved | - | - | - | - | - | 45 | 22 | 13 | 2 |
| 10/13/2000 | Totals | 124 | 14.3 | 89.1 | 313 | 244 | - | - | 14 | - |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| Unit | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| MCL/(SMCL) | | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | - | - | - | - |
| | Averages | 132.63 | 15.29 | 92.5 | 298 | 232 | 49 | 25 | 13 | 3 |
| **Quapaw #2** | | | | | | | | | | |
| 11/6/1997 | Totals | 210 | 59.4 | 243.6 | **774** | 410 | 114 | 47 | 33 | 5 |
| | Dissolved | - | - | - | - | - | 113 | 47 | 33 | 4 |
| 7/17/1997 | Totals | 205 | 65.6 | **269** | **713** | 457 | 114 | 46 | 33 | 3 |
| | Dissolved | - | - | - | - | - | 115 | 46 | 33 | 3 |
| 2/4/1997 | Totals | 193.8 | 44.63 | 212.1 | **607** | 322 | 86 | 39 | 25 | < 1 |
| | Dissolved | - | - | - | - | - | 88 | 40 | 25 | 5 |
| 10/14/1996 | Totals | 151.5 | 31.87 | 121.9 | 452 | 228.85 | 74 | 31 | 22 | 5 |
| | Dissolved | - | - | - | - | - | 74 | 31 | 21 | 5 |
| | Averages | 202.93 | 56.54 | 241.6 | **698** | 396 | 105 | 44 | 30 | 4 |
| **Quapaw #4** | | | | | | | | | | |
| 4/22/2008 | Totals | 112 | <10 | 13.2 | 144 | 123 | 26.4 | 13.4 | 5.6 | 1.4 |
| | Dissolved | - | - | - | - | - | 25.6 | 13.1 | 5.3 | 1.3 |
| 10/24/2007 | Totals | 113 | 10.8 | 14.3 | 137 | 127 | 27.1 | 13.7 | 6.7 | 1.5 |
| | Dissolved | - | - | - | - | - | 23.4 | 12 | 5.8 | 1.3 |
| 5/9/2007 | Totals | 107 | 13.4 | 12.6 | 145 | 132 | 26.2 | 13.7 | 9 | 1.7 |
| | Dissolved | - | - | - | - | - | 26.6 | 13.4 | 8.6 | 1.6 |
| 11/9/2006 | Totals | 112 | 18.6 | 20 | 160 | 134 | 29 | 14 | 12 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 13 | 11 | 2 |
| 4/12/2006 | Totals | 109 | <10 | 15.2 | 118 | 118 | 24 | 13 | 5 | 1 |
| | Dissolved | - | - | - | - | - | 25 | 13 | 5 | 1 |
| 10/18/2005 | Totals | 115 | 18.6 | 16.4 | 184 | 136 | 30 | 14 | 11 | 2 |
| | Dissolved | - | - | - | - | - | 30 | 14 | 11 | 2 |
| 4/26/2005 | Totals | 109 | <10 | 13.5 | 138 | 119 | 26 | 13 | 6 | 1 |
| | Dissolved | - | - | - | - | - | 25 | 13 | 6 | 1 |
| 10/13/2004 | Totals | 104 | <10 | 12.7 | 149 | 121 | 27 | 14 | 5 | 1 |
| | Dissolved | - | - | - | - | - | 27 | 13 | 5 | 1 |
| *10/13/2004 | Totals | 104 | <10 | 12.8 | 147 | 121 | 27 | 13 | 5 | 1 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 27 | 14 | 5 | 1 |
| 4/28/2004 | Totals | 107 | <10 | 11.8 | 152 | 122 | 25 | 13 | 8 | 2 |
| | Dissolved | - | - | - | - | - | 24 | 13 | 7 | 2 |
| 11/6/2003 | Totals | 109 | <10 | 11.1 | 129 | 120 | 25 | 13 | 5 | 1 |
| | Dissolved | - | - | - | - | - | 24 | 13 | 5 | 1 |
| *11/6/2003 | Totals | 109 | <10 | 11.1 | 131 | 121 | 24 | 13 | 5 | 1 |
| | Dissolved | - | - | - | - | - | 25 | 13 | 5 | 1 |
| | Averages | 109 | 11.8 | 13.7 | 145 | 125 | 26 | 13 | 7 | 1 |
| **Quapaw #5** | | | | | | | | | | |
| 4/23/2008 | Totals | 267 | 99.1 | **456** | **1080** | 807 | 158 | 74.2 | 56.9 | 8.4 |
| | Dissolved | - | - | - | - | - | 156 | 73.4 | 54.8 | 8.3 |
| *4/23/2008 | Totals | 268 | 98.5 | **464** | **1100** | 808 | 161 | 75.9 | 57.5 | 8.4 |
| | Dissolved | - | - | - | - | - | 158 | 73.2 | 54.9 | 8.3 |
| 10/24/2007 | Totals | 268 | 95.4 | **429** | **1040** | 703 | 158 | 73.5 | 53 | 8.3 |
| | Dissolved | - | - | - | - | - | 144 | 67.6 | 48.1 | 7.4 |
| *10/24/2007 | Totals | 268 | 95.4 | **459** | **1020** | 707 | 160 | 75.1 | 53.2 | 8.4 |
| | Dissolved | - | - | - | - | - | 142 | 66.6 | 48.9 | 7.4 |
| 5/9/2007 | Totals | 253 | 92.9 | **264** | **1000** | 716 | 154 | 75 | 54.2 | 8.6 |
| | Dissolved | - | - | - | - | - | 154 | 74 | 53.5 | 8.4 |
| 11/9/2006 | Totals | 251 | 95.4 | **391** | **968** | 709 | 156 | 69 | 50 | 8 |
| | Dissolved | - | - | - | - | - | 143 | 69 | 49 | 8 |
| 4/12/2006 | Totals | 252 | 93.6 | **434** | **992** | 767 | 151 | 69 | 54 | 8 |
| | Dissolved | - | - | - | - | - | 150 | 68 | 53 | 8 |
| *4/12/2006 | Totals | 253 | 93.8 | **422** | **993** | 764 | 150 | 69 | 54 | 8 |
| | Dissolved | - | - | - | - | - | 147 | 67 | 53 | 8 |
| 10/18/2005 | Totals | 249 | 95.1 | **417** | **1020** | 358 | 162 | 72 | 53 | 8 |
| | Dissolved | - | - | - | - | - | 168 | 73 | 50 | 7 |
| 4/26/2005 | Totals | 246 | 92.4 | **412** | **1020** | 733 | 159 | 72 | 52 | 7 |
| | Dissolved | - | - | - | - | - | 152 | 68 | 51 | 7 |
| 10/13/2004 | Totals | 250 | 95.9 | **410** | **1010** | 739 | 159 | 70 | 53 | 7 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| | Dissolved | - | - | - | - | - | 144 | 65 | 48 | 7 |
| 4/28/2004 | Totals | 254 | 104 | **455** | **1083** | 754 | 148 | 71 | 59 | 8 |
| | Dissolved | - | - | - | - | - | 147 | 72 | 58 | 7 |
| 11/6/2003 | Totals | 250 | 102 | **401** | **1050** | 751 | 146 | 70 | 58 | 8 |
| | Dissolved | - | - | - | - | - | 147 | 71 | 59 | 8 |
| | Averages | 256 | 96.4 | **416.5** | **1029** | 717 | 153 | 71 | 53 | 8 |
| 4/18/2002 | Totals | 224 | 86.6 | **305** | **890** | 665 | 135 | 63 | 47 | 7 |
| | Dissolved | - | - | - | - | - | 130 | 61 | 46 | 7 |
| 12/14/2001 | Totals | 234 | 80.3 | **376** | **828** | 610 | 133 | 61 | 49 | 7 |
| | Dissolved | - | - | - | - | - | 126 | 59 | 48 | 7 |
| 3/9/2001* | Totals | 226 | 68.3 | **290** | **809** | 555 | 149 | 74 | 33 | 3 |
| | Dissolved | - | - | - | - | - | 125 | 57 | 40 | 6 |
| 3/9/2001 | Totals | 224 | 69.2 | **293** | **814** | 558 | 124 | 57 | 41 | 6 |
| | Dissolved | - | - | - | - | - | 148 | 74 | 33 | 3 |
| 10/13/2000 | Totals | 221 | 71.3 | **279** | **825** | 907 | - | - | 42 | - |
| | Dissolved | - | - | - | - | - | - | - | - | - |
| | Averages | 225.8 | 75.14 | **308.6** | **833** | 659 | 134 | 63 | 42 | 6 |
| **RWD4 #3** | | | | | | | | | | |
| 4/23/2008 | Totals | 117 | 18.1 | <10 | 157 | 135 | 28.1 | 15.3 | 6.9 | 1.6 |
| | Dissolved | - | - | - | - | - | 26.8 | 14.7 | 6.6 | 1.6 |
| 10/24/2007 | Totals | 116 | 17.7 | <10 | 141 | 137 | 27.1 | 15.1 | 6.8 | 1.6 |
| | Dissolved | - | - | - | - | - | 24.3 | 13.6 | 6 | 1.3 |
| 5/9/2007 | Totals | 110 | 17.8 | <10 | 151 | 141 | 26.8 | 15.1 | 7.2 | 1.5 |
| | Dissolved | - | - | - | - | - | 26.6 | 15 | 7.1 | 1.6 |
| *5/9/2007 | Totals | 110 | 17.7 | <10 | 147 | 143 | 26.5 | 15 | 7 | 1.5 |
| | Dissolved | - | - | - | - | - | 26.6 | 15 | 7.1 | 1.6 |
| 11/9/2006 | Totals | 111 | 18.1 | 11 | 160 | 135 | 27 | 15 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 15 | 7 | 2 |
| 4/2/2006 | Totals | 114 | 17.9 | 10.5 | 134 | 130 | 25 | 15 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 15 | 7 | 2 |

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | | 82/25 | | | | | | |
| 10/18/2005 | Totals | 114 | 17.7 | 10.4 | 168 | 140 | 29 | 16 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 15 | 6 | 2 |
| 4/26/2005 | Totals | 114 | 16.5 | 10.2 | 157 | 133 | 28 | 15 | 6 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 15 | 6 | 2 |
| 10/13/2004 | Totals | 109 | 16.6 | 10.2 | 154 | 132 | 29 | 16 | 7 | 2 |
| | Dissolved | - | - | - | - | - | 28 | 15 | 6 | 2 |
| 4/28/2004 | Totals | 110 | 15.2 | <10 | 160 | 135 | 26 | 15 | 6 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 15 | 6 | 2 |
| *4/28/2004 | Totals | 110 | 15.2 | <10 | 159 | 132 | 25 | 15 | 6 | 2 |
| | Dissolved | - | - | - | - | - | 26 | 15 | 6 | 2 |
| 11/7/2003 | Totals | 114 | 14.8 | <10 | 133 | 135 | 27 | 15 | 6 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 15 | 6 | 2 |
| *11/7/2003 | Totals | 114 | 14.6 | <10 | 136 | 134 | 27 | 16 | 6 | 2 |
| | Dissolved | - | - | - | - | - | 27 | 16 | 6 | 2 |
| | Averages | 113 | 16.8 | 10.2 | 151 | 136 | 27 | 15 | 6 | 2 |
| **RWD7 #2** | | | | | | | | | | |
| 5/9/2008 | Totals | 145 | **277** | 12.4 | 392 | 171 | 35.3 | 16.7 | 176 | 5.7 |
| | Dissolved | - | - | - | - | - | 35.2 | 16.5 | 175 | 5.6 |
| 10/24/2007 | Totals | 147 | **277** | 13.4 | **596** | 168 | 36.2 | 17.4 | 177 | 5.7 |
| | Dissolved | - | - | - | - | - | 32.5 | 15.7 | 162 | 5.2 |
| 5/9/2007 | Totals | 139 | **272** | 13 | **573** | 170 | 35.3 | 17.4 | 184 | 6.2 |
| | Dissolved | - | - | - | - | - | 34.6 | 17.5 | 182 | 6 |
| 11/9/2006 | Totals | 139 | **286** | 18.6 | **606** | 159 | 37 | 16 | 172 | 6 |
| | Dissolved | - | - | - | - | - | 32 | 16 | 164 | 5 |
| *11/9/2006 | Totals | 140 | **287** | 18.8 | **598** | 160 | 36 | 16 | 171 | 6 |
| | Dissolved | - | - | - | - | - | 33 | 16 | 167 | 6 |
| | Averages | 142 | **279.8** | 15.2 | **553** | 166 | 35 | 17 | 173 | 6 |

**Notes:**
mg/l milligrams per liter

TABLE 7-6
General Chemistry Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | **Alkalinity** | **Chloride** | **Sulfate** | **Tot Dis Sol** | **Hardness** | **Calcium** | **Magnesium** | **Sodium** | **Potassium** |
|---|---|---|---|---|---|---|---|---|---|
| | CaCO3 | Cl | SO4 | TDS | CaCO3 | Ca | Mg | Na | K |
| Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| MCL/(SMCL) | | (250) | (250) | (500) | | | | | |
| Roubidoux Tolerance Limit / Background Level | | | 82/25 | | | | | | |

MCL maximum contaminant level as of May, 2009 (EPA, 2009)
SMCL secondary maximum contaminant level as of May, 2009 (EPA, 2009)
**bold** **indicates value greater than MCL or SMCL**
*itallicized* *indicates value greater than tolerance limit for Roubidoux aquifer*

**Roubidoux Water Quality Interpretation (per guidelines est. by ODEQ)**
Indicator parameters are iron, sulfate, and zinc.

- A well producing water with concentrations in excess of the tolerance limits for all three indicator parameters indicates the Roubidoux is impacted by mine water locally near the well site.

- A well producing water with concentrations in excess of the background concentrations for all three indicator parameters and above the tolerance limits for two of the indicator parameters indicates the Roubidoux is probably impacted by mine water locally near the well site.

- A well producing water with concentrations in excess of the background concentrations for two of the three indicator parameters and above the tolerance limits for one of the indicator parameters indicates the Roubidoux is possibly impacted by mine water locally near the well site.

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TABLE 7-7
Dissolved Trace Metals Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BMW01** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 15-Jul-08 | | 20-Oct-08 | | 5-Feb-09 | | 15-Apr-09 | | 28-Jul-09 | | 5-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 6.8 | U | **8.7** | = | **10.2** | = | **9.2** | = | **7.6** | = | **7.4** | = |
| Barium (Dissolved) | 2000[a] | µg/L | **30.8** | = | **26.7** | = | **14.8** | = | **20.8** | = | 10 | U | **10.5** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[b] | µg/L | **47.9** | = | 10 | U | 10 | U | 10 | U | 10 | U | **12.2** | = |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a] / 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **35.6** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Selenium (Dissolved) | 50[a] | µg/L | 10.4 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[b] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **31.4** | = | **22.3** | = | **105** | = | **72.6** | = | **68** | J | **31.8** | = |

| | | **Well ID:** | **BMW02** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 15-Jul-08 | | 15-Jul-08 | | 22-Oct-08 | | 22-Oct-08 | | 5-Feb-09 | | 5-Feb-09 | | 15-Apr-09 | | 15-Apr-09 | | 29-Jul-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **12.1** | = | **12.3** | = | **12.8** | = | **12.9** | = | **14.5** | = | **15.1** | = | **16.2** | = | **15.7** | = | **22.8** | = | **21.6** | = |
| Barium (Dissolved) | 2000[a] | µg/L | **34.9** | = | **35.9** | = | **30.9** | = | **30.0** | = | **18.2** | = | **17.6** | = | **15.0** | = | **14.8** | = | **15.7** | = | **10.6** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[b] | µg/L | 10 | U | **13.7** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | **49.4** | = | **54.6** | = | **40.2** | = | **39.4** | = | **34.2** | = | **31.6** | = | **53.6** | = | **53.1** | = | **31.3** | = | **32.8** | = |
| Copper (Dissolved) | 1300[a] / 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 2 | U | **2.7** | = |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **183** | = | **196** | = | **231** | = | **230** | = | **231** | = | **232** | = | **240** | = | **251** | = | **196** | = | **216** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 10.4 | U | 10.4 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[b] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **4,700** | = | **4,870** | = | **4,260** | = | **4,250** | = | **5,860** | = | **5,760** | = | **6,440** | = | **6,470** | = | **6,300** | = | **7,610** | = |

**Notes:**
[a]MCL
[b]SMCL
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
NA - not applicable
FD - field duplicate
All results in micrograms per liter (µg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration
Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-7
Dissolved Trace Metals Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BMW05** | | | | | | **BMW06** | | | | **BMW07** | | | | **BMW08** | | | | | | **BMW09** | | | | **BMW11** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 21-Apr-09 | | 3-Aug-09 | | 8-Oct-09 | | 30-Jul-09 | | 13-Oct-09 | | 3-Aug-09 | | 13-Oct-09 | | 3-Aug-09 | | 3-Aug-09 | | 13-Oct-09 | | 3-Aug-09 | | 8-Oct-09 | | 21-Apr-09 | | 4-Aug-09 | | 13-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | **134** | = | **193** | = |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **2.1** | = | **2.5** | = | **2.8** | = | 2 | U | 5 | U | **10.1** | = | **20.3** | = | **20.1** | = | **20.7** | = | **12.6** | = | **33.5** | = | **36.1** | = | **5.4** | = | **9.5** | = | **13.1** | = |
| Barium (Dissolved) | 2000[a] | µg/L | **31.5** | = | **28.1** | = | **25.5** | = | **33.0** | = | **30.3** | = | **51.6** | = | **23.0** | = | **102** | = | **106** | = | **92.0** | = | **13.9** | = | **12.3** | = | **80.2** | = | **33.7** | = | **23.9** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | **32.8** | = | **77.5** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **21.9** | = | 20 | U | 20 | U | 20 | U | **24.9** | = | **26.4** | = | **128** | = | **53.3** | = | **27.6** | = |
| Copper (Dissolved) | 1300[a] / 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **29.8** | = | 20 | U | 20 | U | 20 | U | 20 | U | **43.9** | = | **123** | = | 20 | U | 20 | U | 20 | U | **173** | = | **168** | = | **246** | = | **137** | = | **152** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 2 | U | 2 | U | 2 | U | **52.3** | = | **69.6** | = | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[b] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Vanadium (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **61** | = | 20 | U | **26** | = | 20 | U | **27** | **J** | **691** | = | **3,840** | = | 20 | U | 20 | U | **21.9** | **J** | **5,120** | = | **4,960** | = | **819** | = | **421** | = | **800** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-7
Dissolved Trace Metals Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BMW12** | | | | | | **BMW13** | | | | | | **BMW14** | | | | **BMW15** | | | | **BW02** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 20-Apr-09 | | 4-Aug-09 | | 13-Oct-09 | | 5-May-09 | | 29-Jul-09 | | 6-Oct-09 | | 3-Aug-09 | | 8-Oct-09 | | 5-Aug-09 | | 13-Oct-09 | | 16-Apr-09 | | 16-Apr-09 | | 29-Jul-09 | | 29-Jul-09 | | 7-Oct-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | FD | | Normal | | FD | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | **109** | = | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 5 | U | 1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **5.6** | = | **9.6** | = | **13.6** | = | 1 | U | 2 | U | 2 | U | **5** | = | **15.4** | = | **2.1** | = | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Barium (Dissolved) | 2000[a] | µg/L | **45.5** | = | **33.3** | = | **21.5** | = | **122** | = | **86.8** | = | **99.3** | = | **117** | = | **54.9** | = | **52.9** | = | **49.1** | = | **48.7** | = | **47.3** | = | **44.2** | = | **44.4** | = | **46.6** | = | **45.1** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | **101** | = | **49.2** | = | **36.1** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a] / 1000[b] | µg/L | **56.1** | = | 20 | U | 20 | U | **38** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 5 | U | 1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **364** | = | **265** | = | **264** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Selenium (Dissolved) | 50[a] | µg/L | 2 | U | 2 | U | 5 | U | 1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[b] | µg/L | 2 | U | 2 | U | 5 | U | 1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **25.4** | = | **37.3** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **2,270** | = | **1,210** | = | **1,980** | = | **163** | = | 20 | U | 20 | U | 20 | U | 20 | U | **37** | **J** | **61.6** | **J** | **58.9** | = | **35.9** | = | 20 | U | 20 | U | 20 | U | 20 | U |

**Notes:**
[a]MCL
[b]SMCL
MCL - Maximum Contaminant Level
SMCL - Secondary Maximum Contaminant Level
NA - not applicable
FD - field duplicate
All results in micrograms per liter (µg/L).
= : Detected concentration
U: Not detected
J: Estimated concentration
Detections are in **BOLD** and highlighted in yellow
Exceedences of the MCL are in **BOLD** and highlighted in green
Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-7
Dissolved Trace Metals Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BW06** | | | | | | **BW07** | | | | | | | | **BW11** | | | | | | **BW13** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 20-Apr-09 | | 29-Jul-09 | | 7-Oct-09 | | 21-Apr-09 | | 21-Apr-09 | | 5-Aug-09 | | 14-Oct-09 | | 20-Apr-09 | | 30-Jul-09 | | 12-Oct-09 | | 22-Apr-09 | | 29-Jul-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **52.2** | = | **67.6** | = | **65.5** | = | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Barium (Dissolved) | 2000[a] | µg/L | **19.4** | = | **17.0** | = | **20.0** | = | 10 | U | 10 | U | 10 | U | 10 | U | **13.4** | = | **11.8** | = | **12.6** | = | **429** | = | **383** | = | **428** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | **23.2** | = | **21.6** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a] / 1000[b] | µg/L | **33.2** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **21.1** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | **2.4** | = |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **102** | = | **143** | = | **124** | = | **26.2** | = | **28.1** | = | **26.4** | = | **29.5** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Selenium (Dissolved) | 50[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[b] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **8,380** | = | **8,730** | = | **9,410** | = | 20 | U | 20 | U | 20 | U | **43.3** | J | 20 | U | 20 | U | **28.8** | J | **75.6** | = | **51.4** | J | **52.1** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-7
Dissolved Trace Metals Analytical Results in Boone Aquifer Wells
*Tar Creek Superfund Site. Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **BW14** | | | | | | | | | | **BW15** | | | | | | **BW16** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 16-Apr-09 | | 4-Aug-09 | | 4-Aug-09 | | 13-Oct-09 | | 13-Oct-09 | | 20-Apr-09 | | 3-Aug-09 | | 13-Oct-09 | | 15-Apr-09 | | 30-Jul-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | Normal | | FD | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | **2.7** | **=** | **2.8** | **=** | **5.4** | **=** | 2 | U | 2 | U | 2 | U |
| Barium (Dissolved) | 2000[a] | µg/L | **31.5** | **=** | **30.9** | **=** | **31.5** | **=** | **30.9** | **=** | **31.9** | **=** | **15.9** | **=** | **13.1** | **=** | **15.6** | **=** | 10 | U | **23.8** | **=** | **41.2** | **=** |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | **7** | **=** | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a] / 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **114** | **=** | **101** | **=** | **133** | **=** | 20 | U | 20 | U | 20 | U |
| Selenium (Dissolved) | 50[a] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[b] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **47.7** | **=** | 20 | U | 20 | U | **23.2** | **J** | **21.6** | **J** | **1,570** | **=** | **1,470** | **=** | **2,220** | **=** | **556** | **=** | **93** | **J** | **76.1** | **=** |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

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TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **FCB2** | | | | | | | | | | | | | | | | | | **FCB3** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 27-Feb-07 | | 22-Oct-07 | | 23-Apr-08 | | 28-Oct-08 | | 16-Apr-09 | | 30-Jul-09 | | 30-Jul-09 | | 12-Oct-09 | | 12-Oct-09 | | 27-Feb-07 | | 22-Oct-07 | | 23-Apr-08 | | 28-Oct-08 | | 16-Apr-09 | | 30-Jul-09 | | 12-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | **120** | = | **117** | = | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 5 | U | 1.1 | U | 1.1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 5 | U | 1.1 | U | 1.1 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **49.1** | = | **38.9** | = | **37.5** | = | **36.1** | = | **35.8** | = | **32.6** | = | **31.2** | = | **34.3** | = | **33.9** | = | **17.1** | = | 6.8 | U | 6.8 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Barium (Dissolved) | 2000[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **26.5** | = | **37.5** | = | **33** | = | **33.1** | = | **31.3** | = | **27.5** | = | **34.4** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **6.5** | = | **5.4** | = | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 5 | U | 0.8 | U | 0.8 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 5 | U | **14.0** | = | 0.8 | U | 2 | U | 2 | U | **2.2** | **J** | 5 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | **0.233** | = | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **91.5** | = | **96.4** | = | **77.1** | = | **94.3** | = | **90.1** | = | **75.3** | = | **77.8** | = | **78.4** | = | **80.8** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Selenium (Dissolved) | 50[a] | µg/L | 26 | U | 10.2 | U | 10.2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 26 | U | 10.2 | U | 10.2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 5 | U | 1.2 | U | 1.2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 5 | U | 1.2 | U | 1.2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **2,850** | = | **3,230** | = | **2,130** | = | **5,770** | = | **5,550** | = | **5,470** | = | **5,830** | = | **3,900** | = | **3,890** | = | **1,640** | = | **347** | = | 20 | U | **64.5** | = | **124** | = | **164** | **J** | **40.3** | **J** |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **LMB2** | | | | | | | | | | | | | | | | **MD2** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 28-Feb-07 | | 28-Feb-07 | | 24-Oct-07 | | 22-Apr-08 | | 28-Oct-08 | | 20-Apr-09 | | 5-Aug-09 | | 8-Oct-09 | | 15-Apr-09 | | 4-Aug-09 | | 15-Oct-09 | | 15-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | **106** | = | **117** | = | 100 | U | **155** | = | **183** | = | 100 | U | **109** | = | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 5 | U | 5 | U | 1.1 | U | 1.1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 17.1 | U | 17.1 | U | 6.8 | U | **14.1** | = | **15.2** | = | **11.0** | = | **14.1** | = | **16.4** | = | **14.5** | = | **12.5** | = | **12.5** | = | **12.1** | = |
| Barium (Dissolved) | 2000[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **12.6** | = | **13.8** | = | **15.6** | = | **14.2** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **38.2** | = | **39.5** | = | **42.2** | = | **10.0** | = | **9.2** | = | **6.8** | = | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | **34.7** | = | **35.0** | = | **34.8** | = | **33.7** | = | **33.4** | = | **26.0** | = | **28.6** | = | **26.1** | = | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | **5.2** | = | **6.6** | = | **65.7** | = | **36.7** | = | **8.8** | = | **3.1** | = | **5.7** | = | **15.0** | = | 2 | U | 2 | U | 5 | U | 5 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | **0.223** | = | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **301** | = | **309** | = | **321** | = | **315** | = | **313** | = | **226** | = | **260** | = | **262** | = | **20.9** | = | **21.7** | = | **23.8** | = | **20** | -- |
| Selenium (Dissolved) | 50[a] | µg/L | 26 | U | 26 | U | 10.2 | U | 10.2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 5 | U | 5 | U | 1.2 | U | 1.2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **15,500** | = | **15,900** | = | **18,400** | = | **15,200** | = | **14,600** | = | **14,800** | = | **11,100** | = | **10,000** | = | **1,510** | = | **1,590** | -- | **1,530** | J | **1,510** | J |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **MMB2** | | | | | | | | | | | | **MP04** | | | | | | **MP05** | | | | **MP06** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 17-Jul-08 | | 23-Oct-08 | | 4-Feb-09 | | 14-Apr-09 | | 28-Jul-09 | | 6-Oct-09 | | 21-Apr-09 | | 30-Jul-09 | | 14-Oct-09 | | 4-Aug-09 | | 12-Oct-09 | | 5-Aug-09 | | 12-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | **917** | = | **837** | = | **929** | = | 100 | U | 100 | U | 100 | U | **388** | = |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 5 | U | 2 | U | 5 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 6.8 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | **19.2** | = | **23.5** | = | **20.4** | = | **69** | = | **69.3** | = | 2 | U | **11.0** | = |
| Barium (Dissolved) | 2000[a] | µg/L | **24.2** | = | **19.7** | = | **11.3** | = | **12.4** | = | **10.3** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **391** | = | **246** | = | **157** | = | **206** | = | **151** | = | **154** | = | **9.1** | = | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | **26** | = | **22.5** | = | **25.5** | = | **22.3** | = | 20 | U | **296** | = | **265** | = | **293** | = | **24.4** | = | 20 | U | 20 | U | **92.4** | = |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 24.3 | U | 20 | U | 20 | U | **22.2** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | **276** | = | **69.3** | = | **70.9** | = | **147** | = | **17** | = | **26.9** | = | **3.0** | = | **3.1** | **J** | 5 | U | 2 | U | 5 | U | 2 | U | 5 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **167** | = | **244** | = | **243** | = | **242** | = | **164** | = | **184** | = | **1,910** | = | **1,770** | = | **1,960** | = | **284** | = | **277** | = | 20 | U | **802** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 10.4 | U | **2.7** | = | 5 | U | **3.2** | = | **2.0** | = | 2.8 | = | **2.9** | = | **2.4** | = | 5 | U | 2 | U | 5 | U | 2 | U | 5 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 5 | U | 2 | U | 5 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | **42** | = | 20 | U | **33.3** | = | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **25,900** | = | **28,400** | = | **26,200** | = | **27,500** | = | **17,500** | = | **20,600** | = | **52,600** | = | **47,400** | = | **52,500** | = | **9,720** | = | **10,100** | = | 20 | U | **7,020** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **MP17** | | | | | | **MP20** | | | | | | **OCC3** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 15-Apr-09 | | 30-Jul-09 | | 7-Oct-09 | | 22-Apr-09 | | 29-Jul-09 | | 6-Oct-09 | | 23-Apr-08 | | 27-Oct-08 | | 15-Apr-09 | | 5-Aug-09 | | 14-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | **583** | **=** | **622** | **=** | **537** | **=** | **522** | **=** | **512** | **=** |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 1.1 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 2 | U | 2 | U | 2 | U | **5.4** | **=** | **10.6** | **=** | **9.2** | **=** | **6.9** | **=** | **5.2** | **=** | **6.2** | **=** | **5.2** | **=** | **5.8** | **=** |
| Barium (Dissolved) | 2000[a] | µg/L | **28.7** | **=** | **25.4** | **=** | **27.8** | **=** | 10 | U | 10 | U | 10 | U | **10.5** | **=** | 10 | U | 10 | U | 10 | U | **10.9** | **=** |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | **62.1** | **=** | **56.0** | **=** | **42.5** | **=** | **32.4** | **=** | **37.0** | **J** |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | **12.5** | **=** | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | **22.2** | **=** | 20 | U | 20 | U | **32.0** | **=** | **36.3** | **=** | **34.3** | **=** | **32.9** | **=** | **30.6** | **=** |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | **6.1** | **=** | **5.3** | **=** | **2.1** | **=** | 2 | U | 5 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | **139** | **=** | **108** | **=** | **126** | **=** | **214** | **=** | **239** | **=** | **228** | **=** | **226** | **=** | **234** | **=** |
| Selenium (Dissolved) | 50[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 10.2 | U | **4.0** | **=** | **4.7** | **=** | **2.6** | **=** | 5 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 1.2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Vanadium (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **155** | **=** | **92.1** | **=** | **132** | **=** | **3,070** | **=** | **2,320** | **=** | **2,490** | **=** | **54,300** | **=** | **58,800** | **=** | **55,100** | **=** | **53,500** | **=** | **53,400** | **=** |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **RMB3** | | | | | | | | | | | | | | **RMB4** | | | | | | | | **SMB2** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 1-Mar-07 | | 23-Oct-07 | | 24-Apr-08 | | 29-Oct-08 | | 16-Apr-09 | | 4-Aug-09 | | 14-Oct-09 | | 1-Mar-07 | | 23-Oct-07 | | 24-Apr-08 | | 29-Oct-08 | | 11-Jul-07 | | 24-Oct-07 | |
| | | **Type:** | 1-Mar-07 | | 23-Oct-07 | | 24-Apr-08 | | 29-Oct-08 | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | **179** | = | **145** | = | **130** | = | **215** | = | **168** | = | **140** | = | **122** | = | **127** | = | **101** | = | **148** | = | **114** | = | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 5 | U | 1.1 | U | 1.1 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 1.1 | U | 1.1 | U | 2 | U | 1.1 | U | 1.1 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **50.2** | = | **40.6** | = | **40.5** | = | **35.3** | = | **41.6** | = | **37.6** | = | **39.2** | = | **43.6** | = | **39.2** | = | **39.1** | = | **27.5** | = | **6.9** | = | 6.8 | U |
| Barium (Dissolved) | 2000[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **11.6** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **5.6** | = | 5 | U | **5.7** | = | 5 | U | 5 | U | 5 | U | 5 | U | **8.6** | = | **6.7** | = | **5.8** | = | 5 | U | **8.3** | = | **246** | = |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **29.8** | = |
| Lead (Dissolved) | 15[a] | µg/L | 5 | U | 0.8 | U | 0.8 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | **4.9** | = | **5.2** | = | **3.1** | = | **3.3** | = | **78.1** | = |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **112** | = | **114** | = | **102** | = | **106** | = | **99.7** | = | **98.6** | = | **92.5** | = | **113** | = | **110** | = | **103** | = | **98.1** | = | **107** | = | **107** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 26 | U | 10.2 | U | 10.2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 26 | U | 10.2 | U | 10.2 | U | 2 | U | 10.2 | U | 10.2 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 5 | U | 1.2 | U | 1.2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 1.2 | U | 1.2 | U | 2 | U | 2.4 | U | 1.2 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **3,560** | = | **3,670** | = | **3,050** | = | **3,490** | = | **3,100** | = | **2,690** | = | **4,150** | = | **8,530** | = | **4,080** | = | **3,130** | = | **3,430** | = | **11,800** | = | **20,100** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **SMB3** | | | | | | | | | | | | **SMB5** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 16-Jul-08 | | 20-Oct-08 | | 3-Feb-09 | | 14-Apr-09 | | 27-Jul-09 | | 6-Oct-09 | | 16-Jul-08 | | 21-Oct-08 | | 3-Feb-09 | | 15-Apr-09 | | 27-Jul-09 | | 5-Oct-09 | |
| | | **Type:** | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 6.8 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 6.8 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Barium (Dissolved) | 2000[a] | µg/L | **31.4** | = | **31.1** | = | **12.7** | = | **13.4** | = | **10.4** | = | **11.2** | = | **31.3** | = | **24.2** | = | **13.3** | = | **17.6** | = | **11.5** | = | **12.0** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **145** | = | **224** | = | **136** | = | **138** | = | **120** | = | **132** | = | 5 | U | **177** | = | **95.6** | = | **110** | = | **87.3** | = | **110** | **J** |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **16.4** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | **24.5** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **23.0** | = | 20 | U | **23.4** | = | **21.3** | = | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | **63.4** | = | **140** | = | **69.2** | = | **114** | = | **138** | = | **128** | = | **13.1** | = | **20.4** | = | **57.1** | = | **72.4** | = | **79.4** | = | **121** | = |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **97.7** | = | **192** | = | **156** | = | **161** | = | **129** | = | **154** | = | **70.8** | = | **182** | = | **179** | = | **212** | = | **130** | = | **158** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 10.4 | U | 2.5 | U | 5 | U | 2.6 | U | 2.4 | U | 2.5 | U | 10.4 | U | **3.0** | = | 5 | U | **2.6** | = | **2.3** | = | **2.6** | = |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **2,490** | = | **20,600** | = | **16,400** | = | **16,500** | = | **13,600** | = | **10,300** | = | **3,850** | = | **19,500** | = | **18,700** | = | **20,200** | = | **11,200** | = | **11,100** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **SMB6** | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 21-Apr-08 | | 16-Jul-08 | | 16-Jul-08 | | 21-Oct-08 | | 21-Oct-08 | | 4-Feb-09 | | 4-Feb-09 | | 15-Apr-09 | | 15-Apr-09 | | 7-Oct-09 | |
| | | **Type:** | Normal | | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | | FD | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 1.1 | U | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 6.8 | U | 6.8 | U | 6.8 | U | 2 | U | 2 | U | 5 | U | 5 | U | **2.4** | = | **3.4** | = | **3.0** | = |
| Barium (Dissolved) | 2000[a] | µg/L | **20.8** | = | **30.5** | = | **30.0** | = | **23.1** | = | **24.4** | = | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **275** | = | **13.2** | = | **12.8** | = | **247** | = | **262** | = | **69.7** | = | **69.4** | = | **93.8** | = | **88.7** | = | **146** | = |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | **29.2** | = | 20 | U | 20 | U | **41.4** | = | **42.3** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | **26.7** | = | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | **133** | = | **18.7** | = | **15.8** | = | **42** | = | **43.6** | = | **7.7** | = | **7.5** | = | **21.7** | = | **21.7** | = | **171** | = |
| Mercury (Dissolved) | 2[a] | µg/L | **0.527** | = | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **228** | = | **64.8** | = | **67.2** | = | **191** | = | **204** | = | **198** | = | **200** | = | **209** | = | **192** | = | **193** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 10.2 | U | 10.4 | U | 10.4 | U | **2.3** | = | **2.4** | = | 5 | U | 5 | U | **4.1** | = | **4.6** | = | **2.8** | = |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | **2.4** | = | 2 | U | 2 | U | 2 | U | 2 | U | 5 | U | 5 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **27,000** | = | **5,270** | = | **5,100** | = | **21,400** | = | **22,700** | = | **16,200** | = | **16,300** | = | **15,600** | = | **14,700** | = | **18,600** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **SMB7** | | | | | | | | | | | | | | **SMB8** | | | | | | | | **SMB9** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 16-Jul-08 | | 16-Jul-08 | | 21-Oct-08 | | 4-Feb-09 | | 15-Apr-09 | | 27-Jul-09 | | 6-Oct-09 | | 28-Jul-09 | | 28-Jul-09 | | 6-Oct-09 | | 6-Oct-09 | | 28-Jul-09 | | 6-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | FD | | Normal | | FD | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | **129** | = | **126** | = | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | **617** | = | **585** | = | **319** | = | **318** | = | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | **10.7** | = | **11.9** | = | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | **18.0** | = | **17.7** | = | **38.5** | = | **39.1** | = | 2 | U | 2 | U |
| Barium (Dissolved) | 2000[a] | µg/L | 10 | U | 10 | U | **14.0** | = | 10 | U | **10.7** | = | **11.0** | = | **10.1** | = | 10 | U | 10 | U | 10 | U | 10 | U | **12.8** | = | **11.8** | = |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | **26.1** | = | **25.3** | = | **150** | = | **127** | = | **166** | = | **171** | = | **160** | = | 5 | U | 5 | U | 5 | U | 5 | U | **176** | = | **150** | = |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | **10.3** | = |
| Cobalt (Dissolved) | NA | µg/L | **28.7** | = | **26.1** | = | **30.0** | = | **26.6** | = | **28.7** | = | **22.5** | = | 20 | U | **196** | = | **187** | = | **112** | = | **116** | = | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | **4.2** | = | **3.7** | = | **6.5** | = | **14.5** | = | **113** | = | **54.7** | = | **14.1** | = | **21.2** | = | **20.7** | = | **7.1** | = | **6.5** | = | **148** | = | **138** | = |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | **274** | = | **275** | = | **270** | = | **257** | = | **260** | = | **195** | = | **217** | = | **1,150** | = | **1,110** | = | **975** | = | **981** | = | **203** | = | **215** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 10.4 | U | 10.4 | U | 2 | U | 5 | U | **3.1** | = | 2 | U | 2 | U | **2.8** | = | **2.9** | = | 2 | U | 2 | U | 2 | U | **2.8** | = |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 2 | U | 2 | U | 2 | U | 5 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **14,200** | = | **14,200** | = | **23,000** | = | **22,800** | = | **25,400** | = | **20,200** | = | **19,200** | = | **45,900** | = | **44,500** | = | **20,700** | = | **20,900** | = | **20,800** | = | **23,800** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

TABLE 7-8
Dissolved Trace Metals Analytical Results in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | **Well ID:** | **TMB2** | | | | | | | | | | **TMB3** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Sample Date:** | 23-Oct-07 | | 23-Oct-07 | | 22-Apr-08 | | 22-Apr-08 | | 27-Oct-08 | | 28-Feb-07 | | 24-Oct-07 | | 23-Apr-08 | | 23-Oct-08 | | 16-Apr-09 | | 4-Aug-09 | | 12-Oct-09 | |
| | | **Type:** | Normal | | FD | | Normal | | FD | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | | Normal | |
| **Analyte** | **MCL/SMCL** | **Unit** | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier | Result | Qualifier |
| ***Trace Metals*** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum (Dissolved) | 50 - 200[b] | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | 6[a] | µg/L | 1.1 | U | 1.1 | U | 1.1 | U | 1.1 | U | 2 | U | 5 | U | 1.1 | U | 1.1 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Arsenic (Dissolved) | 10[a] | µg/L | 6.8 | U | 6.8 | U | **49.4** | = | **52.4** | = | **23.0** | = | **17.1** | **U** | **18.1** | = | **12.4** | = | **19.3** | = | **5.7** | = | **13.2** | = | **6.6** | = |
| Barium (Dissolved) | 2000[a] | µg/L | **22.1** | = | **22** | = | **21.1** | = | **25.6** | = | 10 | U | 10 | U | 10 | U | **10.9** | = | 10 | U | 10 | U | 10 | U | 10 | U |
| Beryllium (Dissolved) | 4[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | 5[a] | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | **53.7** | = | **10.0** | = | **6.3** | = | 5 | U | 5 | U | 5 | U | 5 | U |
| Chromium (Dissolved) | 100[a] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | **30.0** | = | 20 | U | 20 | U |
| Copper (Dissolved) | 1300[a]/ 1000[b] | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Lead (Dissolved) | 15[a] | µg/L | 0.8 | U | 0.8 | U | **6.9** | = | **10.6** | = | **4.3** | = | 5 | U | **9.2** | = | **4.2** | = | **2.4** | = | **6.8** | = | 2 | U | 5 | U |
| Mercury (Dissolved) | 2[a] | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | NA | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | **49.7** | = | **61.4** | = | **46.6** | = | **50.8** | = | **47.7** | = | **74.2** | = | **39.8** | = | **45.3** | = |
| Selenium (Dissolved) | 50[a] | µg/L | 10.2 | U | 10.2 | U | 10.2 | U | 10.2 | U | 2 | U | 26 | U | 10.2 | U | 10.2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Silver (Dissolved) | 100[b] | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Thallium (Dissolved) | 2[a] | µg/L | 1.2 | U | 1.2 | U | 1.2 | U | 1.2 | U | 2 | U | 5 | U | 1.2 | U | 1.2 | U | 2 | U | 2 | U | 2 | U | 5 | U |
| Vanadium (Dissolved) | NA | µg/L | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 30 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | 5000[b] | µg/L | **413** | = | **302** | = | **681** | = | **632** | = | **3930** | **J** | **12,700** | = | **6,770** | = | **6,560** | = | **3,950** | = | **14,200** | = | **3,080** | = | **6,690** | = |

**Notes:**

[a]MCL

[b]SMCL

MCL - Maximum Contaminant Level

SMCL - Secondary Maximum Contaminant Level

NA - not applicable

FD - field duplicate

All results in micrograms per liter (µg/L).

= : Detected concentration

U: Not detected

J: Estimated concentration

Detections are in **BOLD** and highlighted in yellow

Exceedences of the MCL are in **BOLD** and highlighted in green

Exceedences of the SMCL are in **BOLD** and highlighted in blue

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TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| **Cardin #1** | | | | | | | | | | | | | |
| 4/21/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.193 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.169 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.027 |
| 10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.132 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.007 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.118 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.096 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.076 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.103 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.094 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.14 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.121 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/17/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.17 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.156 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| 4/25/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.193 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.036 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.152 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.139 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.114 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.132 | <0.01 | 0.009 | 0.00005 | <0.01 | <0.01 | <0.01 | 0.033 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.112 | <0.01 | 0.009 | <0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.101 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.022 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.098 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.01 | 0.13 | 0.006 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.002 | 0.011 |
| **Commerce #3 - (Plugged - 2004)** | | | | | | | | | | | | | |
| 11/6/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.575** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.03 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.568** | <0.005 | - | <0.00005 | <0.01 | 0.01 | <0.001 | <0.001 |
| 7/23/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.862** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.03 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.859** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.001 |
| *4/17/1997 | Totals | <0.002 | <0.002 | <0.002 | 0.011 | **0.338** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.039 |
| | Dissolved | <0.002 | <0.002 | <0.002 | 0.011 | **0.346** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 4/17/1997 | Totals | <0.002 | <0.002 | <0.002 | 0.012 | **0.354** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.04 |
| | Dissolved | <0.002 | <0.002 | <0.002 | 0.011 | **0.352** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.015 |
| 1/10/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.21 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.036 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.197 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.065 |
| 12/11/1996 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.269 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.052 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.264 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.018 |
| 10/14/1996 | Totals | <0.002 | <0.002 | <0.002 | 0.013 | **0.307** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.038 |
| | Dissolved | <0.002 | <0.002 | <0.002 | 0.012 | 0.281 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.011 | **0.413** | <0.005 | - | 0.0006 | 0.01 | 0.01 | 0.001 | 0.029 |
| **Commerce #4** | | | | | | | | | | | | | |
| 4/22/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.112 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.012 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.094 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.094 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.027 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.084 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.151 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.028 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.129 | <0.005 | 0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.106 | <0.005 | 0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.015 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.103 | <0.005 | 0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.009 |
| 4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.079 | <0.005 | 0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.027 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.079 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/18/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.132 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.104 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/26/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.077 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.072 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.09 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.086 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.087 | <0.01 | 0.009 | <0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.085 | <0.01 | 0.01 | <0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.095 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.086 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.01 | 0.097 | 0.006 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.002 | 0.01 |
| **Commerce #5** | | | | | | | | | | | | | |
| 4/22/2008 | Totals | <0.002 | <0.002 | <0.002 | 0.01 | 0.045 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | 0.002 | 0.002 | 0.01 | 0.035 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | 0.01 | 0.04 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | 0.002 | 0.002 | 0.01 | 0.031 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.008 |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.042 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.031 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.033 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.028 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.038 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.026 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/18/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.043 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.023 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/26/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.07 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.034 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.092 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.093 | <0.01 | <0.01 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.034 | <0.01 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| *4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.114 | <0.01 | <0.01 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.039 | <0.01 | <0.01 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.08 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.048 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.01 |
| | Averages | 0.003 | 0.003 | 0.003 | 0.009 | 0.047 | 0.006 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.003 | 0.006 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| 4/18/2002 | Totals | <0.002 | <0.002 | <0.01 | <0.01 | 0.116 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.01 | <0.01 | 0.082 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 12/13/2001 | Totals | <0.002 | <0.002 | <0.01 | <0.01 | 0.159 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.01 | <0.01 | 0.12 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 3/9/2001 | Totals | <0.002 | <0.002 | <0.01 | <0.01 | 0.197 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.01 | <0.01 | 0.137 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/13/2000 | Totals | <0.002 | <0.002 | <0.01 | <0.01 | 0.22 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.01 | <0.01 | 0.179 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/13/2000 | Totals | <0.002 | <0.002 | <0.01 | <0.01 | 0.208 | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | - | - | - | - | - | - | - | - | - | - | - | - |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | 0.157 | 0.005 | - | 0.00005 | 0.01 | 0.01 | 0.001 | 0.01 |
| **Ontario (Fernandez) Well** | | | | | | | | | | | | | |
| 4/21/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.447** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.308* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.386** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.065* |
| 10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.549** | <0.005 | 0.014 | <0.00005 | <0.01 | <0.01 | <0.001 | *1.08* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.526** | <0.005 | 0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.231* |
| 5/7/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.681** | <0.005 | 0.012 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.999* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.477** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.35** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.273* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.334** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.039 |
| 4/10/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.302** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.09* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.277* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/17/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.393** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.251* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.391** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.14* |
| 4/25/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.63** | <0.005 | 0.011 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.689* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.526** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.321* |
| 1/28/2005 | Totals | - | - | <0.002 | <0.005 | **0.512** | <0.005 | 0.013 | - | - | - | - | *1.2* |
| 10/11/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.349** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.244* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.343** | 0.015 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.148* |
| *10/11/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.358** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.251* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.318** | **0.021** | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.169* |
| 4/29/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | **0.359** | <0.01 | 0.006 | 0.00006 | <0.01 | <0.01 | <0.01 | *0.299* |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | *0.238* | 0.012 | <0.005 | <0.00005 | <0.01 | <0.01 | <0.01 | *0.089* |
| *4/29/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | **0.359** | <0.01 | 0.006 | <0.00005 | <0.01 | <0.01 | <0.01 | *0.228* |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | *0.249* | <0.01 | <0.005 | <0.00005 | <0.01 | <0.01 | <0.01 | 0.037 |
| 12/19/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.319** | **0.026** | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.236* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.464** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.464* |
| 11/4/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.316** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.083* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.246* | 0.013 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.07* |
| 10/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | *0.208* | **0.017** | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.05* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.288* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.067* |
| *10/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | *0.287* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.065* |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.224* | 0.008 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.033 |
| 7/30/2003 | Dis Met | - | - | - | - | **0.41** | **0.056** | <0.01 | - | <0.01 | - | - | *0.239* |
| | Averages | 0.003 | 0.003 | 0.002 | 0.009 | **0.379** | 0.009 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.002 | *0.265* |
| **Miami #1** | | | | | | | | | | | | | |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | **1.13** | 0.01 | 0.012 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.042 | 0.01 | <0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/4/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.372** | 0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.062 | 0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| *11/4/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.057 | 0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | 0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.005 | 0.005 | 0.003 | 0.008 | 0.281 | 0.007 | 0.01 | 0.0001 | 0.01 | 0.01 | 0.004 | 0.008 |
| **Miami #3** | | | | | | | | | | | | | |
| 4/22/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.113 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/18/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *10/18/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/26/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *4/26/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | 0.024 | 0.005 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.001 | 0.005 |
| **Miami #11** | | | | | | | | | | | | | |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.065 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.035 | <0.005 | <0.01 | <0.00015 | <0.01 | <0.01 | <0.001 | <0.005 |
| *5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.055 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.026 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.081 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.058 | <0.005 | <0.01 | 0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| *11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.08 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.05 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | 0.056 | 0.005 | 0.01 | 0.00006 | 0.01 | 0.01 | 0.001 | 0.005 |
| **Picher #2 - (Plugged - 2004)** | | | | | | | | | | | | | |
| 8/12/1999 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.674** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.639** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 11/6/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.225 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.014 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.138 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 7/15/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.277 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.267 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 4/9/1997 | Totals | <0.002 | <0.002 | <0.002 | 0.01 | **0.745** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.028 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.719** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.027 |
| 10/25/1996 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.181 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.171 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/1/1996 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.44 | <0.005 | - | <0.0005 | 0.01 | <0.01 | <0.001 | 0.27 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.376** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.172 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | **0.404** | 0.005 | - | 0.0005 | 0.01 | 0.01 | 0.001 | 0.014 |
| **Picher #3 - (Plugged - 2004)** | | | | | | | | | | | | | |
| 11/6/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 1.024 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **1.116** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.016 |
| 7/15/1997 | Totals | <0.002 | 0.002 | <0.002 | 0.014 | **0.803** | <0.005 | - | <0.0005 | 0.014 | <0.01 | <0.001 | 0.025 |
| | Dissolved | <0.002 | 0.002 | <0.002 | 0.012 | **0.778** | <0.005 | - | <0.0005 | 0.014 | <0.01 | <0.001 | 0.025 |
| 6/6/1997 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | **0.468** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.052 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | **0.444** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.063 |
| 9/23/1996 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.377** | <0.005 | - | <0.0005 | 0.013 | <0.01 | <0.001 | 0.093 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.264 | <0.005 | - | <0.0005 | 0.012 | <0.01 | <0.001 | 0.089 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.011 | **0.772** | 0.005 | - | 0.0005 | 0.011 | 0.01 | 0.001 | 0.032 |
| **Picher #4 - (Plugged - 2004)** | | | | | | | | | | | | | |
| 12/11/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.716** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.022 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.568** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 9/16/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.404** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.38** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 8/28/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.709** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.015 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.659** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 4/9/1997 | Totals | <0.002 | <0.002 | <0.002 | 0.01 | **2.566** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | 0.011 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **2.539** | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/8/1996 | Totals | <0.002 | <0.002 | <0.002 | 0.013 | 0.279 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | 0.012 | 0.247 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 9/16/1996 | Totals | <0.002 | 0.003 | <0.002 | 0.017 | **7.174** | <0.005 | - | <0.0008 | 0.067 | 0.095 | <0.001 | 2.43 |
| | Dissolved | <0.002 | <0.002 | <0.002 | 0.016 | **3.212** | <0.005 | - | <0.0008 | 0.041 | 0.024 | <0.001 | 0.104 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.011 | **0.907** | 0.005 | - | 0.0005 | 0.01 | 0.01 | 0.001 | 0.012 |
| **Picher #5** | | | | | | | | | | | | | |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| Unit | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| MCL/(SMCL) | | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| 4/22/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.113 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.11 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.118 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.115 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | 0.042 |
| *10/23/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.118 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.101 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.116 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.11 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/8/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.118 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.108 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.629** | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.112 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| *4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | *0.227* | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.1 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/17/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.098 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.046 | <0.005 | <0.01 | 0.00015 | <0.01 | <0.01 | <0.001 | <0.005 |
| *10/17/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.107 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.043 | <0.005 | <0.01 | 0.0001 | <0.01 | <0.01 | <0.001 | 0.009 |
| 4/25/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.093 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.061 | <0.005 | <0.01 | 0.00011 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.171 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.151 | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | **0.433** | <0.01 | 0.007 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | **0.39** | <0.01 | 0.007 | 0.00008 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/5/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | *0.232* | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.213* | <0.005 | <0.01 | <0.01 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.01 | 0.163 | 0.005 | 0.01 | 0.00007 | 0.01 | 0.01 | 0.002 | 0.007 |
| 4/18/2002 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.332** | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.323** | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 12/13/2001 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.54** | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.393** | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | 0.014 |
| 3/9/2001 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.173 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.156 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 10/11/2000 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.218 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.206 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 2/25/2000 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | *0.223* | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.216 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 8/12/1999 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.169 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | - | - | - | - | - | - | - | - | - | - | - | - |
| 7/22/1999* | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.155 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.129 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 7/22/1999 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.146 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.116 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 3/25/1999 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.21 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.010 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 12/15/1998* | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.087 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.034 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 12/15/1998 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.068 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.044 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 8/25/1998 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.122 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.069 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 7/31/1998 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.08 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.064 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 3/20/1998 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.096 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.058 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 12/4/1997* | Totals | <0.002 | <0.002 | <0.002 | <0.01 | *0.084* | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.063 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 12/4/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.08 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.075 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 9/16/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.136 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.133 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 8/15/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.145 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.069 | <0.005 | - | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| 7/30/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.23 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.001 |
| | Dissolved | <0.002 | - | - | - | - | - | - | - | - | - | - | - |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | 0.151 | 0.005 | 0.01 | 0.0005 | 0.011 | 0.01 | 0.001 | 0.01 |
| **Picher #6** | | | | | | | | | | | | | |
| 4/21/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.369** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.008 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.339** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.007 |
| *4/21/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.379** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.355** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.007 |
| 10/22/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.351** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.008 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.275* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.009 |
| *10/22/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.35** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.014 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.259* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.011 |
| 5/7/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.325** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.302** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *5/7/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.327** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.307** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/7/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.302** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.008 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.274* | <0.005 | <0.01 | 0.00005 | <0.01 | <0.01 | <0.001 | 0.008 |
| 4/10/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.309** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.284* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *4/10/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.301** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Analysis | | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| Unit | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| MCL/(SMCL) | | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.222* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/27/2005 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | *0.296* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | *0.238* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *10/27/2005 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | *0.298* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | *0.282* | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| 4/25/2005 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | **0.345** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | **0.341** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.007 |
| *4/25/2005 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | **0.338** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | **0.331** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.006 |
| 10/11/2004 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | **0.531** | <0.005 | 0.012 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.021 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | **0.507** | <0.005 | 0.012 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.02 |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | **0.444** | <0.01 | 0.011 | 0.00005 | <0.01 | <0.01 | <0.01 | 0.015 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | **0.414** | <0.01 | 0.011 | 0.00005 | <0.01 | <0.01 | <0.01 | 0.019 |
| 12/9/2003 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | **0.464** | <0.005 | 0.013 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.016 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | **0.337** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.015 |
| *12/9/2003 | Totals | <0.002 | 0.002 | <0.002 | <0.01 | **0.46** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.014 |
| | Dissolved | <0.002 | 0.002 | <0.002 | <0.01 | **0.337** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.016 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | **0.341** | 0.005 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.002 | 0.009 |
| 4/18/2002 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **0.6** | <0.0005 | 0.011 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.015 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **0.563** | <0.0005 | 0.011 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.017 |
| 12/13/2001 | Totals | <0.002 | 0.003 | <0.002 | <0.01 | **0.677** | <0.0005 | 0.012 | <0.00005 | 0.01 | <0.01 | <0.001 | 0.016 |
| | Dissolved | <0.002 | 0.003 | <0.002 | <0.01 | **0.653** | <0.0005 | 0.012 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.016 |
| 2/26/2001 | Totals | <0.002 | 0.004 | <0.002 | <0.01 | **1.669** | <0.0005 | 0.024 | <0.00005 | 0.032 | <0.01 | <0.001 | 0.079 |
| | Dissolved | <0.002 | 0.004 | <0.002 | <0.01 | **1.659** | <0.0005 | 0.025 | <0.00005 | 0.032 | <0.01 | <0.001 | 0.078 |
| 10/17/2000 | Totals | <0.002 | 0.004 | <0.002 | <0.01 | **2.304** | <0.0005 | 0.027 | <0.00005 | 0.03 | <0.01 | <0.001 | 0.11 |
| | Dissolved | <0.002 | 0.004 | <0.002 | <0.01 | **2.295** | <0.0005 | 0.028 | <0.00005 | 0.033 | <0.01 | <0.001 | 0.112 |
| 10/12/2000 | Totals | <0.002 | 0.004 | <0.002 | <0.01 | **2.288** | <0.0005 | 0.032 | <0.00005 | 0.026 | <0.01 | <0.001 | 0.098 |
| | Dissolved | - | - | - | - | - | - | - | - | - | - | - | - |
| | Averages | 0.002 | 0.003 | 0.002 | 0.01 | **1.412** | 0.005 | 0.02 | 0.00005 | 0.021 | 0.01 | 0.001 | 0.06 |
| **Picher #7** | | | | | | | | | | | | | |
| 4/21/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.176 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.187 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/22/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.079 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.071 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 5/8/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.079 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.075 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/7/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.124 | <0.005 | 0.006 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.113 | <0.005 | 0.006 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/11/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.079 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.065 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/17/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.064 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.062 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| 4/25/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.09 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.09 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/12/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.127 | <0.005 | <0.01 | 0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.121 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/27/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.078 | <0.01 | 0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.072 | <0.01 | <0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/5/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.166 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.16 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.01 | 0.104 | 0.006 | 0.009 | 0.00005 | 0.01 | 0.01 | 0.002 | 0.006 |
| 4/19/2002* | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.111 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.079 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 4/19/2002 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.092 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.073 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 12/13/2001* | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.074 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.048 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 12/13/2001 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.063 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.049 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 3/9/2001 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.173 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.16 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/17/2000* | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.18 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.164 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/17/2000 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.163 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.159 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| 10/13/2000 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.348 | <0.005 | <0.01 | <0.0005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | - | - | - | - | - | - | - | - | - | - | - | - |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | 0.129 | 0.005 | 0.01 | 0.0005 | 0.01 | 0.01 | 0.001 | 0.01 |
| **Quapaw #2** | | | | | | | | | | | | | |
| 11/6/1997 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **1.688** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.061 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **1.653** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.059 |
| 7/17/1997 | Totals | <0.002 | 0.002 | <0.002 | 0.015 | **1.807** | <0.005 | - | <0.00005 | 0.01 | <0.01 | <0.001 | 0.063 |
| | Dissolved | <0.002 | 0.002 | <0.002 | 0.015 | **1.765** | <0.005 | - | <0.00005 | 0.01 | <0.01 | <0.001 | 0.06 |
| 2/4/1997 | Totals | <0.002 | <0.002 | <0.002 | 0.014 | **1.335** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.044 |
| | Dissolved | <0.002 | <0.002 | <0.002 | 0.013 | **1.336** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.043 |
| 10/14/1996 | Totals | <0.002 | 0.003 | <0.002 | 0.015 | **1.707** | <0.005 | - | 0.0007 | <0.01 | <0.01 | <0.001 | 0.146 |
| | Dissolved | <0.002 | 0.002 | <0.002 | 0.013 | **1.566** | <0.005 | - | <0.00005 | <0.01 | <0.01 | <0.001 | 0.029 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.013 | **1.597** | 0.005 | - | 0.0005 | 0.01 | 0.01 | 0.001 | 0.055 |
| **Quapaw #4** | | | | | | | | | | | | | |
| 4/22/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/24/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.01 |
| 5/9/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.043 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.041 |
| 11/9/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/12/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/18/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/26/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/13/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.005 |
| *10/13/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/28/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | <0.02 | <0.01 | <0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | 0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | <0.02 | <0.01 | <0.005 | <0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| *11/6/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.01 | 0.02 | 0.005 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.002 | 0.009 |
| **Quapaw #5** | | | | | | | | | | | | | |
| 4/23/2008 | Totals | <0.002 | 0.004 | <0.002 | <0.01 | **2.88** | <0.005 | 0.026 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.135* |
| | Dissolved | <0.002 | 0.006 | <0.002 | <0.01 | **2.77** | <0.005 | 0.036 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.126* |
| *4/23/2008 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **2.92** | <0.005 | 0.031 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.138* |
| | Dissolved | <0.002 | 0.006 | <0.002 | <0.01 | **2.79** | <0.005 | 0.034 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.129* |
| 10/24/2007 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **2.77** | <0.005 | 0.033 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.13* |
| | Dissolved | <0.002 | 0.005 | <0.002 | <0.01 | **2.42** | <0.005 | 0.032 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.126* |
| *10/24/2007 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **2.81** | <0.005 | 0.034 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.132* |
| | Dissolved | <0.002 | 0.004 | <0.002 | <0.01 | **2.33** | <0.005 | 0.03 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.116* |
| 5/9/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **2.62** | <0.005 | 0.026 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.121* |
| | Dissolved | <0.002 | 0.004 | <0.002 | <0.01 | **2.45** | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.114* |
| 11/9/2006 | Totals | <0.002 | 0.004 | <0.002 | <0.01 | **2.48** | <0.005 | 0.035 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.113* |
| | Dissolved | <0.002 | 0.004 | <0.002 | <0.01 | **2.42** | <0.005 | 0.035 | 0.00005 | <0.01 | <0.01 | <0.001 | *0.11* |
| 4/12/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **2.62** | <0.005 | 0.027 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.118* |
| | Dissolved | <0.002 | 0.005 | <0.002 | <0.01 | **2.57** | <0.005 | 0.037 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.112* |
| *4/12/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | **2.61** | <0.005 | 0.026 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.119* |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | **2.53** | <0.005 | 0.037 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.11* |
| 10/18/2005 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **2.44** | <0.005 | 0.036 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.139* |
| | Dissolved | <0.002 | 0.005 | <0.002 | <0.01 | **2.34** | <0.005 | 0.038 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.143* |
| 4/26/2005 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **2.86** | <0.005 | 0.039 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.167* |
| | Dissolved | <0.002 | 0.005 | <0.002 | <0.01 | **2.68** | <0.005 | 0.039 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.159* |
| 10/13/2004 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **3.06** | <0.005 | 0.043 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.178* |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| | Dissolved | <0.002 | 0.005 | <0.002 | <0.01 | **2.75** | <0.005 | 0.042 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.16* |
| 4/28/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | **3.68** | <0.01 | 0.05 | <0.00005 | <0.01 | <0.01 | <0.01 | *0.208* |
| | Dissolved | <0.01 | **0.011** | <0.005 | <0.005 | **3.58** | <0.01 | 0.049 | <0.00005 | <0.01 | <0.01 | <0.01 | *0.194* |
| 11/6/2003 | Totals | <0.002 | 0.005 | <0.002 | <0.01 | **3.72** | <0.005 | 0.046 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.222* |
| | Dissolved | <0.002 | 0.005 | <0.002 | <0.01 | **3.69** | <0.005 | 0.047 | <0.00005 | <0.01 | <0.01 | <0.001 | *0.213* |
| | Averages | 0.003 | 0.005 | 0.002 | 0.01 | **2.8** | 0.005 | 0.035 | 0.00005 | 0.01 | 0.01 | 0.002 | *0.144* |
| 4/18/2002 | Totals | <0.002 | 0.003 | <0.002 | <0.01 | **3.072** | <0.005 | 0.037 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.08* |
| | Dissolved | <0.002 | 0.003 | <0.002 | <0.01 | **2.943** | <0.005 | 0.037 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.08* |
| 12/14/2001 | Totals | <0.002 | 0.003 | <0.002 | <0.01 | **2.762** | 0.012 | 0.037 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.135* |
| | Dissolved | <0.002 | 0.004 | <0.002 | <0.01 | **2.619** | <0.005 | 0.037 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.141* |
| 3/9/2001* | Totals | <0.002 | 0.003 | <0.002 | <0.01 | **2.855** | <0.005 | 0.036 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.113* |
| | Dissolved | <0.002 | 0.003 | <0.002 | <0.01 | **2.082** | <0.005 | 0.035 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.109* |
| 3/9/2001 | Totals | <0.002 | 0.003 | <0.002 | <0.01 | **2.325** | <0.005 | 0.036 | <0.0005 | <0.01 | <0.01 | <0.01 | *0.118* |
| | Dissolved | <0.002 | 0.003 | <0.002 | <0.01 | **2.599** | <0.005 | 0.036 | <0.0005 | <0.01 | <0.01 | <0.01 | *0.115* |
| 10/13/2000 | Totals | <0.002 | 0.003 | <0.002 | <0.01 | **2.832** | <0.005 | 0.036 | <0.0005 | <0.01 | <0.01 | <0.001 | *0.132* |
| | Dissolved | - | - | - | - | - | - | - | - | - | - | - | - |
| | Averages | 0.002 | 0.003 | 0.002 | 0.01 | **2.677** | 0.006 | 0.036 | 0.0005 | 0.01 | 0.01 | 0.001 | *0.114* |
| **RWD4 #3** | | | | | | | | | | | | | |
| 4/23/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.039 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.033 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/24/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.026 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 5/9/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.024 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.021 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *5/9/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.022 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/9/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.025 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.022 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/2/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.022 | <0.005 | 0.015 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/18/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.025 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.022 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/26/2005 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.031 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.026 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/13/2004 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.026 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | <0.02 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 4/28/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.026 | <0.01 | <0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.027 | <0.01 | <0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| *4/28/2004 | Totals | <0.01 | <0.01 | <0.005 | <0.005 | 0.025 | <0.01 | <0.005 | 0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| | Dissolved | <0.01 | <0.01 | <0.005 | <0.005 | 0.029 | <0.01 | <0.005 | <0.00005 | <0.01 | <0.01 | <0.01 | <0.005 |
| 11/7/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.044 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.038 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |

TABLE 7-9
Dissolved Trace Metals Analytical Results in Roubidoux Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | Analysis | **Antimony** | **Arsenic** | **Cadmium** | **Chromium** | **Iron** | **Lead** | **Manganese** | **Mercury** | **Nickel** | **Selenium** | **Thallium** | **Zinc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sb | As | Cd | Cr | Fe | Pb | Mn | Hg | Ni | Se | Tl | Zn |
| | Unit | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| | MCL/(SMCL) | 0.006 | 0.010 | 0.005 | 0.1 | (0.3) | 0.015 | (0.05) | 0.002 | | 0.05 | 0.002 | (5) |
| Roubidoux Tolerance Limit / Background Level | | | | | | .207/.062 | | | | | | | .043/.009 |
| *11/7/2003 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.045 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.038 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.01 |
| | Averages | 0.003 | 0.003 | 0.002 | 0.009 | 0.028 | 0.006 | 0.009 | 0.00005 | 0.01 | 0.01 | 0.002 | 0.006 |
| **RWD7 #2** | | | | | | | | | | | | | |
| 5/9/2008 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.078 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.105 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 10/24/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.144 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.012 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.081 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | 0.007 |
| 5/9/2007 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.118 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.095 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| 11/9/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.087 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.076 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| *11/9/2006 | Totals | <0.002 | <0.002 | <0.002 | <0.01 | 0.09 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Dissolved | <0.002 | <0.002 | <0.002 | <0.01 | 0.075 | <0.005 | <0.01 | <0.00005 | <0.01 | <0.01 | <0.001 | <0.005 |
| | Averages | 0.002 | 0.002 | 0.002 | 0.01 | 0.095 | 0.005 | 0.01 | 0.00005 | 0.01 | 0.01 | 0.001 | 0.006 |

**Notes:**

mg/l milligrams per liter
MCL maximum contaminant level as of May, 2009 (EPA, 2009)
SMCL secondary maximum contaminant level as of May, 2009 (EPA, 2009)
**bold** **indicates value greater than MCL or SMCL**
*itallicized* *indicates value greater than tolerance limit for Roubidoux aquifer*

**Roubidoux Water Quality Interpretation (per guidelines est. by ODEQ)**
Indicator parameters are iron, sulfate, and zinc.

- A well producing water with concentrations in excess of the tolerance limits for all three indicator parameters indicates the Roubidoux is impacted by mine water locally near the well site.

- A well producing water with concentrations in excess of the background concentrations for all three indicator parameters and above the tolerance limits for two of the indicator parameters indicates the Roubidoux is probably impacted by mine water locally near the well site.

- A well producing water with concentrations in excess of the background concentrations for two of the three indicator parameters and above the tolerance limits for one of the indicator parameters indicates the Roubidoux is possibly impacted by mine water locally near the well site.

TABLE 7-10

Summary Statistics for Trace Metals Analytical Results for Samples Collected during 2009

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| | Aluminum | Antimony | Arsenic | Barium | Beryllium | Cadmium | Chromium | Cobalt | Copper | Lead | Mercury | Nickel | Selenium | Silver | Thallium | Vanadium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Boone Aquifer** | | | | | | | | | | | | | | | | | |
| **min** | 109.0 | 0.0 | 2.1 | 10.5 | 0.0 | 7.0 | 12.2 | 21.6 | 21.1 | 2.4 | 0.0 | 26.4 | 52.3 | 0.0 | 0.0 | 25.4 | 21.9 |
| **max** | 193.0 | 0.0 | 67.6 | 429.0 | 0.0 | 7.0 | 77.5 | 128.0 | 56.1 | 2.7 | 0.0 | 364.0 | 69.6 | 0.0 | 0.0 | 37.3 | 9410.0 |
| **mean** | 145.3 | -- | 16.4 | 59.9 | -- | 7.0 | 40.8 | 44.5 | 37.1 | 2.6 | -- | 152.6 | 61.0 | -- | -- | 31.4 | 1950.3 |
| **median** | 134.0 | -- | 11.4 | 31.2 | -- | 7.0 | 32.8 | 32.8 | 35.6 | 2.6 | -- | 152.0 | 61.0 | -- | -- | 31.4 | 1210.0 |
| **std dev** | 43.1 | -- | 17.2 | 93.9 | -- | -- | 33.4 | 30.9 | 14.5 | 0.2 | -- | 89.3 | 12.2 | -- | -- | 8.4 | 2867.2 |
| **n** | 3 | 0 | 32 | 51 | 0 | 1 | 3 | 15 | 4 | 2 | 0 | 24 | 2 | 0 | 0 | 2 | 42 |
| **total** | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| **% Detections** | 5% | 0% | 57% | 91% | 0% | 2% | 5% | 27% | 7% | 4% | 0% | 43% | 4% | 0% | 0% | 4% | 75% |
| **Mine Pool** | | | | | | | | | | | | | | | | | |
| **min** | 109.0 | 0.0 | 3.0 | 10.1 | 0.0 | 6.8 | 10.3 | 21.3 | 22.2 | 2.1 | 0.0 | 20.9 | 2.0 | 0.0 | 2.0 | 33.3 | 40.3 |
| **max** | 929.0 | 0.0 | 41.6 | 34.4 | 0.0 | 206.0 | 12.5 | 296.0 | 22.2 | 171.0 | 0.0 | 1960.0 | 4.7 | 0.0 | 2.0 | 42.0 | 55100.0 |
| **mean** | 477.8 | -- | 17.9 | 16.2 | -- | 115.4 | 11.4 | 75.9 | 22.2 | 56.2 | -- | 306.5 | 2.9 | -- | 2.0 | 37.7 | 16455.2 |
| **median** | 522.0 | -- | 14.3 | 12.7 | -- | 129.5 | 11.4 | 28.7 | 22.2 | 21.7 | -- | 193.0 | 2.8 | -- | 2.0 | 37.7 | 13900.0 |
| **std dev** | 308.5 | -- | 12.6 | 7.6 | -- | 53.1 | 1.6 | 96.5 | -- | 55.9 | -- | 460.6 | 0.7 | -- | -- | 6.2 | 16029.1 |
| **n** | 12 | 0 | 28 | 26 | 0 | 26 | 2 | 21 | 1 | 32 | 0 | 47 | 18 | 0 | 1 | 2 | 53 |
| **total** | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 |
| **% Detections** | 23% | 0% | 53% | 49% | 0% | 49% | 4% | 40% | 2% | 60% | 0% | 89% | 34% | 0% | 2% | 4% | 100% |

**Notes:**

min = minimum detected concentration

max = maximum detected concentration

mean = mean of detected concentrations

std dev = standard deviation

n = number of samples in which analyte was detected

total = total number of samples

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TABLE 7-11

Comparison of Analytical Results For Trace Metals from 0.10- and 0.45-Micron Filtered Groundwater and Mine Water Samples

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| Station ID : | | BMW02 | | | | BMW05 | | | | BMW12 | | | | FT059-MW3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date Collected : | | 7/29/2009 | | | | 8/3/2009 | | | | 8/4/2009 | | | | 7/28/2009 | | | |
| Filter Type : | | 0.1 µm | | 0.45 µm | | 0.1 µm | | 0.45 µm | | 0.1 µm | | 0.45 µm | | 0.1 µm | | 0.45 µm | |
| **Parameter Name** | **Units** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** |
| Aluminum (Dissolved) | µg/L | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U | 100 | U |
| Antimony (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | µg/L | **22.7** | = | **22.8** | = | **2** | = | **2.5** | = | **8.8** | = | **9.6** | = | **10** | = | **7.6** | = |
| Barium (Dissolved) | µg/L | **14.2** | = | **15.7** | = | **30** | = | **28.1** | = | **32.6** | = | **33.3** | = | **25.3** | = | **24.2** | = |
| Beryllium (Dissolved) | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Calcium (Dissolved) | µg/L | **490,000** | = | **517,000** | = | **580,000** | = | **568,000** | = | **550,000** | = | **562,000** | = | **278,000** | = | **272,000** | = |
| Chromium (Dissolved) | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | µg/L | **30.8** | = | **31.3** | = | 20 | U | 20 | U | **51.9** | = | **49.2** | = | **40.5** | = | **48.6** | = |
| Copper (Dissolved) | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Iron (Dissolved) | µg/L | **20,200** | = | **21,800** | = | **27,300** | **J** | **27,300** | **J** | **136,000** | = | **141,000** | = | **58,900** | = | **63,400** | = |
| Lead (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Magnesium (Dissolved) | µg/L | **52,800** | = | **56,700** | = | **54,700** | = | **54,700** | = | **55,500** | = | **56,400** | = | **55,500** | = | **55,000** | = |
| Manganese (Dissolved) | µg/L | **1,720** | = | **1,840** | = | **1,040** | = | **1,040** | = | **3,180** | = | **3,230** | = | **8,380** | = | **9,570** | = |
| Mercury (Dissolved) | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | µg/L | 184 | = | 196 | = | 20 | U | 20 | U | 259 | = | 265 | = | 20 | U | 20 | U |
| Potassium (Dissolved) | µg/L | **14,500** | = | **15,000** | = | **14,500** | = | **14,300** | = | **5,000** | = | **5,170** | = | **4,260** | = | **3,970** | = |
| Selenium (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Sodium (Dissolved) | µg/L | **52,200** | = | **56,000** | = | **51,600** | = | **47,900** | = | **32,500** | = | **34,000** | = | **69,400** | = | **69,800** | = |
| Thallium (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | µg/L | **6,030** | = | **6,300** | = | 20 | U | 20 | U | **1,200** | = | **1,210** | = | **95.1** | **J** | **94** | **J** |

**Notes:**

= - Detected concentration

U - Not detected

J - Estimated concentration

µg/L - micrograms per liter

µm - micrometers

Detections are indicated by **bold** text

TABLE 7-11

Comparison of Analytical Results For Trace Metals from 0.10- and 0.45-Micron Filtered Groundwater and Mine Water Samples

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| Station ID : | | LMB2 | | | | RMB3 | | | | TMB3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date Collected : | | 8/5/2009 | | | | 8/4/2009 | | | | 8/4/2009 | | | |
| Filter Type : | | 0.1 µm | | 0.45 µm | | 0.1 µm | | 0.45 µm | | 0.1 µm | | 0.45 µm | |
| **Parameter Name** | **Units** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** | **Result** | **Qualifier** |
| Aluminum (Dissolved) | µg/L | **109** | = | **100** | = | **144** | = | **140** | = | 100 | U | 100 | U |
| Antimony (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Arsenic (Dissolved) | µg/L | **14.1** | = | **13.8** | = | **38.7** | = | **37.6** | = | **13.8** | = | **13.2** | = |
| Barium (Dissolved) | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Beryllium (Dissolved) | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Cadmium (Dissolved) | µg/L | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U | 5 | U |
| Calcium (Dissolved) | µg/L | **521,000** | = | **510,000** | = | **466,000** | = | **479,000** | = | **586,000** | = | **599,000** | = |
| Chromium (Dissolved) | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Cobalt (Dissolved) | µg/L | **28.6** | = | **28.5** | = | 20 | U | 20 | U | 20 | U | 20 | U |
| Copper (Dissolved) | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Iron (Dissolved) | µg/L | **38,600** | = | **37,400** | = | **40,400** | **J** | **41000** | **J** | **28,400** | = | **29,800** | = |
| Lead (Dissolved) | µg/L | 5.7 | U | **10.1** | = | 2 | U | 2 | U | 2 | U | 2 | U |
| Magnesium (Dissolved) | µg/L | **57,200** | = | **56,100** | = | **19,400** | = | **19,900** | = | **42,000** | = | **43,800** | = |
| Manganese (Dissolved) | µg/L | **1,520** | = | **1,500** | = | **577** | **J** | **588** | **J** | **1,240** | = | **1,290** | = |
| Mercury (Dissolved) | µg/L | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U | 0.2 | U |
| Nickel (Dissolved) | µg/L | **260** | = | **257** | = | **95.8** | = | **98.6** | = | **37.4** | = | **39.8** | = |
| Potassium (Dissolved) | µg/L | **3,330** | = | **3,240** | = | **1,990** | = | **2,020** | = | **5,330** | = | **5,800** | = |
| Selenium (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Silver (Dissolved) | µg/L | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U | 10 | U |
| Sodium (Dissolved) | µg/L | **56,500** | = | **53,700** | = | **18,100** | = | **18,000** | = | **22,800** | = | **24,700** | = |
| Thallium (Dissolved) | µg/L | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U | 2 | U |
| Vanadium (Dissolved) | µg/L | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U | 20 | U |
| Zinc (Dissolved) | µg/L | **11,100** | = | **11,100** | = | **2,580** | = | **2,690** | = | **3,100** | = | **3,080** | = |

**Notes:**

= - Detected concentration

U - Not detected

J - Estimated concentration

µg/L - micrograms per liter

µm - micrometers

Detections are indicated by **bold** text

TABLE 7-12
Statistical Analysis of Groundwater Chemistry Parameters for Representative Well Set
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | | Field Parameters | | | General Chemistry Parameters (milligrams per liter) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Source | No. Locations | Statistic | pH | SC | Temp | T_Alk | Cl | F | NH3N | NO3N | SO4 | S2- | TDS | Na | K | Ca | Mg | Fe | Mn | Al |
| Boone | 18 | Min | 5.73 | 472 | 15.0 | 24 | <5 | <0.25 | <0.05 | <0.02 | <5 | <0.01 | 338 | 14.9 | 0.5 | 11.9 | 3.4 | <0.025 | 0.0164 | <100 |
| | | Median | 6.57 | 2,264 | 16.1 | 221 | 11 | 0.465 | 0.165 | <0.02 | 1395 | 0.015 | 2085 | 48.1 | 4.745 | 423 | 44.65 | 5.7035 | 1.14 | <100 |
| | | Max | 7.97 | 4,144 | 19.4 | 500 | 74 | 3.29 | 0.76 | 0.09 | 2350 | 23.1 | 4360 | 164 | 18.5 | 595 | 289 | 107 | 13 | 193 |
| Mine Pool | 22 | Min | 5.88 | 221 | 15.6 | 47 | <5 | <0.25 | <0.05 | <0.02 | 24 | <0.01 | 178 | 3.49 | 1.42 | 30.2 | 3.87 | <0.025 | 0.178 | <100 |
| | | Median | 6.53 | 2,465 | 16.2 | 154.5 | 14 | 2.2 | 0.205 | <0.02 | 1545 | <0.01 | 2345 | 47.4 | 3.46 | 546 | 53.6 | 22.05 | 0.922 | <100 |
| | | Max | 7.98 | 3,402 | 27.3 | 274 | 51 | 6.54 | 2.43 | 0.71 | 2600 | 2.45 | 4100 | 86.1 | 9.84 | 631 | 255 | 297 | 4.2 | 929 |
| Roubidoux | 19 | Min | 6.5 | 276 | 16.0 | 107 | <10 | 0 | 0 | 0 | <10 | 0 | 149 | 6 | <2 | 22 | 12 | <0.020 | <0.005 | 0 |
| | | Median | 7.23 | 533 | 20.3 | 128 | 24.5 | NA | NA | NA | 66 | NA | 265 | 15 | 2 | 43 | 20 | 0.121 | <0.010 | NA |
| | | Max | 8.27 | 1,497 | 23.0 | 265 | 277 | 0 | 0 | 0 | 456 | 0 | 1080 | 175 | 8.3 | 156 | 73.4 | 2.79 | 0.036 | 0 |

**Abbreviations**

| | |
|---|---|
| SC | Specific Conductance (microSiemens/cm) |
| Temp | Temperature (degrees Centigrade) |
| Turb | Turbidity (NTU) |
| T_Alk | Total Alkalinity (mg/L CaCO3) |
| Cl | Chloride |
| F | Fluoride |
| NH3N | Ammonia as Nitrogen |
| NO3N | Nitrate as Nitrogen |
| SO4 | Sulfate |
| S2- | Sulfide |
| TDS | Total Dissolved Solids |
| Na | Sodium |
| K | Potassium |
| Ca | Calcium |
| Mg | Magnesium |
| Fe | Iron |
| Mn | Manganese |
| Al | Aluminum |
| Sb | Antimony |
| As | Arsenic |
| Ba | Barium |
| Be | Beryllium |
| Cd | Cadmium |
| Cr | Chromium |
| Co | Cobalt |
| Cu | Copper |
| Pb | Lead |
| Hg | Mercury |
| Ni | Nickel |
| Se | Selenium |
| Ag | Silver |
| Tl | Thallium |
| V | Vanadium |
| Zn | Zinc |

**Well Sets**

| Boone | Mine Pool | Roubidoux |
|---|---|---|
| BMW01 | FCB2 | Cardin #1 |
| BMW02 | FCB3 | Commerce #3 |
| BMW05 | LMB2 | Commerce #4 |
| BMW07 | MD2 | Commerce #5 |
| BMW08 | MMB2 | Miami #1 |
| BMW09 | MP04 | Miami #11 |
| BMW11 | MP05 | Miami #3 |
| BMW12 | MP06 | Ontario (Fernandez) Well |
| BMW13 | MP17 | Picher #2 |
| BMW15 | MP20 | Picher #3 |
| BW02 | OCC3 | Picher #4 |
| BW06 | RMB3 | Picher #5 |
| BW07 | RMB4 | Picher #6 |
| BW11 | SMB2 | Picher #7 |
| BW13 | SMB3 | Quapaw #2 |
| BW14 | SMB5 | Quapaw #4 |
| BW15 | SMB6 | Quapaw #5 |
| BW16 | SMB7 | RWD4 #3 |
| | SMB8 | RWD7 #2 |
| | SMB9 | |
| | TMB2 | |
| | TMB3 | |

**Missing Wells**

| Well | Reason |
|---|---|
| FW1 | No dissolved concentrations available |
| LKP | No general chemistry parameters available |
| RMB1A | No dissolved concentrations or general chemisry parameters available |
| RMB2 | No dissolved concentrations or general chemisry parameters available |
| TMB1 | No dissolved concentrations or general chemisry parameters available |
| BMW04 | Not considered representative (pH>10) |
| BMW06 | Not considered representative (pH>10) |
| BMW14 | Not considered representative (pH>10) |

**Notes**

Single Representatives of each well
All have complete genchem analysis
All trace metal concentrations are dissolved
Statistics calculated by counting non-detects as one half of the reporting limit

TABLE 7-12
Statistical Analysis of Groundwater Chemistry Parameters for Rep
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | | Dissolved Trace Metals (micrograms per liter) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Source | No. Locations | Statistic | Sb | As | Ba | Be | Cd | Cr | Co | Cu | Pb | Hg | Ni | Se | Ag | Tl | V | Zn |
| Boone | 18 | Min | <2 | <2 | <10 | <5 | <5 | <10 | <20 | <20 | <2 | <0.2 | <20 | <2 | <10 | <2 | <20 | <20 |
| | | Median | <4 | 4.1 | 23.45 | <5 | <5 | <10 | <20 | <20 | <5 | <0.2 | <20 | <4 | <10 | <4 | <20 | 56.85 |
| | | Max | <5 | 65.5 | 428 | <5 | <5 | 12.2 | 36.1 | <20 | 2.7 | <0.2 | 264 | <5 | <10 | <5 | <20 | 9410 |
| Mine Pool | 22 | Min | <1 | <2 | <10 | <5 | <5 | <10 | <20 | <20 | <2 | <0.2 | <20 | <2 | <10 | <1 | <20 | 40.3 |
| | | Median | <2 | 8.25 | <10 | <5 | <5 | <10 | <20 | <20 | 3.7 | <0.2 | 156 | <5 | <10 | <2 | <20 | 10050 |
| | | Max | <5 | 69.3 | 34.4 | <5 | 246 | 12.5 | 293 | 29.8 | 148 | <0.2 | 1960 | <10 | <10 | <5 | 33.3 | 53400 |
| Roubidoux | 19 | Min | <2 | <2 | 0 | 0 | <2 | <5 | 0 | 0 | <5 | <0.1 | <10 | <10 | 0 | <1 | 0 | <1 |
| | | Median | <2 | <2 | NA | NA | <2 | <10 | NA | NA | <5 | <0.1 | <10 | <10 | NA | <1 | NA | <5 |
| | | Max | <10 | 6 | 0 | 0 | <5 | 12 | 0 | 0 | 10 | <10.0 | 14 | <10 | 0 | <10 | 0 | 129 |

**Abbreviations**

| | |
|---|---|
| SC | Specific Conductance (microSiemen |
| Temp | Temperature (degrees Centigrade) |
| Turb | Turbidity (NTU) |
| T_Alk | Total Alkalinity (mg/L CaCO3) |
| Cl | Chloride |
| F | Fluoride |
| NH3N | Ammonia as Nitrogen |
| NO3N | Nitrate as Nitrogen |
| SO4 | Sulfate |
| S2- | Sulfide |
| TDS | Total Dissolved Solids |
| Na | Sodium |
| K | Potassium |
| Ca | Calcium |
| Mg | Magnesium |
| Fe | Iron |
| Mn | Manganese |
| Al | Aluminum |
| Sb | Antimony |
| As | Arsenic |
| Ba | Barium |
| Be | Beryllium |
| Cd | Cadmium |
| Cr | Chromium |
| Co | Cobalt |
| Cu | Copper |
| Pb | Lead |
| Hg | Mercury |
| Ni | Nickel |
| Se | Selenium |
| Ag | Silver |
| Tl | Thallium |
| V | Vanadium |
| Zn | Zinc |

**Well Sets**

| Boone | Mine Pool | Roubidoux |
|---|---|---|
| BMW01 | FCB2 | Cardin #1 |
| BMW02 | FCB3 | Commerce #3 |
| BMW05 | LMB2 | Commerce #4 |
| BMW07 | MD2 | Commerce #5 |
| BMW08 | MMB2 | Miami #1 |
| BMW09 | MP04 | Miami #11 |
| BMW11 | MP05 | Miami #3 |
| BMW12 | MP06 | Ontario (Fernandez) Well |
| BMW13 | MP17 | Picher #2 |
| BMW15 | MP20 | Picher #3 |
| BW02 | OCC3 | Picher #4 |
| BW06 | RMB3 | Picher #5 |
| BW07 | RMB4 | Picher #6 |
| BW11 | SMB2 | Picher #7 |
| BW13 | SMB3 | Quapaw #2 |
| BW14 | SMB5 | Quapaw #4 |
| BW15 | SMB6 | Quapaw #5 |
| BW16 | SMB7 | RWD4 #3 |
| | SMB8 | RWD7 #2 |
| | SMB9 | |
| | TMB2 | |
| | TMB3 | |

**Missing Wells**

| Well | Reason |
|---|---|
| FW1 | No dissolved concentrations available |
| LKP | No general chemistry parameters available |
| RMB1A | No dissolved concentrations or general chemisry parameters available |
| RMB2 | No dissolved concentrations or general chemisry parameters available |
| TMB1 | No dissolved concentrations or general chemisry parameters available |
| BMW04 | Not considered representative (pH>10) |
| BMW06 | Not considered representative (pH>10) |
| BMW14 | Not considered representative (pH>10) |

TABLE 8-1

Measured Stage and Discharge Data for Surface Water Stage-Discharge Rating Curves

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| TC-US | | LC-30 | | QC-DS | |
|---|---|---|---|---|---|
| **Stage (feet amsl)** | **Discharge (cfs)** | **Stage (feet amsl)** | **Discharge (cfs)** | **Stage (feet amsl)** | **Discharge* (cfs)** |
| 802.64 | 1 | 804.76 | 0 | 795.12 | 0 |
| 802.94 | 23 | 805.02 | 21 | 796.00 | 10 |
| 803.44 | 55 | 805.08 | 35 | 796.19 | 8 |
| 803.53 | 63 | 805.35 | 51 | 796.52 | 12 |
| 803.90 | 90 | 805.64 | 77 | 796.37 | 16 |
| 804.72 | 185 | 805.75 | 77 | 797.06 | 30 |
| 805.82 | 325 | 805.95 | 129 | 798.13 | *90* |
| 807.35 | 697 | 806.67 | 279 | 798.62 | *160* |
| | | 807.18 | 504 | 798.97 | *210* |

**Notes:**

*Italicized flow values were computed using the HEC-RAS hydraulic model with field measured, water-surface slope as an input parameter.

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TABLE 8-2

Statistics of Surface Water Stage and Flow Data between December 21, 2009 and June 1, 2010

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| Parameter (units) | Statistic | TC-US | LC-30 | QC-DS | USGS TC Gage at Hwy 69[a] |
|---|---|---|---|---|---|
| Stage (feet amsl) | Minimum | 802.34 | 804.11 | 795.07 | - |
| | Median | 802.66 | 804.49 | 795.27 | - |
| | Mean | 802.81 | 804.60 | 795.48 | - |
| | Maximum | 807.99 | 807.46 | 799.43 | - |
| | StDev | 0.57 | 0.42 | 0.60 | - |
| | Range | 5.64 | 3.35 | 4.35 | - |
| Flow (cfs) | Minimum | 0.0 | 0.0 | 0.0 | 4.8 |
| | Median | 2.5 | 0.0 | 0.7 | 20.0 |
| | Mean | 20.9 | 11.0 | 5.9 | 59.3 |
| | Maximum | 1102 | 675 | 378 | 1690 |
| | StDev | 69 | 49 | 26 | 159 |
| | Range | 1102 | 675 | 378 | 1685 |
| | *No. of Values* [b] | *22,385* | *22,408* | *14,300* | *15,473* |

**Notes:**

[a]Only flow data was evaluated from the USGS Tar Creek gage at Highway 69.

[b]10-minute interval data values; except USGS TC Gage at Hwy 69, which was 15-minute interval data.

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TABLE 8-3

Comparison of Monthly Average Flows during the 2010 Study Period versus the Period-of-Record (P.O.R.) for the USGS Tar Creek Gage near Commerce, OK at Highway 69 (Station No. 07185090)

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| | **Flow (cfs)** | |
|---|---|---|
| **Year** | **2010** | **P.O.R.*** |
| January | 49 | 26 |
| February | 36 | 39 |
| March | 83 | 41 |
| April | 17 | 69 |
| May | 112 | 113 |
| Average | 60 | 58 |

**Notes:**

*2005 through 2009

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TABLE 8-4

Summary Statistics of 10-Minute Interval Mine Pool Elevations from Select Monitoring Wells from December 21, 2009, through May 25, 2010

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| Statistic | MP02 | MP03 | MP04 | RMB4 |
|---|---|---|---|---|
| Minimum (feet amsl) | 801.80 | 801.54 | 801.24 | 800.89 |
| Median (feet amsl) | 802.52 | 802.28 | 801.95 | 801.60 |
| Mean (feet amsl) | 802.54 | 802.29 | 801.98 | 801.62 |
| Maximum (feet amsl) | 804.76 | 804.51 | 804.19 | 803.82 |
| StDev (feet) | 0.29 | 0.30 | 0.29 | 0.30 |
| Range (feet) | 2.96 | 2.97 | 2.95 | 2.93 |
| *No. of Values* | 22,323 | 22,355 | 22,332 | 22,223 |

Note: Statistics of MP14 data is not included due to some erroneous data spikes.

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TABLE 8-5

Summary of Precipitation Data for Ottawa County and the Miami, OK, Mesonet Station

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| | Monthly Average | | Monthly Total | Extremes (1917-2002)[a] | | Extremes (1994-2004)[b] | |
|---|---|---|---|---|---|---|---|
| **Month** | **1971-2000[a]** | **1994-2004[b]** | **2010[c]** | **Monthly Max** | **Daily Max** | **Monthly Max** | **Daily Max** |
| January | 1.65 | 2.36 | 1.33 | 6.44 | 1.80 | 4.60 | 2.36 |
| February | 2.15 | 2.22 | 1.43 | 7.83 | 5.78 | 8.71 | 3.90 |
| March | 3.95 | 4.15 | 4.15 | 10.46 | 5.90 | 12.68 | 5.12 |
| April | 4.15 | 6.64 | 1.89 | 10.43 | 3.40 | 28.81 | 10.39 |
| May | 5.29 | 6.08 | 6.95 | 11.57 | 4.00 | 9.91 | 5.12 |
| June | 4.01 | 6.43 | - | 14.10 | 5.40 | 11.97 | 5.59 |
| July | 3.61 | 6.12 | - | 18.81 | 9.15 | 37.02 | 14.57 |
| August | 3.55 | 3.03 | - | 8.35 | 4.08 | 11.09 | 5.04 |
| September | 5.13 | NA | - | 14.94 | 6.00 | 15.63 | 5.91 |
| October | 3.70 | 5.88 | - | 13.15 | 4.95 | 24.98 | 10.20 |
| November | 4.51 | 5.46 | - | 11.08 | 4.47 | 35.10 | 6.97 |
| December | 2.81 | 2.65 | - | 7.27 | 5.57 | 5.89 | 2.44 |
| Annual | 44.51 | 55.54 | - | 18.81 | 9.15 | 37.02 | 14.57 |
| Jan-May total | 17.19 | 21.45 | 15.75 | | | | |

**Notes:**

[a]Source: *The Climate of Ottawa County* , Oklahoma Climatological Survey, http://climate.mesonet.org/county_climate/products/county_climatologies/county_climate_ottawa.pdf, accessed October 8, 2010.

[b]Source: Oklahoma Mesonet Station Summary, http://climate.mesonet.org/county_climate/Products/mesonet_summaries/MIAM_stnsum.html, accessed October 8, 2010

[c]Source: Monthly summation of daily rainfall totals downloaded from the Oklahoma Mesonet Station in Miami, OK.

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TABLE 8-6

Mine Pool Discharge Mass Balance Equation Input Values and Solutions, and Associated Mine Pool Elevations

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| *i* | | $y_i$ | $Q_{TCd/s}$ | $Q_{TCu/s} + Q_{LCu/s} + Q_{QC}$ | $Q_{runoff}$ | $Q_{mine\ pool}$ | MP02 | MP02 |
|---|---|---|---|---|---|---|---|---|
| **Event Date** | **Precipitation Depth (inch)** | **Runoff Ratio** | **USGS Tar Creek at Highway 69 (cfs)** | **Composite (cfs)** | **Precipitation Runoff (cfs)** | **Mine Pool Discharge (cfs)** | **Mine Pool Event Average Elevation (feet amsl)** | **Mine Pool Event Maximum Elevation (feet amsl)** |
| 21-Feb-10 | 0.62 | 28% | 43 | 28 | 3 | 13 | 802.59 | 802.80 |
| 21-Mar-10 | 1.14 | 45% | 158 | 101 | 11 | 46 | 802.83 | 803.12 |
| 25-Mar-10 | 1.73 | 52% | 552 | 365 | 38 | 149 | 803.22 | 804.37 |
| 5-Apr-10 | 0.58 | 12% | 53 | 41 | 4 | 9 | 802.69 | 802.78 |
| 13-May-10 | 3.77 | 48% | 326 | 247 | 28 | 51 | 802.99 | 804.76 |
| 19-May-10 | 2.11 | 43% | 287 | 190 | 20 | 76 | 802.98 | 804.71 |

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TABLE 9-1
Groundwater Model Calibration Targets
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Name | First Measurement Date | Last Measurement Date | Measurement Frequency | Observed Head (feet msl) | Simulated Head (feet msl) | Residual (feet) |
|---|---|---|---|---|---|---|
| BMW01 | Dec-08 | Dec-09 | 1 every 10 minutes | 801.29 | 802.1 | -0.81 |
| BMW02 | Jan-09 | Nov-09 | measurements in | 802.29 | 802.1 | 0.19 |
| BMW05 | Nov-08 | Dec-09 | 1 every 10 minutes | 801.34 | 802.08 | -0.74 |
| BMW06 | May-09 | Dec-09 | 1 every 10 minutes | 809.23 | 793.36 | 15.87 |
| BMW07 | May-09 | Dec-09 | 1 every 10 minutes | 801.22 | 798.95 | 2.27 |
| BMW08 | May-09 | Dec-09 | 1 every 10 minutes | 800.79 | 798.94 | 1.85 |
| BMW09 | May-09 | Dec-09 | 1 every 10 minutes | 801.02 | 798.94 | 2.08 |
| BMW11 | May-09 | Dec-09 | 1 every 10 minutes | 801.18 | 799.7 | 1.48 |
| BMW12 | May-09 | Dec-09 | 1 every 10 minutes | 801.35 | 799.67 | 1.68 |
| BMW13 | May-09 | Dec-09 | 1 every 10 minutes | 831.32 | 803.11 | 28.21 |
| BMW14 | May-09 | Dec-09 | 1 every 10 minutes | 803.16 | 795.71 | 7.45 |
| BMW15 | May-09 | Dec-09 | 1 every 10 minutes | 826.055 | 813.12 | 12.94 |
| BW01 | Nov-08 | Dec-09 | 1 every 10 minutes | 799.5 | 802.12 | -2.62 |
| BW02 | Nov-08 | Dec-09 | 1 every 10 minutes | 763 | 770.96 | -7.96 |
| BW05 | Nov-08 | Jun-09 | 1 every 10 minutes | 798.9 | 801.88 | -2.98 |
| BW06 | Nov-08 | Dec-09 | 1 every 10 minutes | 788.6 | 776.86 | 11.74 |
| BW07 | Nov-08 | Nov-09 | 1 every 10 minutes | 805.2 | 799.07 | 6.13 |
| BW09 | Jan-09 | Nov-09 | measurements in | 786.5 | 776.68 | 9.82 |
| BW11 | Nov-08 | Dec-09 | 1 every 10 minutes | 791 | 796.4 | -5.4 |
| BW12 | Nov-08 | Dec-09 | 1 every 10 minutes | 803.8 | 784.96 | 18.84 |
| BW14 | Jan-09 | Nov-09 | measurements in | 800 | 780.22 | 19.78 |
| BW15 | Nov-08 | Dec-09 | 1 every 10 minutes | 799.7 | 780.22 | 19.48 |
| BW16 | Nov-08 | Dec-09 | 1 every 10 minutes | 830.6 | 805 | 25.6 |
| BW17 | Jan-09 | Nov-09 | measurements in | 828.6 | 808.41 | 20.19 |
| MD5 | Jan-09 | Nov-09 | measurements in | 810.5 | 780 | 30.5 |

TABLE 9-1
Groundwater Model Calibration Targets
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Name | First Measurement Date | Last Measurement Date | Measurement Frequency | Observed Head (feet msl) | Simulated Head (feet msl) | Residual (feet) |
|---|---|---|---|---|---|---|
| USGS_01 | Apr-04 | n/a | measurement | 826.87 | 800.31 | 26.56 |
| USGS_02 | Apr-04 | n/a | measurement | 811.15 | 791 | 20.15 |
| USGS_04 | Apr-04 | n/a | measurement | 803.68 | 779.7 | 23.98 |
| USGS_06 | Apr-04 | n/a | measurement | 801.54 | 802.22 | -0.68 |
| USGS_24 | Apr-04 | n/a | measurement | 804.35 | 795.14 | 9.21 |
| USGS_25 | Apr-04 | n/a | measurement | 790.7 | 780.79 | 9.91 |
| USGS_26 | Apr-04 | n/a | measurement | 778.7 | 767.67 | 11.03 |
| USGS_27 | Apr-04 | n/a | measurement | 787.59 | 774.88 | 12.71 |
| USGS_28 | Apr-04 | n/a | measurement | 818.61 | 816.28 | 2.33 |
| USGS_29 | Apr-04 | n/a | measurement | 801.04 | 802.11 | -1.07 |
| USGS_31 | Apr-04 | n/a | measurement | 801.69 | 801.64 | 0.05 |
| USGS_32 | Apr-04 | n/a | measurement | 792.03 | 778.49 | 13.54 |
| | | | Absolute Mean Residual: | | | 10.32 |

TABLE 10-1
Craig Mine Pilot Study Mine Water Chemistry,
Modeled Chemical Reactions, and Comparison with PHREEQC Output
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| | | | General chemistry parameters in mg/L | | | | | | | | Metals in µg/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Description** | **Sample ID** | **Date** | **Na** | **K** | **Ca** | **Mg** | **pH** | **Alkalinity** | **Cl** | **$SO_4$** | **Fe** | **Zn** | **Cd** | **Pb** |
| Mine pool water used to slurry bulk chat | FCB-2 | 08/09/05 | 17.1 | 2.10 | 415 | 18.8 | 6.05 | 126 | 8.73 | 921 | 34100 | 2,220 | <5 | ND |
| | | Modeled reactions | Dissolution of cadmium and zinc sulfides and calcium/magnesium carbonate; Precipitation of calcium, zinc, and cadmium carbonates and of iron oxide | | | | | | | | | | | |
| Water portion of chat slurry | No analysis available | | | | | | | | | | | | | |
| | | PHREEQC simulation results | 17.1 | 2.10 | 433 | 21.3 | 7.29 | 64 | 9 | 1,020 | 62 | 33,459 | 208 | ND |

| | | | General chemistry parameters in mg/L | | | | | | | | Metals in µg/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Description** | **Sample ID** | **Date** | **Na** | **K** | **Ca** | **Mg** | **pH** | **Alkalinity** | **Cl** | **$SO_4$** | **Fe** | **Zn** | **Cd** | **Pb** |
| Pre-injection mine pool water at Craig Mine | FCB-2 | 08/09/05 | 17.1 | 2.10 | 415 | 18.8 | 6.05 | 126 | 8.73 | 921 | 34100 | 2,220 | <5 | ND |
| Simulated water portion of chat slurry | PHREEQC simulation results | | 17.1 | 2.10 | 433 | 21.3 | 7.29 | 64 | 9 | 1,020 | 62 | 33,459 | 208 | ND |
| | | Modeled reactions | Mix August 2005 pre-injection mine pool water with simulated slurry water in the ratio 2:1; Dissolution of gypsum; Precipitation of iron oxide | | | | | | | | | | | |
| First post-injection mine pool sample at Craig Mine | FCB-2 | 11/11/05 | 15.1 | 1.03 | 627 | 22.5 | 6.17 | 126 | 7.8 | 1,380 | 28,600 | 12,300 | 97 | 6 |
| | | PHREEQC simulation results | 17.1 | 2.10 | 658 | 19.6 | 5.98 | 87 | 9 | 1,522 | 22,766 | 12,629 | 69 | ND |

**Notes:**
Na - sodium
K - potassium
Ca - calcium
Mg - magnesium
Cl - chloride
$SO_4$ - sulfate
Fe - iron
Zn - zinc
Cd - cadmium
Pb - lead
mg/L - milligrams per liter
µg/L - micrograms per liter
ND - no data

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TABLE 10-2
Sooner Pile Pilot Study Mine Water Chemistry,
Modeled Chemical Reactions, and Comparison to PHREEQC Output
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

| Description | Sample ID | Date | General chemistry parameters in mg/L | | | | | | | | Metals in µg/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Na | K | Ca | Mg | pH | Alkalinity | Cl | SO4 | Fe | Zn | Cd | Pb |
| Mine pool water used to slurry fine chat | MMB2 | 07/17/08 | 49.6 | 3.09 | 599 | 45.8 | 6.45 | 140 | 37 | 1,540 | 391 | 25,900 | 391 | 276 |
| | | Modeled reactions | Dissolution of cadmium, lead, and zinc sulfides and calcium/magnesium carbonate; Precipitation of calcium, zinc, and cadmium carbonates and of iron oxide | | | | | | | | | | | |
| Water portion of fine chat slurry in sand screw tank | SNDSCR | 07/17/08 | 48.8 | 2.99 | 605 | 45.0 | 6.87 | 144 | 37 | 1,590 | <25 | 20,300 | 411 | 294 |
| | PHREEQC simulation results | | 49.7 | 3.10 | 608 | 50.8 | 6.98 | 125 | 37 | 1,649 | <25 | 20,967 | 339 | 318 |

| Description | Sample ID | Date | General chemistry parameters in mg/L | | | | | | | | Metals in µg/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Na | K | Ca | Mg | pH | Alkalinity | Cl | $SO_4$ | Fe | Zn | Cd | Pb |
| Pre-injection mine pool water at Sooner Pile | SMB2 | 07/11/07 | 22.7 | 2.81 | 625 | 35.3 | 6.34 | 109 | <5 | 1,500 | 11,900 | 11,800 | 8.3 | 3.3 |
| Water portion of fine chat slurry in sand screw tank | SNDSCR | 07/17/08 | 48.8 | 2.99 | 605 | 45.0 | 6.87 | 144 | 37 | 1,590 | <25 | 20,300 | 411 | 294 |
| | | Modeled reactions | Mix July 2007 pre-injection mine pool water with July 2008 SNDSCR water in the ratio 2:1; Dissolution of gypsum; Precipitation of iron oxide | | | | | | | | | | | |
| First post-injection mine pool sample at Sooner Pile | SMB2 | 10/24/07 | 22.3 | 2.54 | 581 | 33.8 | 6.44 | 142 | <10 | 1,490 | <25 | 20,100 | 246 | 78.1 |
| | | PHREEQC simulation results | 31.5 | 2.88 | 649 | 38.6 | 6.35 | 196 | 14 | 1,603 | <25 | 14,666 | 143 | 100 |

**Notes:**
Na - sodium
K - potassium
Ca - calcium
Mg - magnesium
Cl - chloride
$SO_4$ - sulfate
Fe - iron
Zn - zinc
Cd - cadmium
Pb - lead
mg/L - milligrams per liter
µg/L - micrograms per liter
SNDSCR - sand screw

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TABLE 10-3

Representative Water Chemistries Used in PHAST Simulations

*Tar Creek Superfund Site, Operable Unit 4*

*Ottawa County, Oklahoma*

| | | | General chemistry parameters in mg/L | | | | | | | | Metals in µg/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Description** | **Sample ID** | **Date** | **Na** | **K** | **Ca** | **Mg** | **pH** | **Alkalinity** | **Cl** | **SO4** | **Fe** | **Zn** | **Cd** | **Pb** |
| Boone Aquifer unaffected by mineralization or mine pool discharge | BW13 | 07/17/08 | 180 | 4.68 | 10.7 | 3.43 | 8.58 | 310 | 66 | <5 | 128 | 76 | <5 | <2 |
| Pre-injection mine pool water at Sooner Pile | SMB2 | 07/11/07 | 22.7 | 2.81 | 625 | 35.3 | 6.34 | 109 | <5 | 1,500 | 11,900 | 11,800 | 8.3 | 3.3 |
| | Stage 1 Modeled reactions: | | 40-year transport of SMB2 water into BW13 water | | | | | | | | | | | |
| | | | Precipitation of calcite, siderite, and iron oxide; adsorption of metals to calcite and iron oxide | | | | | | | | | | | |
| Boone Aquifer immediately downgradient from mine workings | BMW07 | 08/03/09 | 55.3 | 14.3 | 321 | 38.6 | 6.86 | 246 | 8 | 761 | 10,900 | 691 | <5 | <2 |
| | BMW08 | 08/03/09 | 57.5 | 9.98 | 50.6 | 20.2 | 7.76 | 242 | <5 | 60 | 44 | <20 | <5 | <2 |
| | BMW09 | 08/03/09 | 25 | 2.41 | 556 | 40.3 | 5.98 | 94 | 11 | 1,430 | 51,400 | 5,120 | <5 | <2 |
| | | | BMW7-9 wells used as general guideline for PHAST model calibration | | | | | | | | | | | |
| Post-injection mine pool sample at Sooner Pile | SMB3 | 10/06/09 | 47.6 | 3.18 | 568 | 53.4 | 7.75 | 196 | 38 | 1,590 | <25 | 10,300 | 132 | 128 |
| | Stage 2 Modeled reactions: | | Mix various proportions of SMB2 and SMB3 to represent mixtures shown on Figure 10-2; simulate 25-year transport into Boone from end of Stage 1 | | | | | | | | | | | |
| | | | Precipitation of calcite, siderite, and iron oxide; adsorption of metals to calcite and iron oxide | | | | | | | | | | | |

**Notes:**

Na - sodium
K - potassium
Ca - calcium
Mg - magnesium
Cl - chloride
SO4 - sulfate
Fe - iron
Zn - zinc
Cd - cadmium
Pb - lead
mg/L - milligrams per liter
µg/L - micrograms per liter

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# Figures

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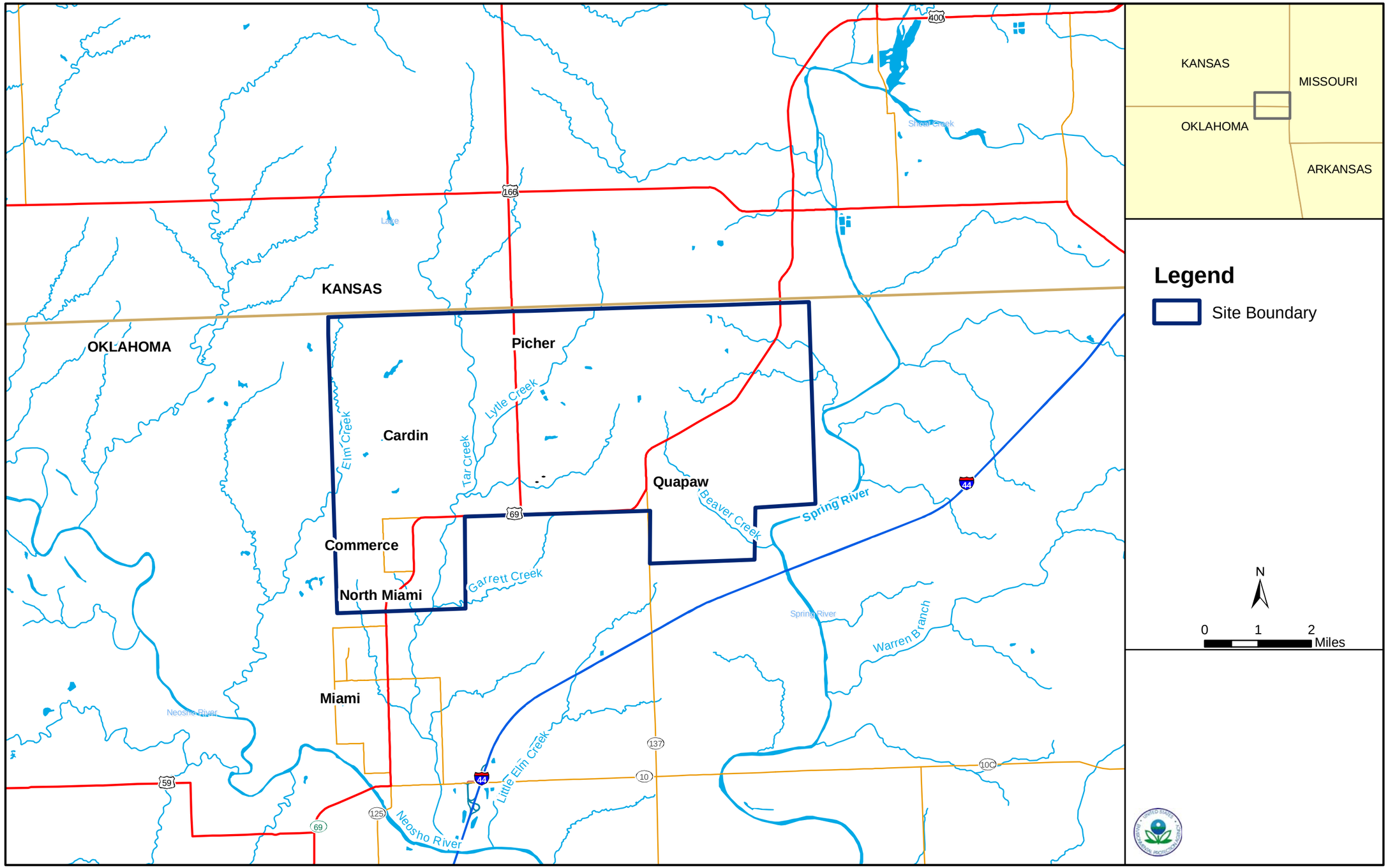
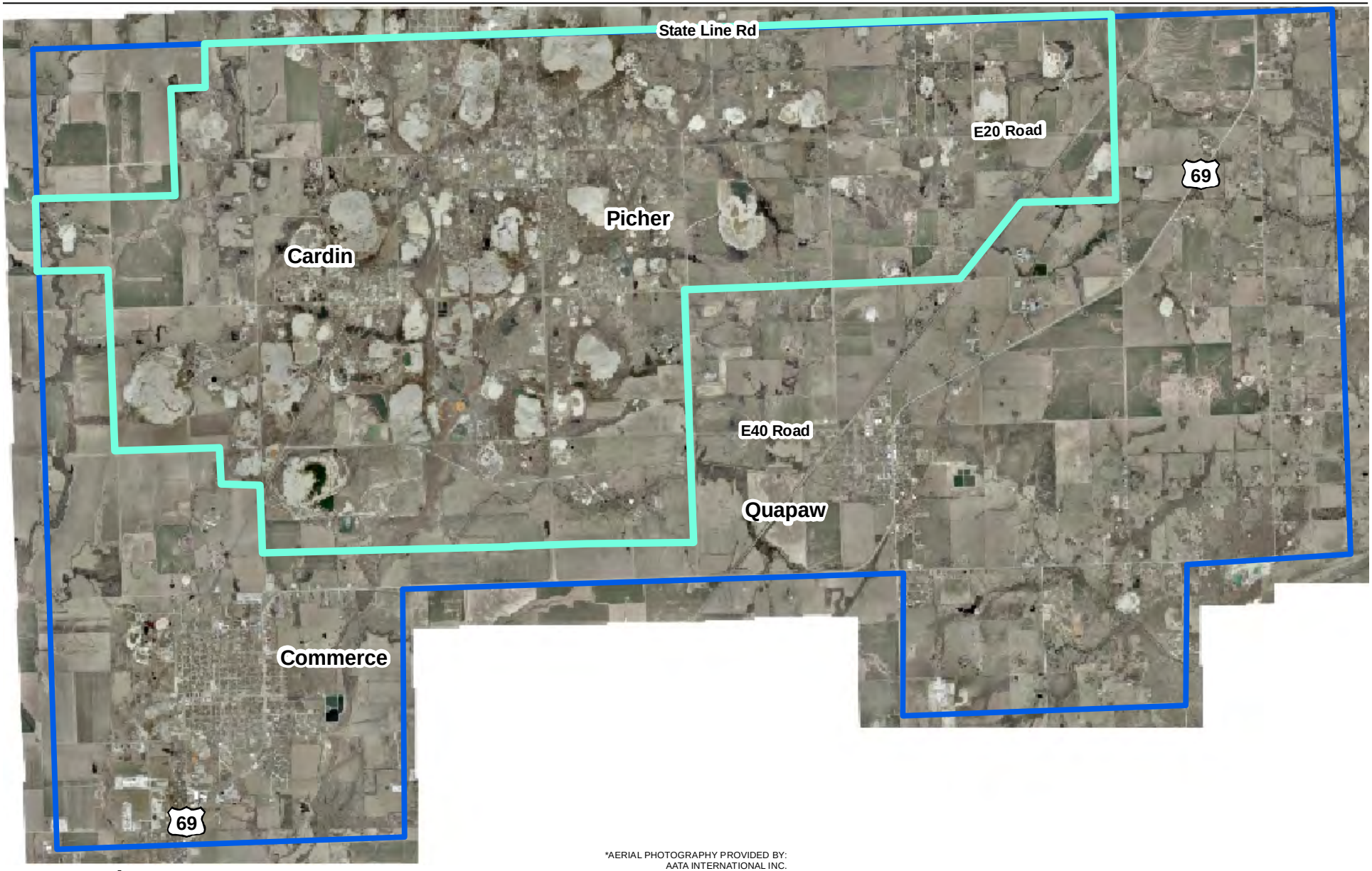



FIGURE 1-1
Tar Creek Superfund Site Map
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




*AERIAL PHOTOGRAPHY PROVIDED BY:
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Fort Collins, Colorado, USA

**Legend**

Voluntary Relocation Boundary

Site Boundary

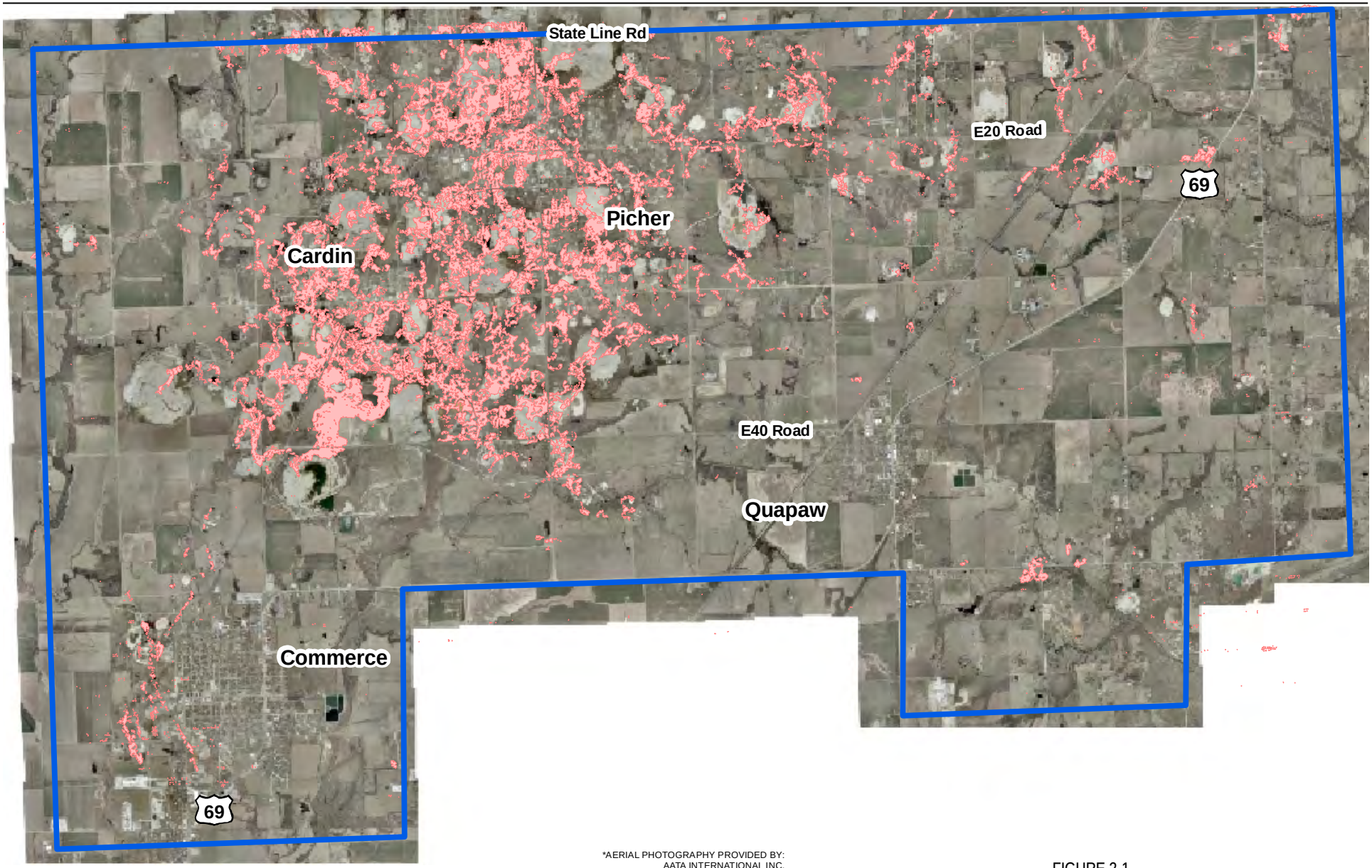
N

0 2,500 5,000 10,000 Feet

FIGURE 1-2
Area of the Site Included in the OU4 Voluntary Relocation
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

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Fort Collins, Colorado, USA

**Legend**

Mine Workings

Site Boundary

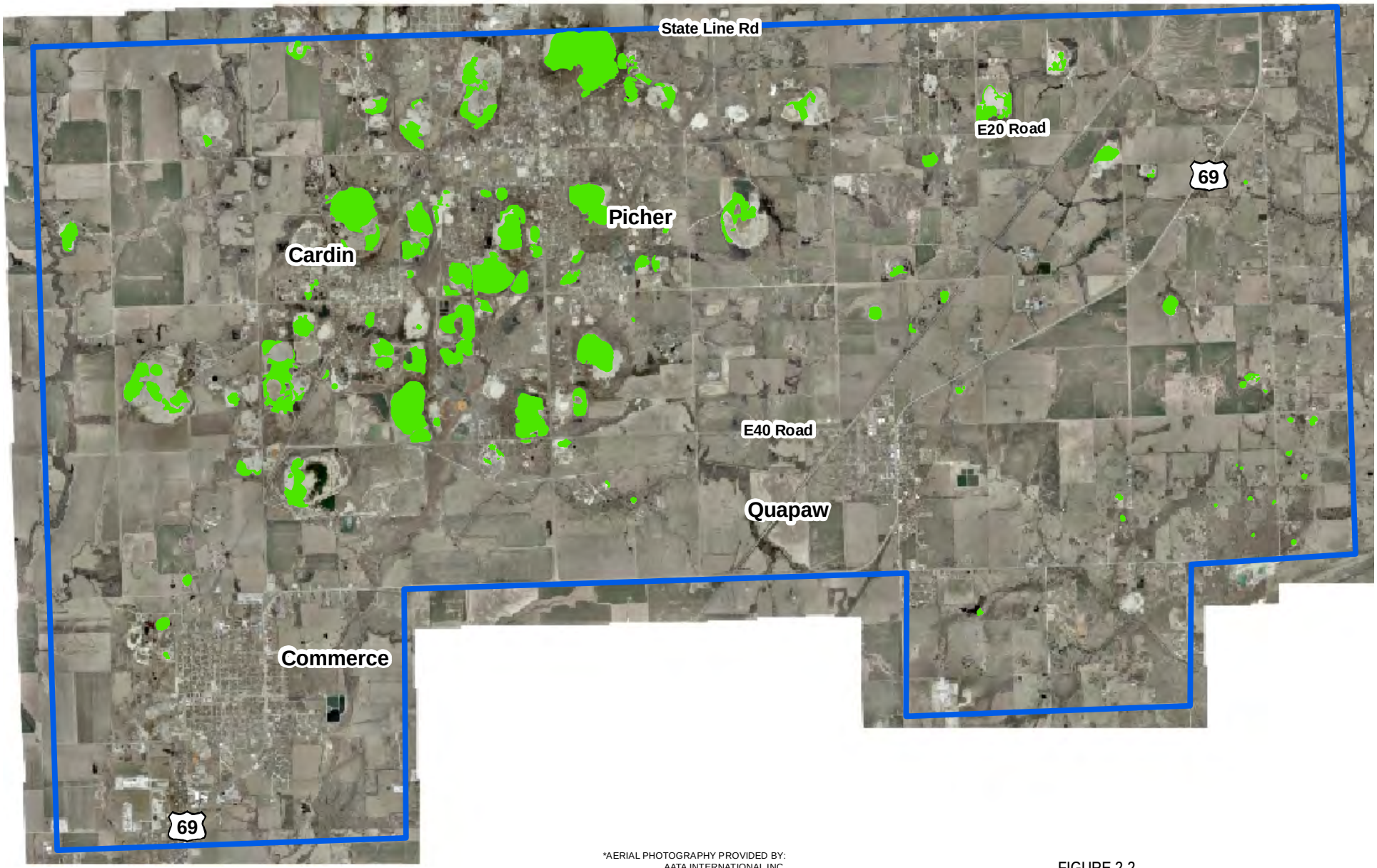
N

0 2,500 5,000 10,000 Feet

FIGURE 2-1
Extent of Underground Mine Workings
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

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**Legend**

Chat Pile

Site Boundary

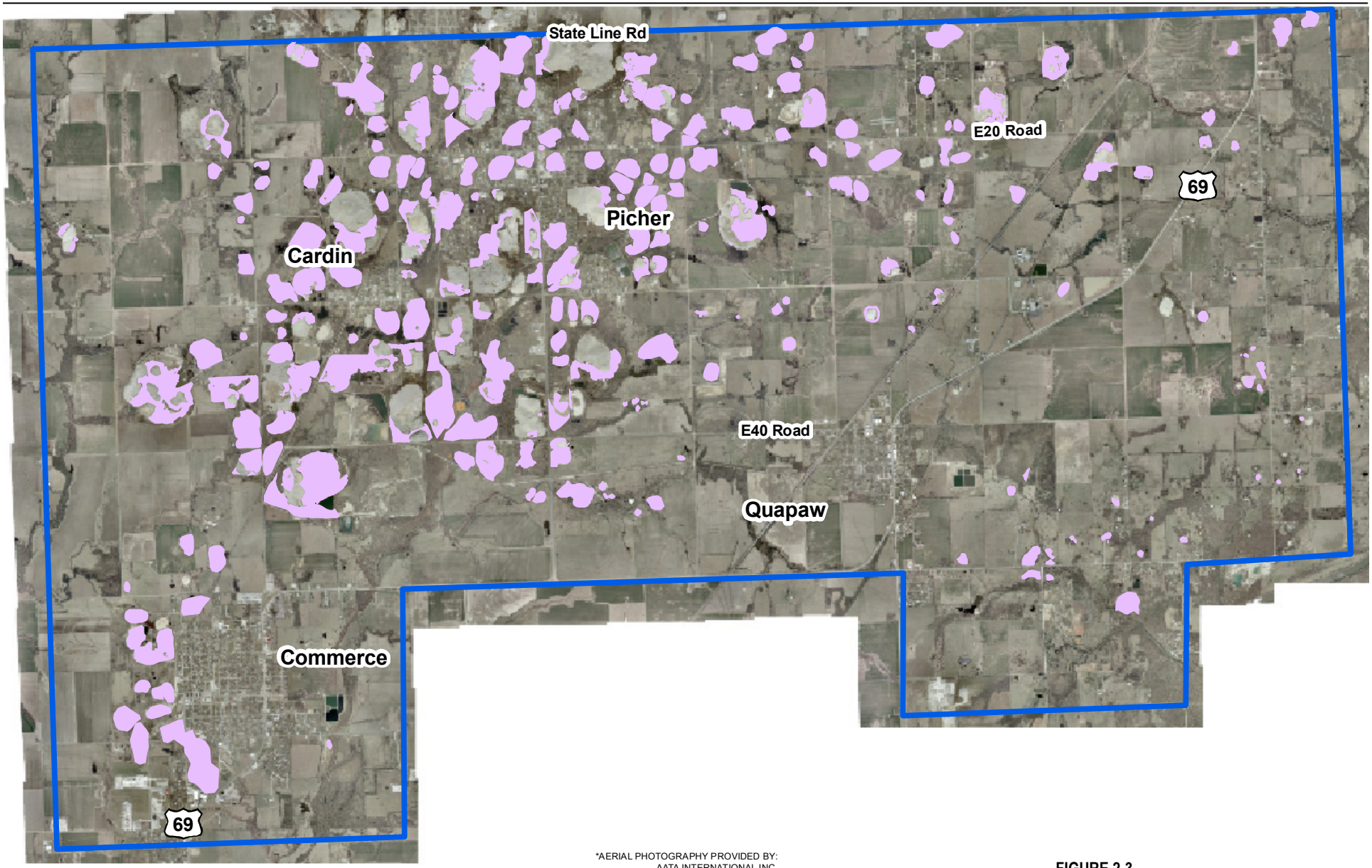
N

0 2,500 5,000 10,000 Feet

FIGURE 2-2
Chat Pile Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

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**Legend**

Chat Base

Site Boundary

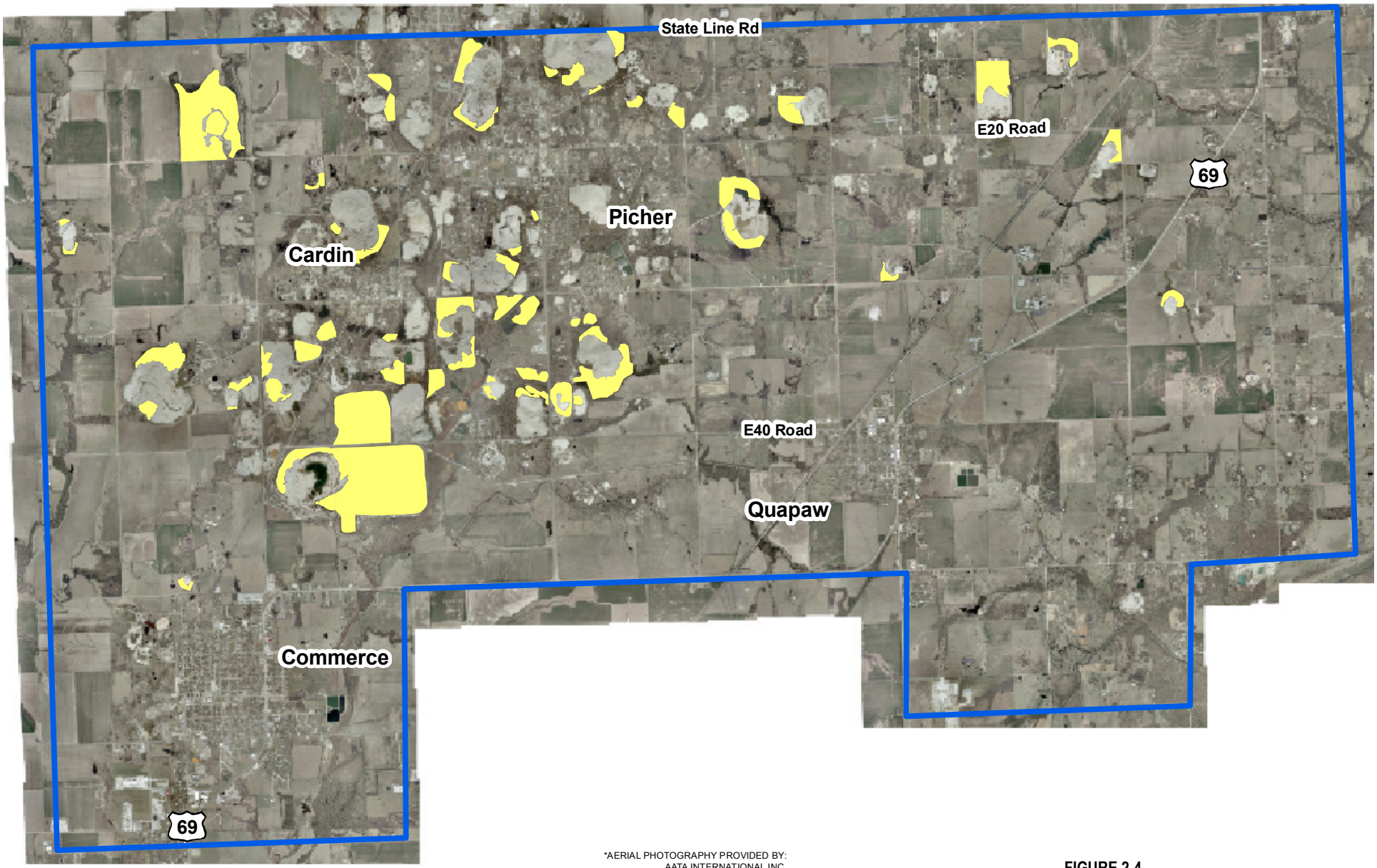
N

0 2,500 5,000 10,000 Feet

**FIGURE 2-3**
Chat Base Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

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**Legend**

Tailings Pond

Site Boundary

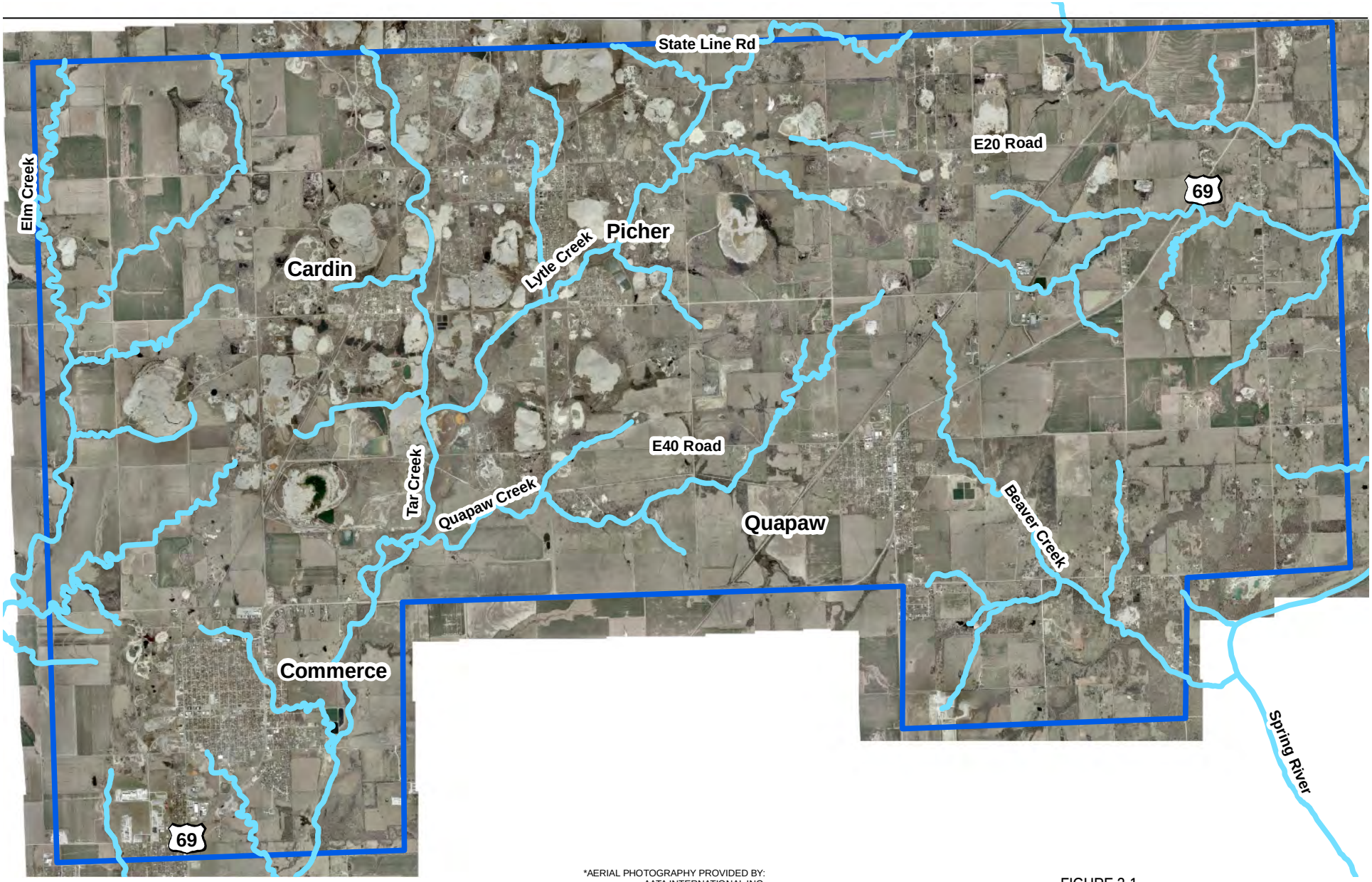
N

0 2,500 5,000 10,000 Feet

**FIGURE 2-4**
Tailings Pond Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

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**Legend**

Stream

Site Boundary

N

0 2,500 5,000 10,000 Feet

FIGURE 3-1
Surface Water Features
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

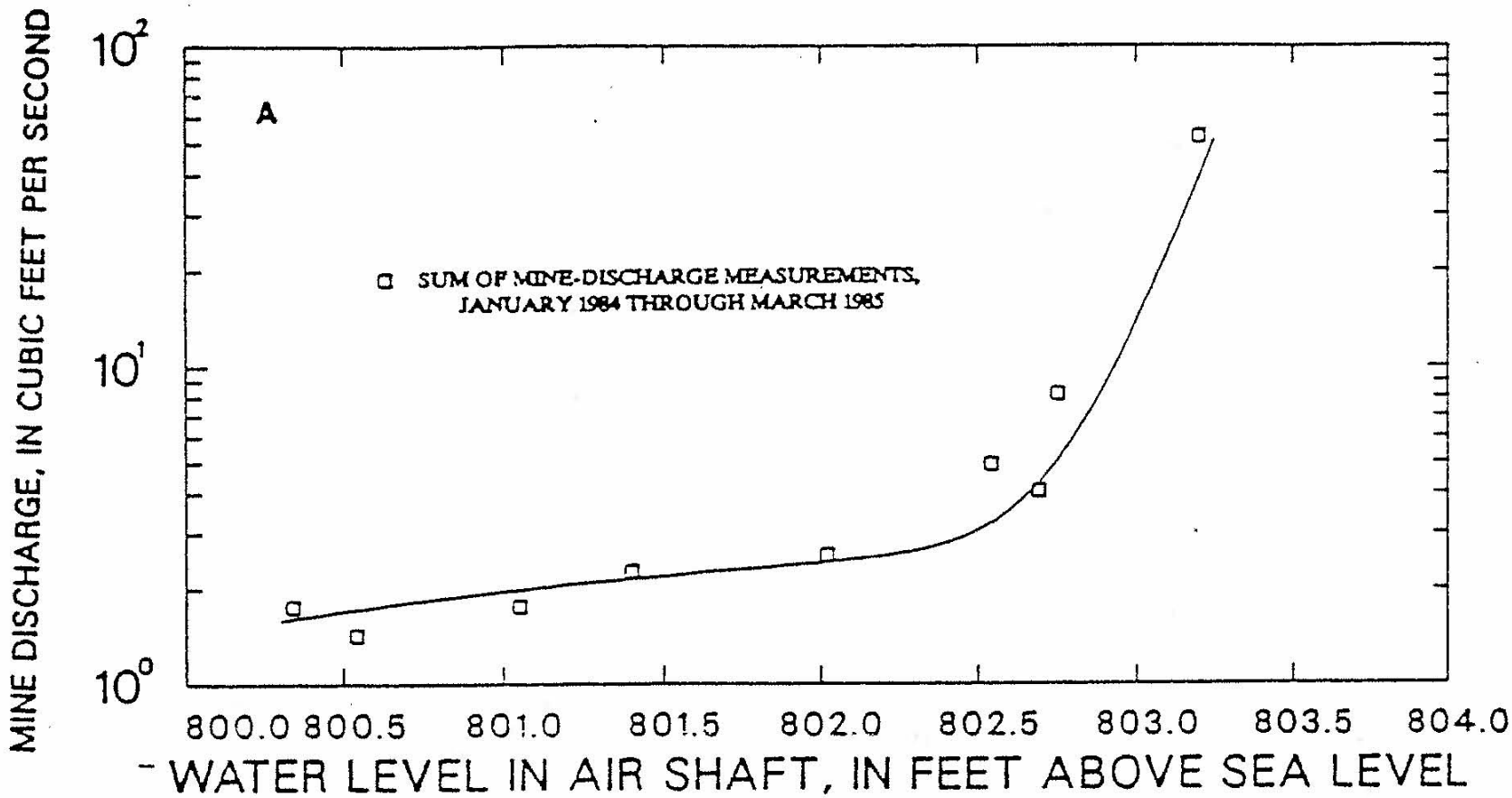


Figure reproduced from Parkhurst, 1988

**FIGURE 3-2**
Parkhurst Mine Pool Elevation - Discharge Rating Curve
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

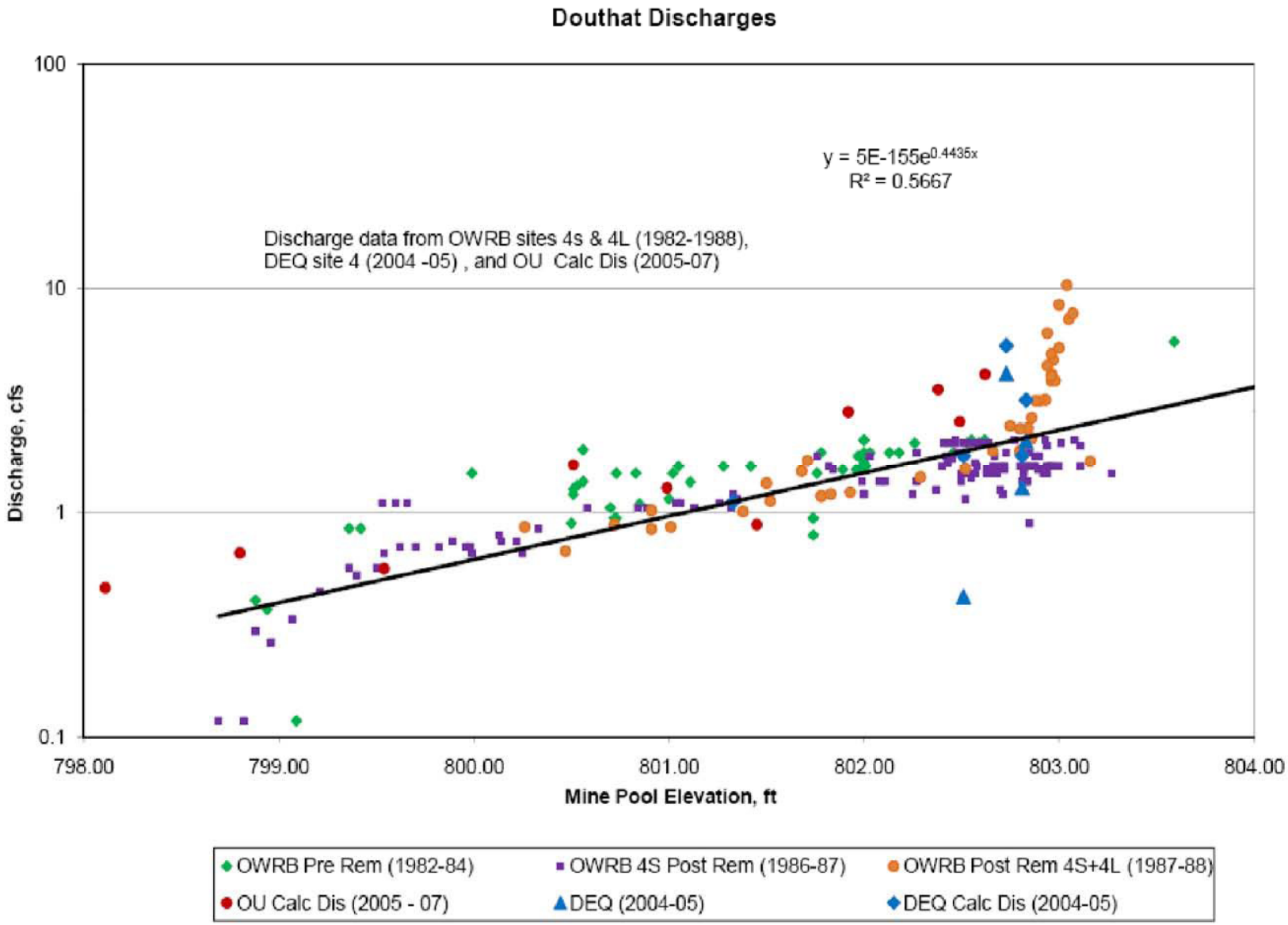


**FIGURE 3-3**
Mine Pool Elevation - Discharge Rating Curve from Various Sources
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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| System | Group/Series | Geologic Unit (Group, Formation, or Member) | Thickness (feet) | Description | Bed* |
|---|---|---|---|---|---|
| Quaternary | | Alluvium | 0 - 30 | Gravel, sand, silt, and clay deposited by streams within current flood plains. | |
| ~~~UNCONFORMITY~~~ | | | | | |
| Pennsylvanian | Krebs Group | Bluejacket Sandstone Member of the Boggy Formation | 0-200 | shales with some sandstone, siltstone, limestone, and coal beds | |
| | | Savannah Shale | | | |
| | | McAlester Shale | | | |
| | | Hartshorne Formation | | | |
| ~~~UNCONFORMITY~~~ | | | | | |
| Mississippian | Chester Series | Fayetteville Shale | 0-200 | marine shale with some limey portions, limestone beds, and coal seams | |
| | | Batesville Sandstone | | fine grained sandstone with some interbedded limestone and shale | |
| | | Hindsville Limestone | | gray, dense limestone with minor amounts of chert and some interbedded sandstone and shale | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Quapaw Limestone | | 0-30 | gray, medium to coarse grained, crinoidal limestone | |
| | Boone Formation | Moccasin Bend | 350-400 | cherty limestone with beds of bluish gray to light gray limestone and gray to white chert | B C D E F G H |
| | | Baxter Springs | | | J K L |
| | | Short Creek Oolite | | | |
| | | *~~~DISCONFORMITY~~~* | | | M |
| | | Joplin Member | | | |
| | | Grand Falls Chert | | | N O P Q |
| | | Reeds Spring | | | R |
| | | St. Joe Limestone | | | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Northview Shale | | 0-30 | greenish-black or dull-blue shale | |
| | Compton Limestone | | | shaley limestone | |
| Devonian & Mississippian | Chattanooga Shale | | 0-30 | black, fissile, carbonaceous shale | |
| ~~~UNCONFORMITY~~~ | | | | | |
| Ordovician | Cotter Dolomite | | 140-180 | cherty dolomites with lenses of sandstone and shale | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Jefferson City Dolomite | | 270-340 | cherty dolomites with lenses of sandstone | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Roubidoux Formation | | 0-190 | cherty dolomite containing two or three sandstone layers | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Gasconade Dolomite | | 0-350 | cherty dolomite and sandy dolomite with sandstone layers | |
| | Gunter Sandstone | | | sandstone and sandy dolomite | |
| ~~~UNCONFORMITY~~~ | | | | | |
| Cambrian | Potosi-Eminence Dolomites | | 0-160 | cherty dolomites containing some oolites, minor amounts of sand, and some shale | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Bonterre Dolomite | | 0-180 | sandy dolomite also containing some chert, oolites, and shale | |
| | ~~~UNCONFORMITY~~~ | | | | |
| | Lamotte Sandstone | | 0-50 | sandstone, siltstone, and shale | |
| ~~~UNCONFORMITY~~~ | | | | | |
| Precambrian | | | ? | granite and volcanics | |

Notes:
* - Informal letter classification from Fowler and Lyden (1932) and Fowler (1942).
Figure modified from McKnight and Fisher, 1970, Luza, 1986, and ODEQ, 2006.

**Figure 3-4**
Generalized Geologic Section of Rocks in the Area of the Site
*Tar Creek Superfund Sit, Operable Unit 4*
*Ottawa County, Oklahoma*

A - Northwest

A' - Southeast

Elm Creek

Miami Trough

Cardin No. 1
(Projected - 775 ft South)

Tar Creek

BMW05
(Projected - 700 ft North)

Picher No. 7
(Projected - 650 ft North)

Lytle Creek

Picher No. 5
(Projected - 750 ft South)

Quapaw No. 5
(Projected - 150 ft North)

Boone Aquifer

Roubidoux Aquifer

U D D U U D

BMW05
Analytical Results
(April 2009)

| Analyte | Result (Total - ug/L) |
|---|---|
| Ar | 2.1 |
| Cd | <5 |
| Pb | <2 |
| Zn | 61 |
| Fe | 32 |
| $SO_4$ | 1,670 |

Picher No. 7
Analytical Results
(April 2008)

| Analyte | Result (Tot/Dis - ug/L) |
|---|---|
| Ar | <2/<2 |
| Cd | <2/<2 |
| Pb | <5/<5 |
| Zn | <5/<5 |
| Fe | 176/187 |
| $SO_4$ | 240 |

Picher No. 5
Analytical Results
(April 2008)

| Analyte | Result (Tot/Dis - ug/L) |
|---|---|
| Ar | <2/<2 |
| Cd | <2/<2 |
| Pb | <5/<5 |
| Zn | <5/<5 |
| Fe | 113/110 |
| $SO_4$ | 135 |

Quapaw No. 5
Analytical Results
(April 2008)

| Analyte | Result (Tot/Dis - ug/L) |
|---|---|
| Ar | 5/6 |
| Cd | <2/<2 |
| Pb | <5/<5 |
| Zn | 2900/2780 |
| Fe | 176/187 |
| $SO_4$ | 460 |

Cardin No. 1
Analytical Results
(April 2008)

| Analyte | Result (Tot/Dis - ug/L) |
|---|---|
| Ar | <2/<2 |
| Cd | <2/<2 |
| Pb | <5/<5 |
| Zn | <5/<27 |
| Fe | 193/169 |
| $SO_4$ | 78.2 |

Elevation (Ft Above/Below Mean Sea Level)

1000, 800, 600, 400, 200, 0, -200, -400, -600, -800, -1000

0, 2000, 4000, 6000, 8000, 10000, 12000, 14000, 16000, 18000, 20000, 22000, 24000, 26000, 28000, 30000, 32000

Distance Along Cross Section (Ft)

## Geologic Units

*Quaternary System*

- Quaternary Alluvium

*Pennsylvanian System*

- Krebs Group (undivided)

*Mississippian System*

- Chester Group (undivided)
- Boone Formation

*Devonian System*

- Northview Shale

*Ordovician System*

- Cotter Dolomite (Swan Creek Member at Base)
- Jefferson City Dolomite
- Roubidoux Formation
- Gasconade Dolomite
- Gunter Sandstone Member of the Van Buren Formation

*Cambrian System*

- Eminence-Potosi Dolomites (undivided)
- Bonterre Dolomite
- Lamotte Sandstone

*Precambrian*

- Granite and volcanics

- Mine Workings

## Scale:

Vertical Scale: 1 inch = 263 ft
Horizontal Scale: 1 inch = 2,632 ft
Vertical Exaggeration: 10:1

## Legend

U D Fault

Lithologic Contact (Dashed where inferred)

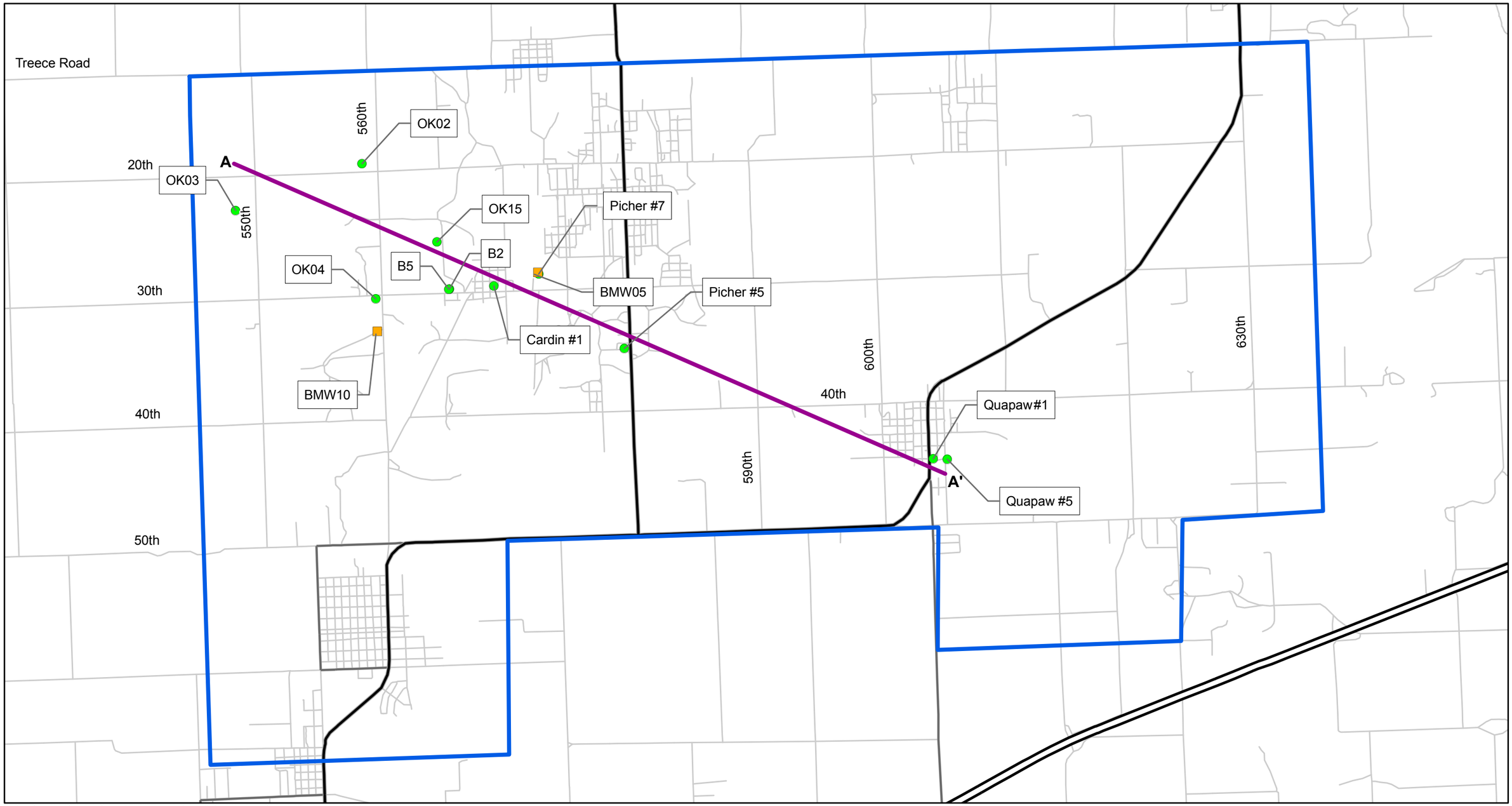
Boone Aquifer Water Level

Roubidoux Aquifer Water Level

Well Location and Screened Interval (Boone Aquifer Wells) or Open (Un-cased) Interval (Roubidoux Aquifer Wells)

**Notes:**
See Section 3.3 for Description of Geologic Units
Analytical Results (Tot/Dis) are for Total and Dissolved Metals
Boone Aquifer Water Level is for April 2009
Roubidoux Aquifer Water Levels are for April 2008
ug/L - micrograms per liter; ft - feet
Ar - arsenic; Cd - cadmium; Pb - lead; Zn - zinc
Fe - iron; $SO_4$ - sulfate

**Figure 3-5**
**Geologic Cross-Section A-A'**
***Tar Creek Superfund Site***
***Operable Unit 4***
***Ottawa County, Oklahoma***




\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\RUBIDOUX.MXD GBOQUIN 12/3/2010 13:57:30

**Legend**

- Boone Well
- Roubidoux Well
- Cross-Section A-A' on Figure 3-5
- Tar Creek OU4 Site Boundary

Note: Only Well Locations with logs used in creating the cross-section are shown in this figure.

N

1 0.5 0 1 Miles

**FIGURE 3-6**
Location of Cross Section A-A'
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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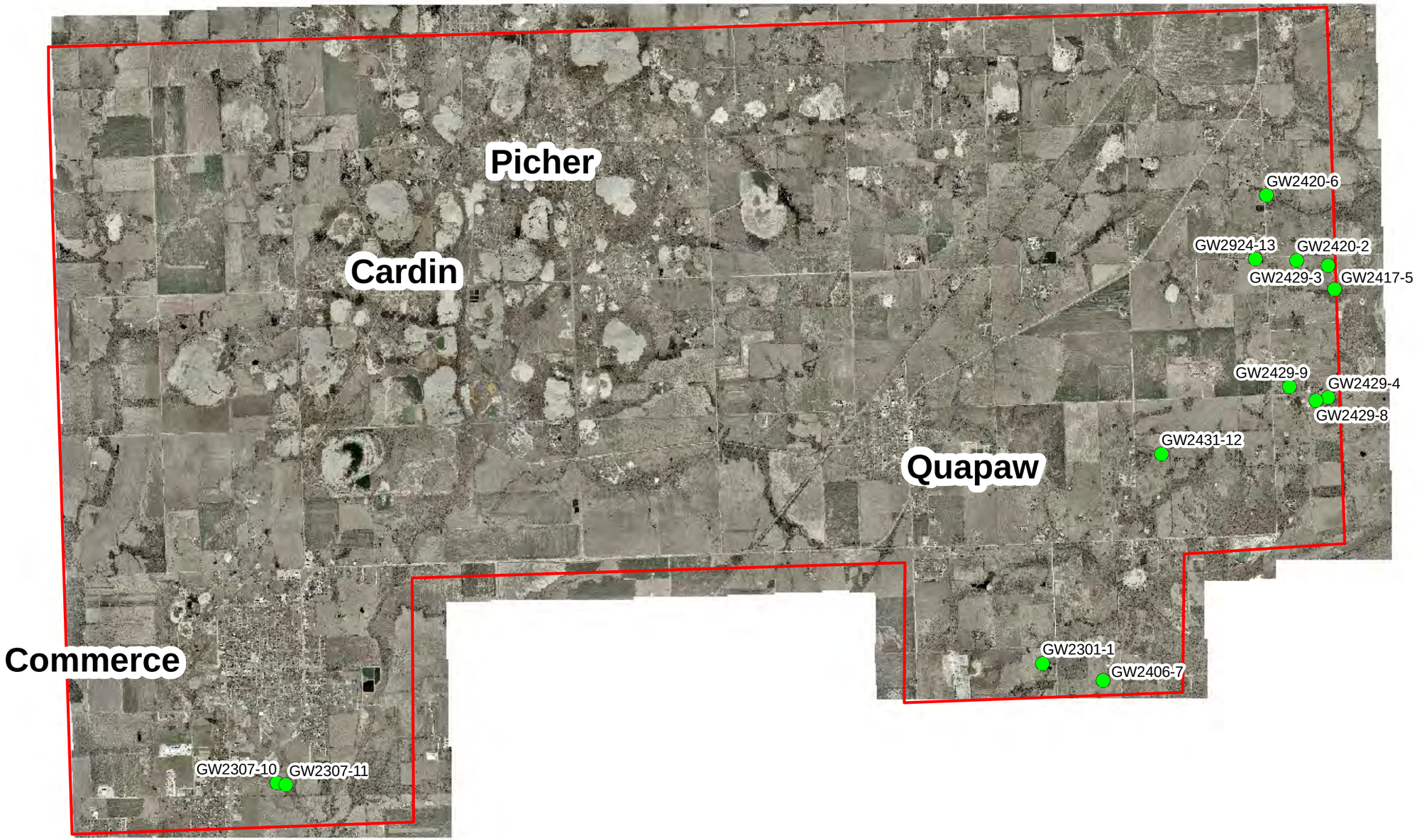


**Legend**

- Rural Residential Well
- Site Boundary

Note:
This figure is adapted from AATA, 2005

N

0 4,000 8,000 Feet

FIGURE 3-7
Boone Aquifer Rural Residential Wells Used for Potable Water Supply
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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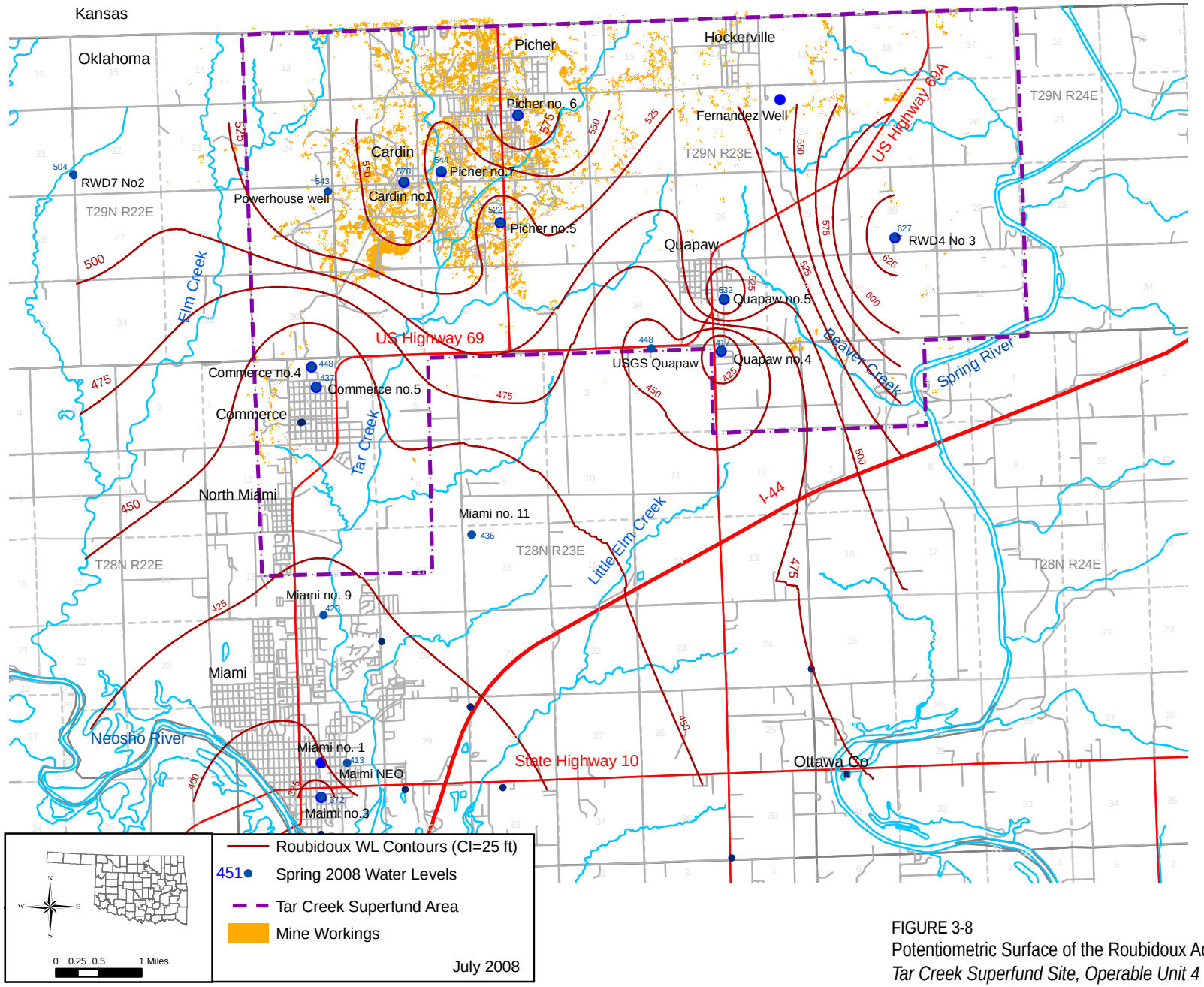
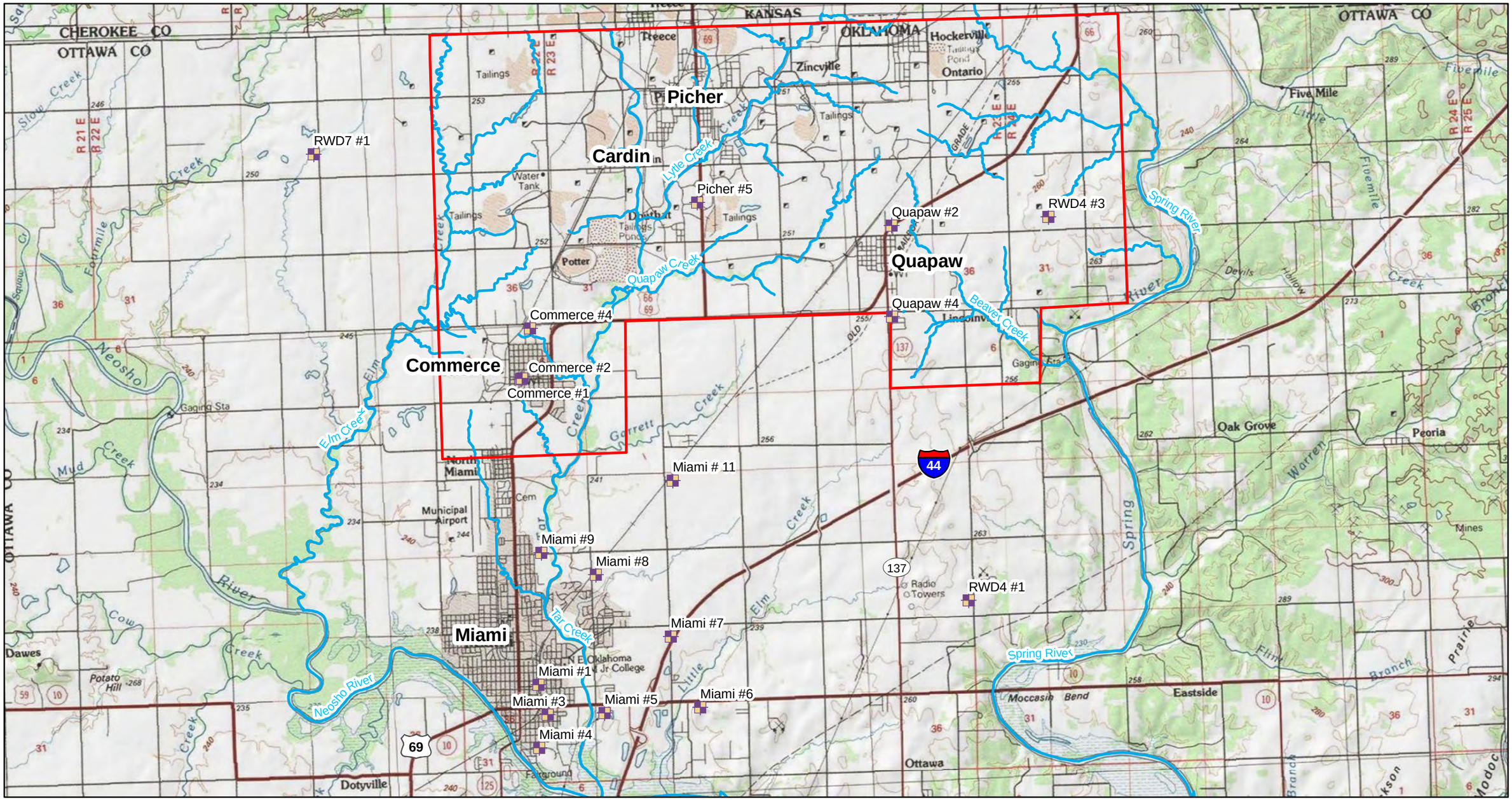



Source: ODEQ, 2008

FIGURE 3-8
Potentiometric Surface of the Roubidoux Aquifer
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




**Legend**

- Public Water Supply Well
- Site Boundary

N

0 6,500 13,000 Feet

FIGURE 3-9
Roubidoux Aquifer Public Water Supply Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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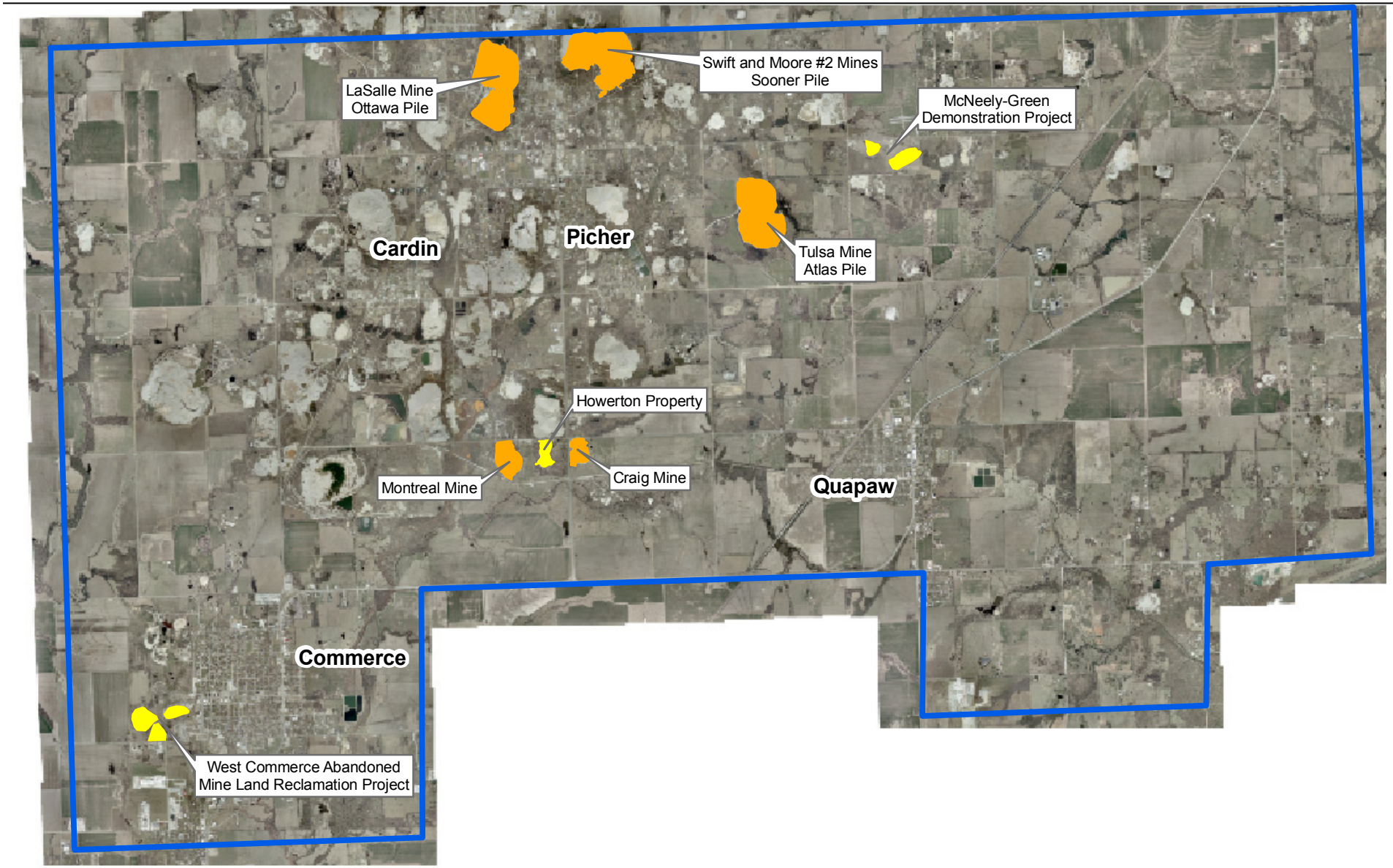


## Legend

- OCC and ODEQ Project Sites
- EPA Pilot Study Mine Sites
- Site Boundary

*AERIAL PHOTOGRAPHY PROVIDED BY:
AATA INTERNATIONAL INC.
Fort Collins, Colorado, USA

N

0 2,500 5,000 10,000 Feet

**FIGURE 4-1**
EPA and OCC/ODEQ Pilot Study Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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# OU4 Injection and Hydrogeological Study Timeline

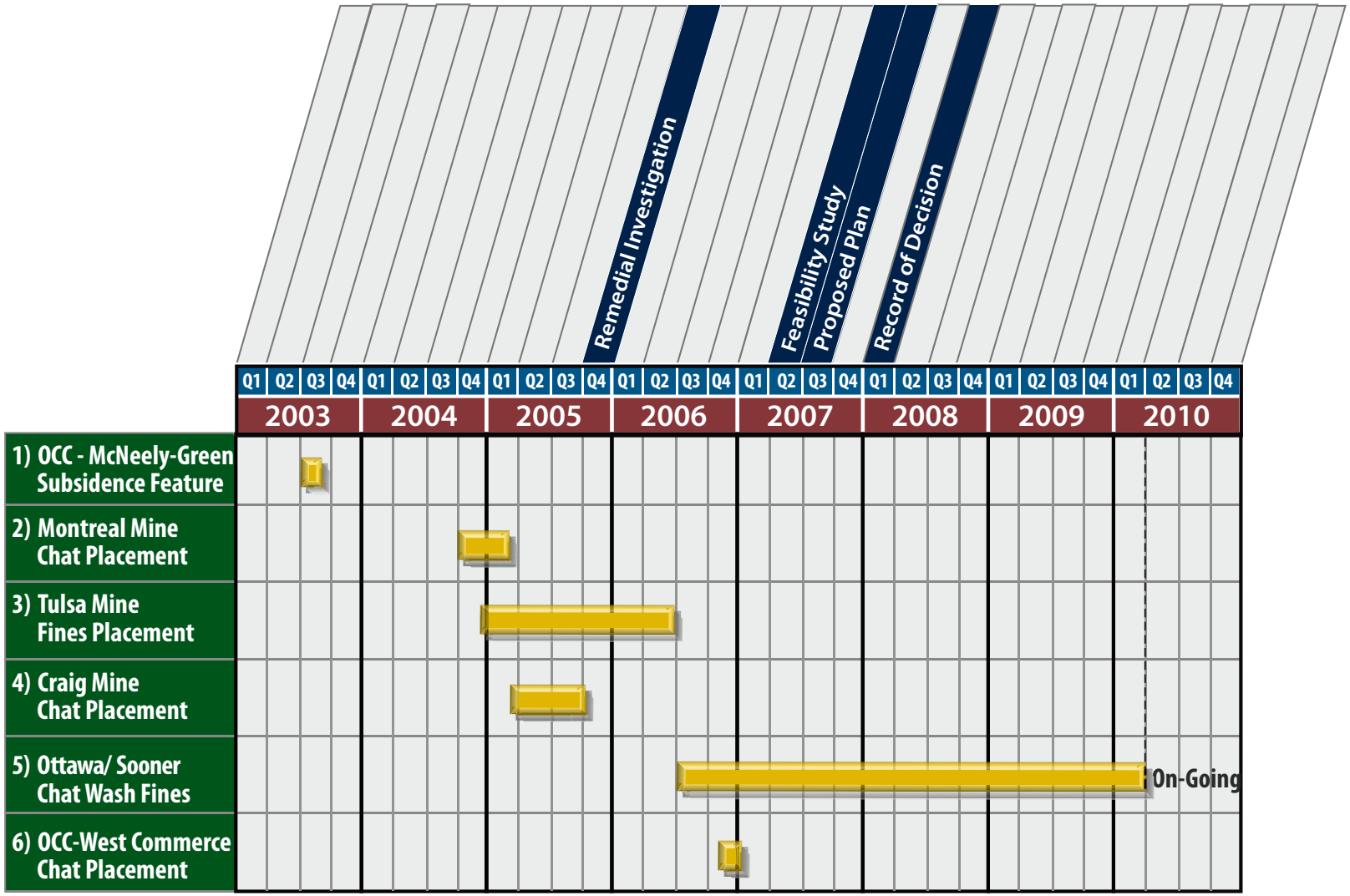


**FIGURE 4-2**
Timeline of EPA and OCC/ODEQ Pilot Studies
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

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Source of Aerial Photography:USGS \\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\MCNEELY_GREEN_DEMO_SITE.MXD JRIVERS 12/2/2010 11:00:11

**Legend**

Former Chat Base

N

0 200 400 800 Feet

**FIGURE 4-3**
McNeely-Green Demonstration Project
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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ES010510072638DFW

Source of Aerial Photography:USGS

**Legend**

- Boring Location
- Mine Outline

N

0 150 300 600 Feet

**FIGURE 4-4**
West Commerce Abandoned Mine Land Reclamation Project
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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ES010510072638DFW

Source of Aerial Photography:USGS

**Legend**

- Boring Location
- Mine Outline

N

0 150 300 600 Feet

**FIGURE 4-5**
Howerton Property Project Site
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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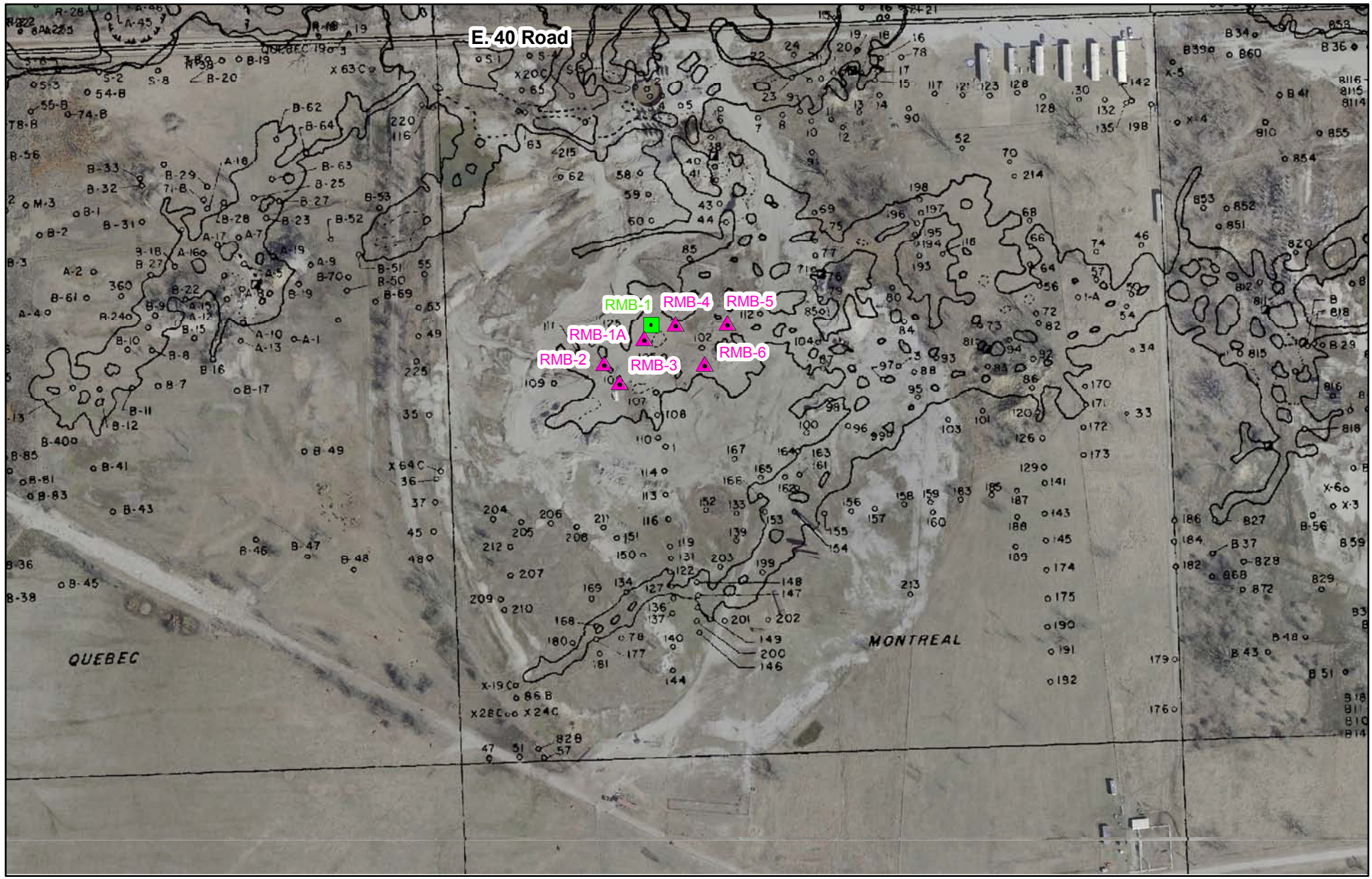


Source of Aerial Photography:USGS

**Legend**

- Injection Boring
- Cored Boring
- Mine Outline

Note:
All borings were interchangeably used for groundwater extraction as needed throughout the course of the pilot study.

N

0 125 250 500 Feet

**FIGURE 4-6**
Montreal Mine Chat Placement Pilot Study
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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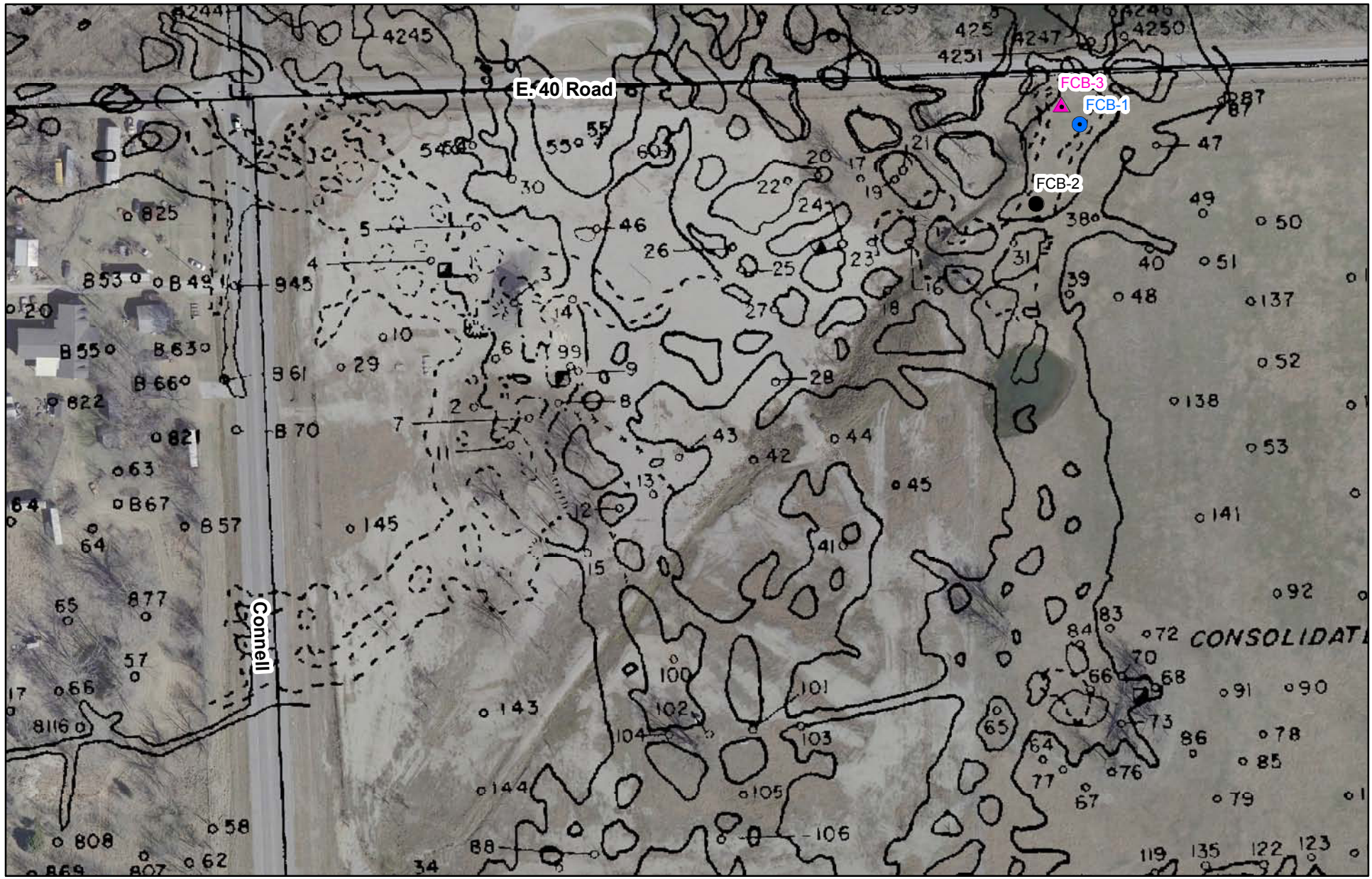


Source of Aerial Photography:USGS

**Legend**

- Boring Not Used for Groundwater Extraction or Injection
- Groundwater Extraction Boring
- Injection Boring
- Mine Outline

N

0 75 150 300 Feet

**FIGURE 4-7**
Craig Mine
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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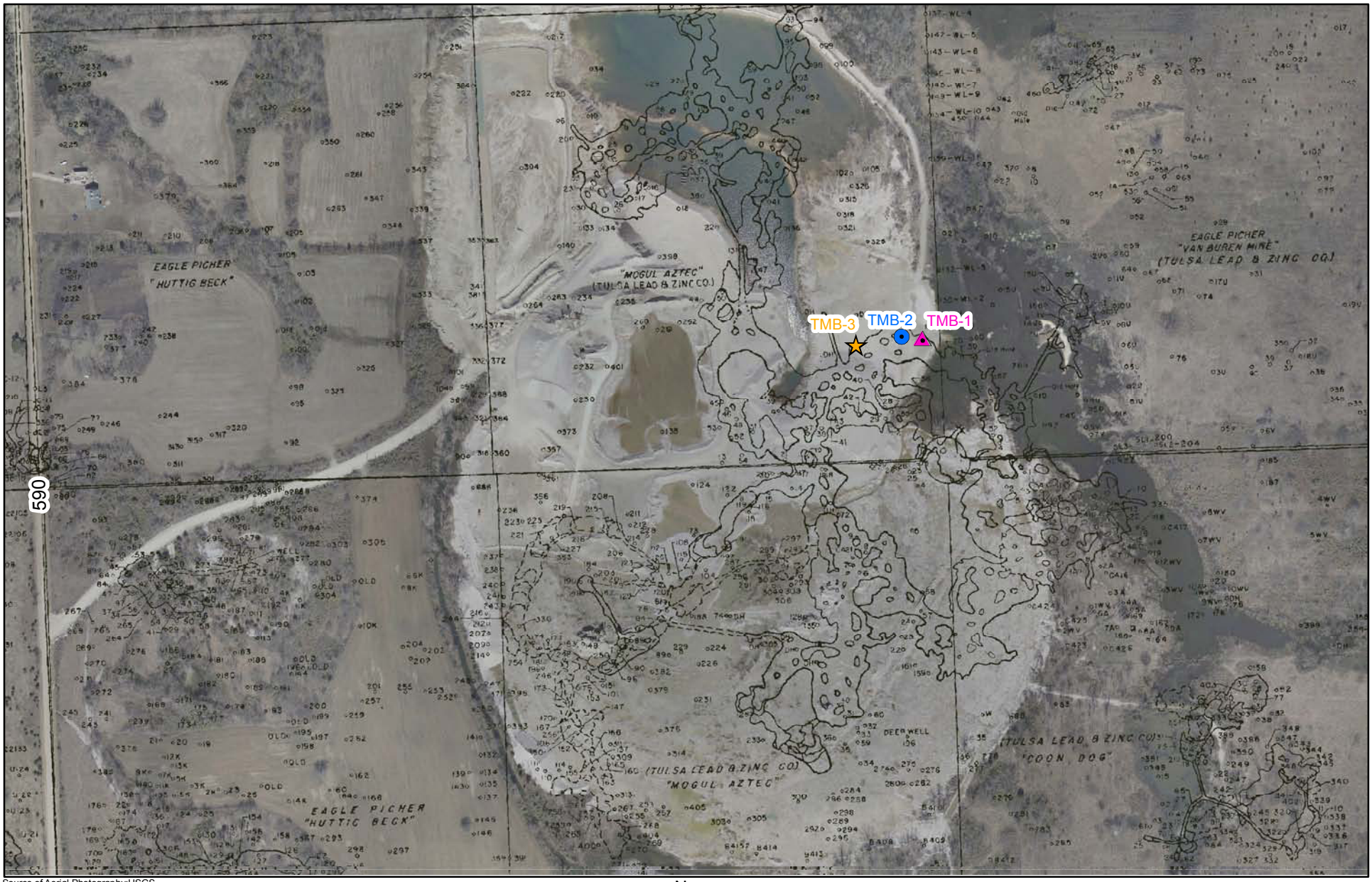
ES010510072638DFW




Source of Aerial Photography:USGS

## Legend

- Groundwater Extraction & Injection Boring
- Groundwater Extraction Boring
- Injection Boring
- Mine Outline

N

0 200 400 800 Feet

**FIGURE 4-8**
Tulsa Mine (Atlas Pile) Fines Injection Pilot Study
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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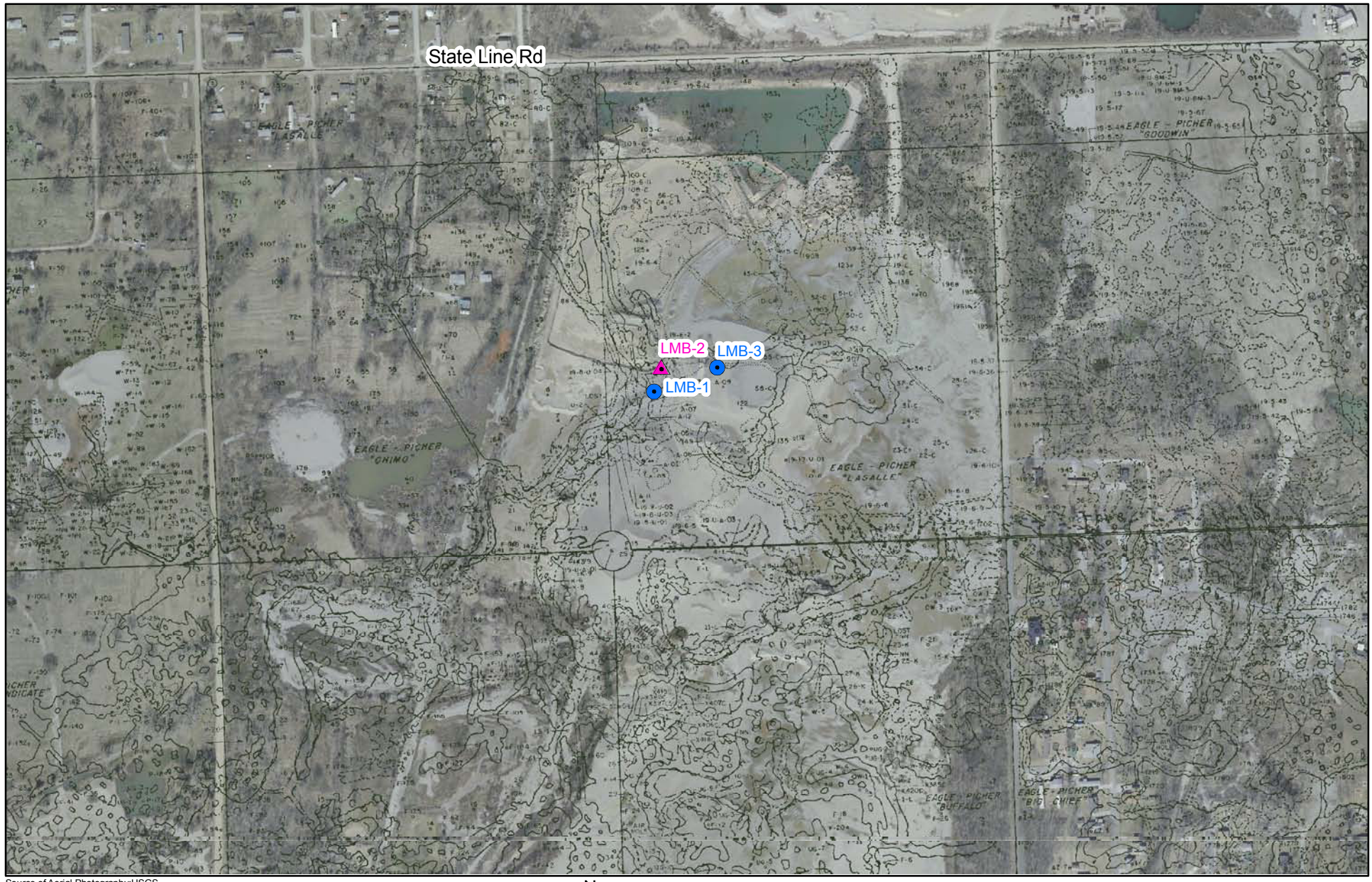



Source of Aerial Photography:USGS

**Legend**

- Groundwater Extraction Boring
- Injection Boring
- Mine Outline

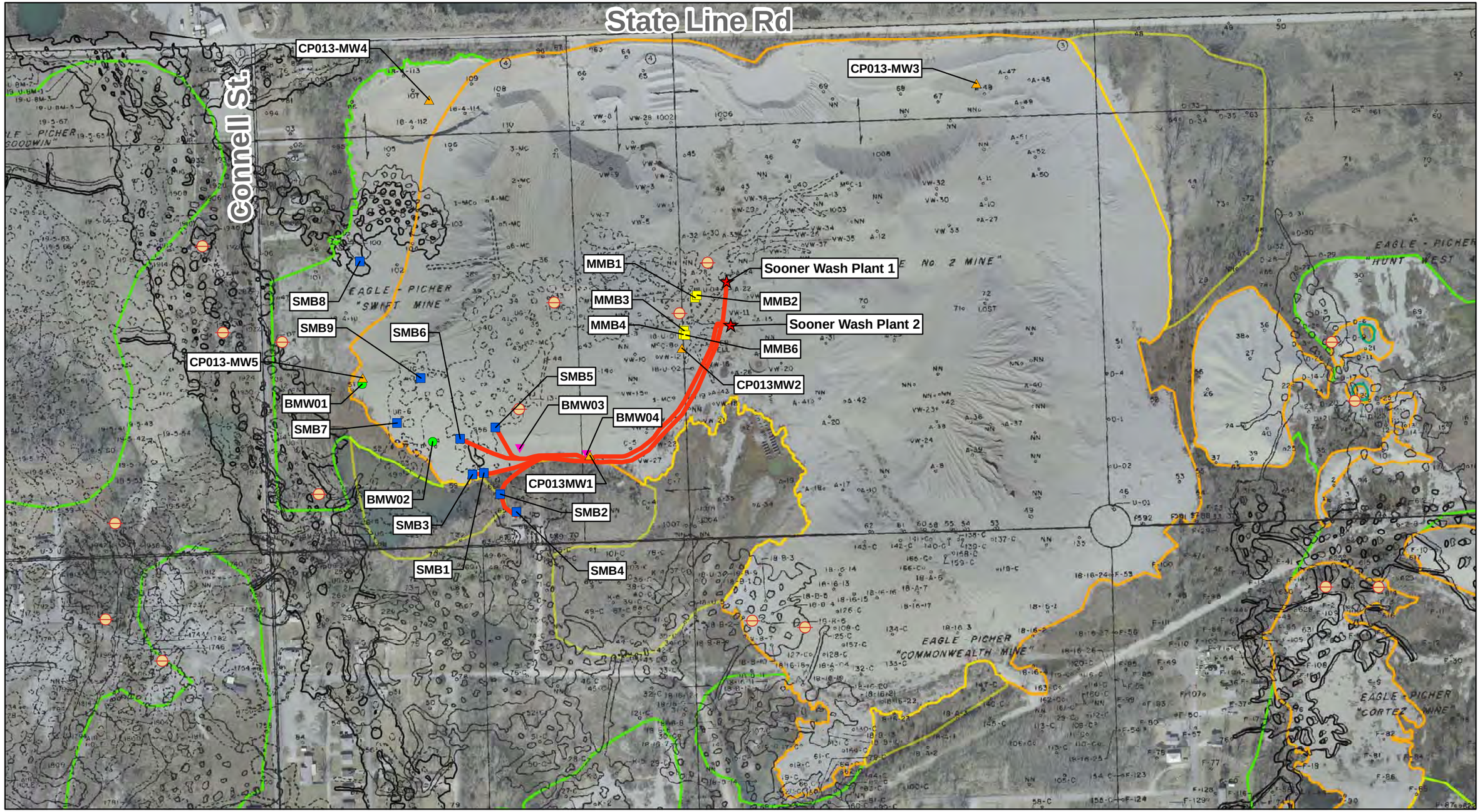
N

0 225 450 900 Feet

**FIGURE 4-9**
LaSalle Mine (Ottawa Pile) Chat Washed Fines Injection
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW




Source of Aerial Photography:USGS

**LEGEND**

- Boone Monitoring Well
- Chat Pile Well
- Extraction Boring
- Injection Boring
- Other Well
- Wash Plant
- Mine Shafts
- Pipeline Track
- Mine Outline
- Chat Bases
- Chat Pile
- Fine Tailings
- Development Rock

N

0 400 800 Feet

FIGURE 4-10
Sooner Pile Pilot Study
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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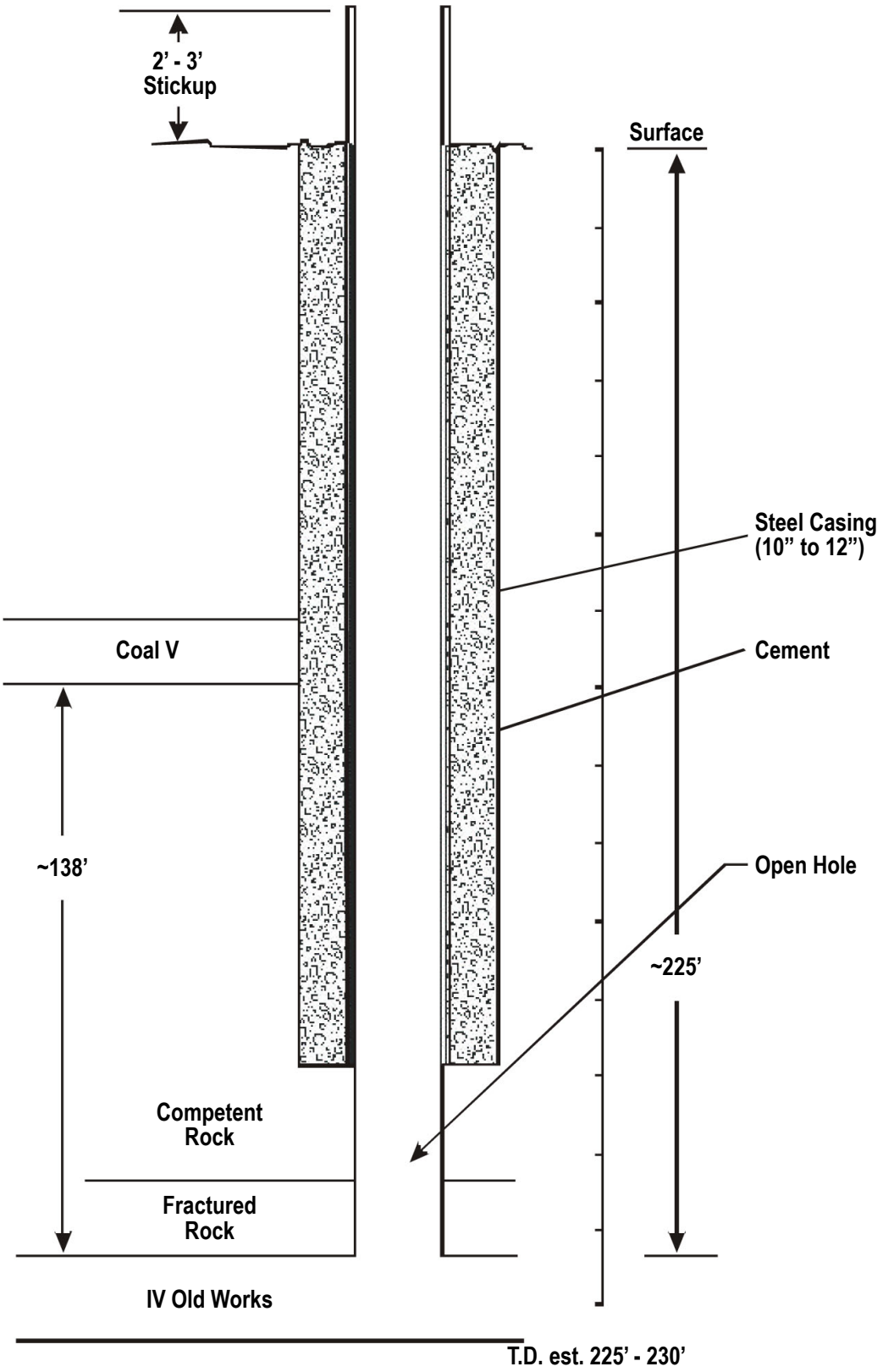



**FIGURE 5-1**
Example of Shallow Mine Backfill Injection Well Construction
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

Source: Endress, 1996

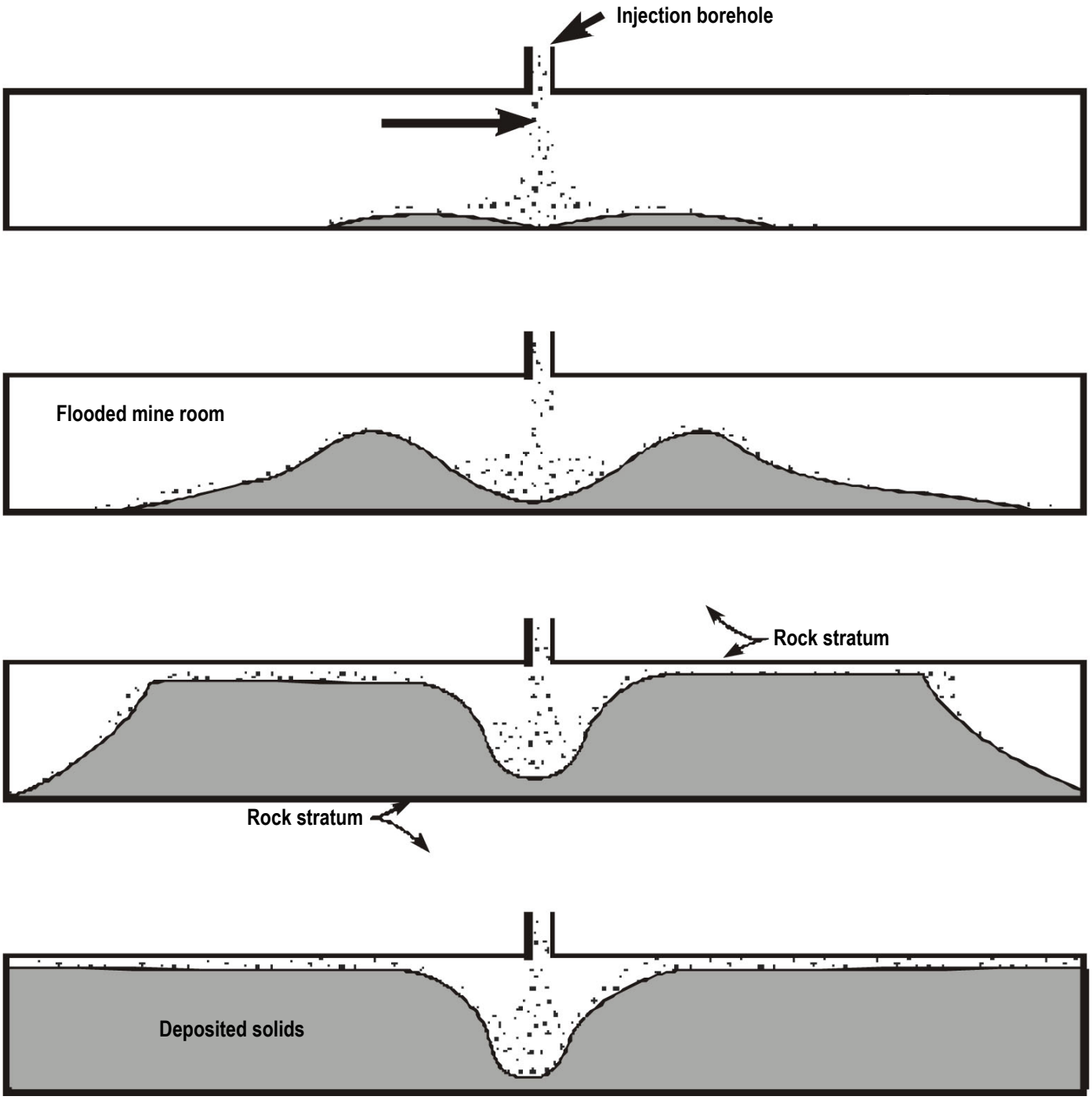
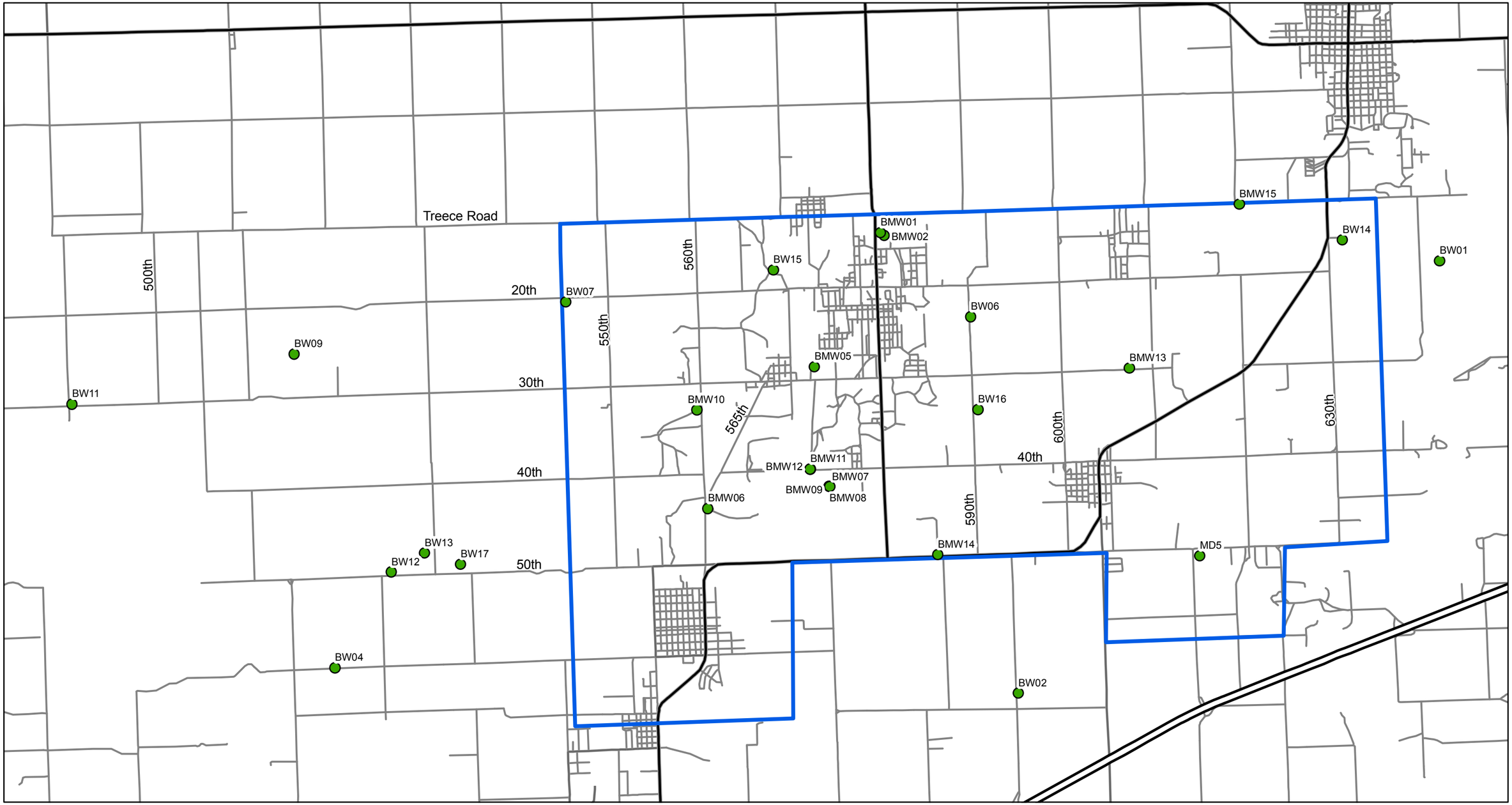



**FIGURE 5-2**
Schematic Depiction of Pumped Slurry Backfill Injection
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

Adapted from: Whaite and Allen, 1975




**Legend**

- Boone Aquifer Monitoring Location
- Tar Creek OU4 Site Boundary

N

2 1 0 2 Miles

**FIGURE 6-1**
Boone Aquifer Monitoring Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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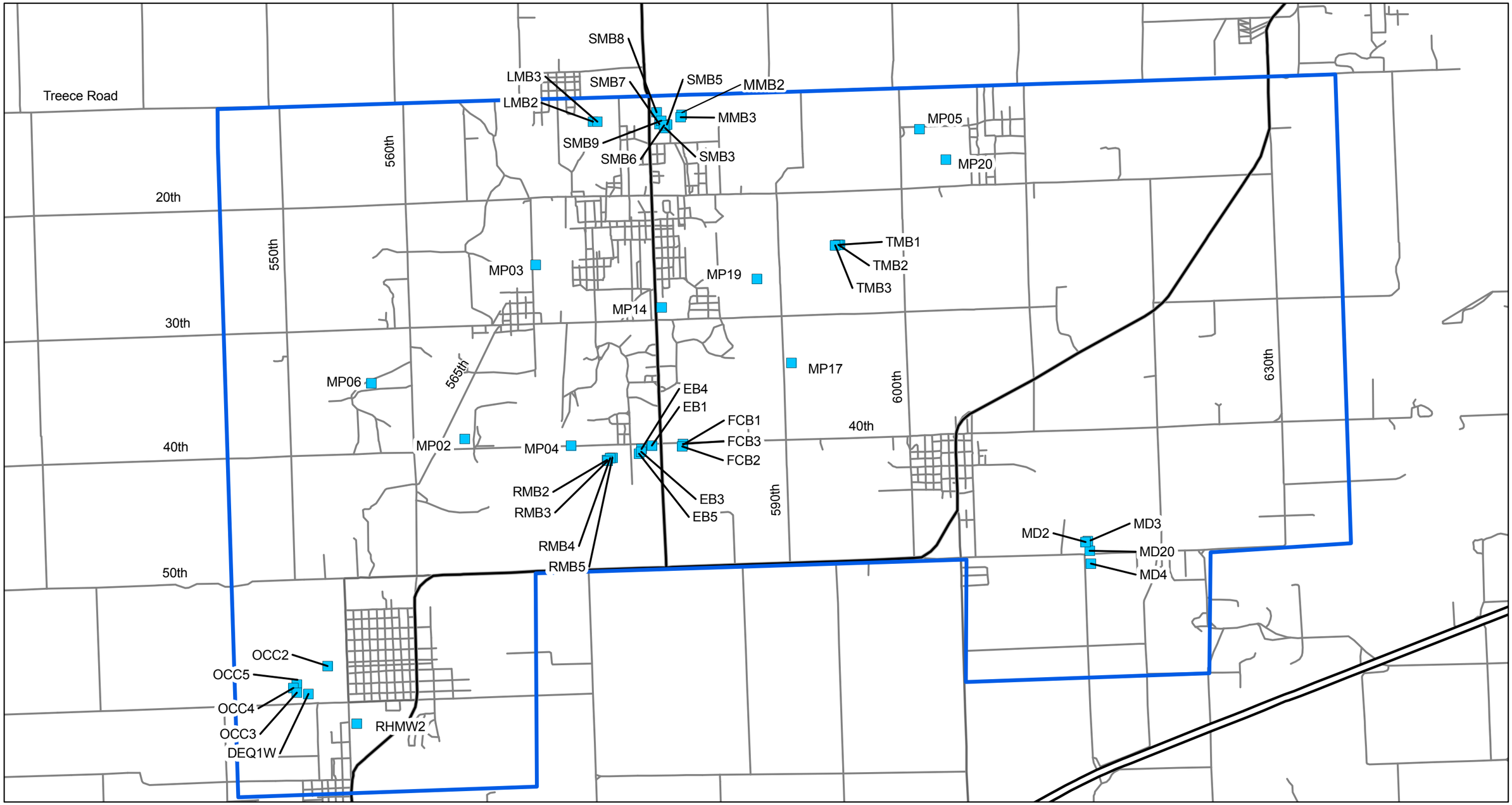
ES010510072638DFW




**Legend**

- Mine Pool Monitoring Location
- Tar Creek OU4 Site Boundary

N

4,000 2,000 0 4,000 Feet

**FIGURE 6-2**
Mine Pool Monitoring Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

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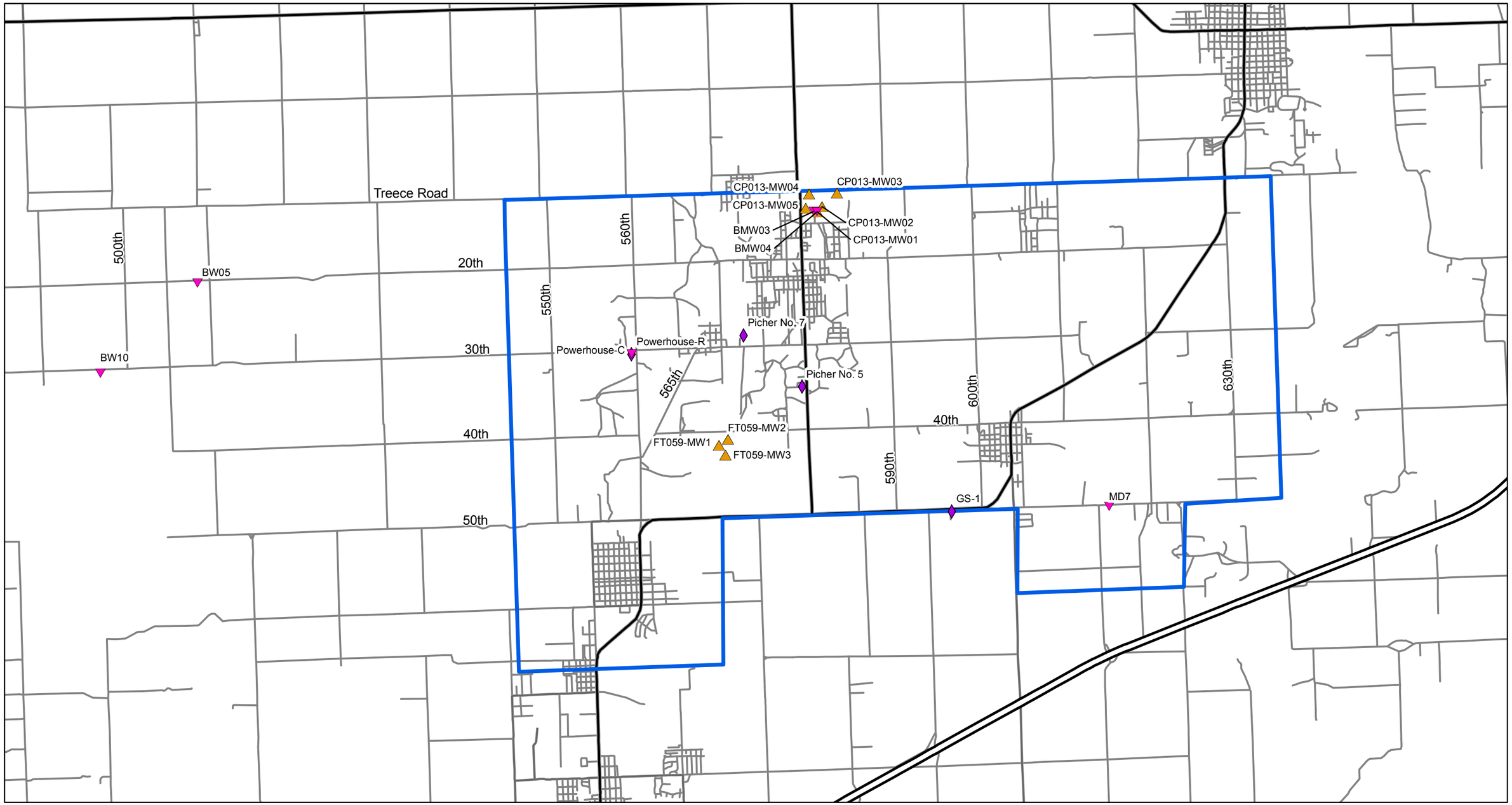


**Legend**

- Other Well
- Roubidoux Well
- Source Material Well
- Tar Creek OU4 Site Boundary

N

2 1 0 2 Miles

**FIGURE 6-3**
Source Material, Roubidoux and Other Well Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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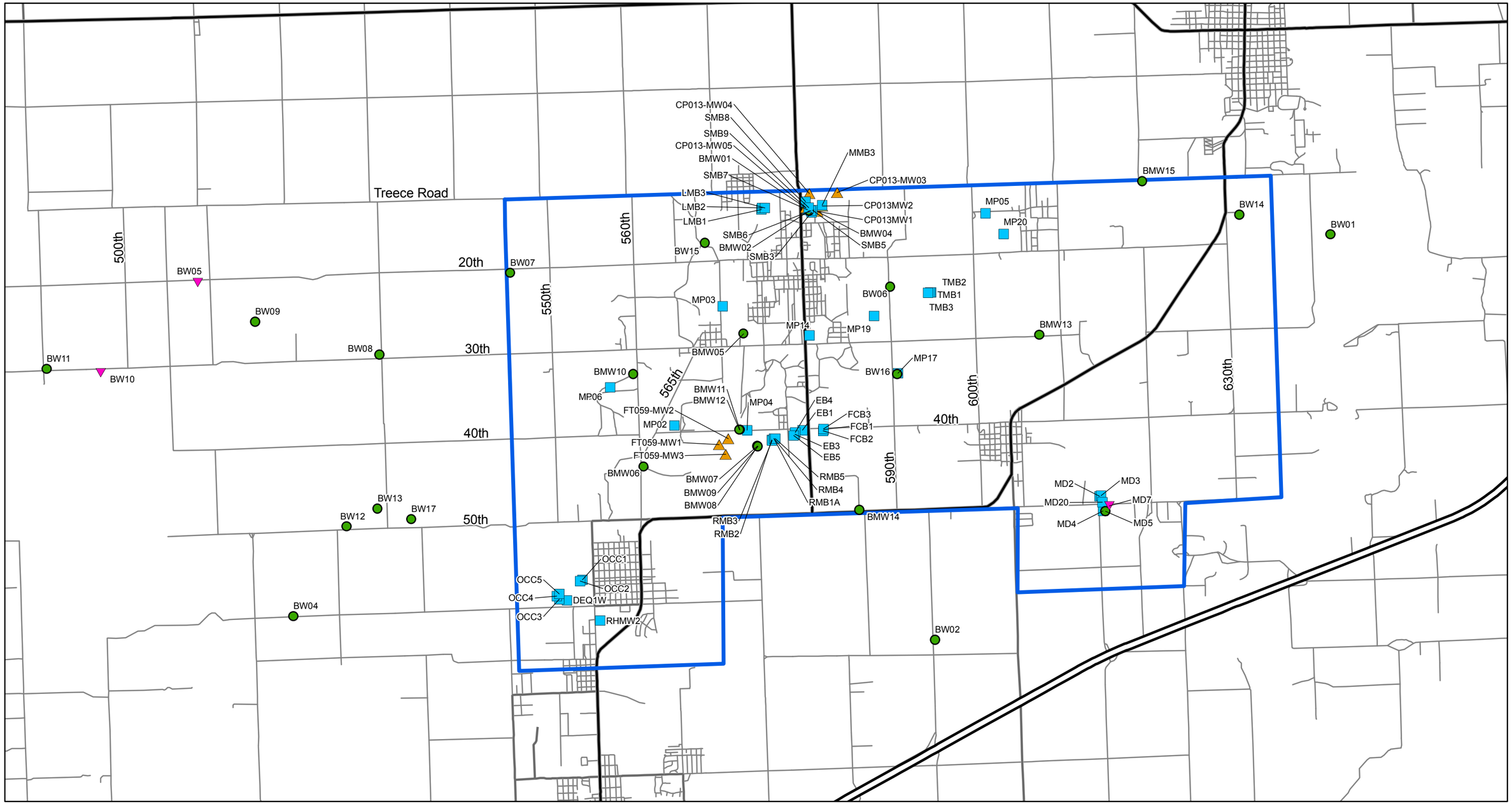


**Legend**

- Boone Formation Monitoring Location
- Mine Pool Location
- Source Material Well
- Other Well
- Tar Creek OU4 Site Boundary

N

2 1 0 2 Miles

**FIGURE 6-4**
OU4 Monitoring Network Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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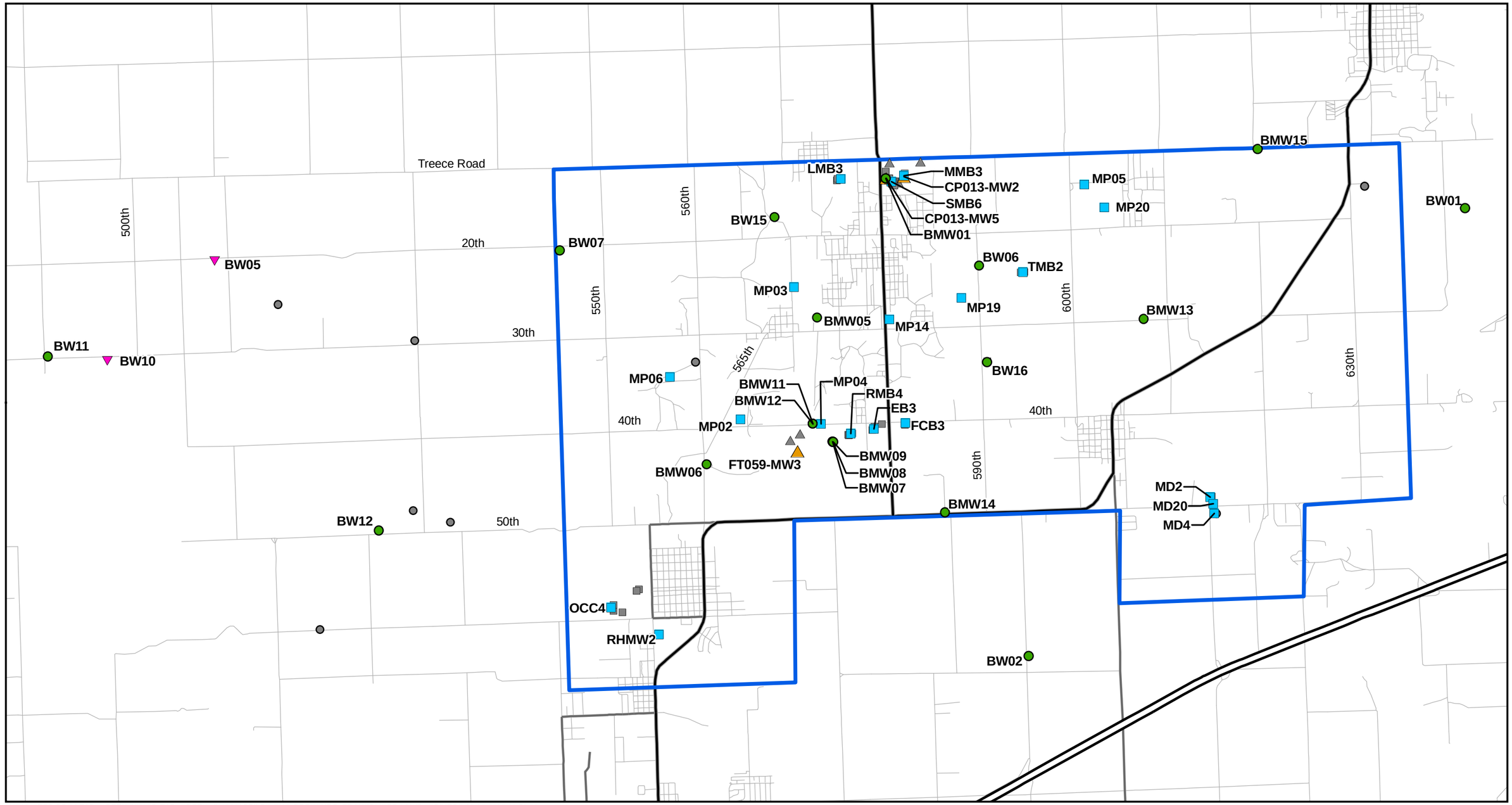


\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\OU4_PRESSURE_TRANSDUCERS.MXD CRIVERS 12/13/2010 11:51:21

**Legend**

- Boone Aquifer Monitoring Location
- Mine Pool Monitoring Location
- Source Material Well
- Other Well
- Tar Creek OU4 Site Boundary

Note:
Gray symbols indicate locations with no transducer

N

2 1 0 2 Miles

FIGURE 6-5
OU4 Monitoring Locations With Pressure Transducers Installed
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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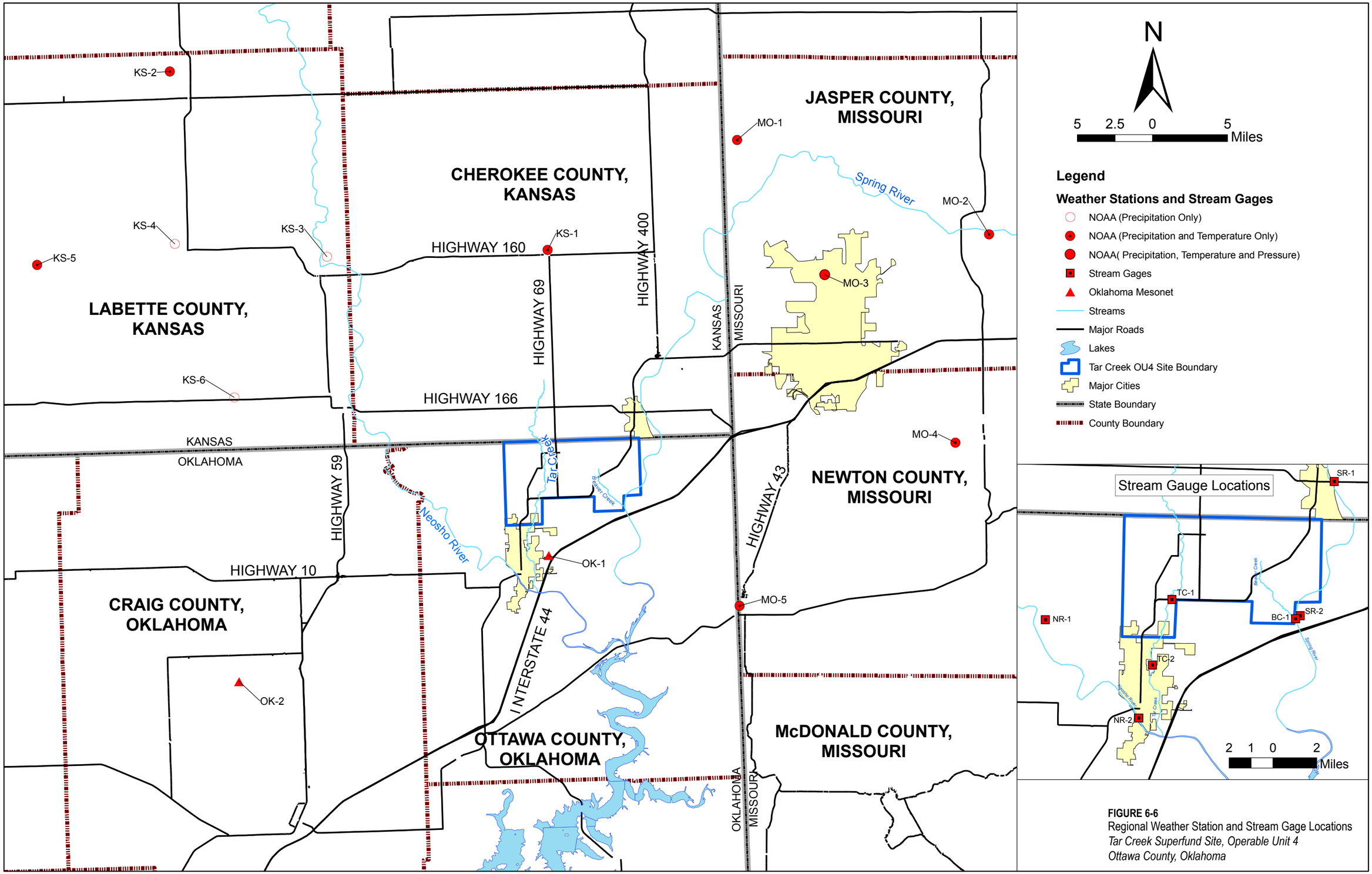
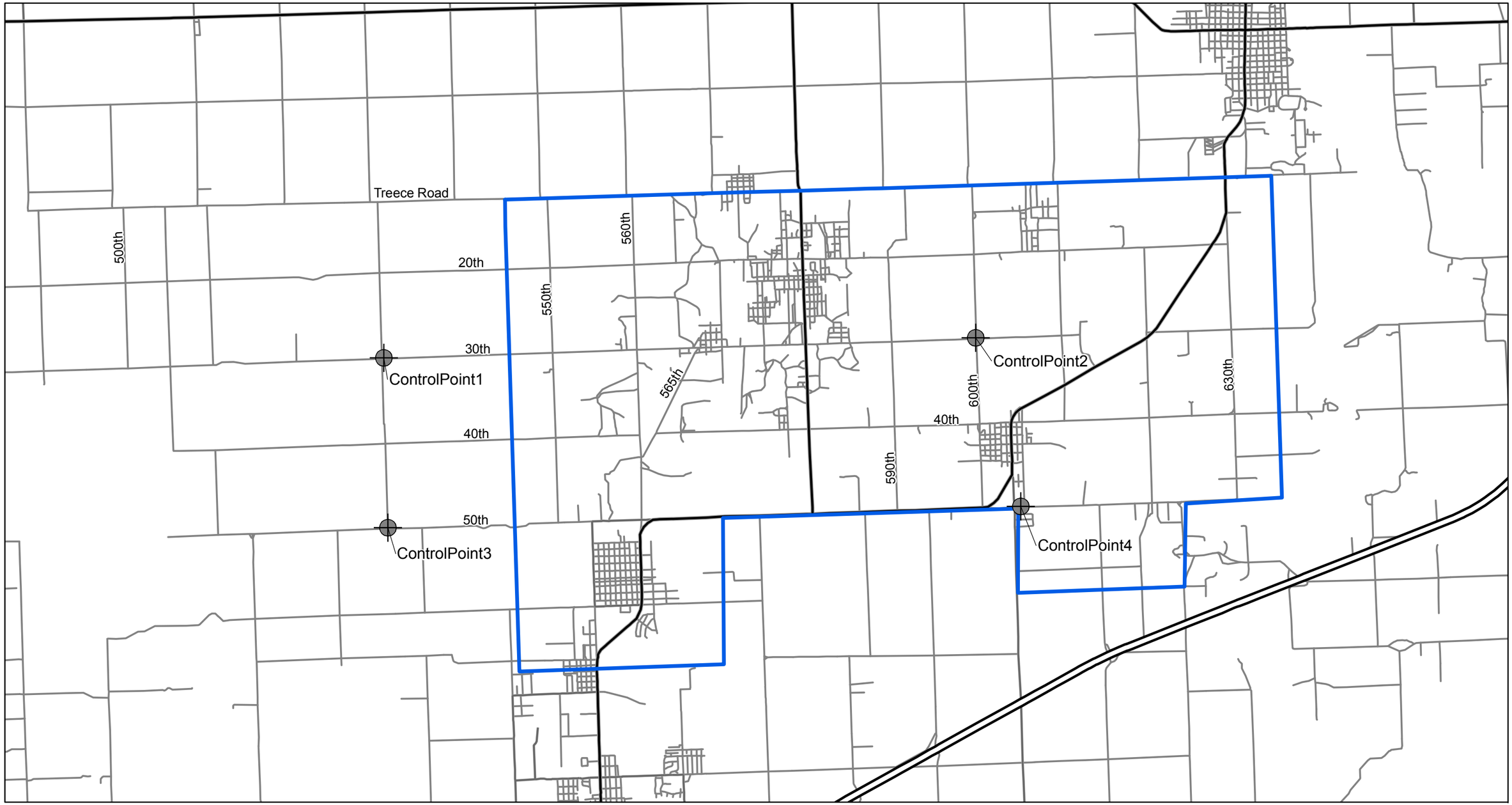



**FIGURE 6-6**
Regional Weather Station and Stream Gage Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




**Legend**

Primary Control Monument

Tar Creek OU4 Site Boundary

N

2 1 0 2 Miles

**FIGURE 6-7**
Primary Control Monument Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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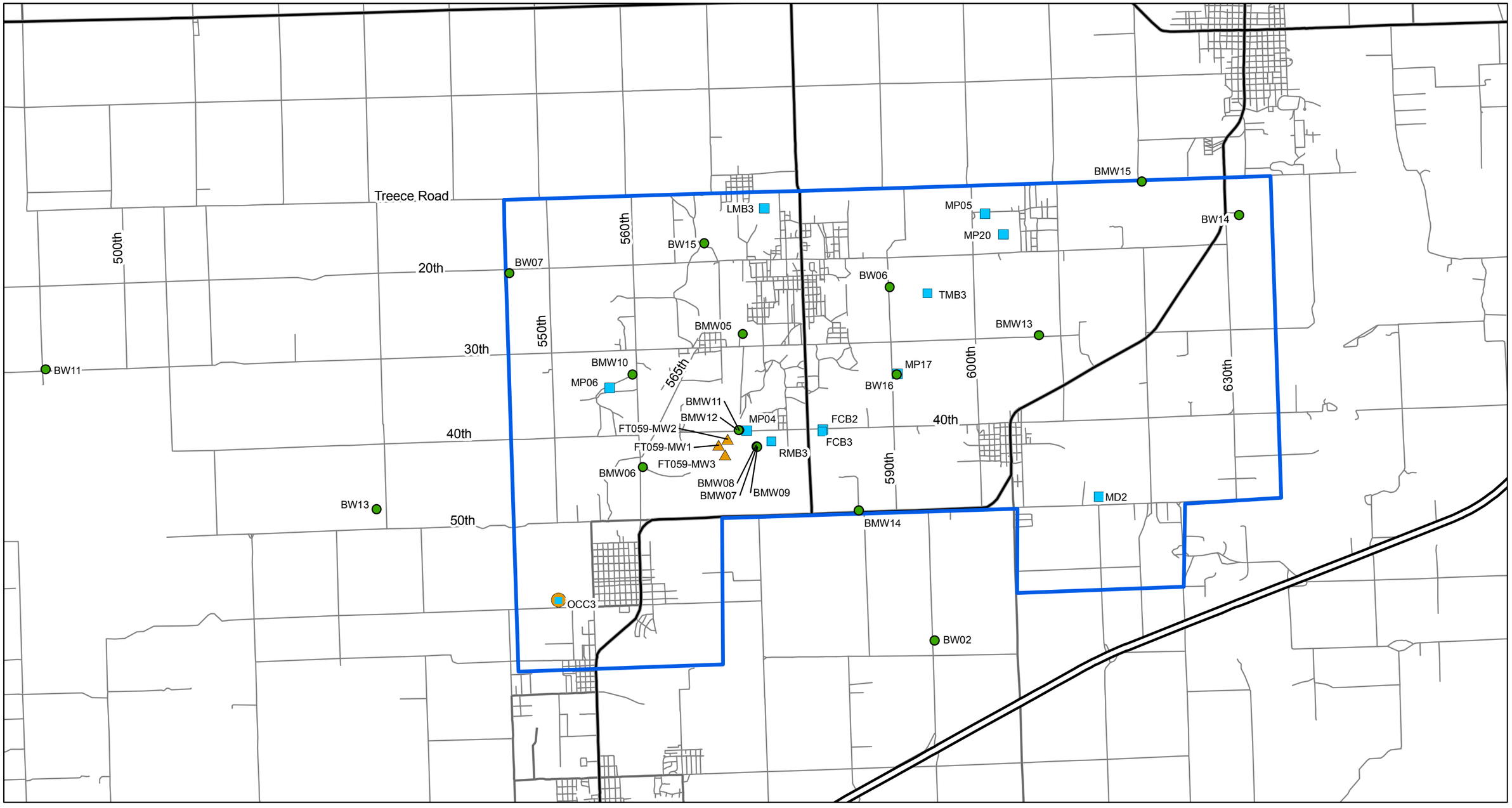


## Legend

- Boone Aquifer Monitoring Location
- Mine Pool Monitoring Location
- Source Material Monitoring Location
- Mine Pool Monitoring Location (Sampled by ODEQ)
- Tar Creek OU4 Site Boundary

N

2 1 0 2 Miles

**FIGURE 6-8**
Quarterly Sampling Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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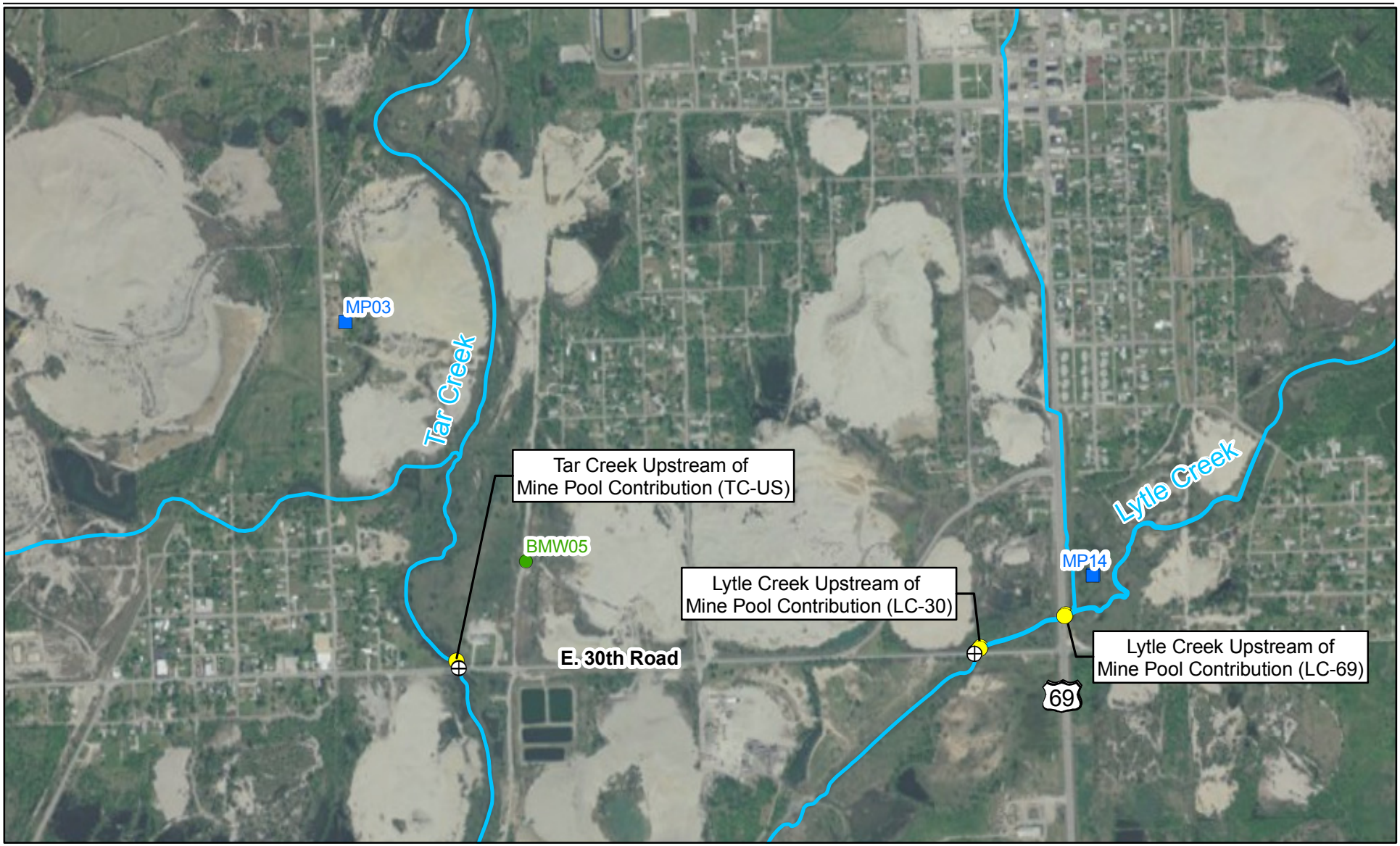


\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\SURF_WAT_GAUGE_LOCS_1_REV2010.MXD GBOQUIN 12/14/2010 13:30:06

**Legend**

- Parkhurst High-Flow Surface Water Discharge Measurement Location
- Boone Formation Monitor Well
- Mine Pool Monitor Well
- Surface Water Gage (flow and stage)
- Surface Water Gage (stage only)
- Stream

500 250 0 500 Feet

N

**FIGURE 6-9**
Stream Gaging Sites on Lytle Creek and Tar Creek
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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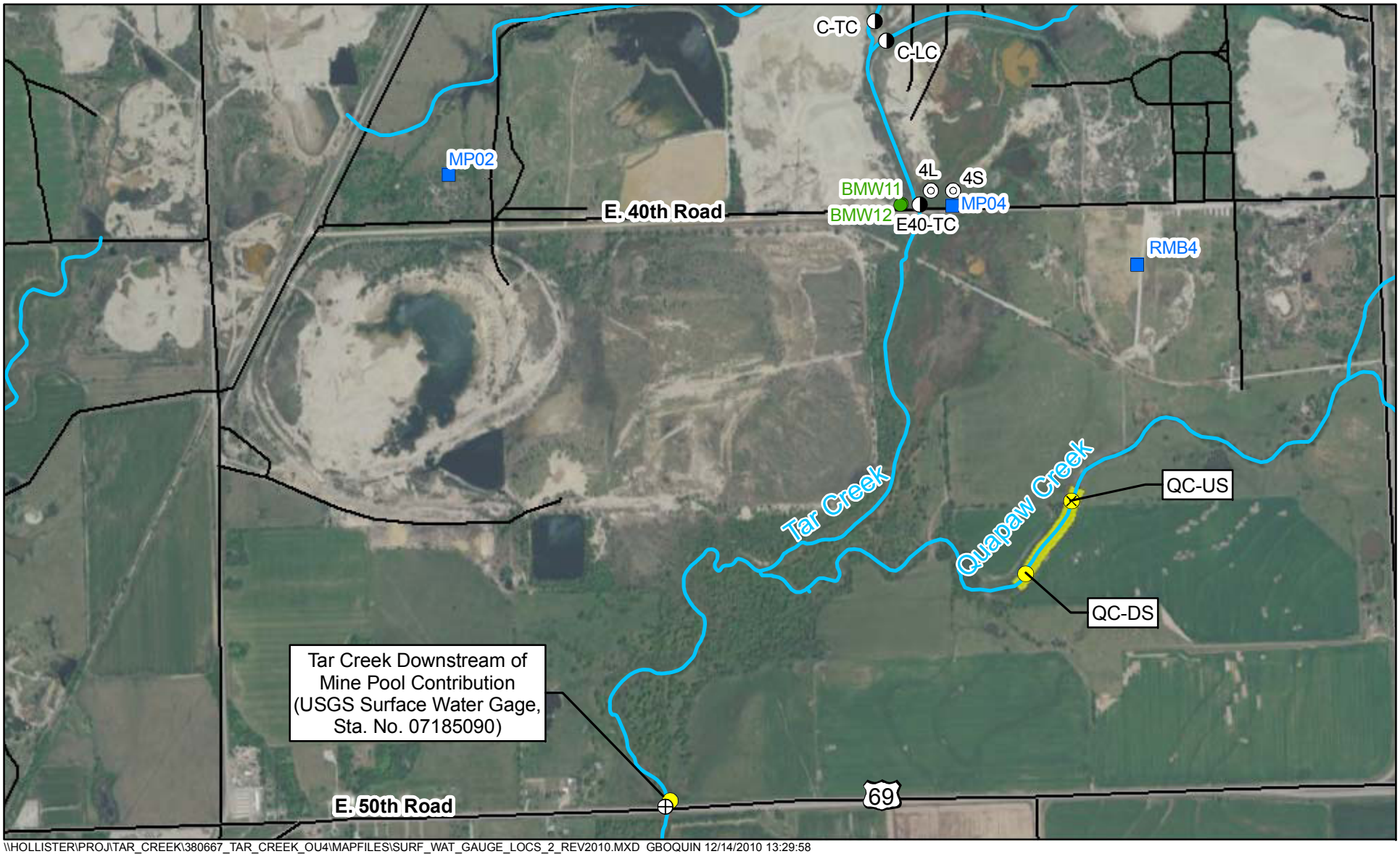


\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\SURF_WAT_GAUGE_LOCS_2_REV2010.MXD GBOQUIN 12/14/2010 13:29:58

**Legend**

- Parkhurst High-Flow Surface Water Discharge Measurement Location
- OWRB Surface Water Discharge Measurement Location (4L same as DEQ Site 4)
- OU Surface Water Discharge Measurement Location
- Boone Formation Monitor Well
- Mine Pool Monitor Well
- Surface Water Gage (flow and stage)
- Stream
- Surface Water Gage (stage only)
- Quapaw Creek Slope -Area Discharge Reach

N

500 250 0 500 Feet

**FIGURE 6-10**
Stream Gaging Sites on Tar Creek and Quapaw Creek
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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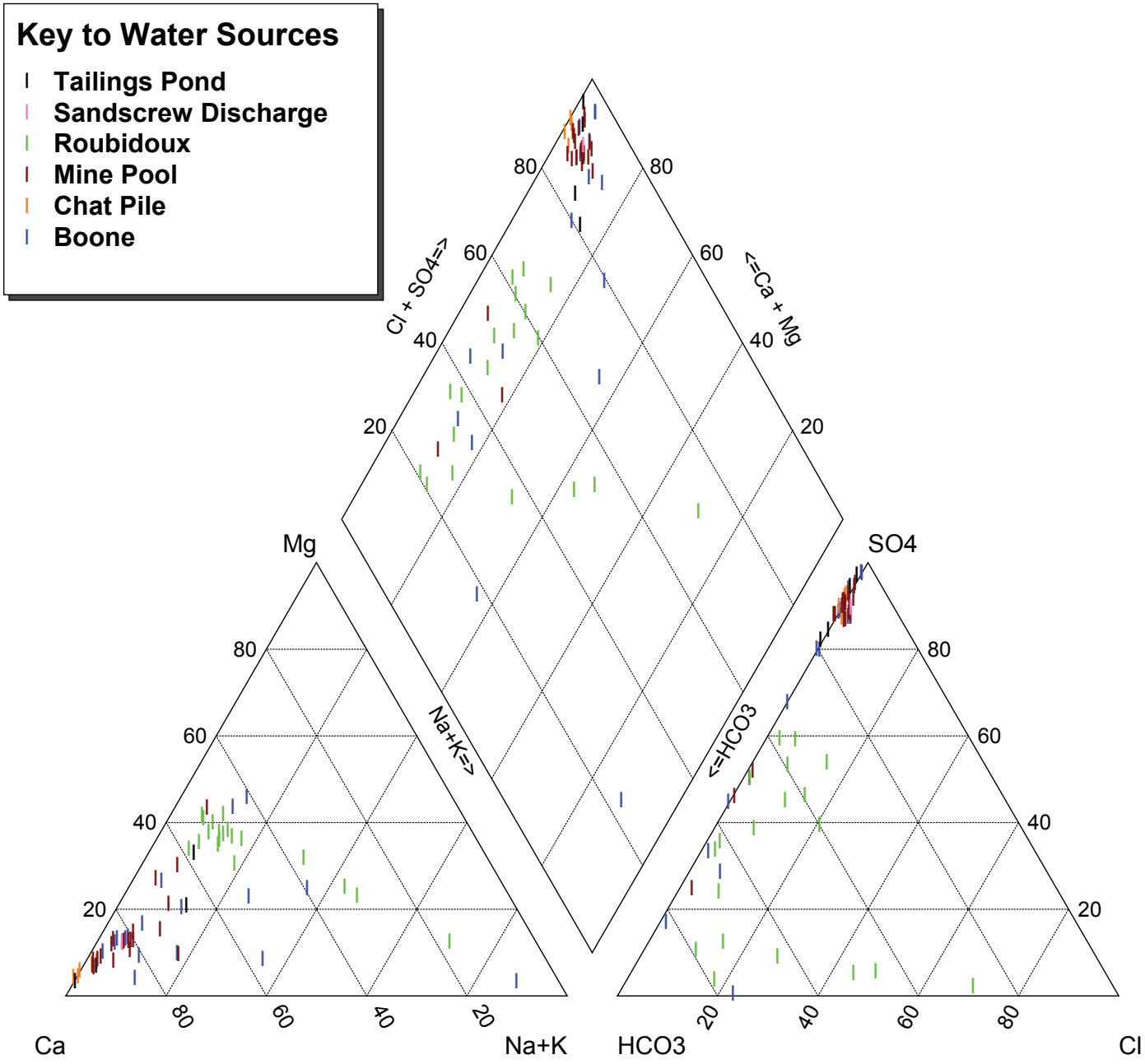
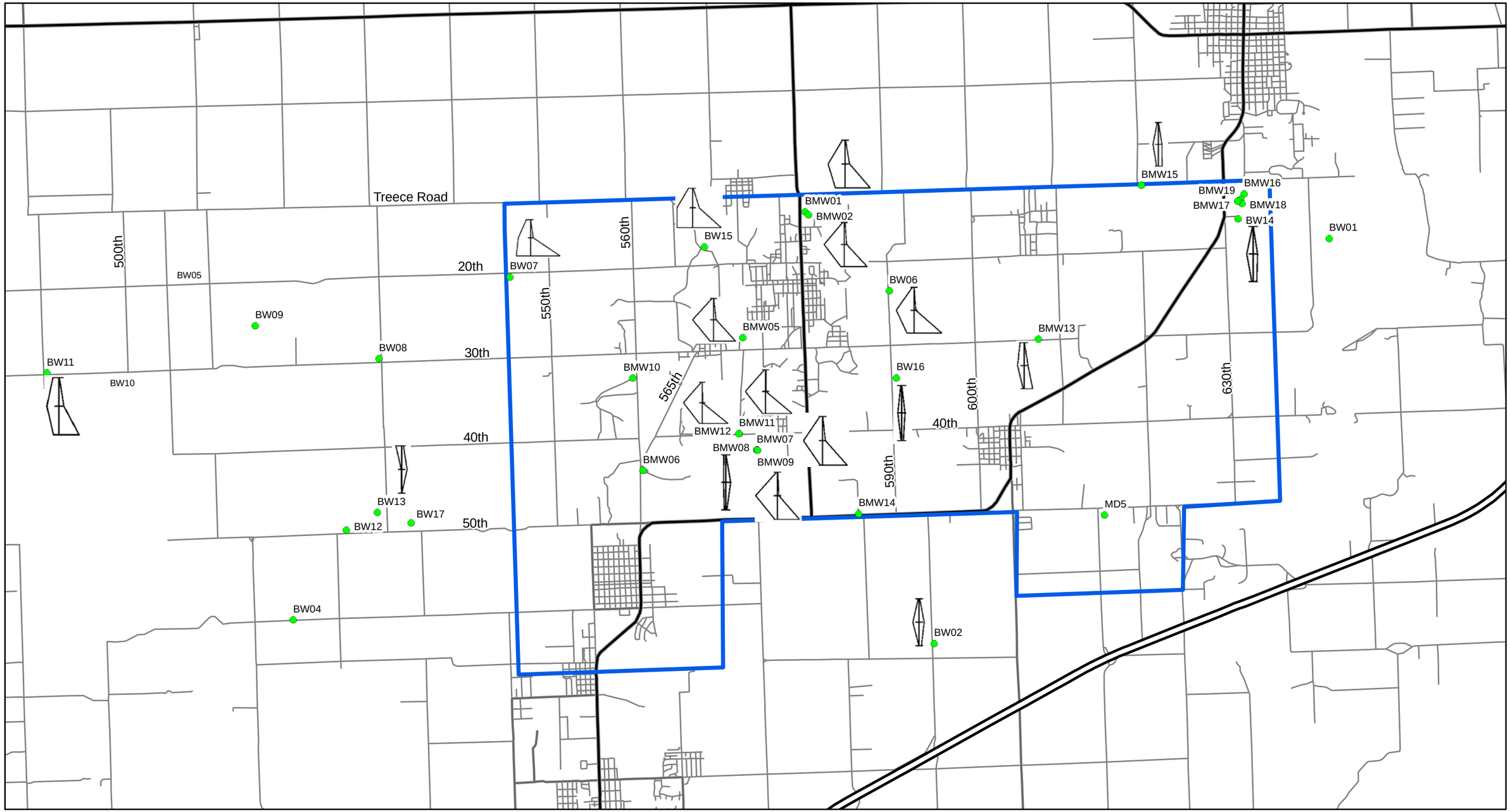


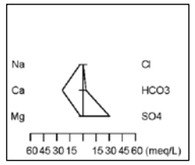

**FIGURE 7-1**
Piper Chemical Diagram of Tar Creek Water Sources
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\STIF_BOONE.MXD JRIVERS 12/3/2010 16:16:43

**Legend**

- Boone Aquifer Monitoring Locations
- Tar Creek OU4 Site Boundary



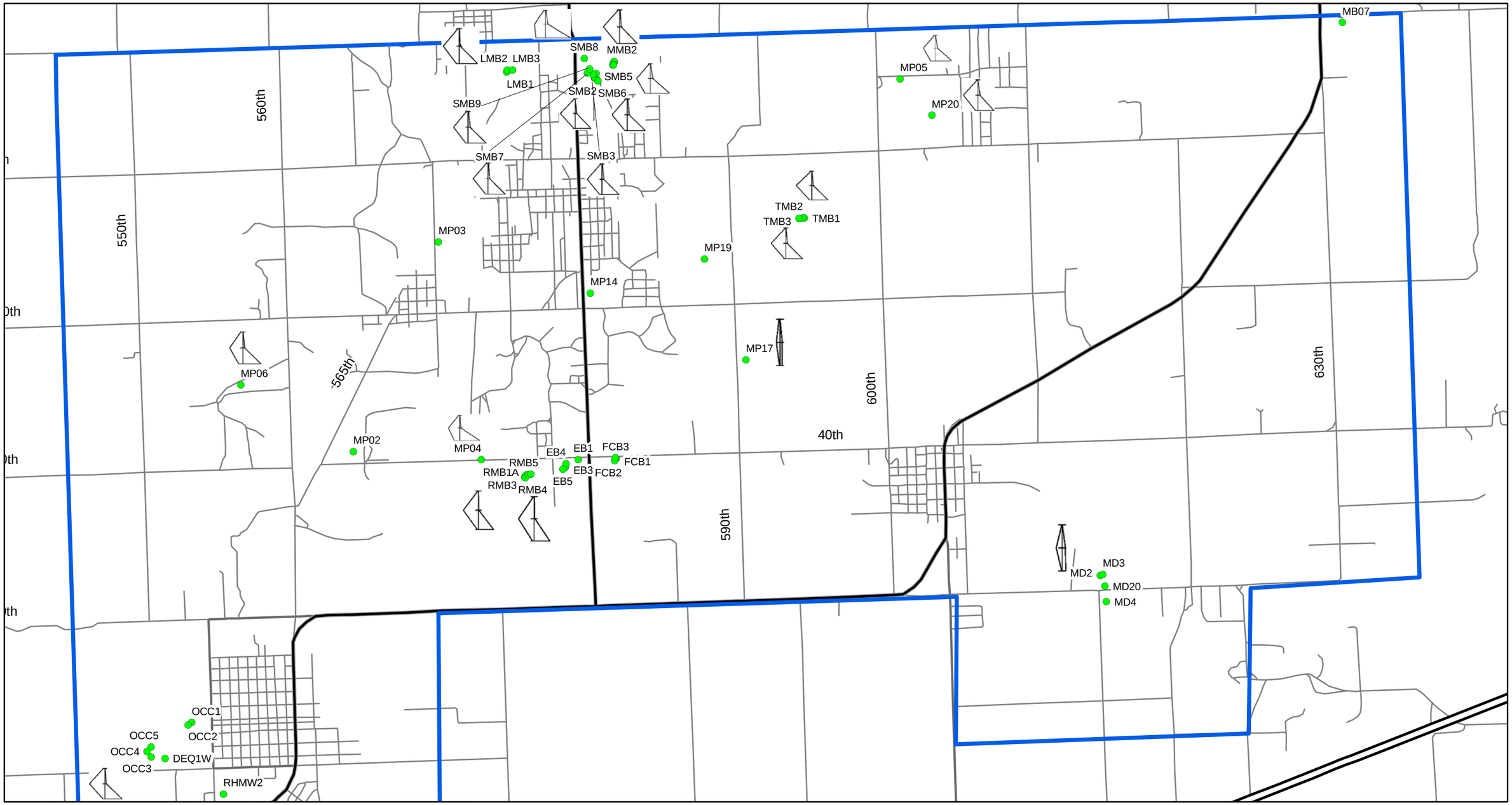

N

2 1 0 2 Miles

FIGURE 7-2
Boone Aquifer General Water Chemistry
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

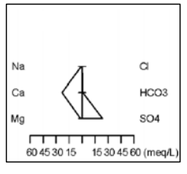
ES010510072638DFW




\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\STIF_MINEPOOL.MXD GBOQUIN 12/3/2010 14:43:09

**Legend**

- Mine Pool Monitoring Locations
- Tar Creek OU4 Site Boundary



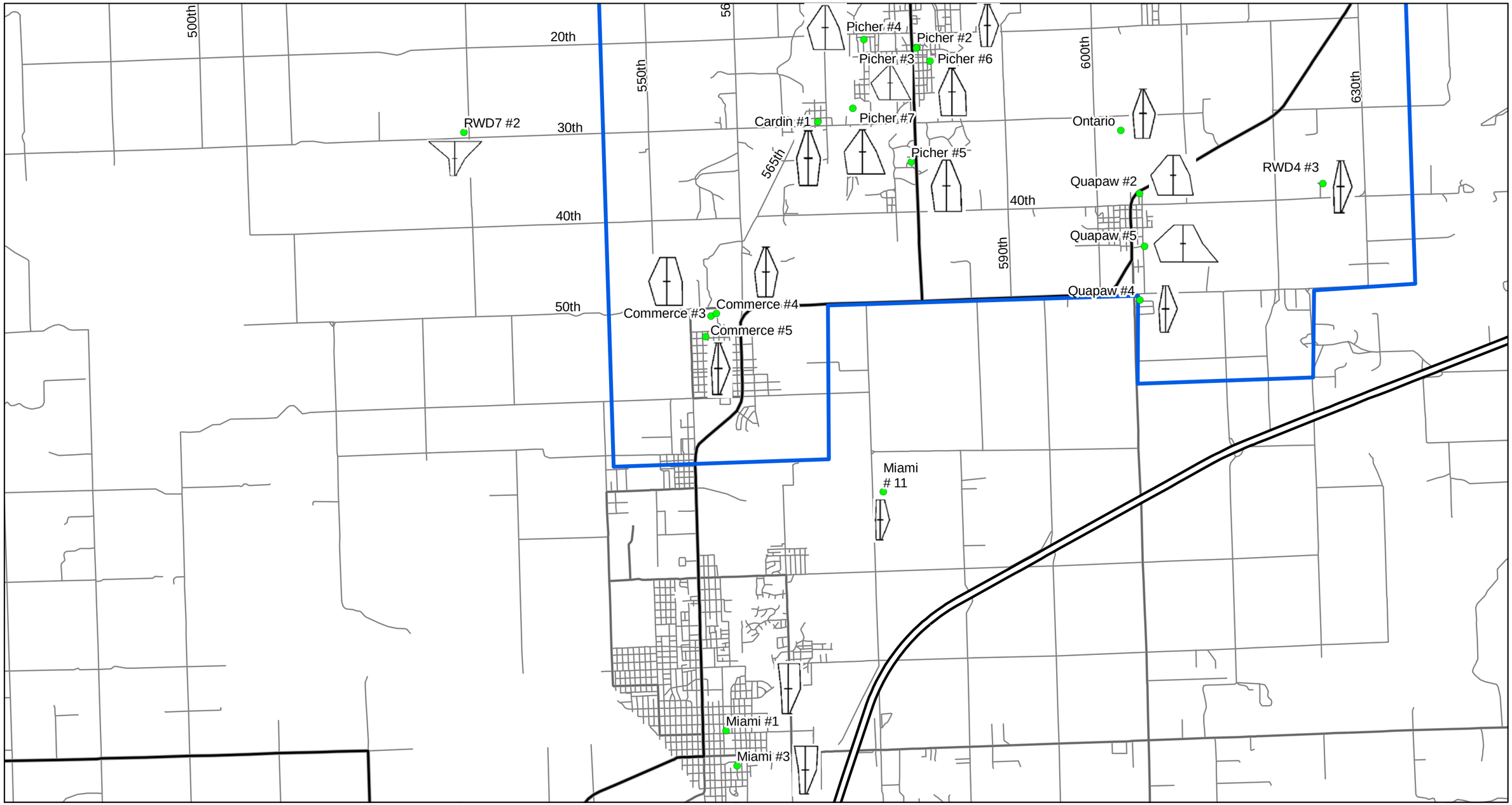

N

1 0.5 0 1 Miles

FIGURE 7-3
Mine Pool General Water Chemistry
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

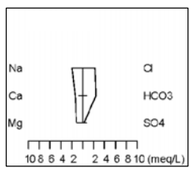
ES010510072638DFW




\\HOLLISTER\PROJ\TAR_CREEK\380667_TAR_CREEK_OU4\MAPFILES\STIF_RUBIDOUX.MXD GBOQUIN 12/21/2010 08:39:51

**Legend**

- Roubidoux Well Location
- Tar Creek OU4 Site Boundary



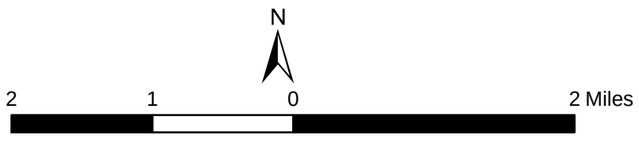
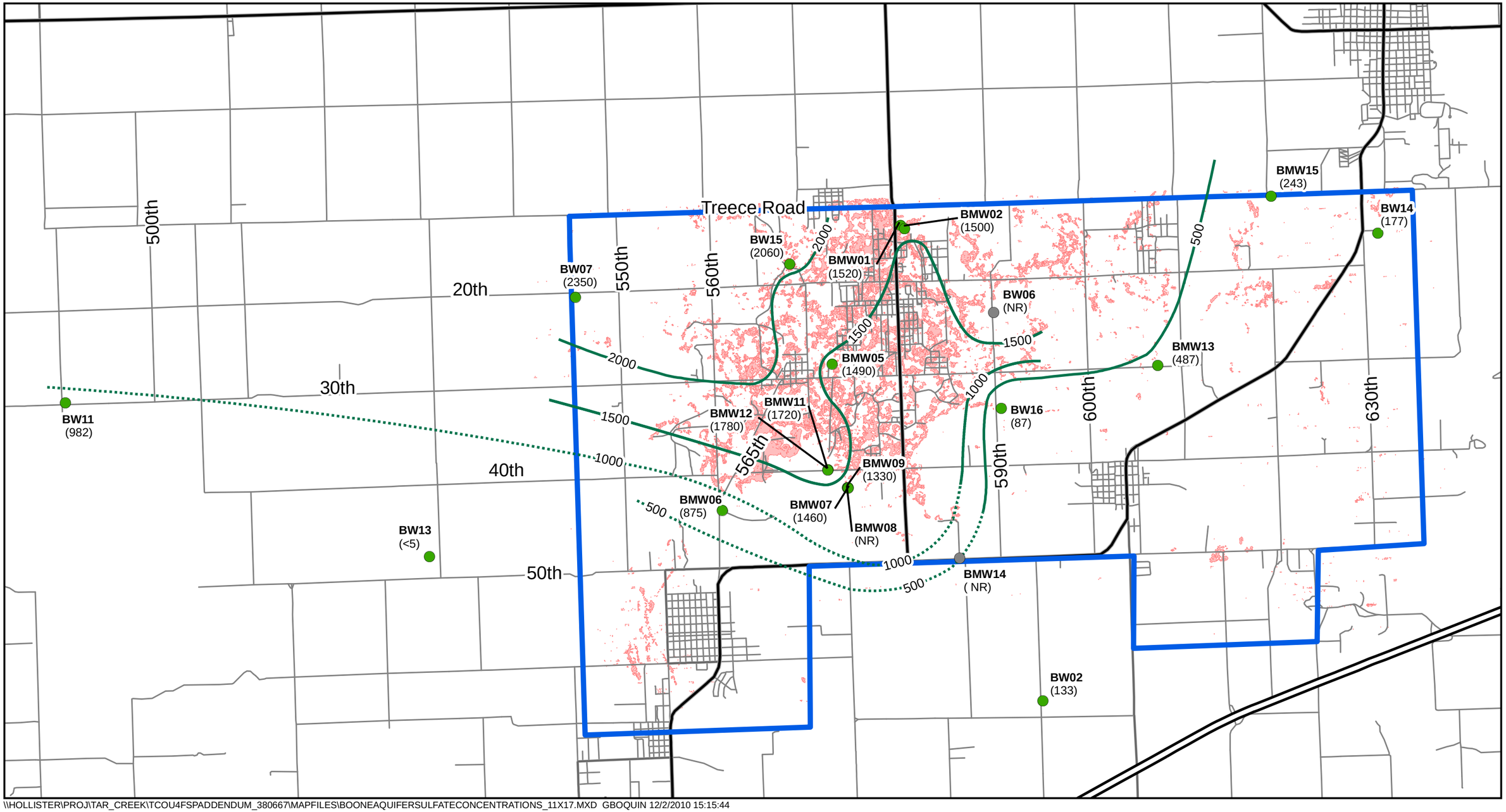




FIGURE 7-4
Rubidoux Aquifer General Water Chemistry
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW




\\HOLLISTER\PROJ\TAR_CREEK\TCOU4FSPADDENDUM_380667\MAPFILES\BOONEAQUIFERSULFATECONCENTRATIONS_11X17.MXD GBOQUIN 12/2/2010 15:15:44

**Legend**

- Boone Wells
- Not Sample
- Estimated Contour
- Calculated Contour
- Tar Creek OU4 Site Boundary
- Mine Workings

**Notes:**
1- Sulfate concentrations in (mg/L)
2- Sulfate concentrations are from October 2009
3- NR - well is not considered representative of Boone aquifer conditions, so the measured concentration is not included in the contouring

N

0 0.5 1 2 Miles

FIGURE 7-5
Boone Aquifer Sulfate Concentrations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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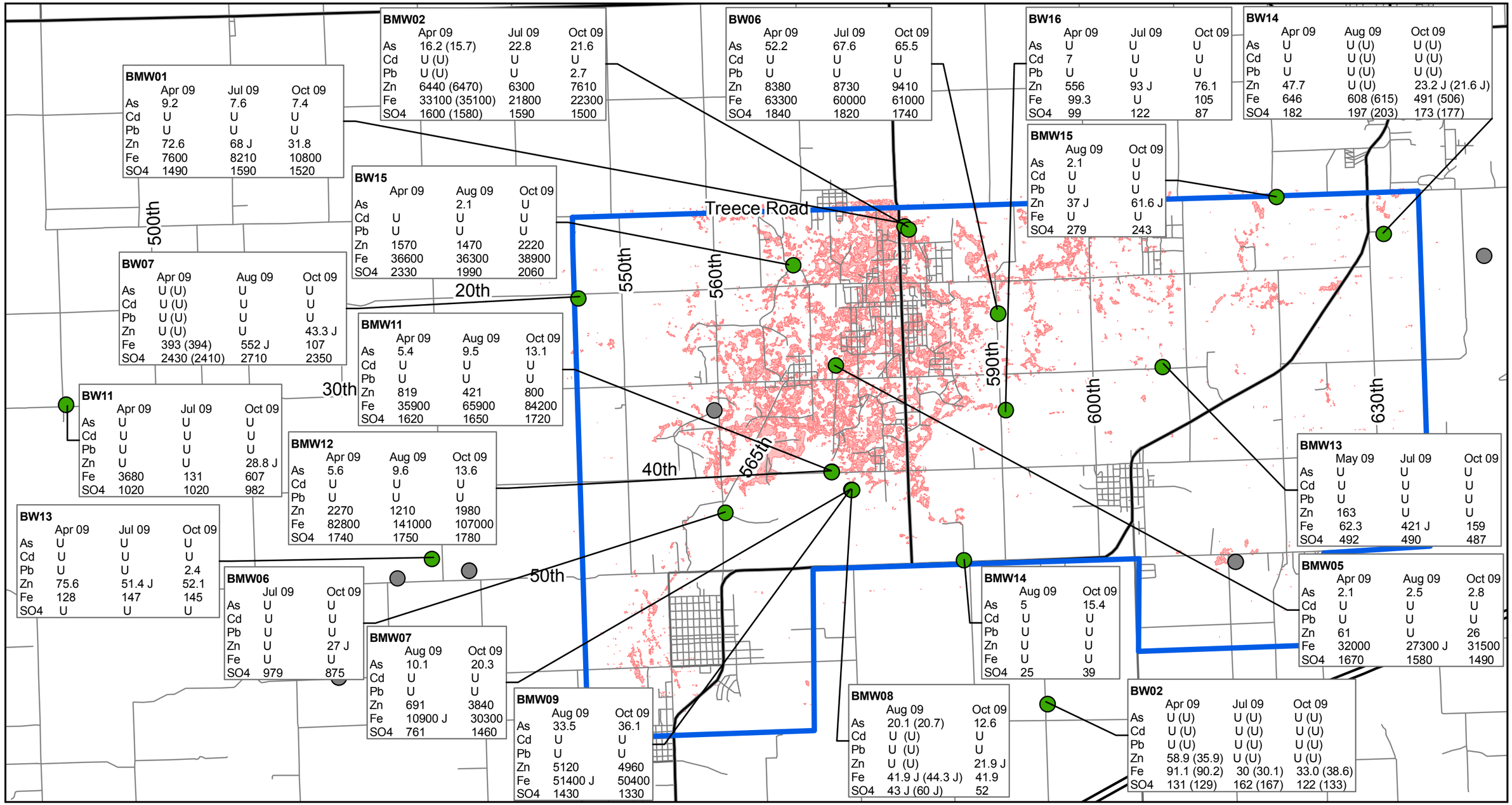


## Legend

- Boone Wells
- Not Sampled
- Tar Creek OU4 Site Boundary
- Mine Workings

**Notes:**
As - Arsenic in ug/L
Cd - Cadmium in ug/L
Pb - Lead in ug/L
Zn - Zinc in ug/L
Fe - Iron in ug/L
SO4 - Sulfate in mg/L
mg/L - Milligrams Per Liter
µg/L - Micrograms Per Liter

J - Estimated Concentration
U - Not Detected
Field Duplicate Concentrations Given in Parentheses.
All Results for Metals are Dissolved

N

0 0.5 1 2 Miles

**FIGURE 7-6**
2009 Quarterly Analytical Results for Arsenic, Cadmium, Iron, Lead, Sulfate and Zinc in Boone Aquifer Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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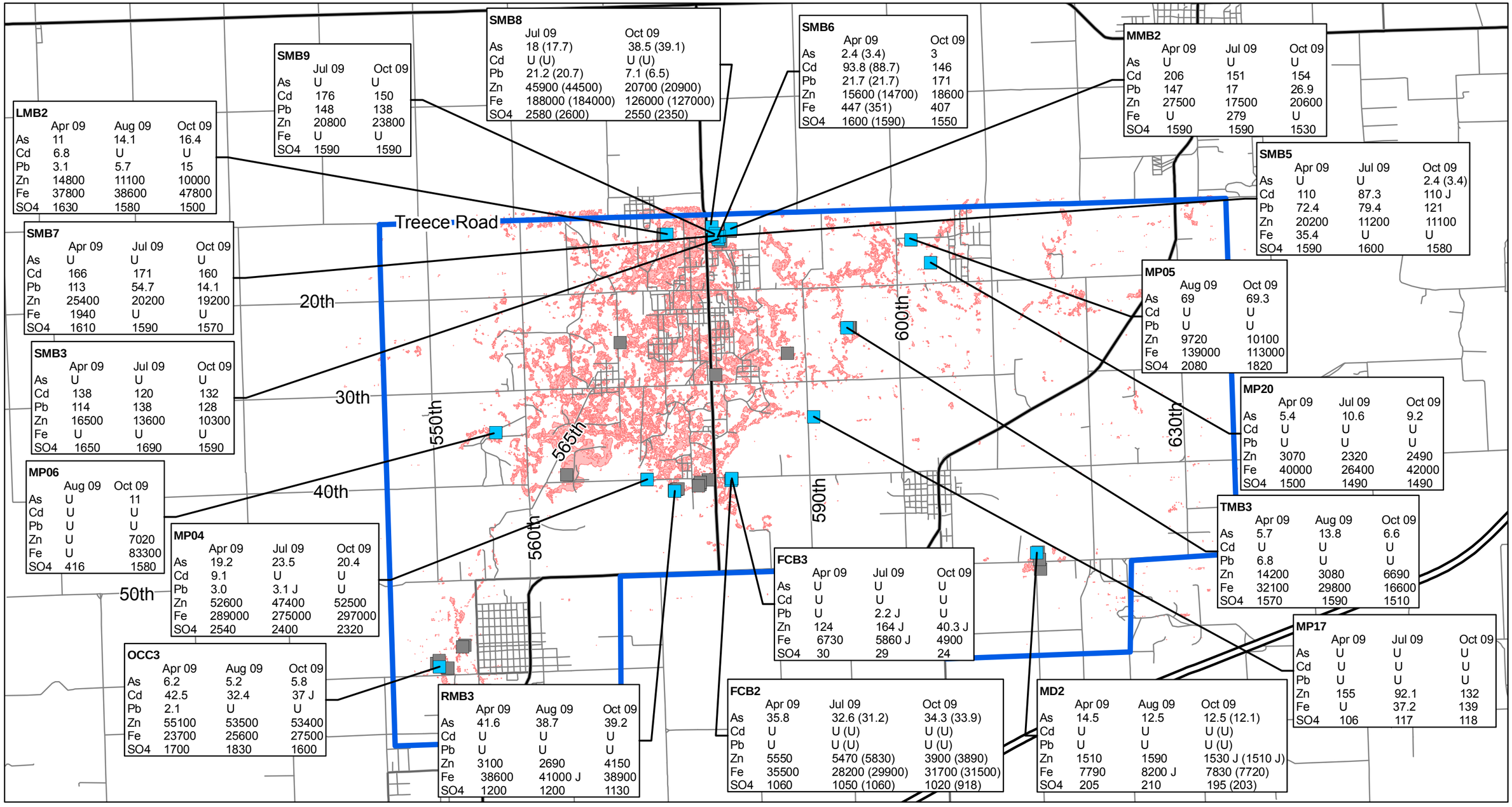


## Legend

- Mine Pool Locations
- Not Sampled
- Tar Creek OU4 Site Boundary
- Mine Workings

**Notes:**

As - Arsenic in ug/L
Cd - Cadmium in ug/L
Pb - Lead in ug/L
Zn - Zinc in ug/L
Fe - Iron in ug/L
SO4 - Sulfate in mg/L
mg/L - Milligrams Per Liter
µg/L - Micrograms Per Liter

J - Estimated Concentration
U - Not Detected
Field Duplicate Concentrations Given in Parentheses.
All Results for Metals are Dissolved

N

0 0.5 1 2 Miles

**FIGURE 7-7**
2009 Quarterly Analytical Results for Arsenic, Cadmium, Iron, Lead, Sulfate and Zinc in Mine Pool Locations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

CH2MHILL

ES010510072638DFW

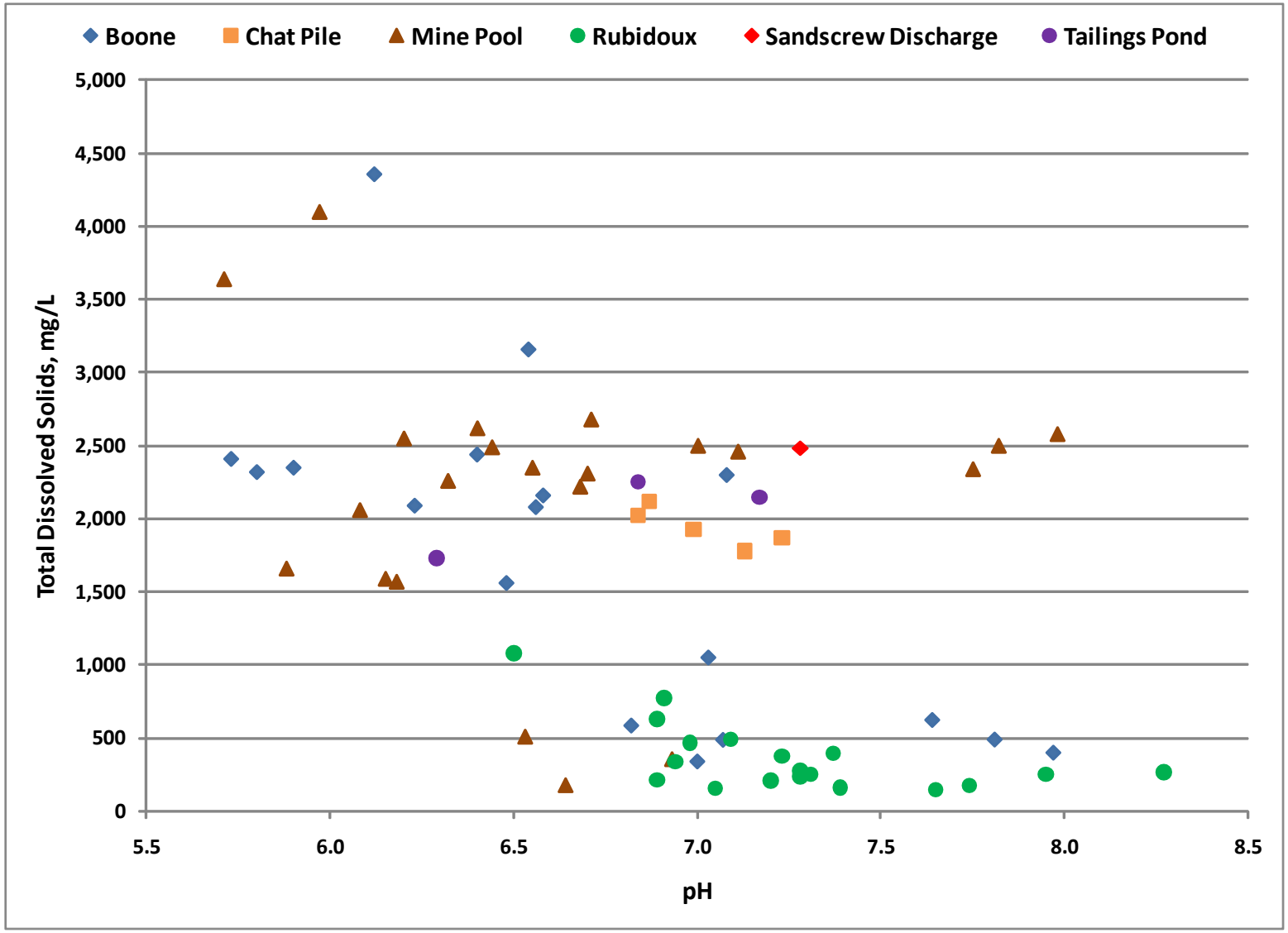


FIGURE 7-8
Total Dissolved Solids Versus pH for Tar Creek Water Sources
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

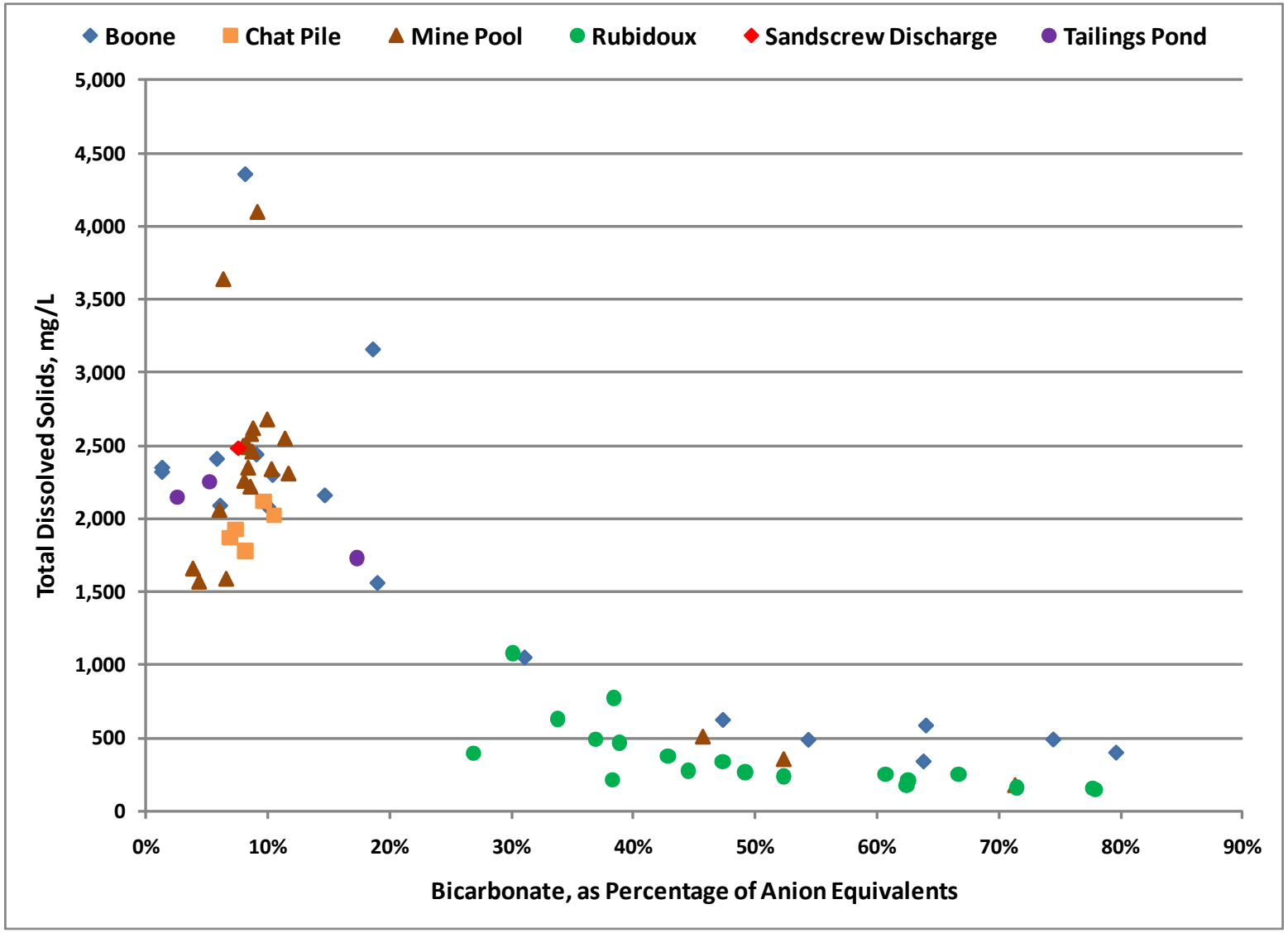


FIGURE 7-9
Total Dissolved Solids Versus Bicarbonate for Tar Creek Water Sources
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

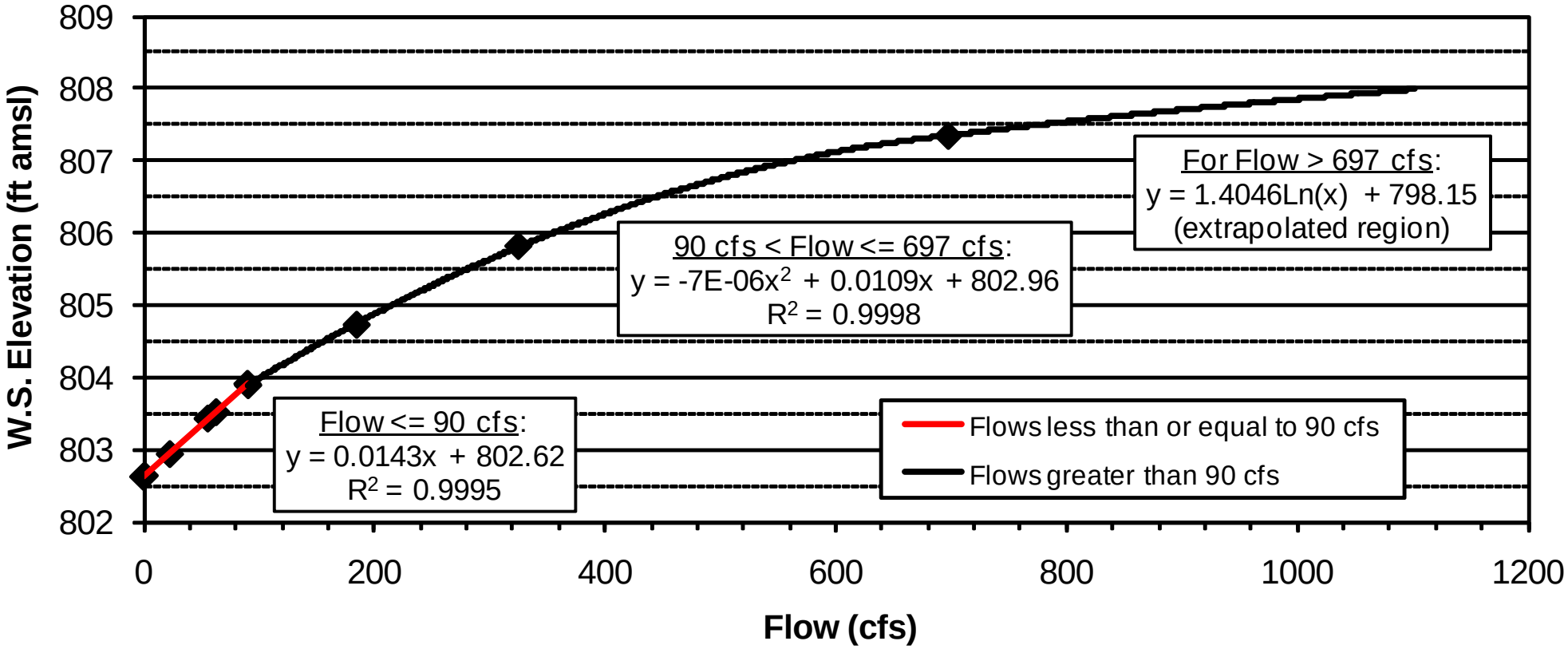


FIGURE 8-1
TC-US Stage-Discharge Rating Curve of 12/22/09 through 6/2/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

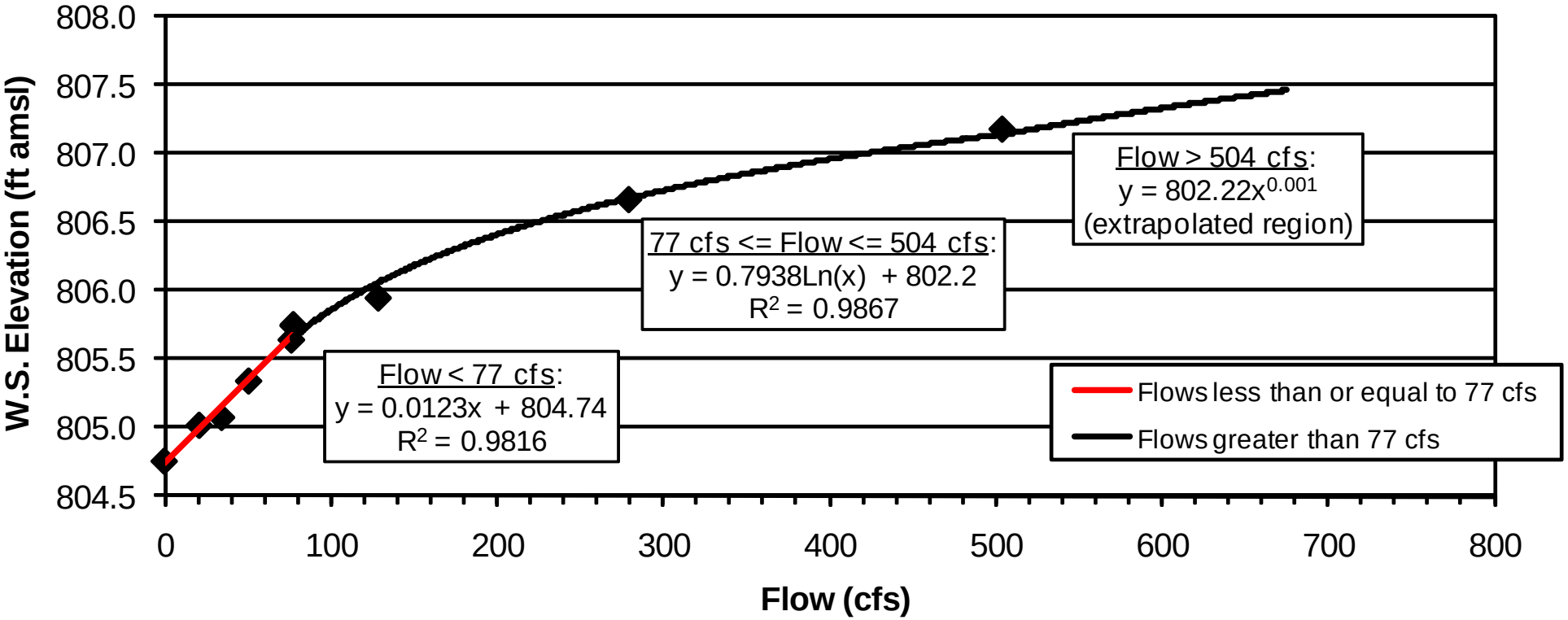


FIGURE 8-2
LC-30 Stage-Discharge Rating Curve of 12/22/09 through 6/2/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

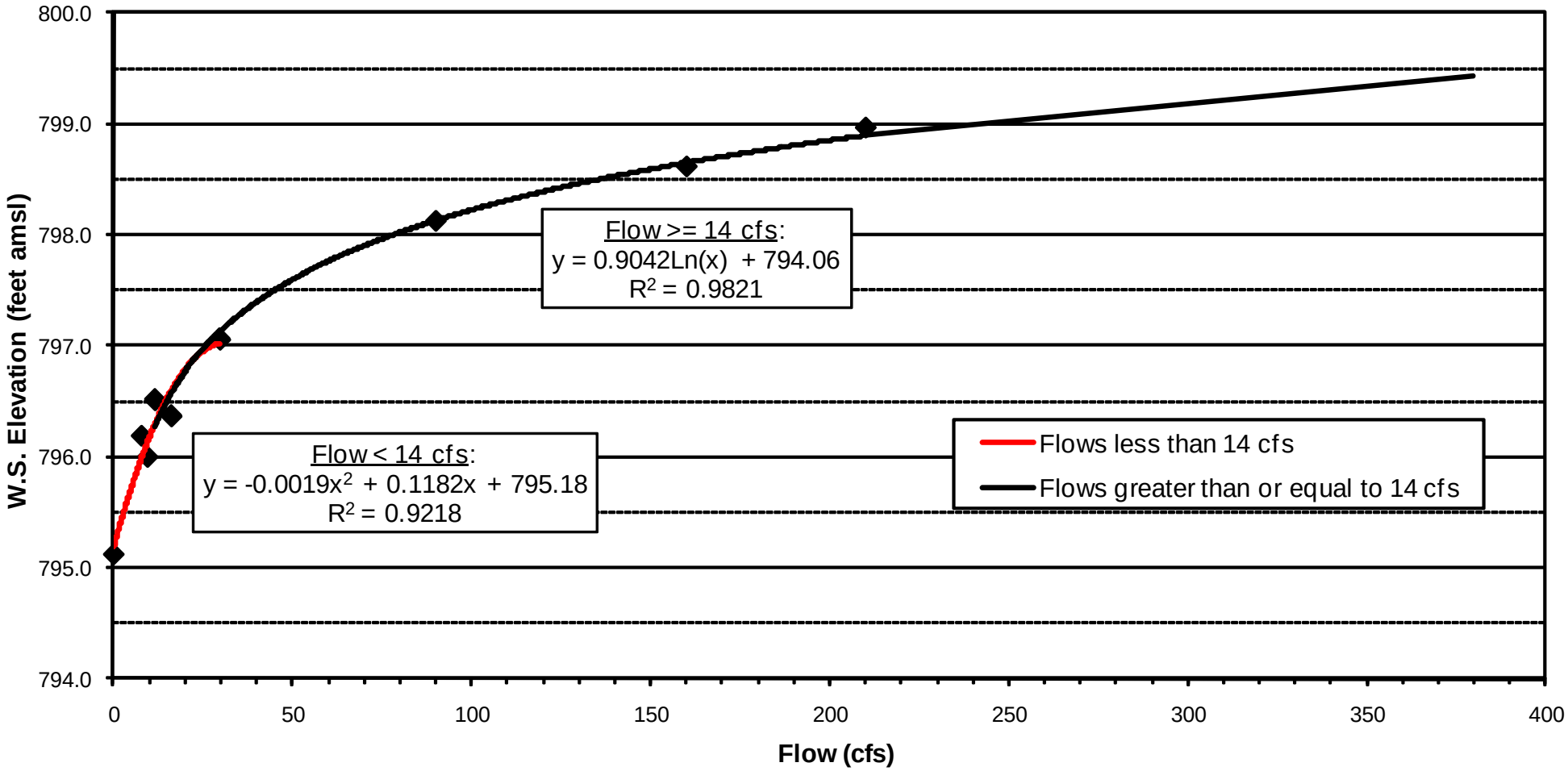


FIGURE 8-3
QC-DS Stage-Discharge Rating Curve of 12/22/09 through 6/2/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

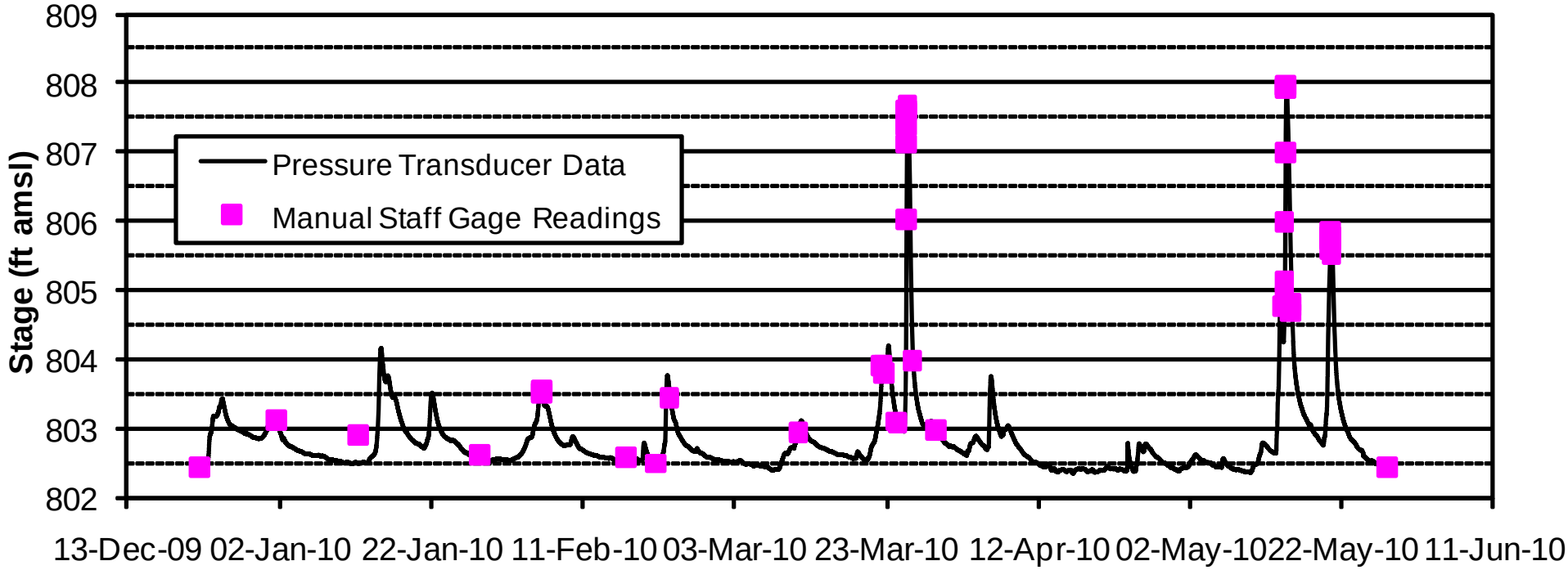


FIGURE 8-4
TC-US Stage Data of 12/22/09 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

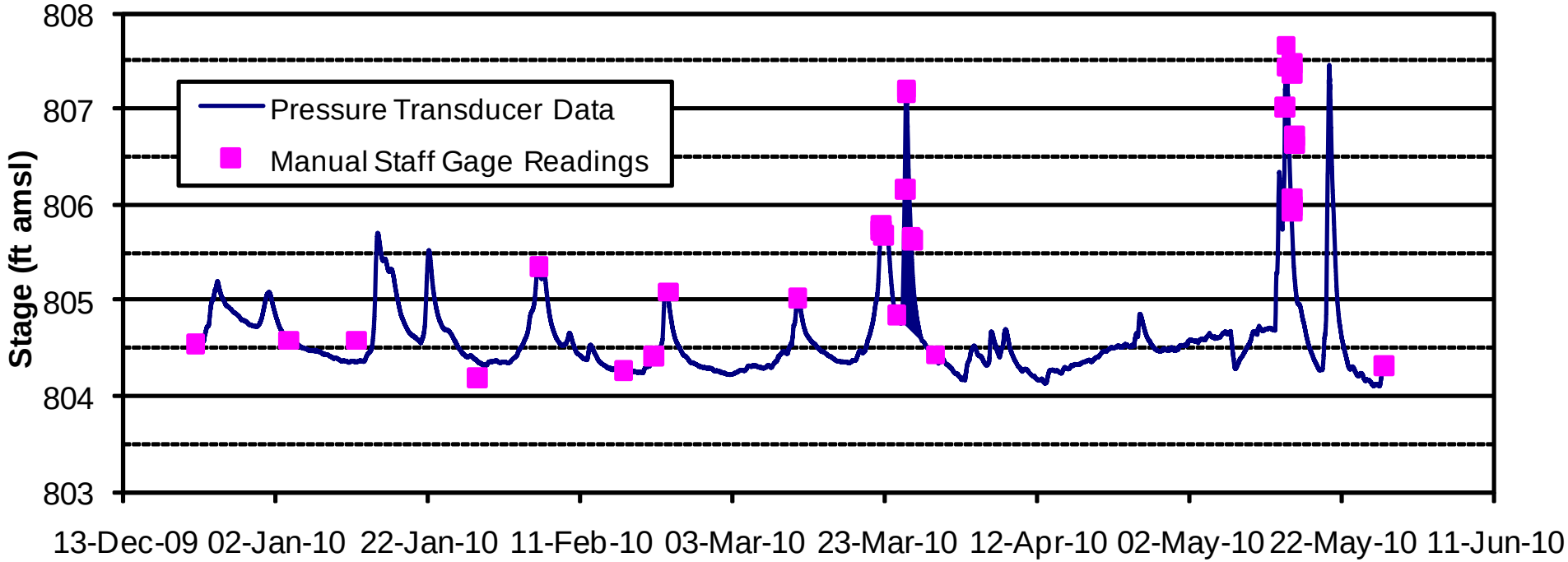


FIGURE 8-5
LC-30 Stage Data of 12/22/09 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

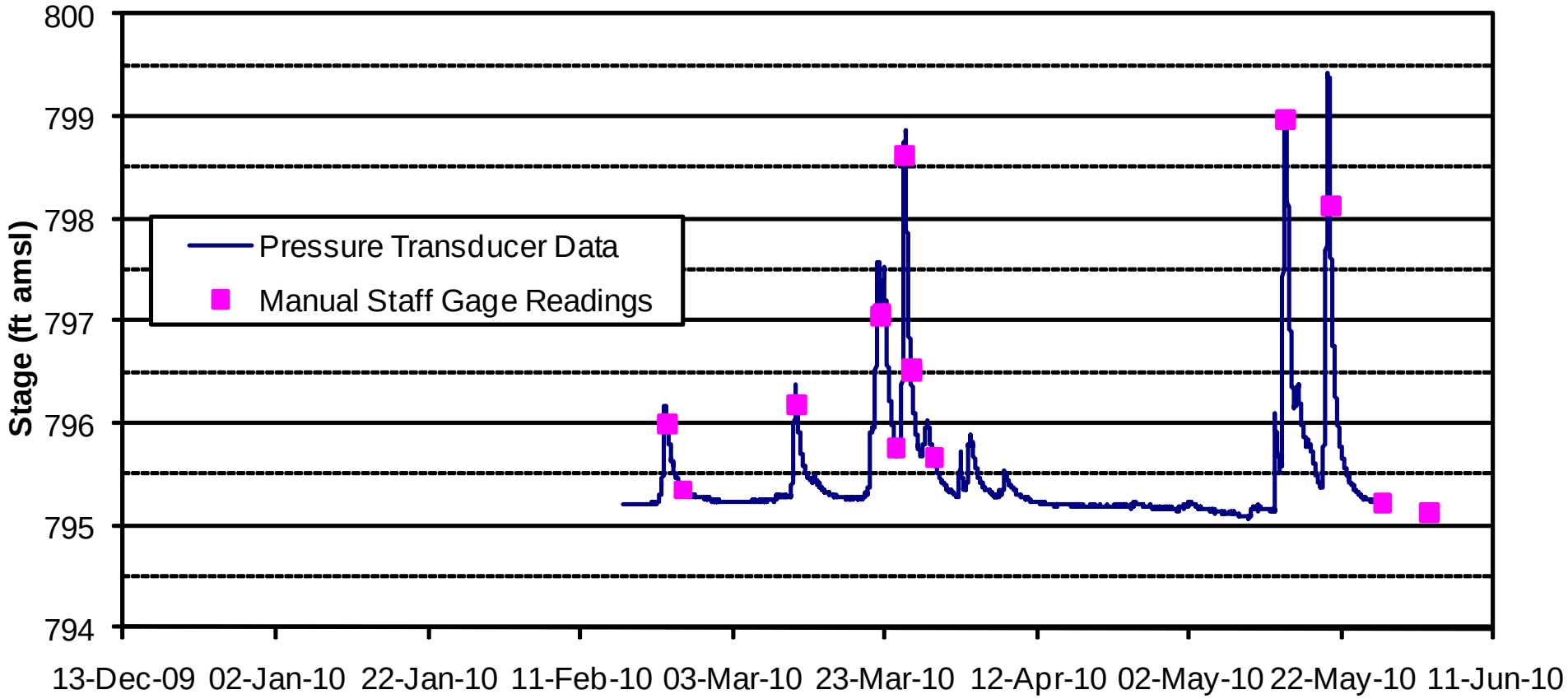


FIGURE 8-6
QC-DS Stage Data of 2/16/10 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

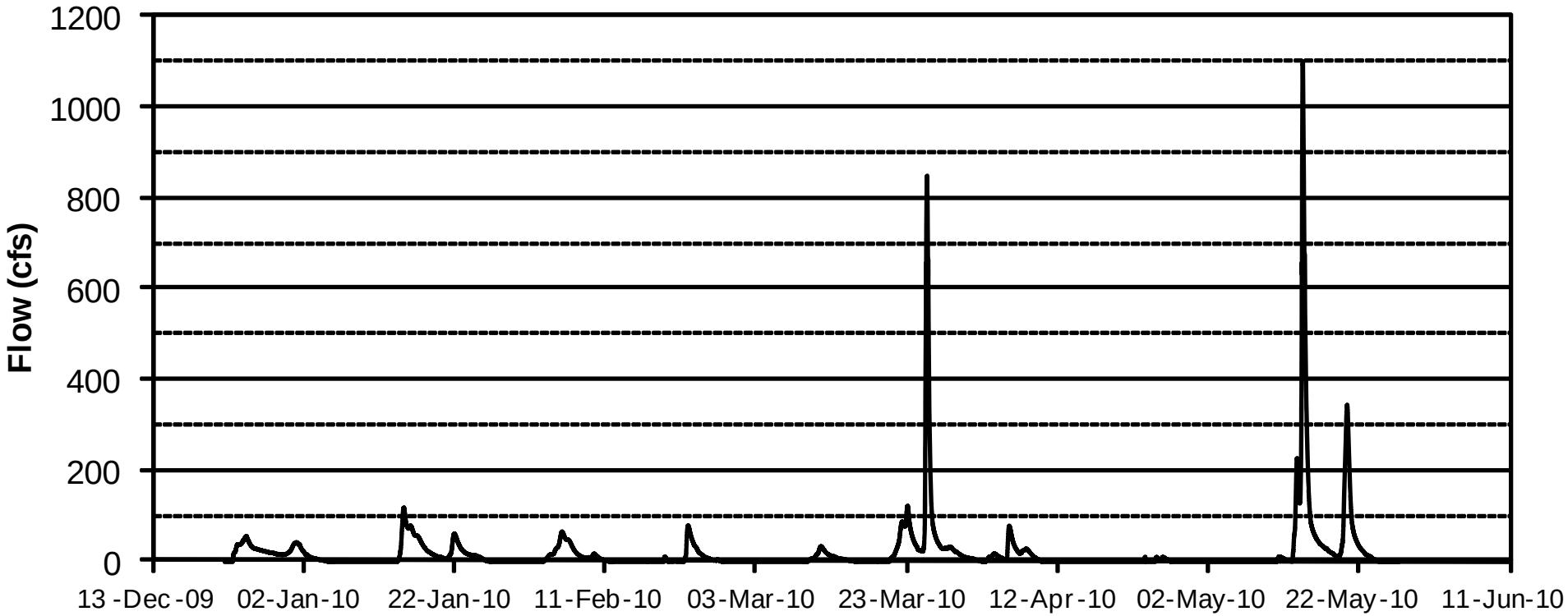


FIGURE 8-7
TC-US Flow Data of 12/22/09 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

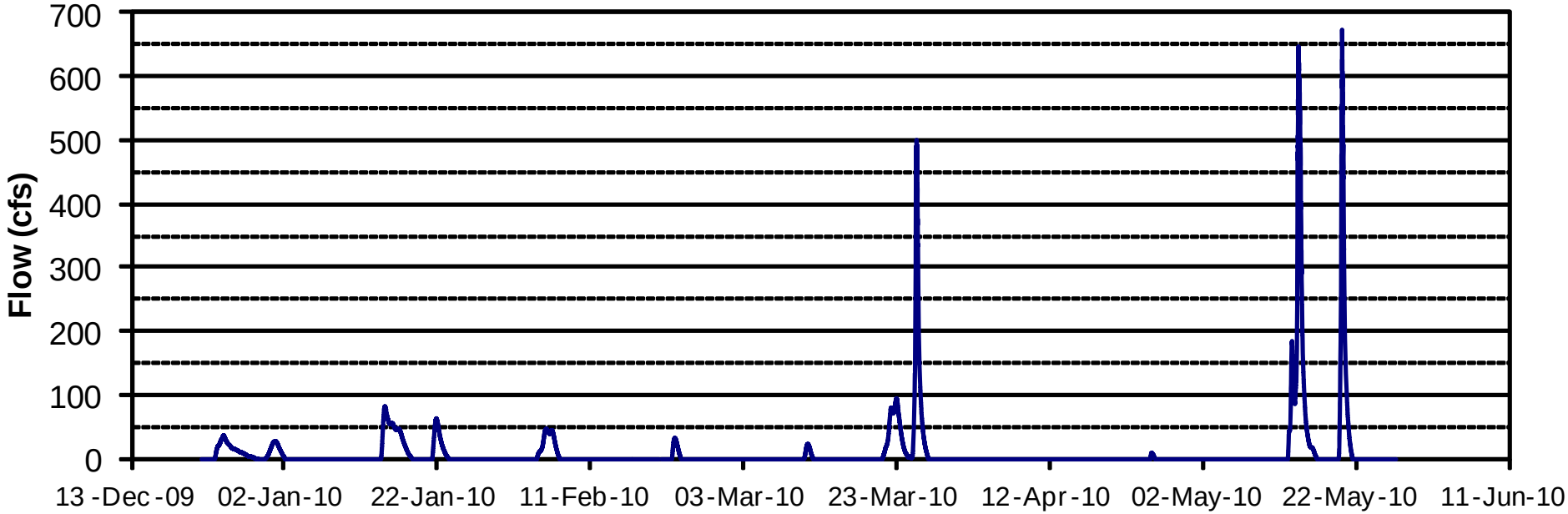


FIGURE 8-8
LC-30 Flow Data of 12/22/09 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

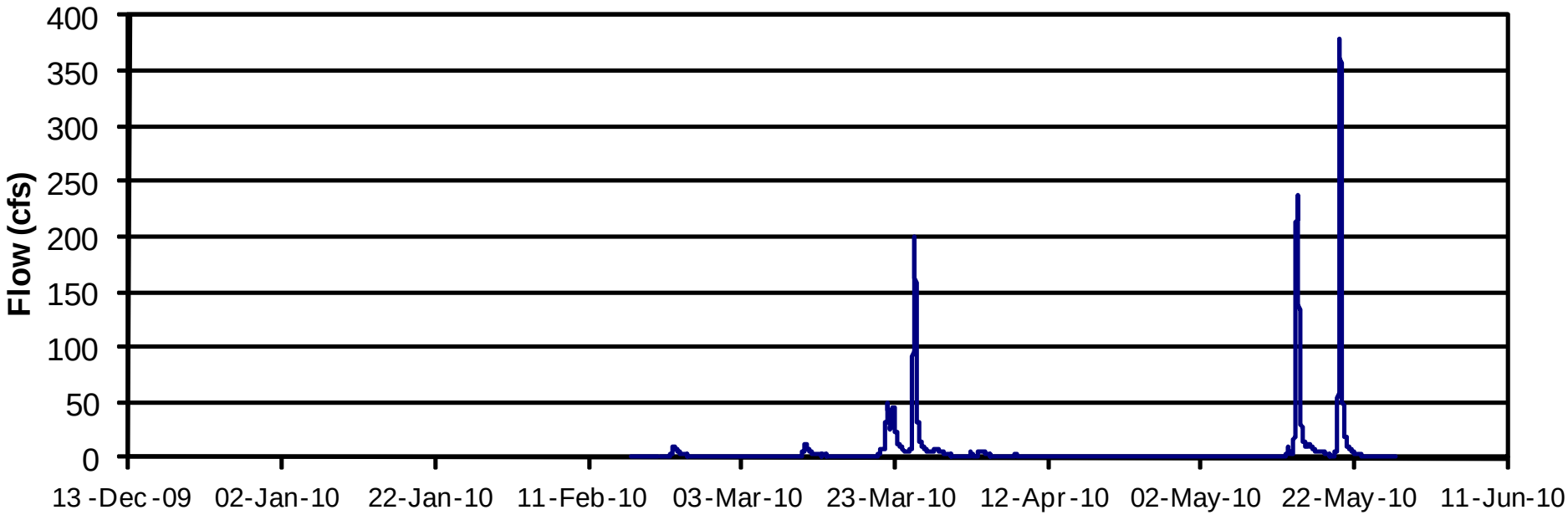


FIGURE 8-9
QC-DS Flow Data of 2/16/10 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

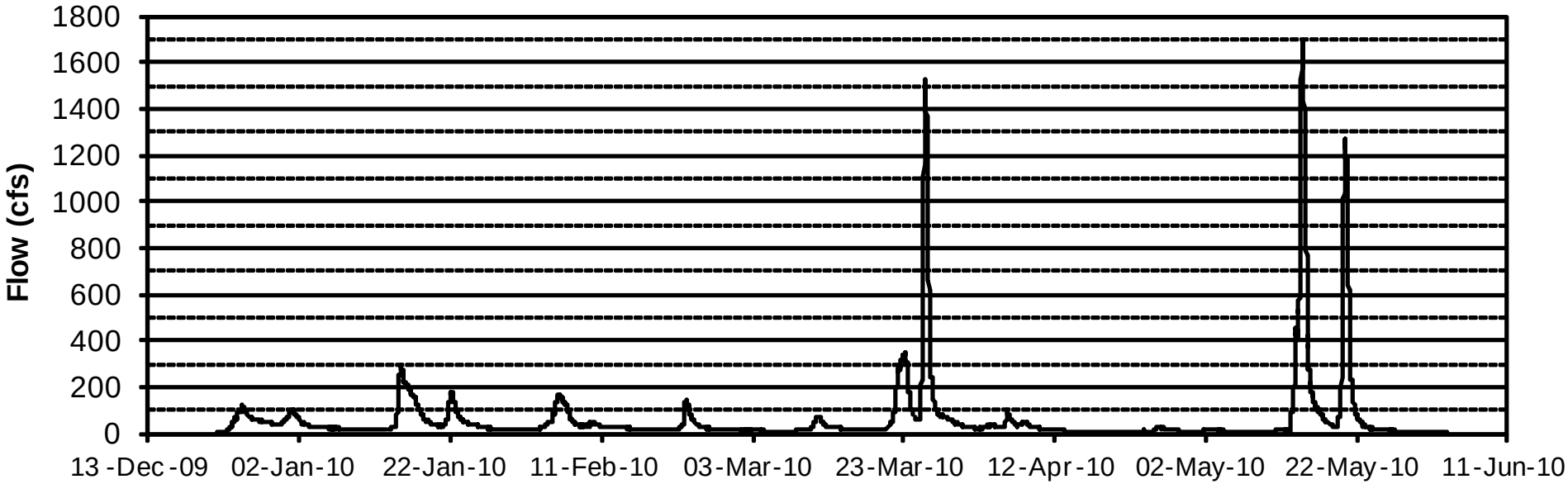


FIGURE 8-10
Tar Creek at Hwy 69 USGS Flow Data of 12/22/09 through 6/2/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

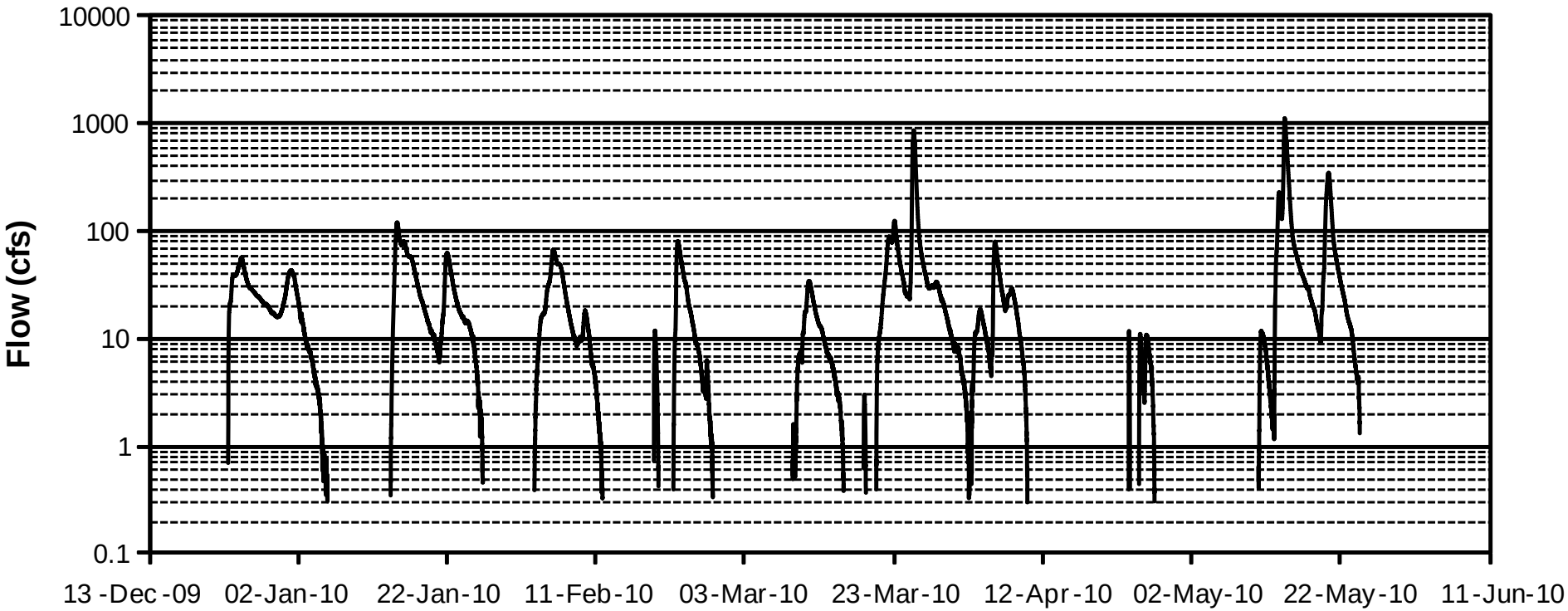


FIGURE 8-11
Logarithmic Plot of TC-US Flow Data from 12/22/09 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

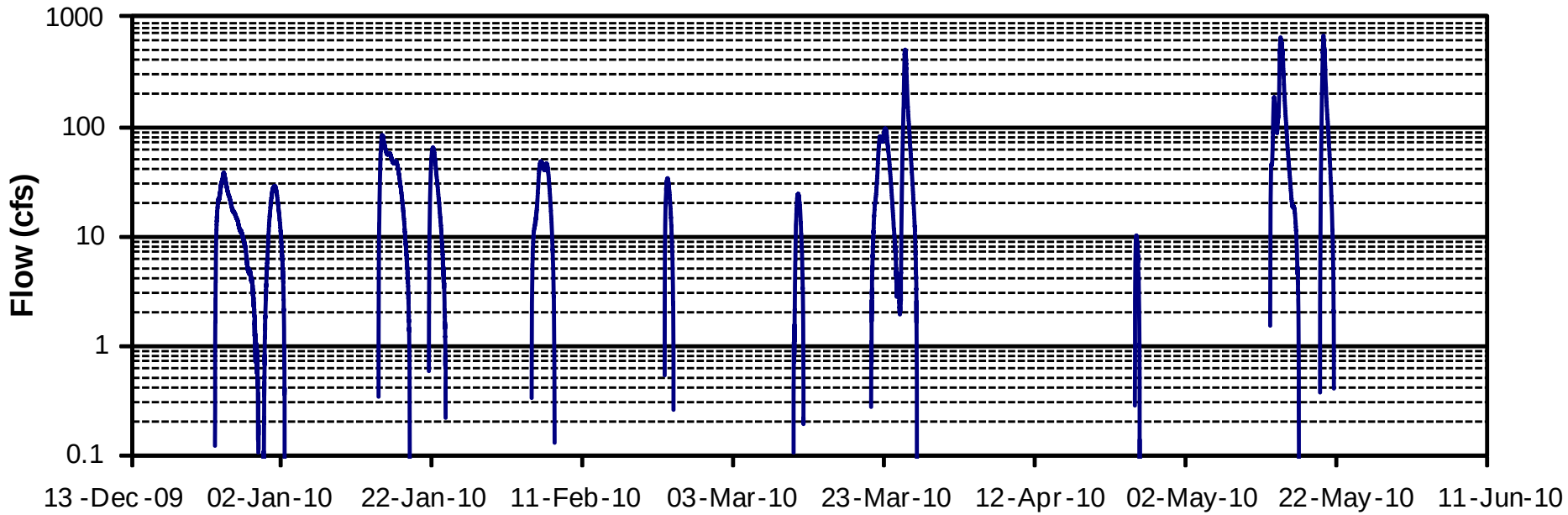


FIGURE 8-12
Logarithmic Plot of LC-30 Flow Data from 12/22/09 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

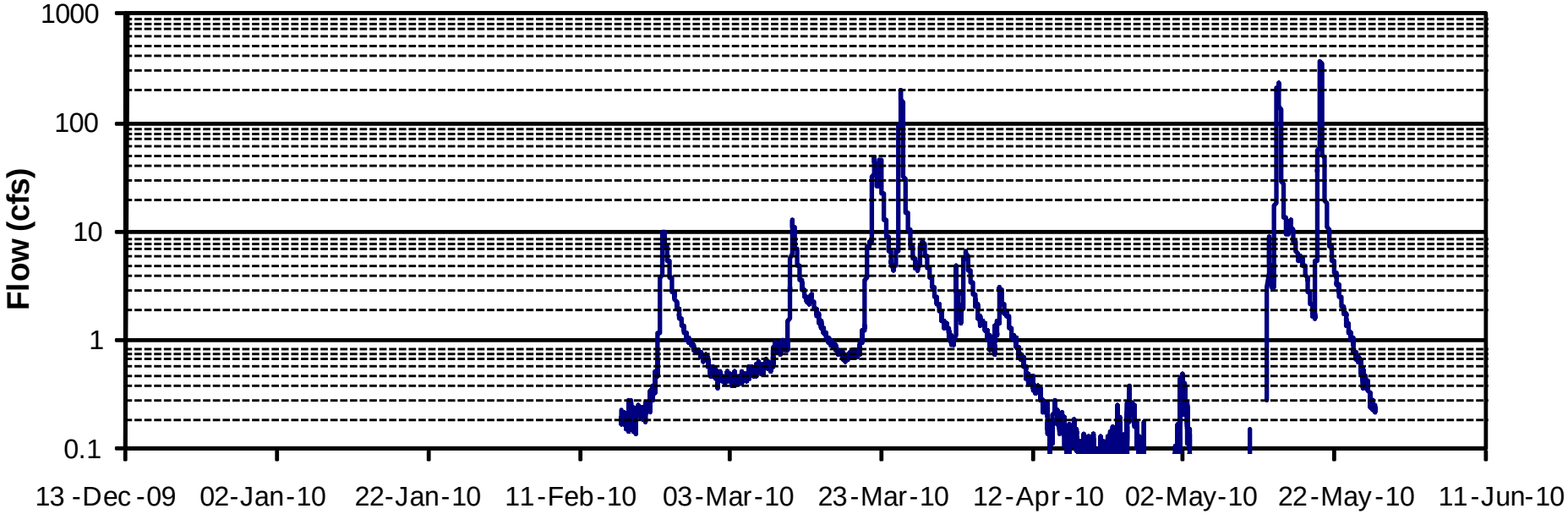


FIGURE 8-13
Logarithmic Plot of QC-DS Flow Data from 2/16/10 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

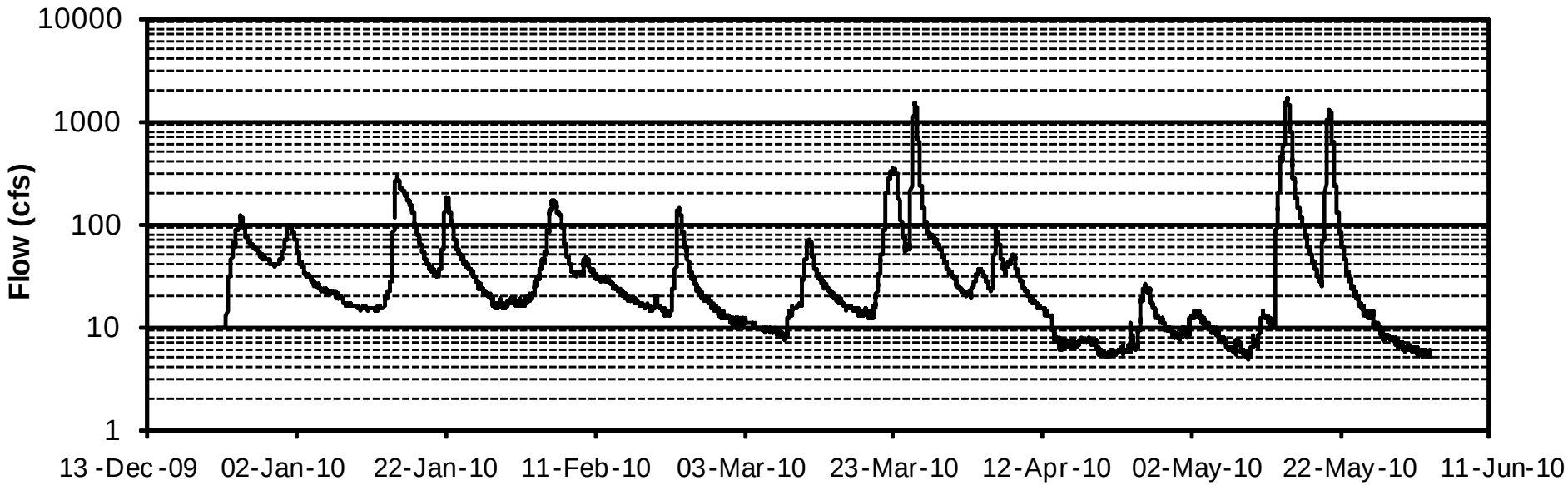


FIGURE 8-14
Logarithmic Plot of Tar Creek at Hwy 69 USGS Flow Data from 12/22/09 through 6/2/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

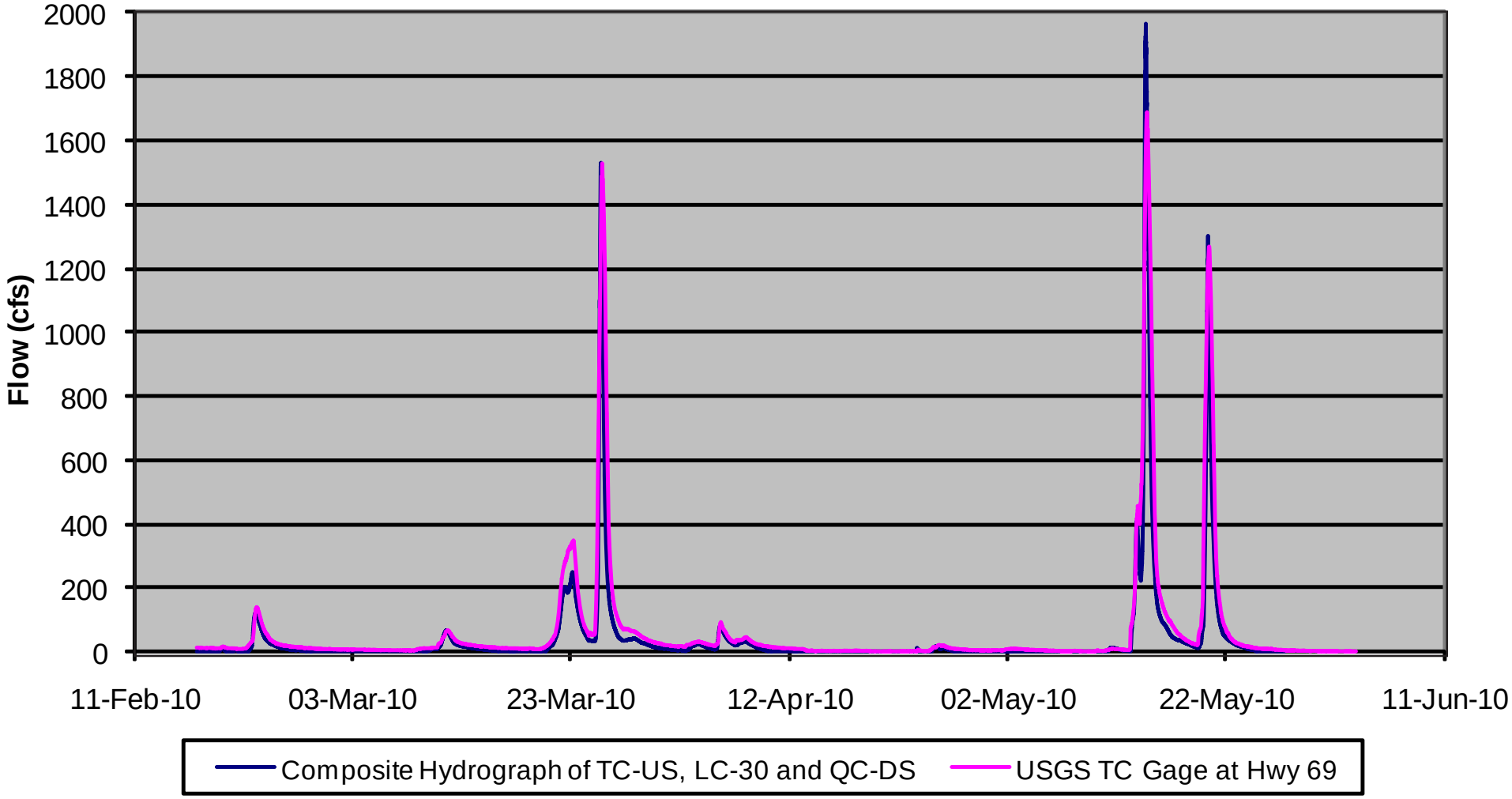


FIGURE 8-15
Composite and Tar Creek at Hwy 69
Hydrographs of 2/16/10 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

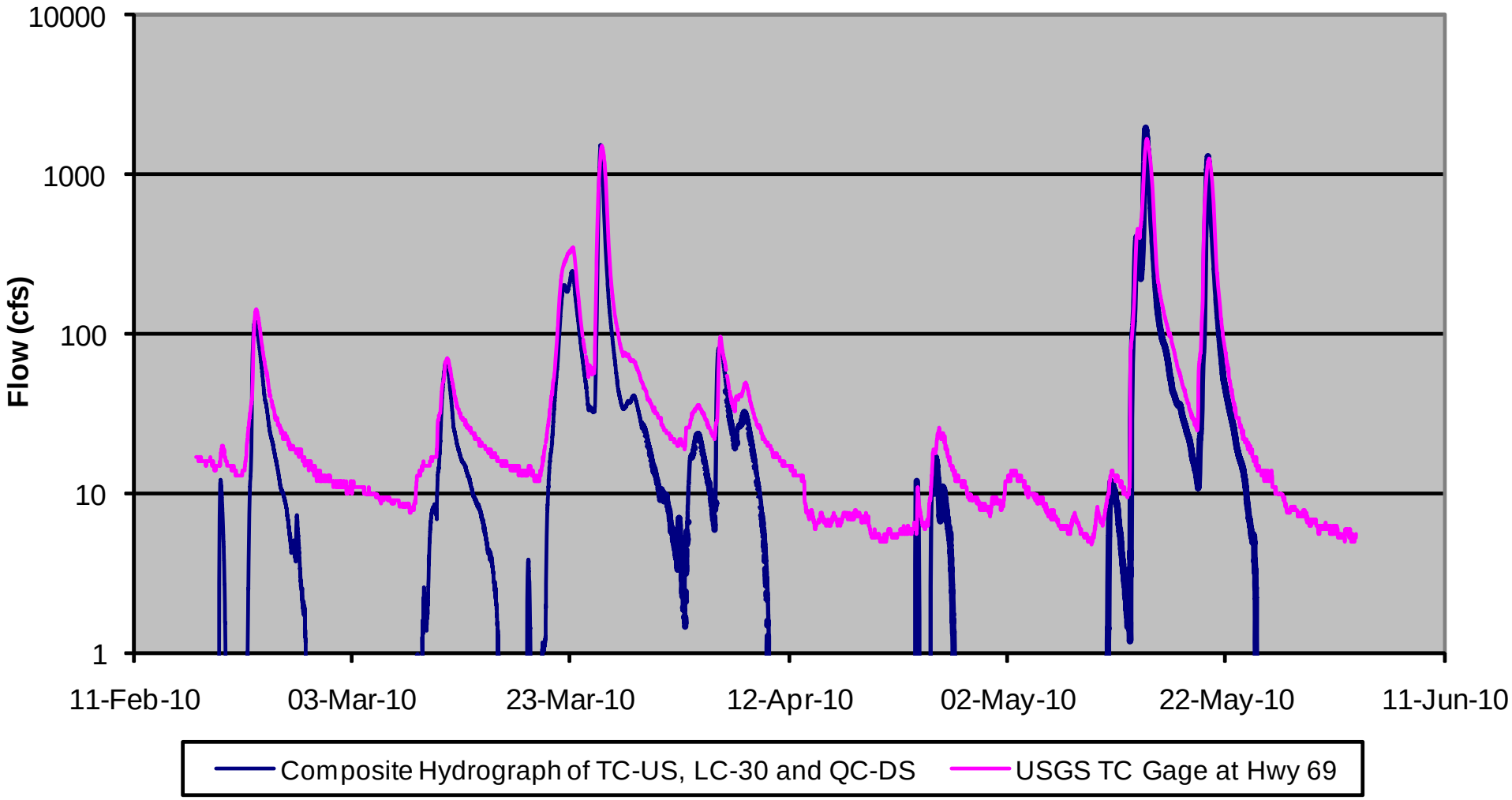


FIGURE 8-16
Logarithmic Plot of the Composite and Tar Creek at Hwy 69 Hydrographs of 2/16/10 through 5/27/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

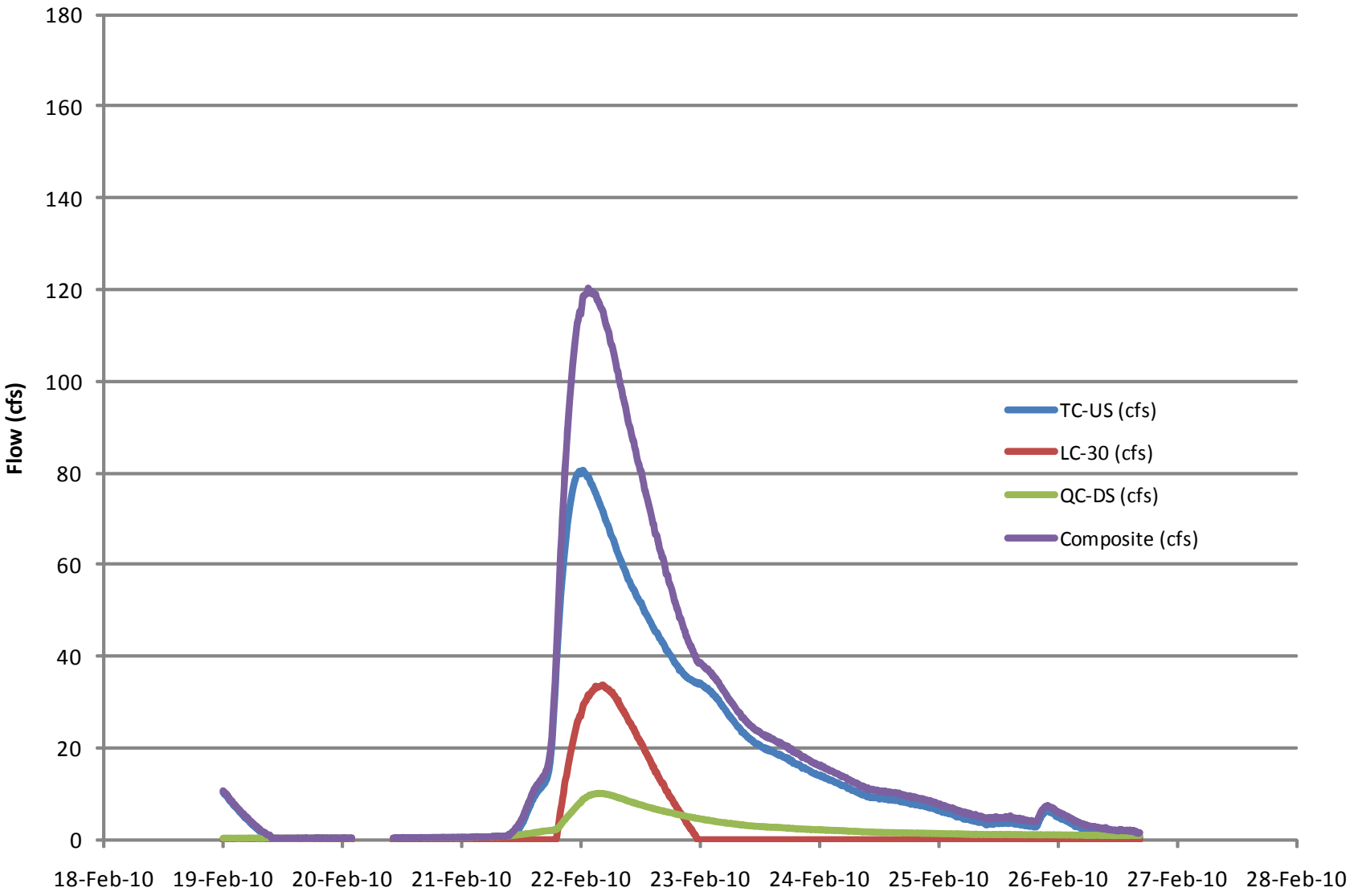


FIGURE 8-17
Individual and Composite Hydrographs during Storm of 2/21/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

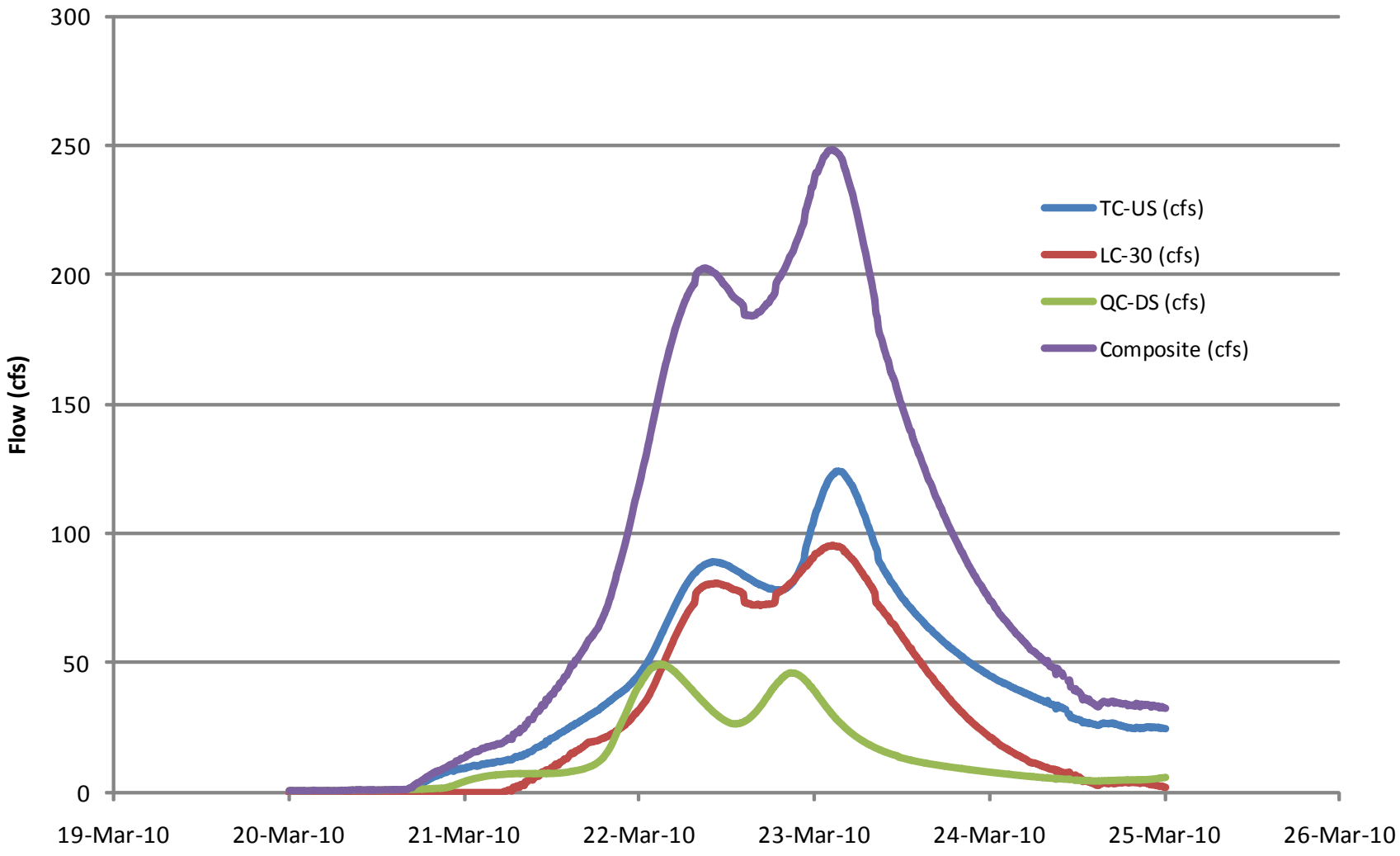


FIGURE 8-18
Individual and Composite Hydrographs during Storm of 3/21/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

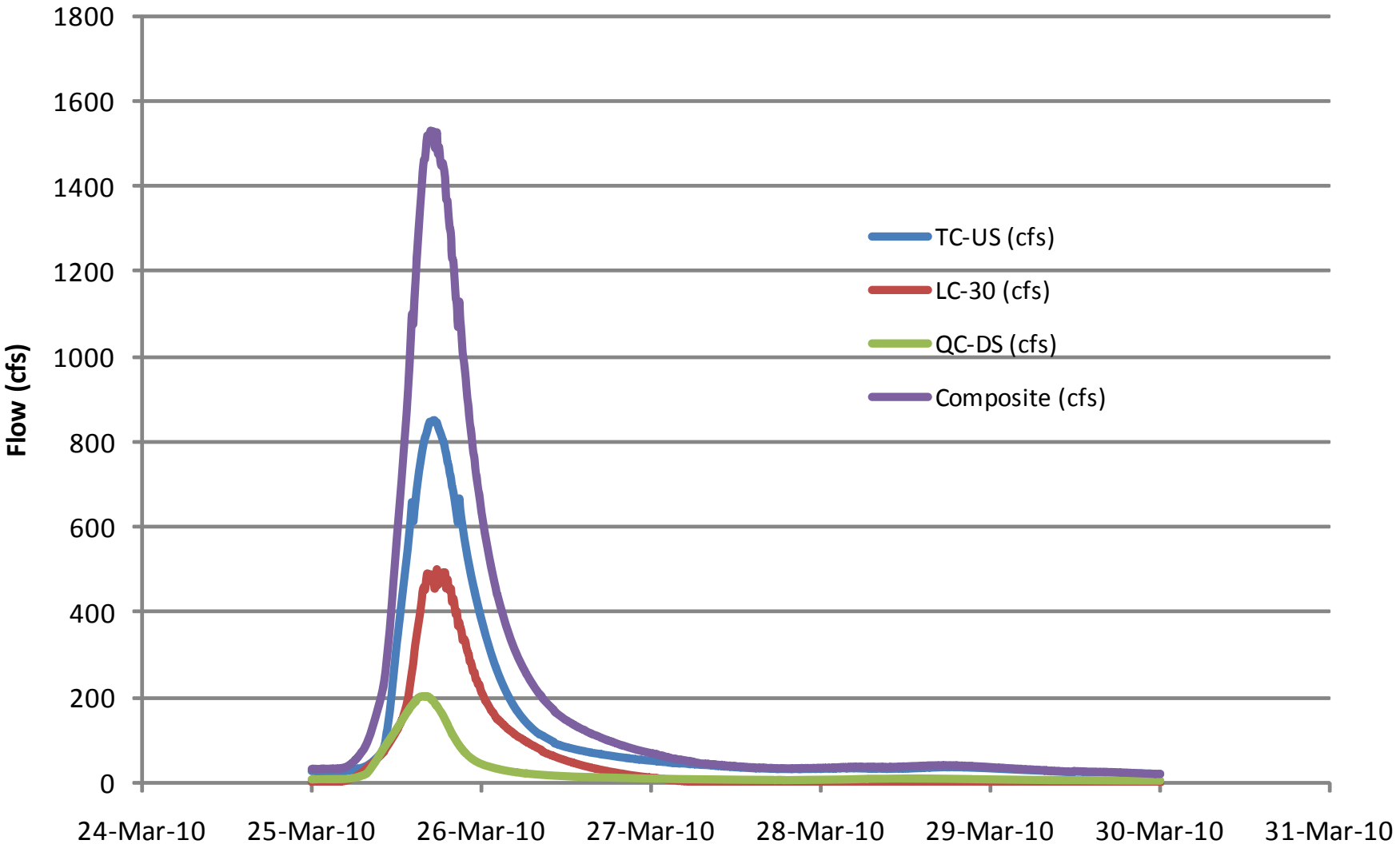


FIGURE 8-19
Individual and Composite Hydrographs during Storm of 3/25/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

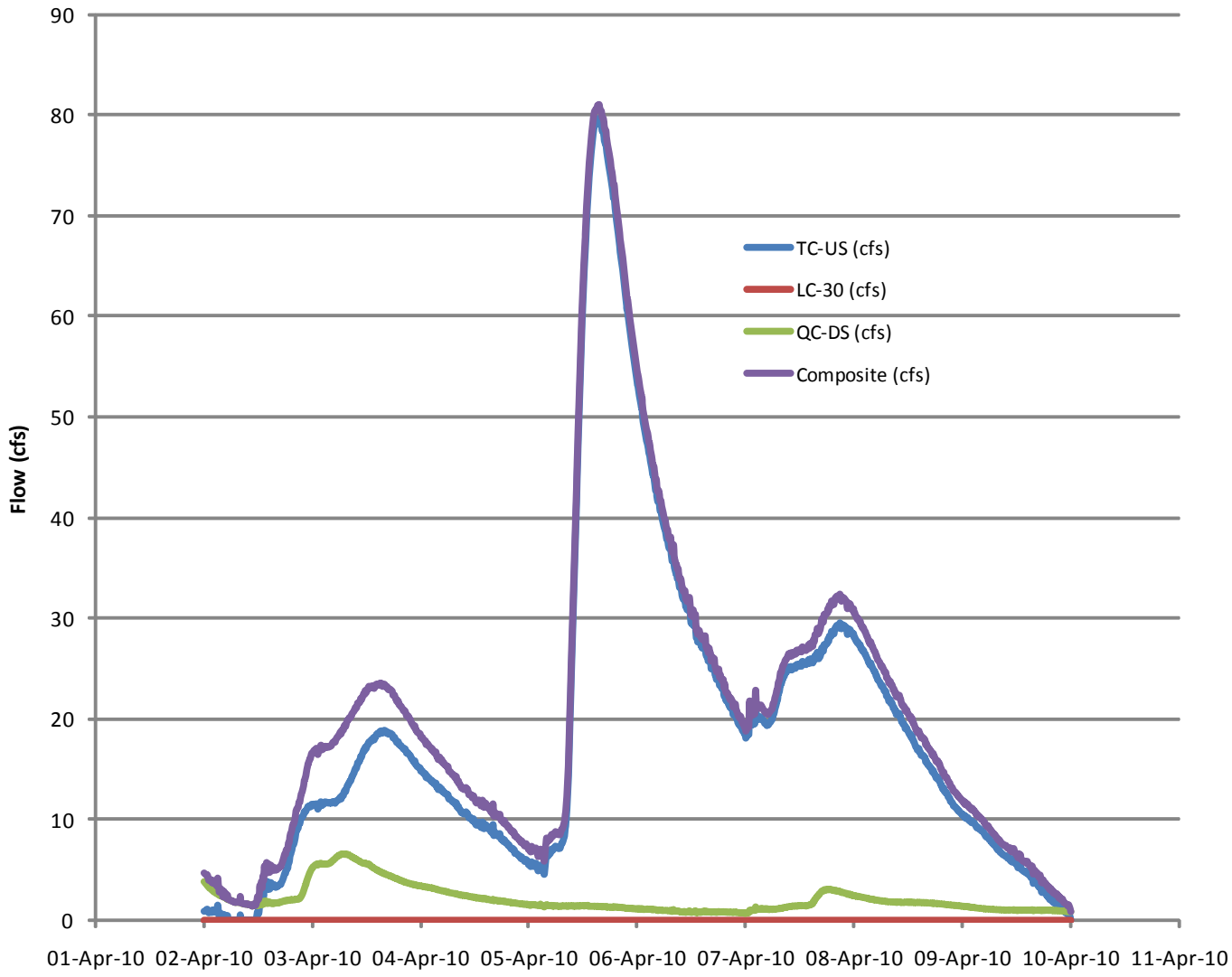


FIGURE 8-20
Individual and Composite Hydrographs during Storm of 4/5/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

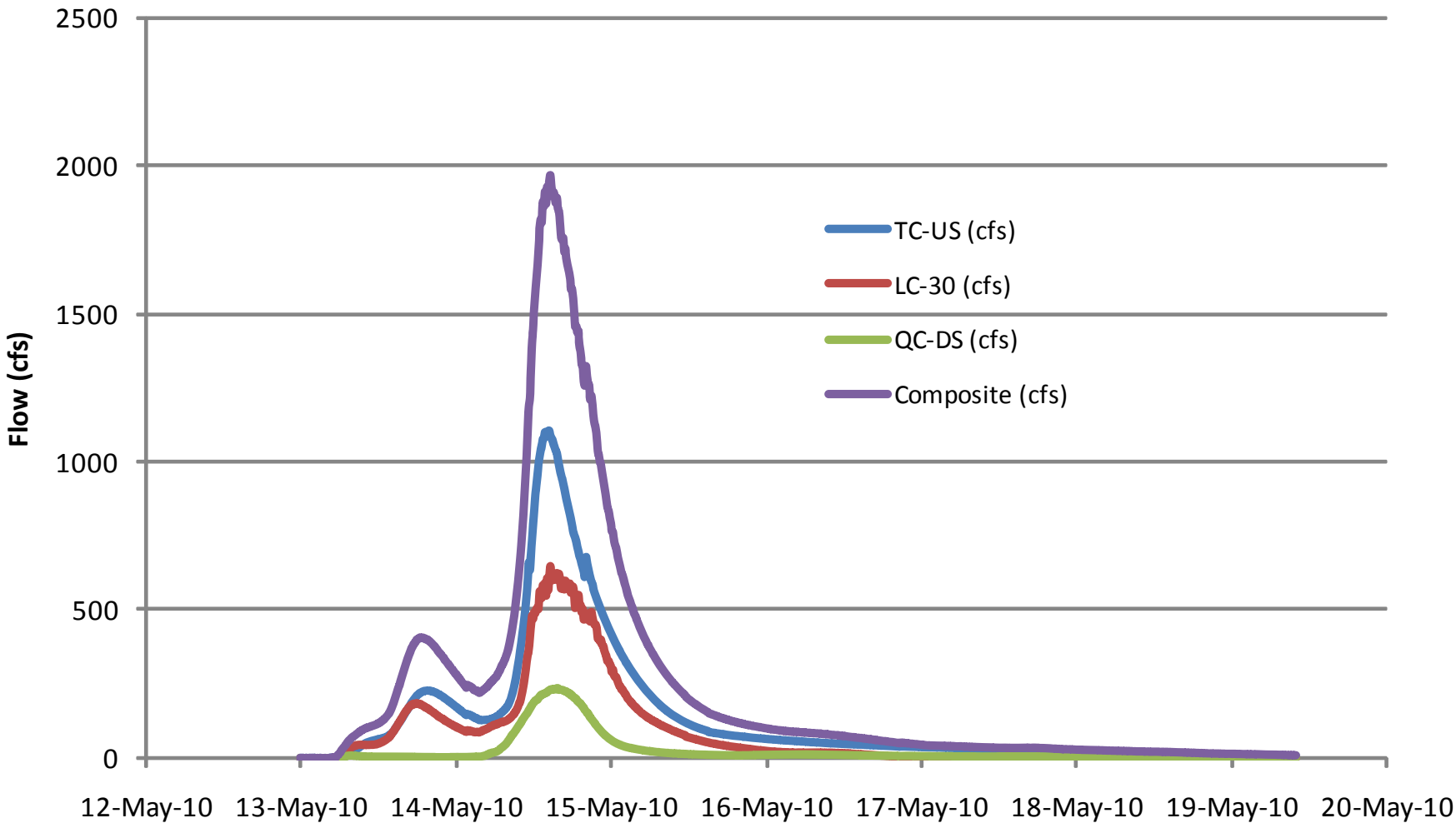


FIGURE 8-21
Individual and Composite Hydrographs during Storm of 5/13/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

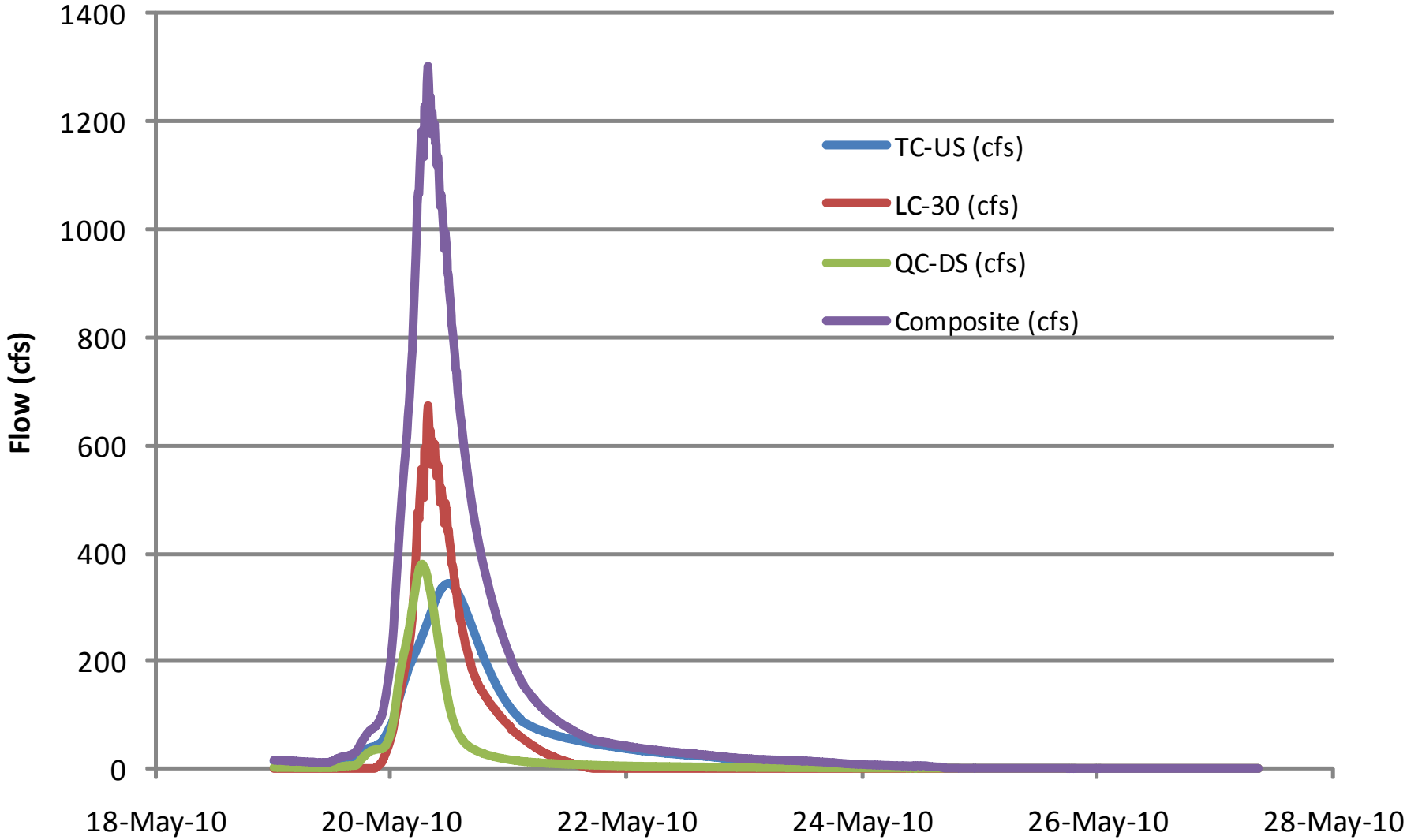


FIGURE 8-22
Individual and Composite Hydrographs during Storm of 5/19/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

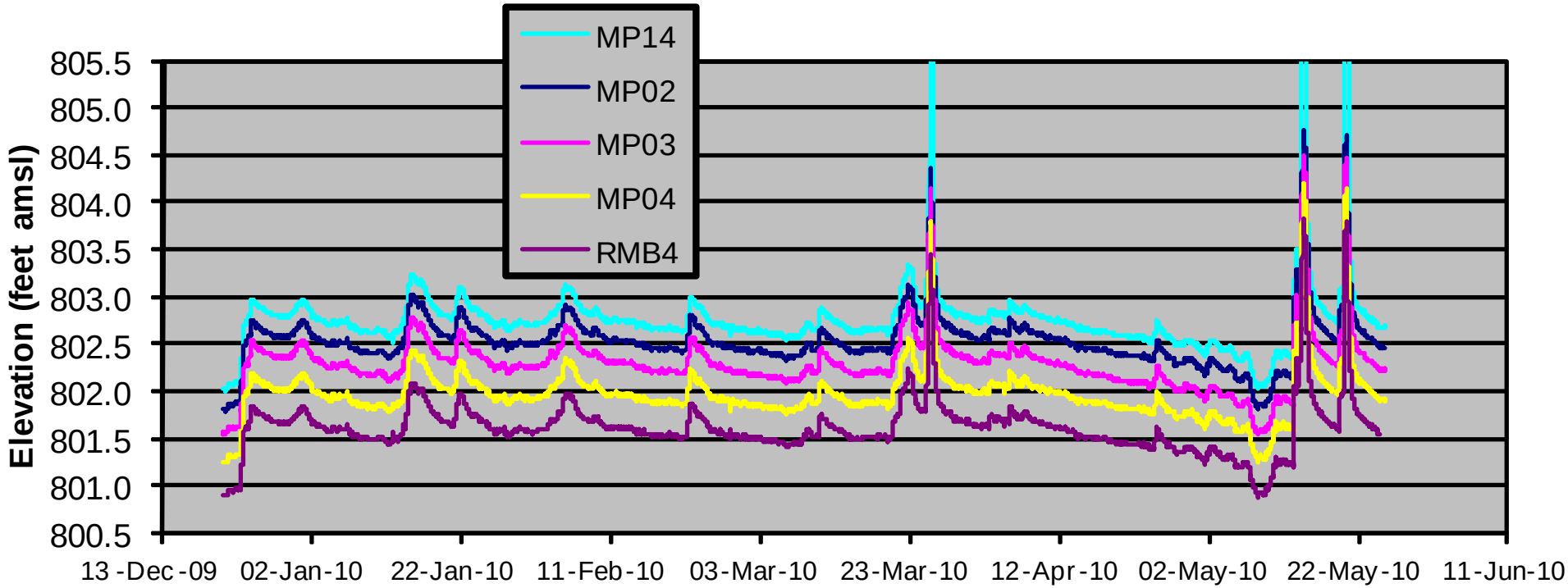


FIGURE 8-23
Mine Pool Elevation Data of 12/21/09 through 5/25/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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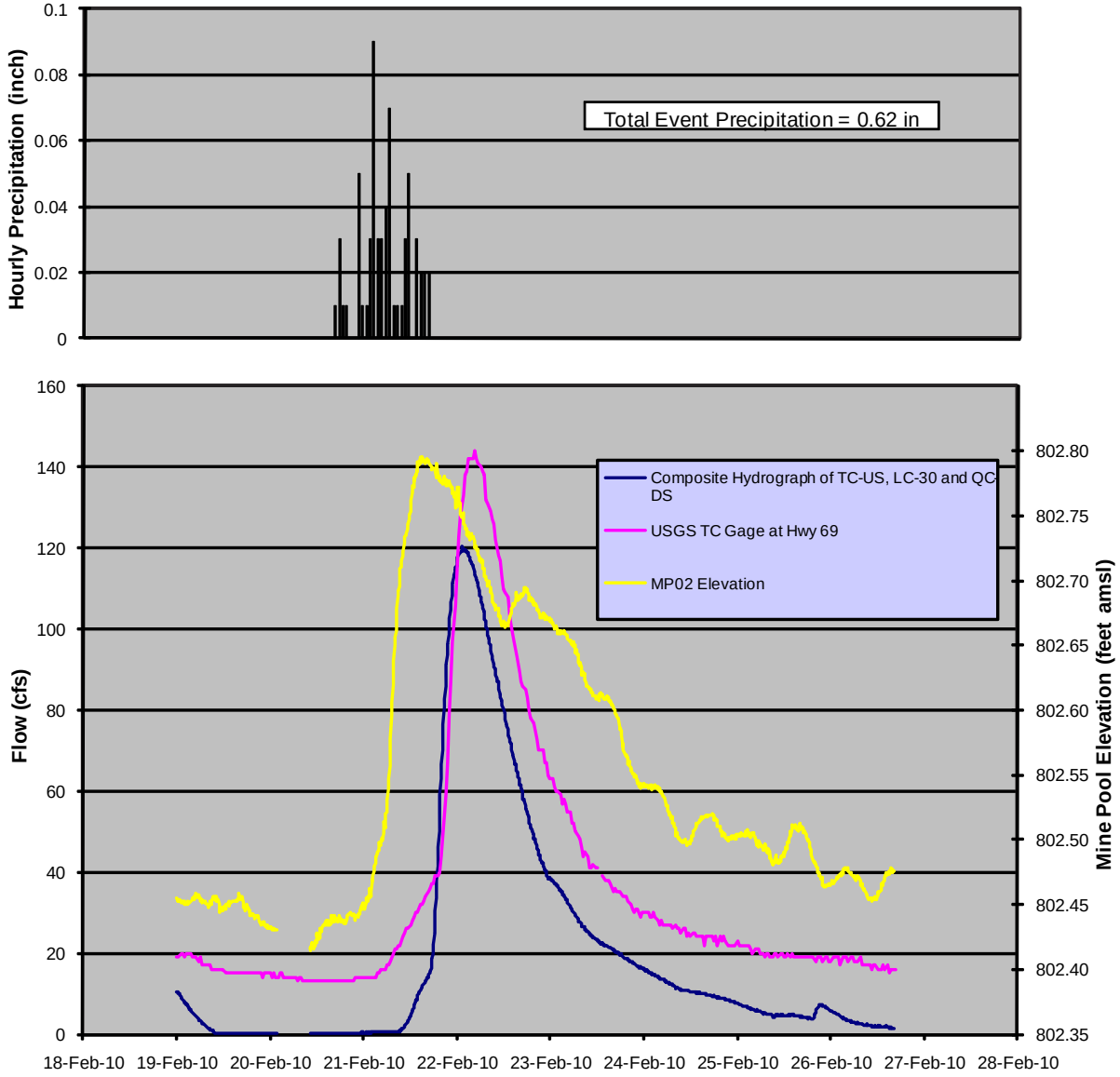



FIGURE 8-24
Storm Hydrograph and Mine Pool Elevation of 2/21/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

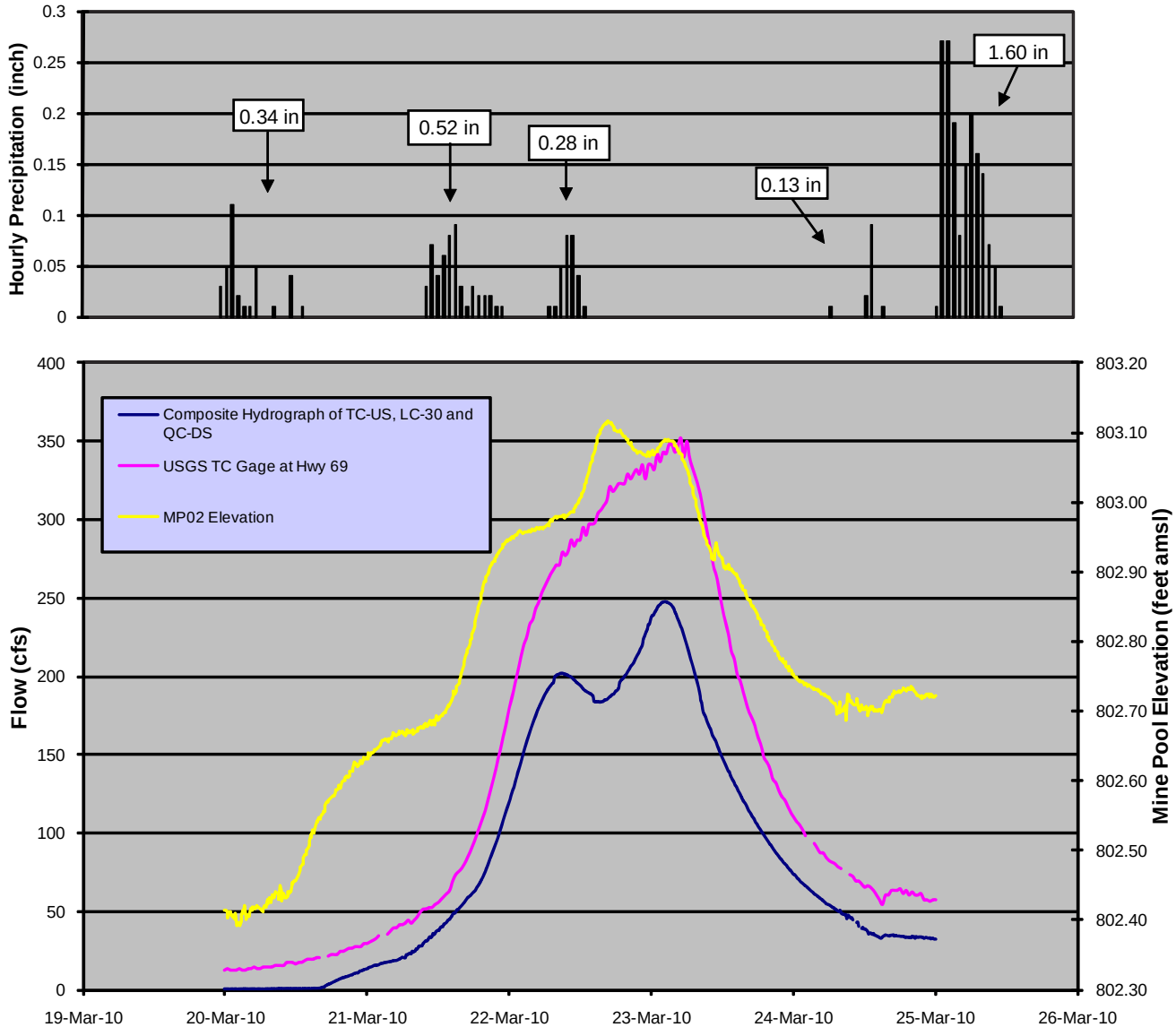



FIGURE 8-25
Storm Hydrograph and Mine Pool Elevation of 3/21/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

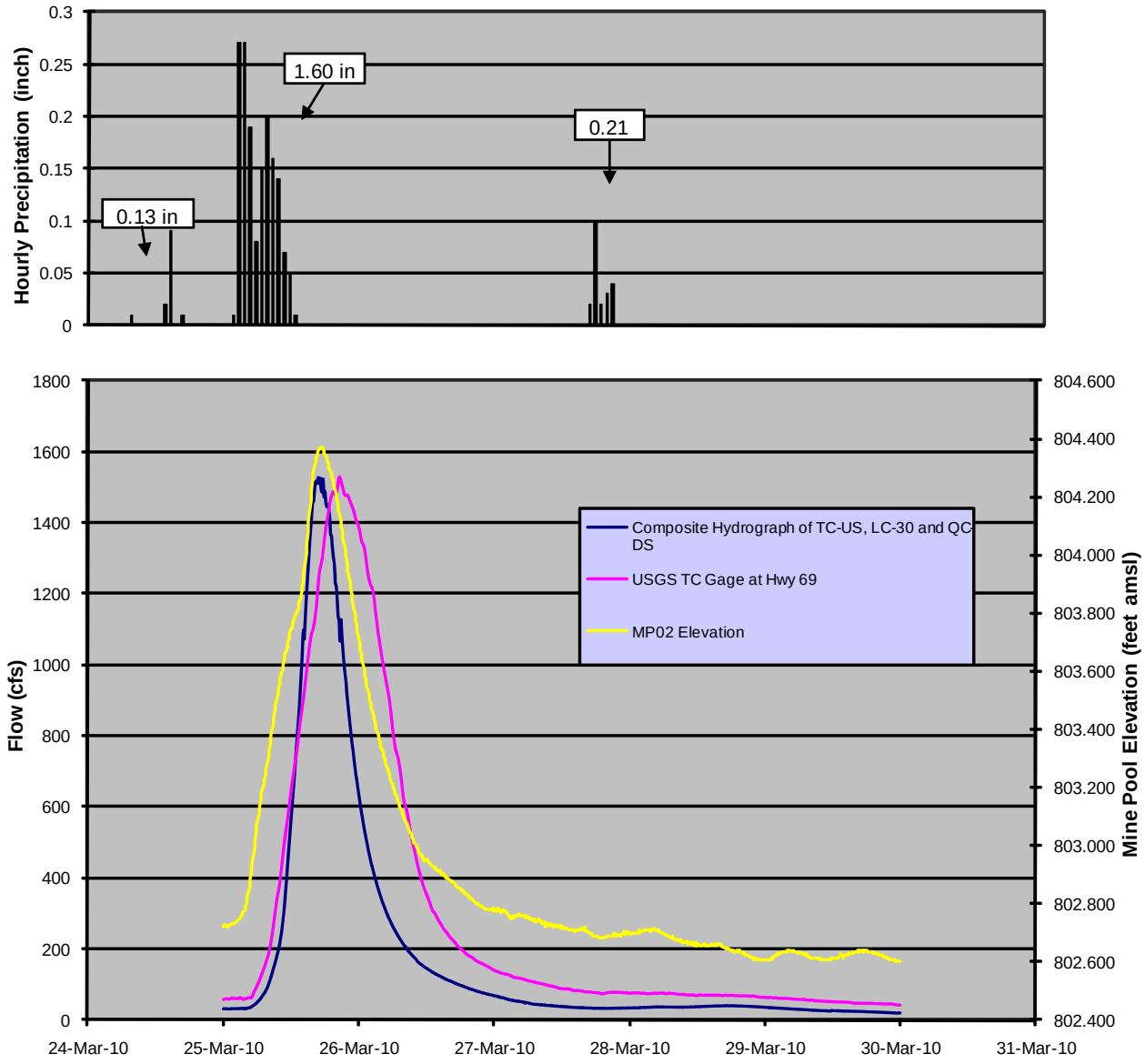



FIGURE 8-26
Storm Hydrograph and Mine Pool Elevation of 3/25/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

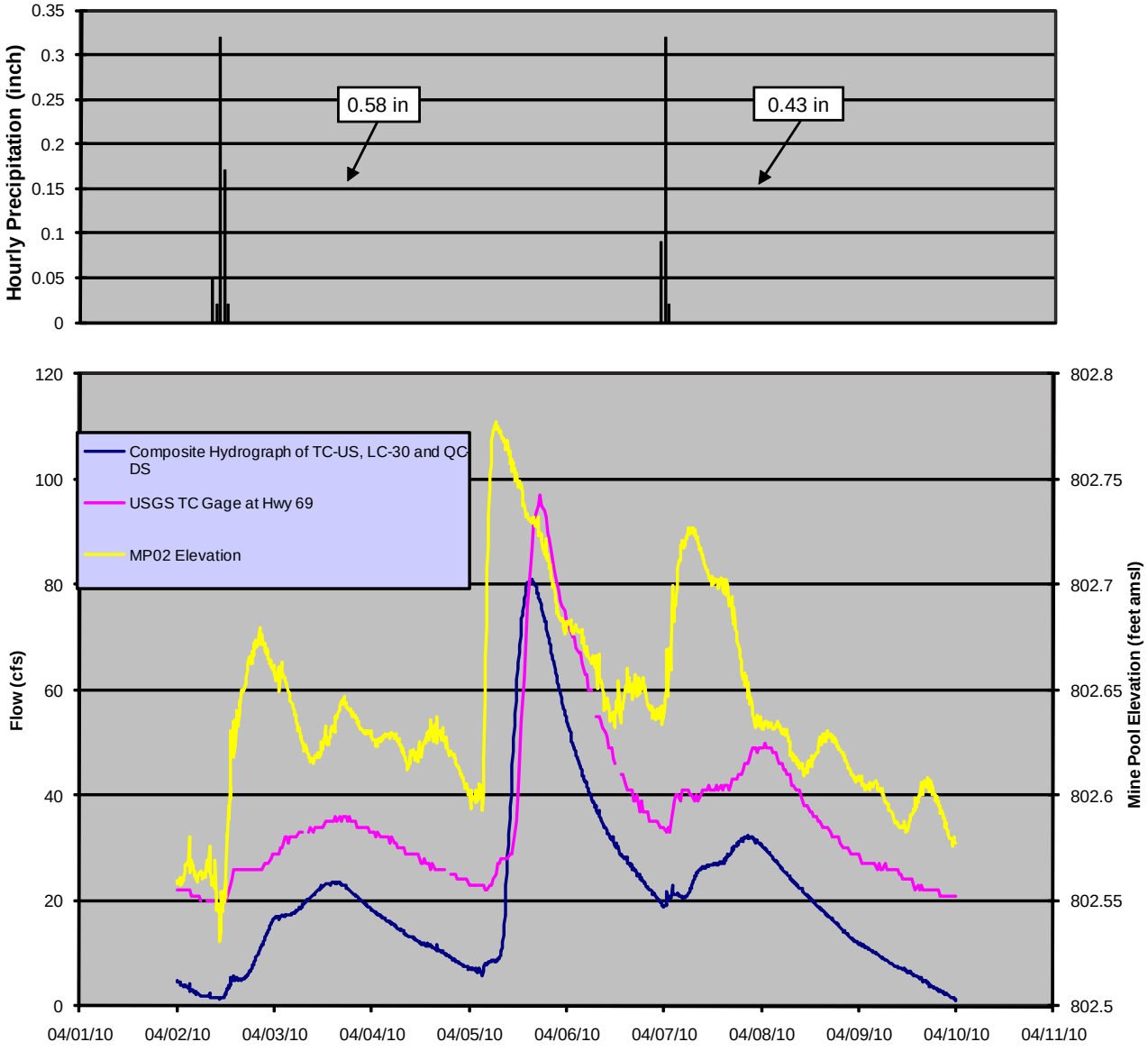



FIGURE 8-27
Storm Hydrograph and Mine Pool Elevation of 4/5/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

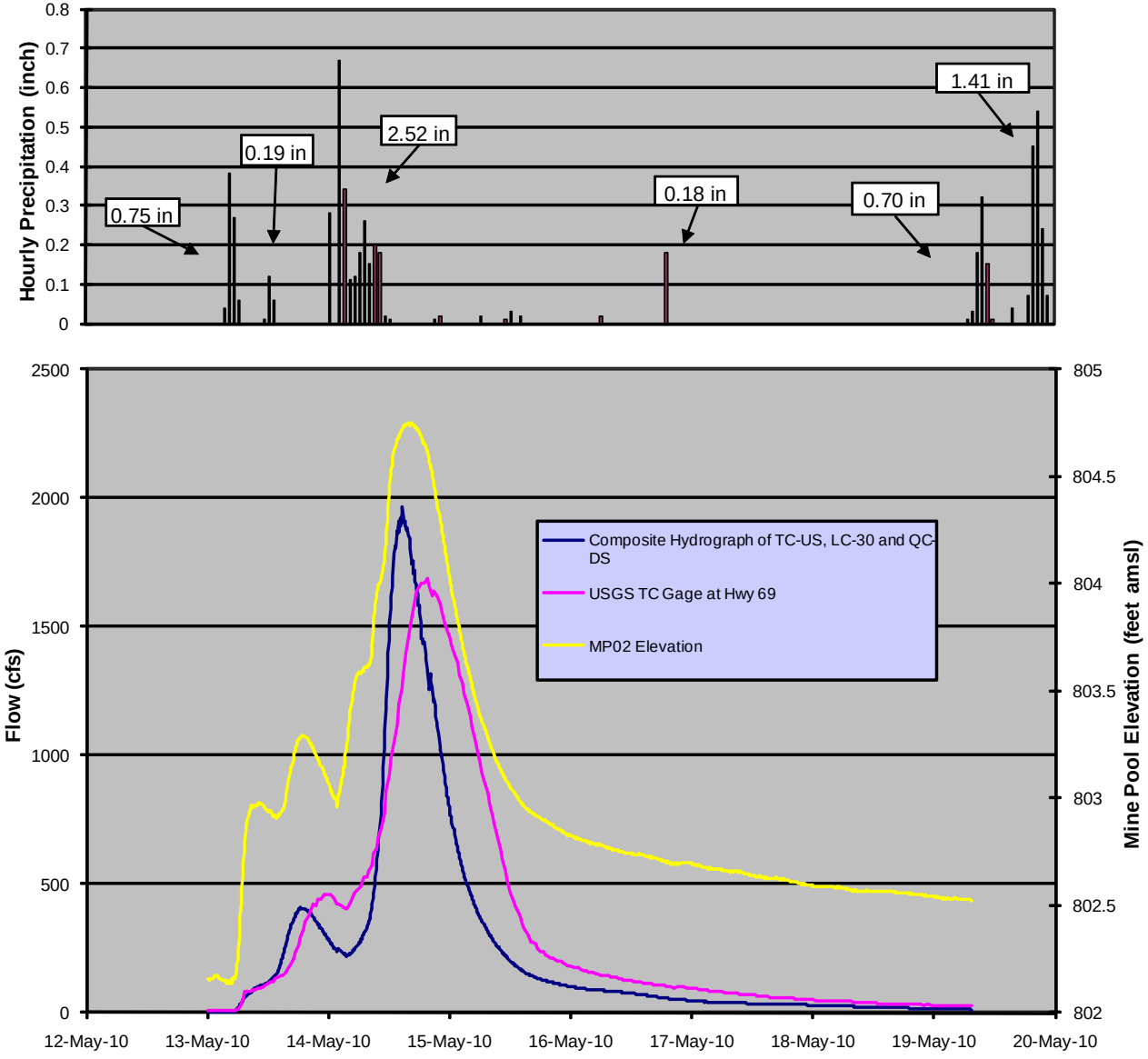



FIGURE 8-28
Storm Hydrograph and Mine Pool Elevation of 5/13/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

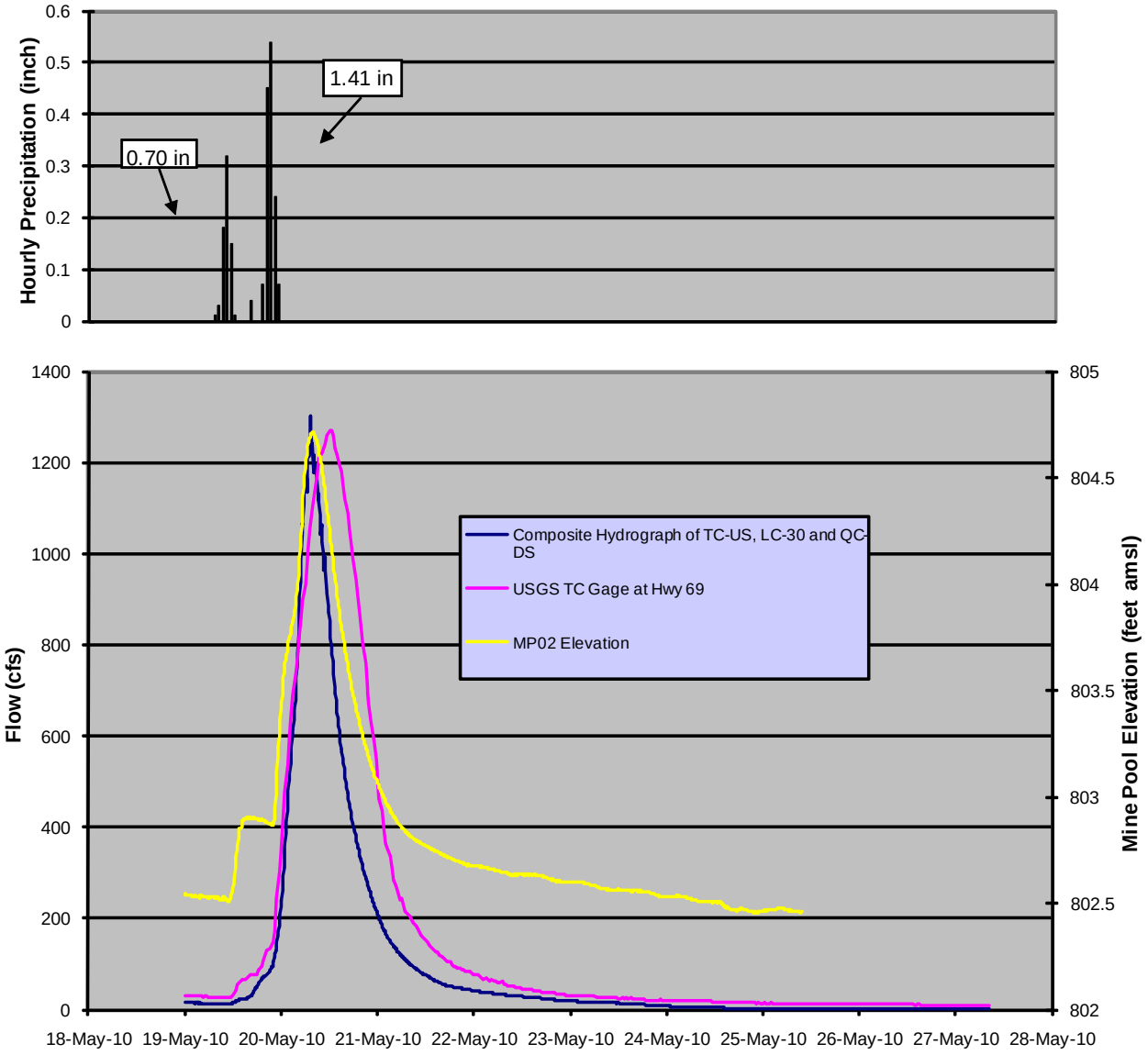



FIGURE 8-29
Storm Hydrograph and Mine Pool Elevation of 5/19/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

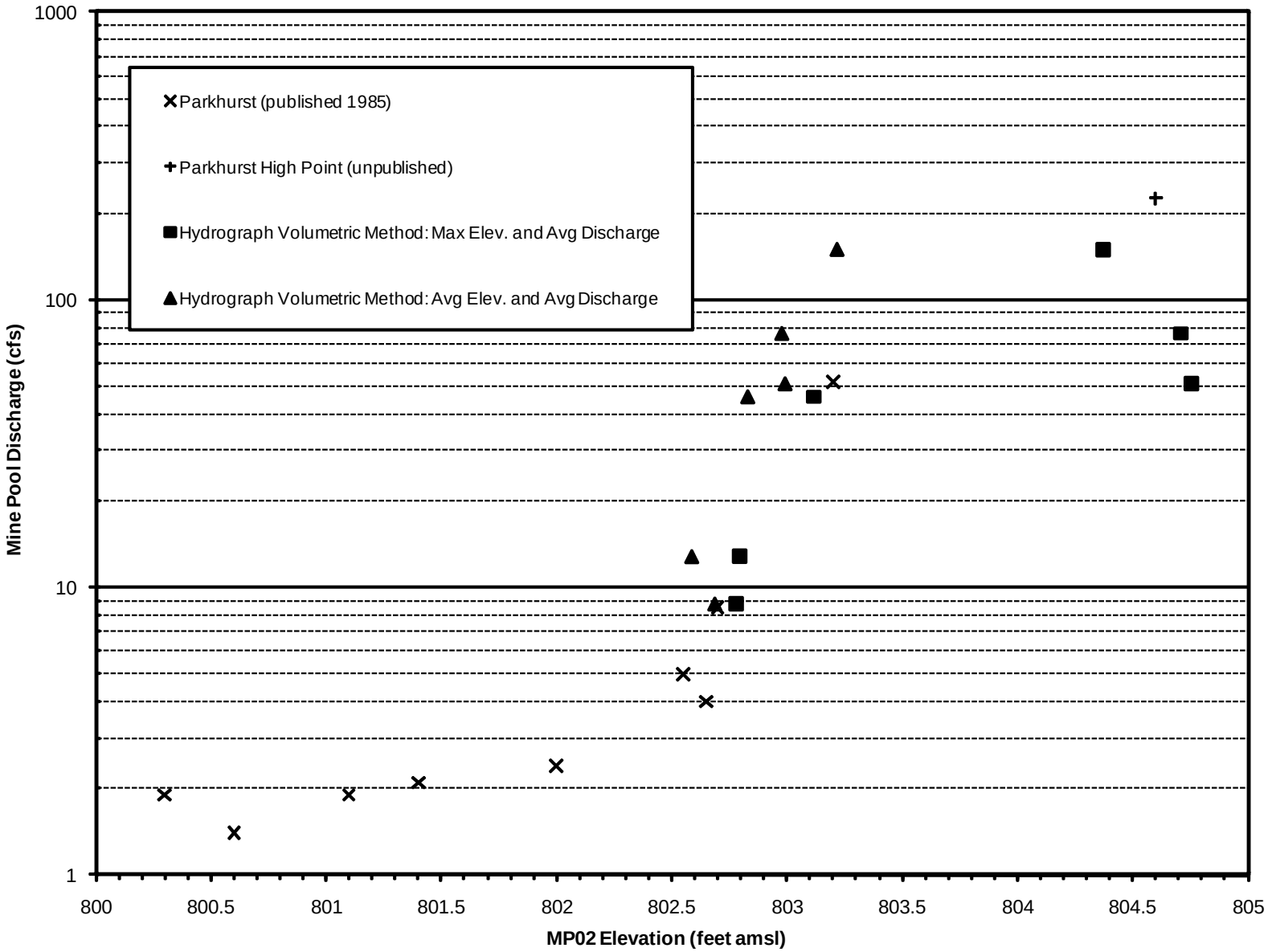



FIGURE 8-30
Updated Parkhurst Mine Pool Elevation - Discharge Rating Curve through 5/31/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

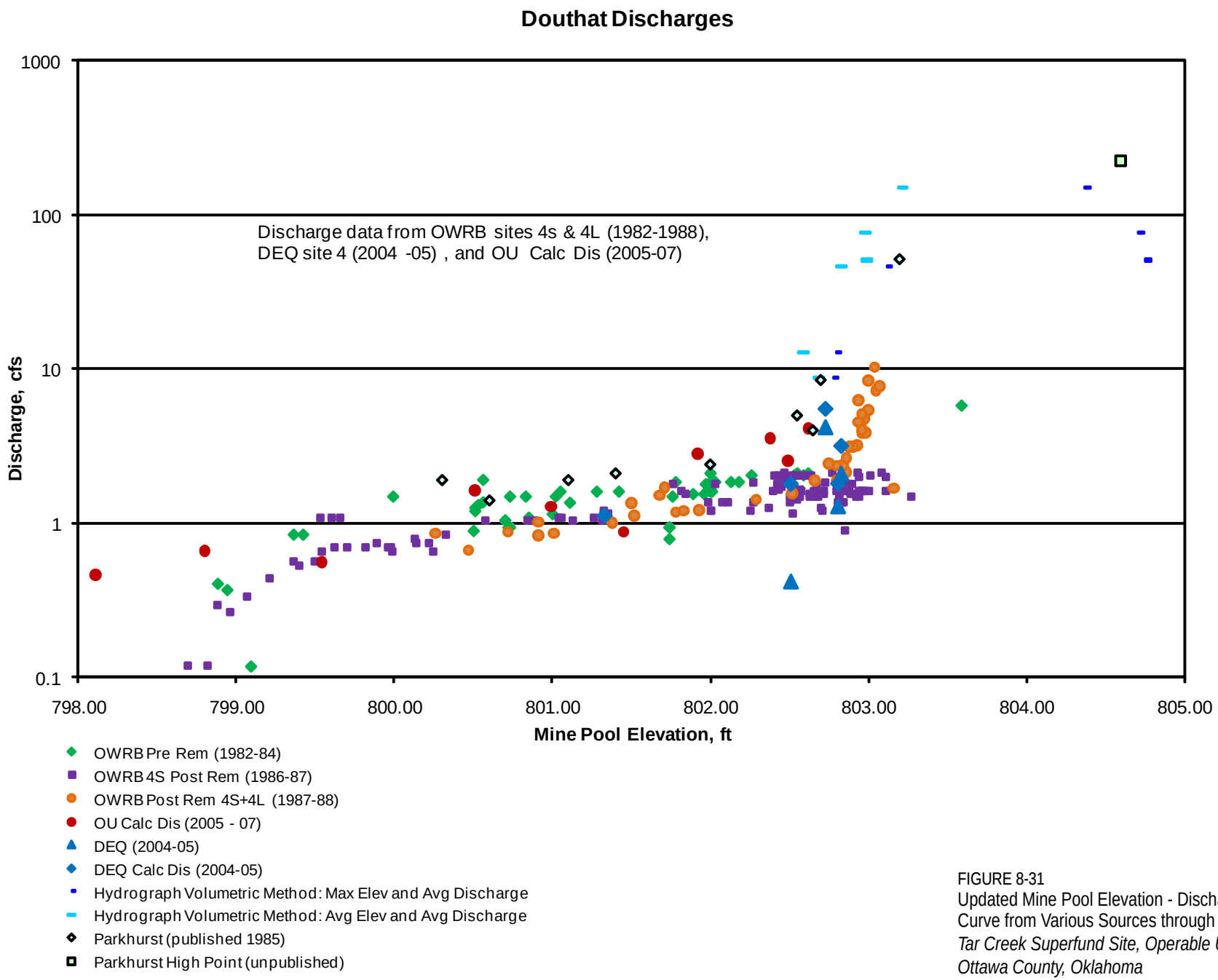



FIGURE 8-31
Updated Mine Pool Elevation - Discharge Rating Curve from Various Sources through 5/31/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

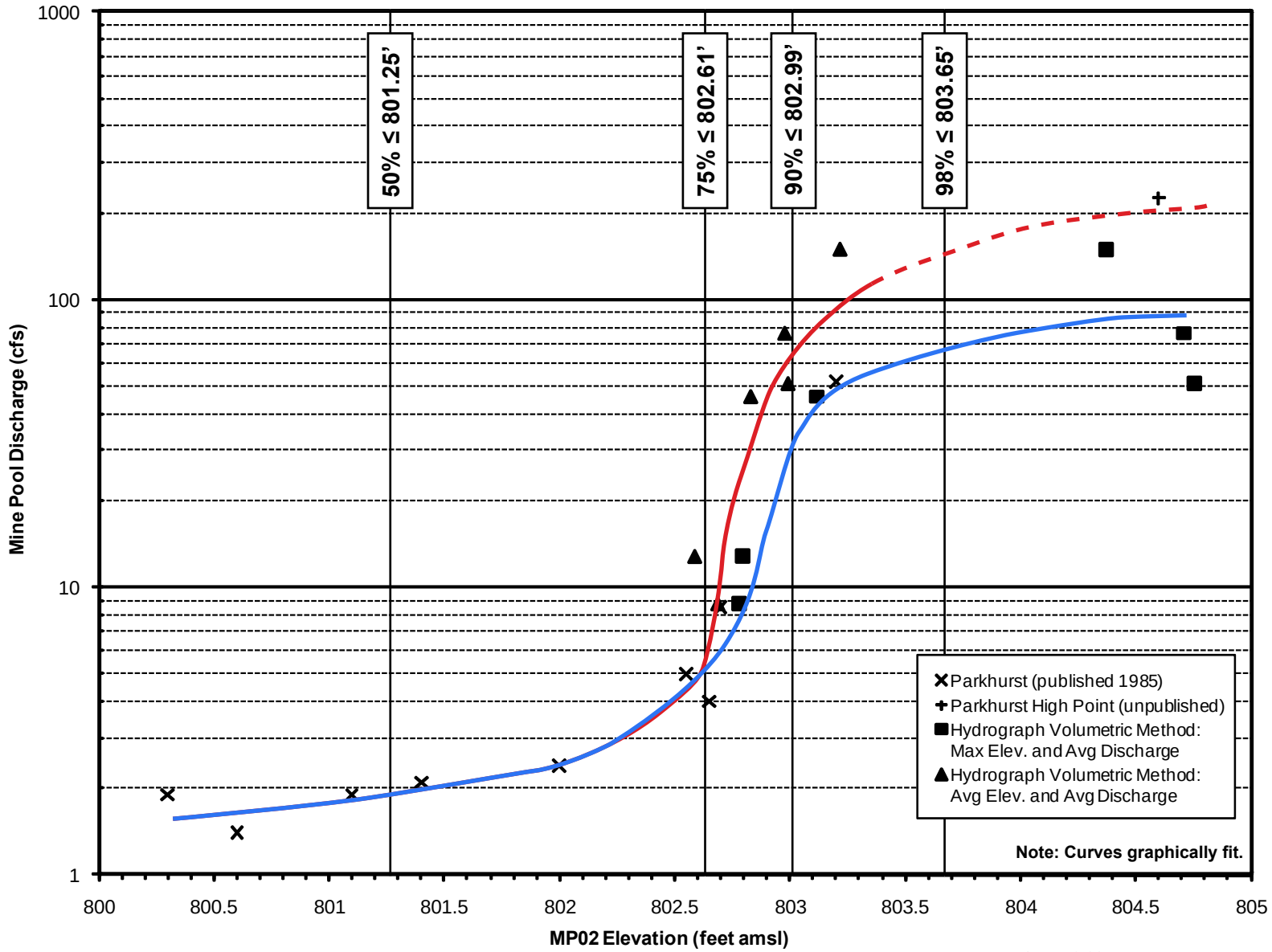



FIGURE 8-32
Updated Parkhurst Mine Pool Rating Curve with Curve Fit and Mine Pool Elevation Frequency Data
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

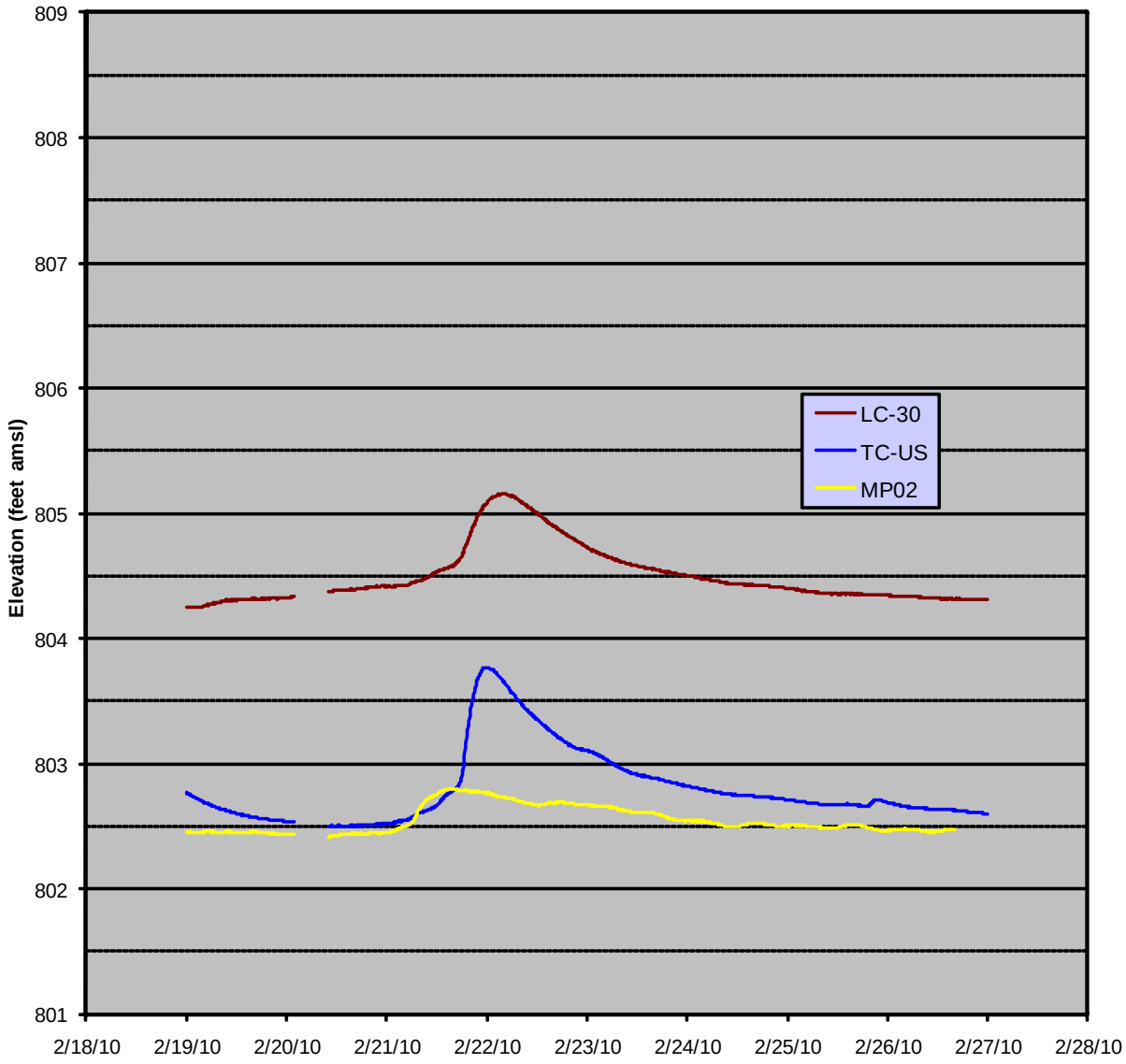



FIGURE 8-33
Surface Water and Mine Pool Elevations during Storm of 2/21/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

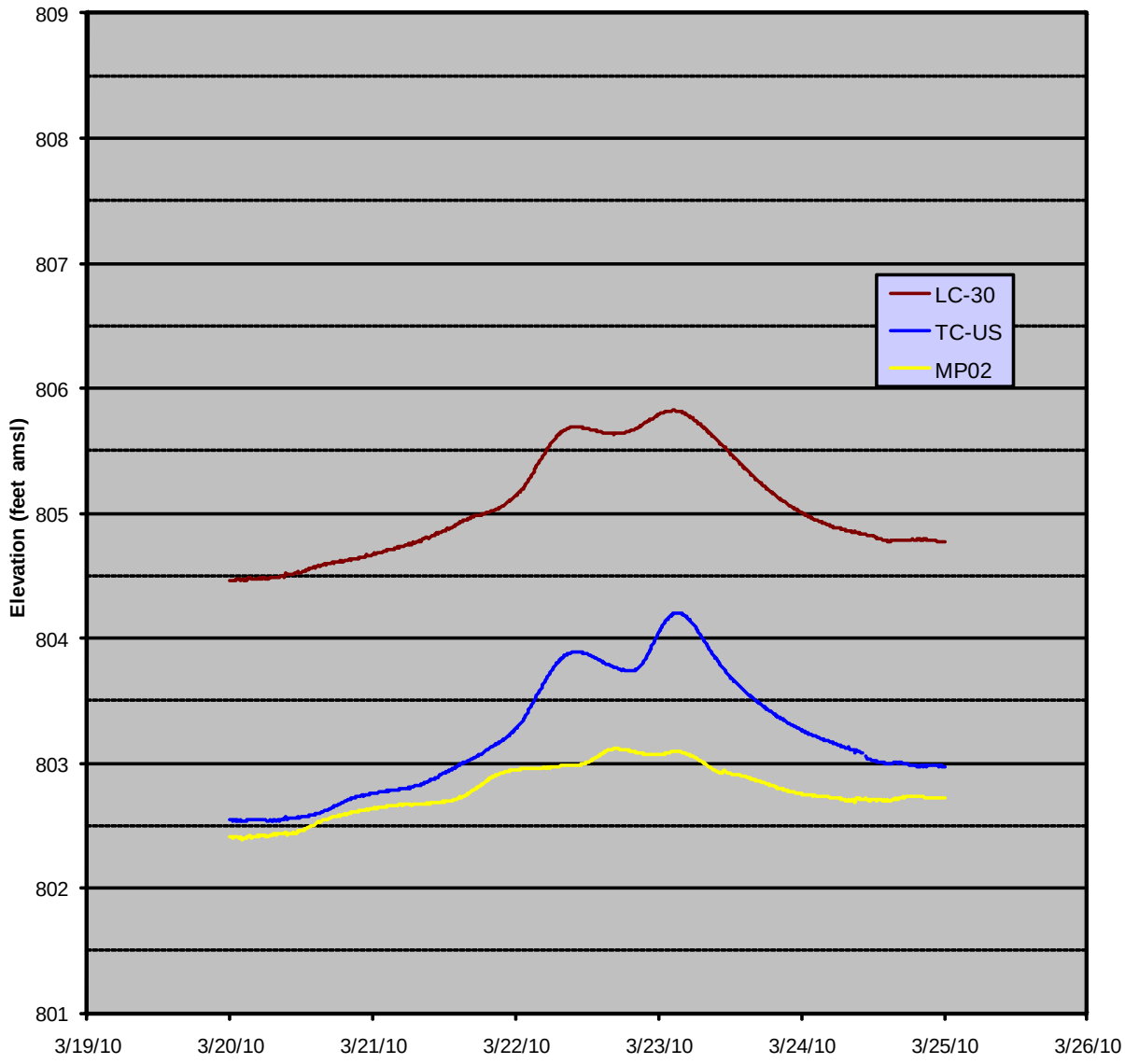



FIGURE 8-34
Surface Water and Mine Pool Elevations during Storm of 3/21/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

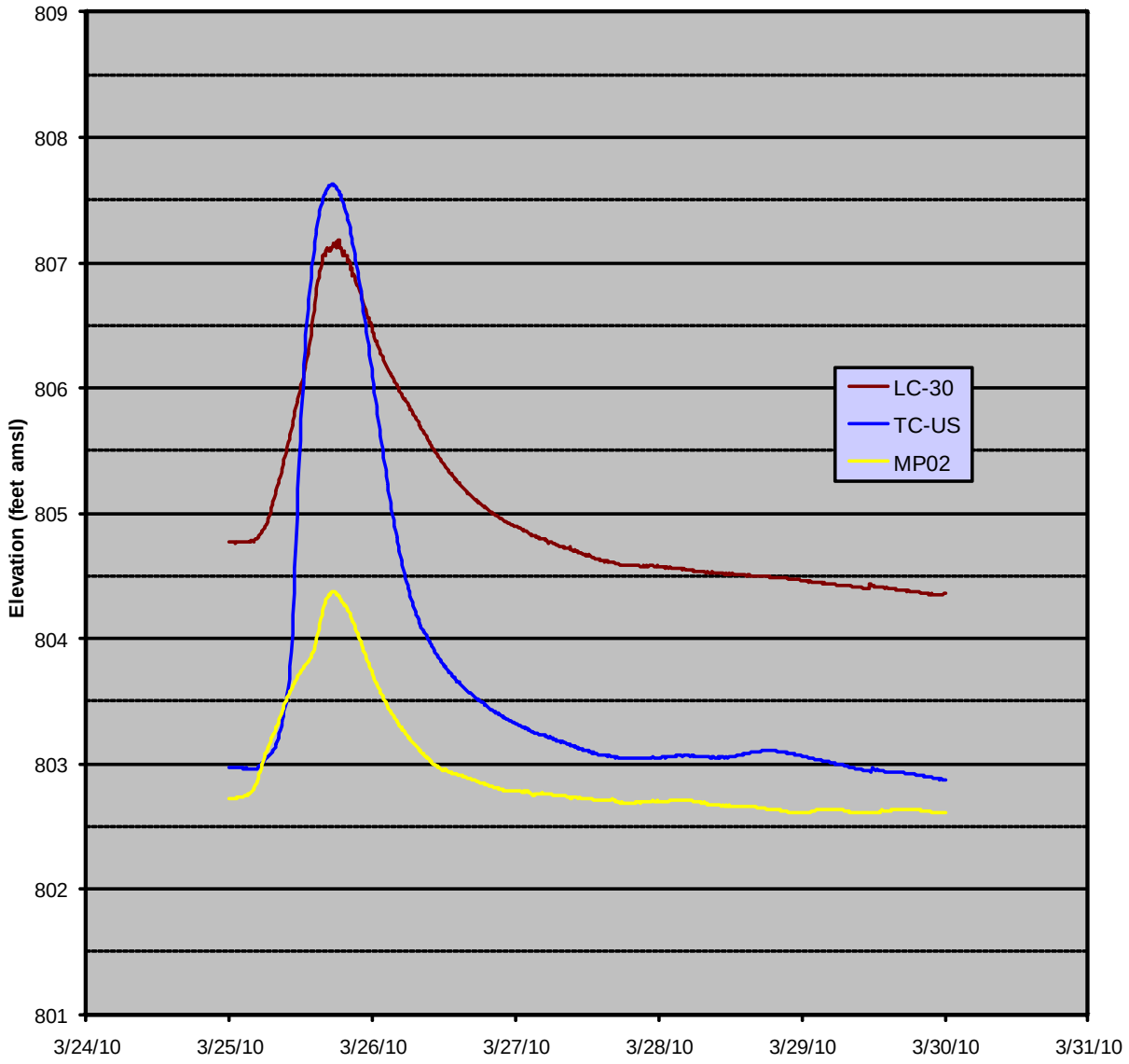



FIGURE 8-35
Surface Water and Mine Pool Elevations during Storm of 3/25/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

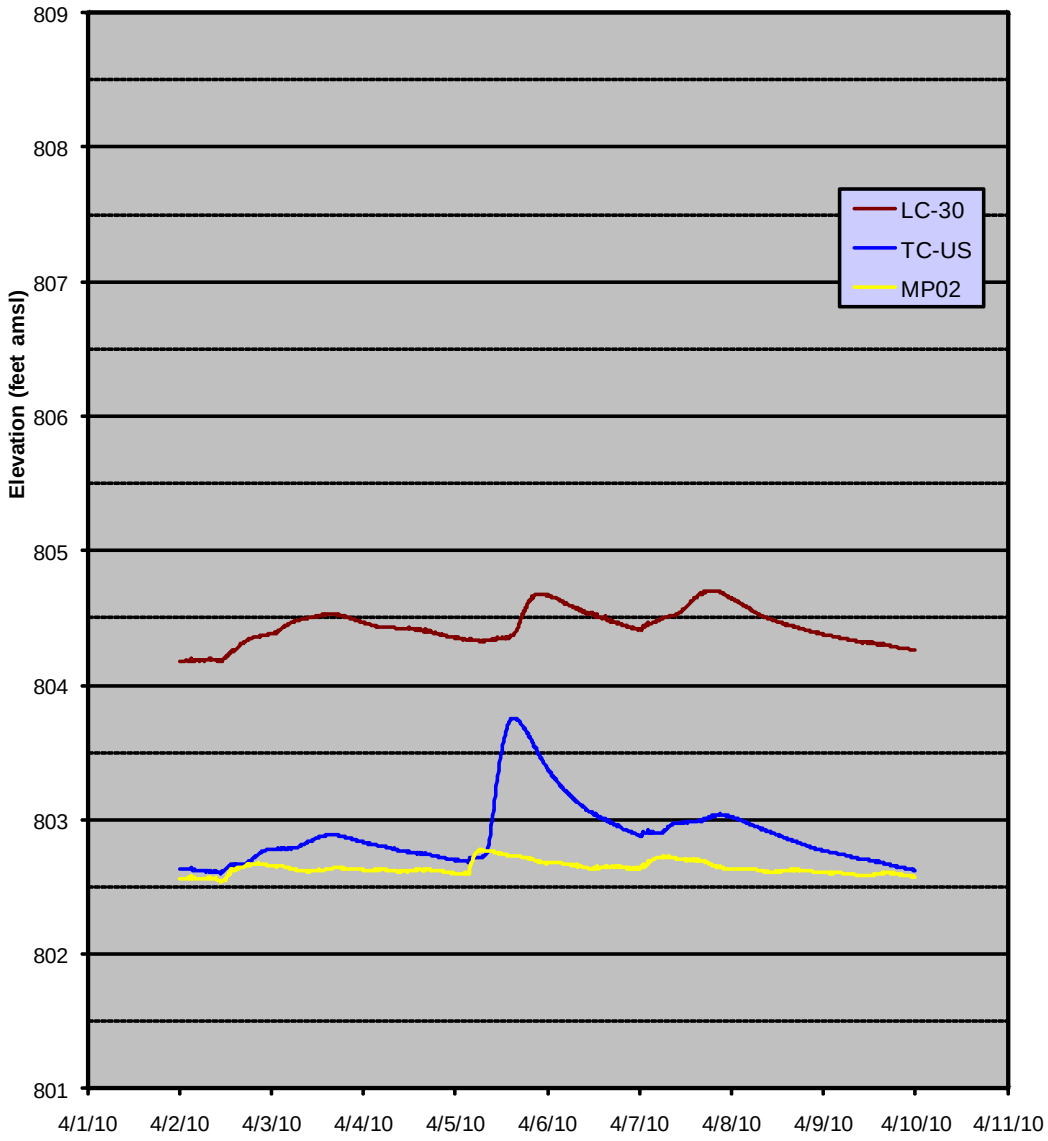



FIGURE 8-36
Surface Water and Mine Pool Elevations during Storm of 4/5/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

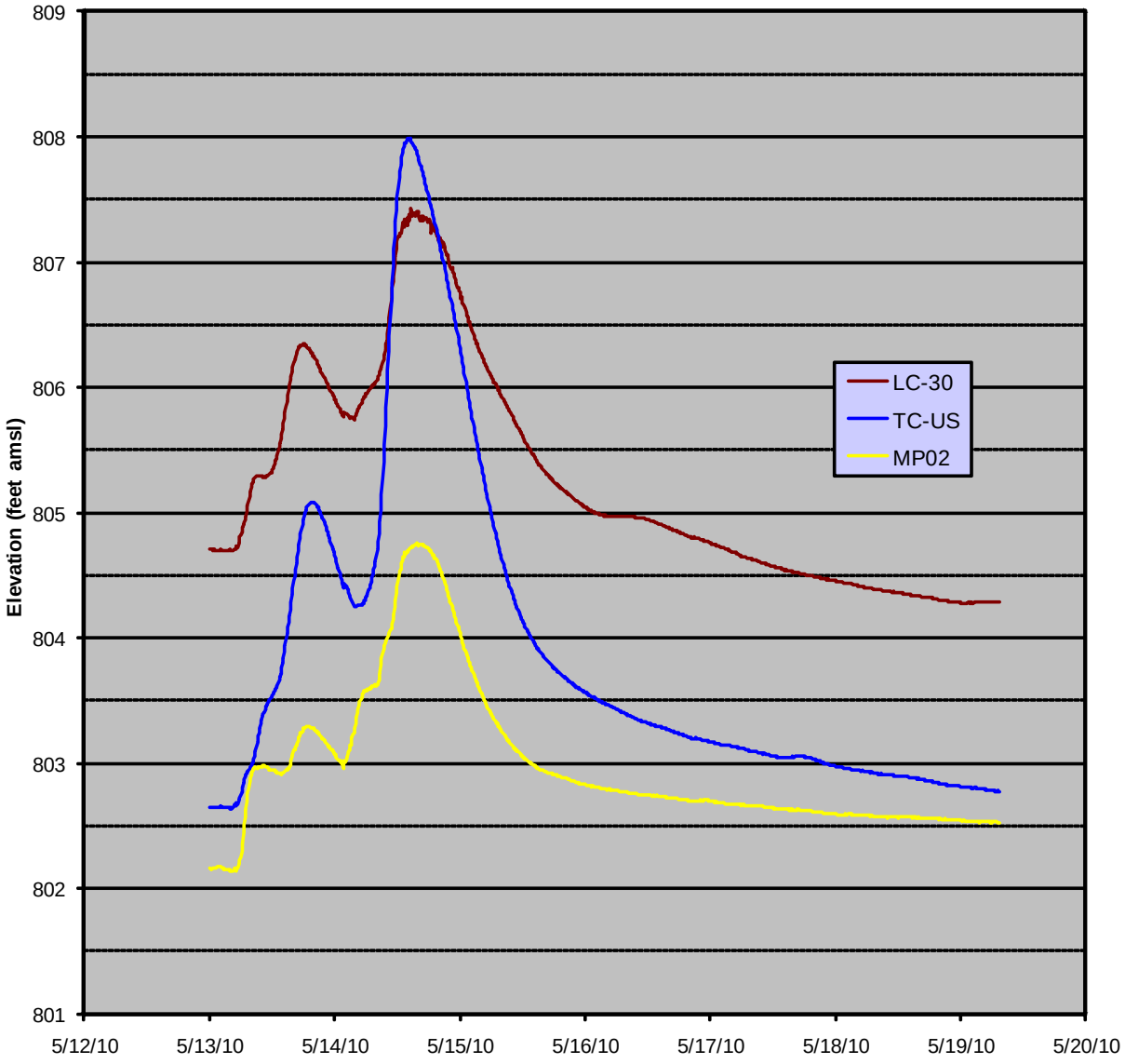



FIGURE 8-37
Surface Water and Mine Pool Elevations during Storm of 5/13/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

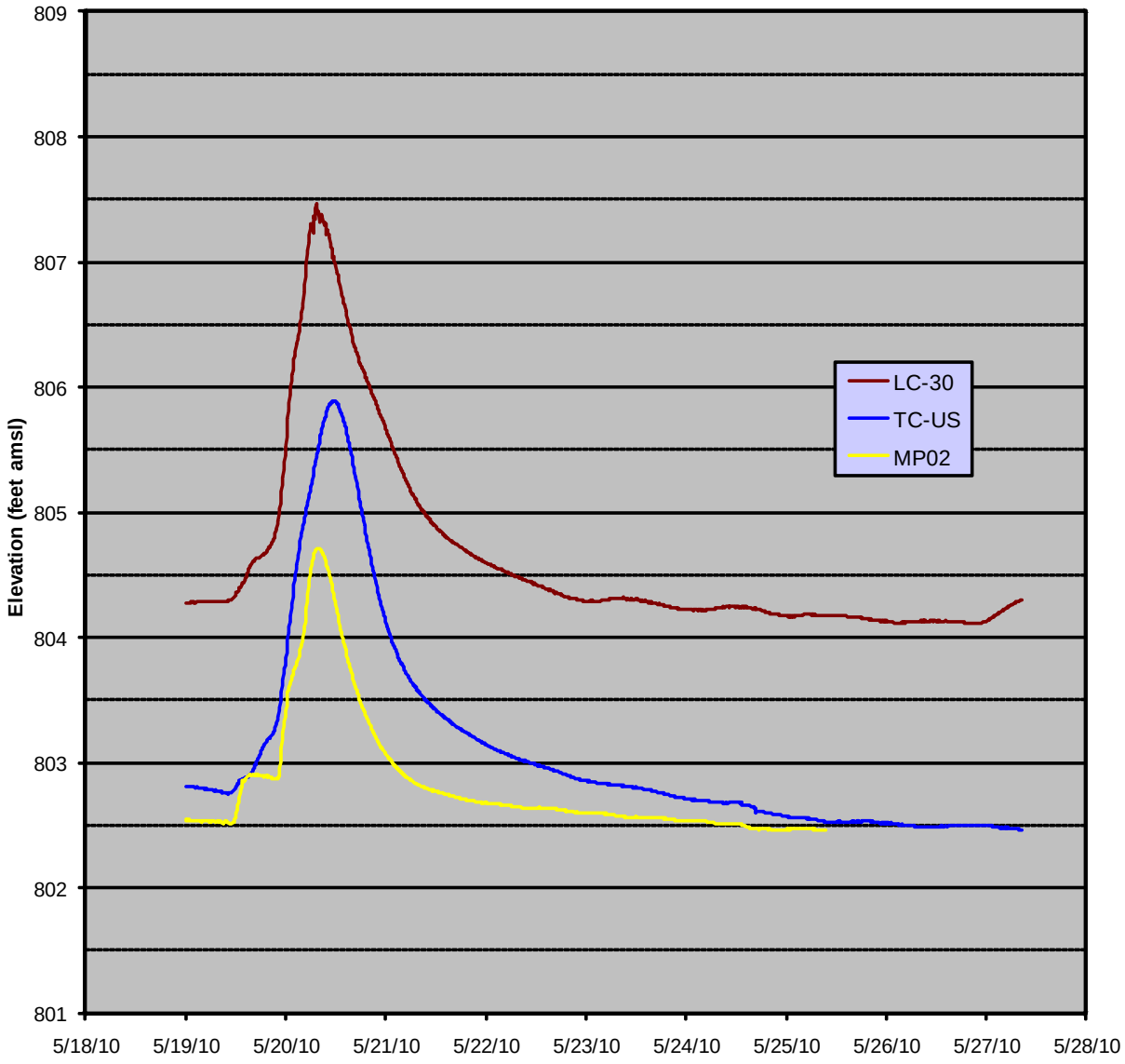
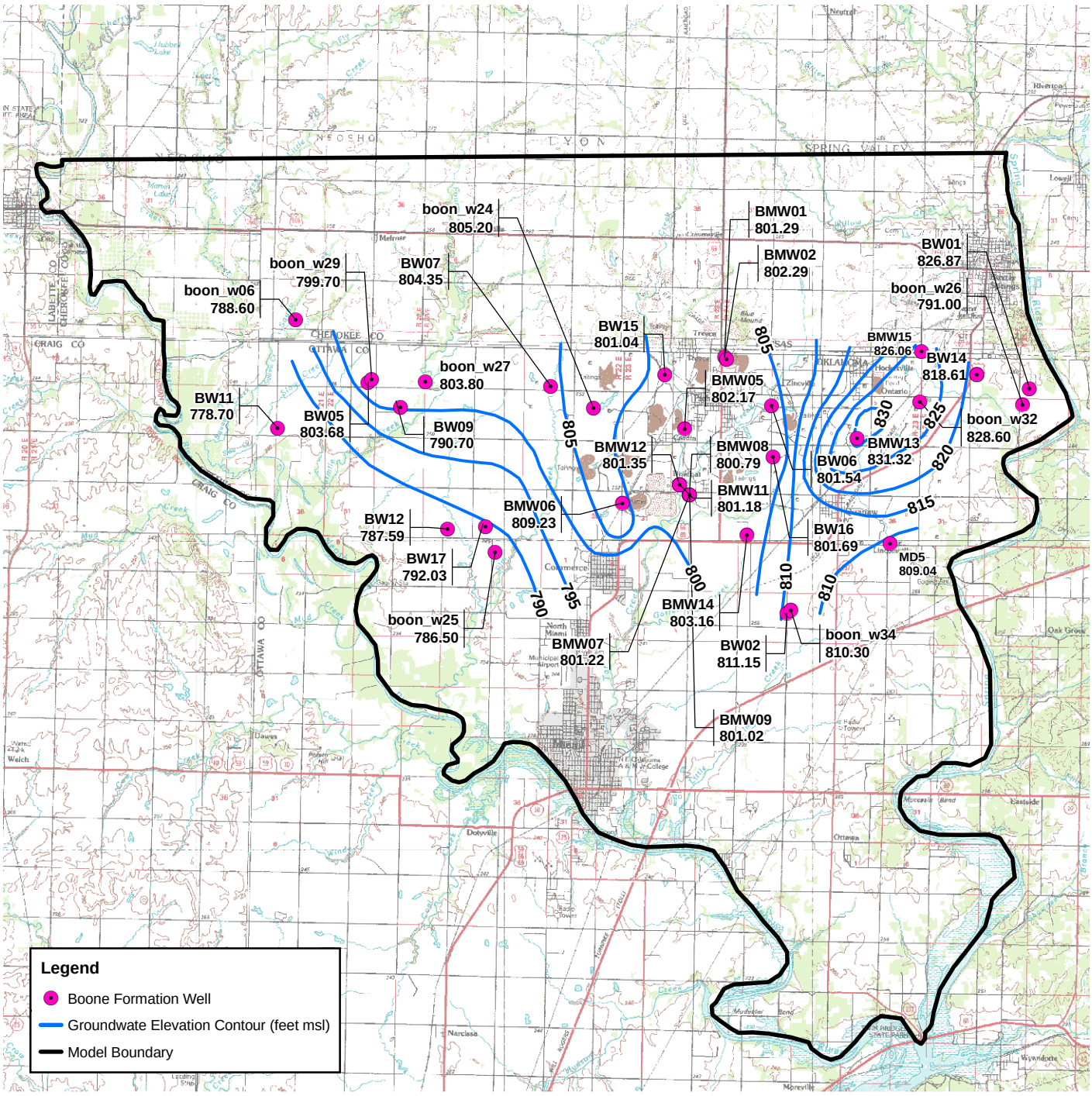



FIGURE 8-38
Surface Water and Mine Pool Elevations during Storm of 5/19/10
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




N

0 3 6 Miles

FIGURE 9-1
Boone Aquifer Groundwater Elevations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

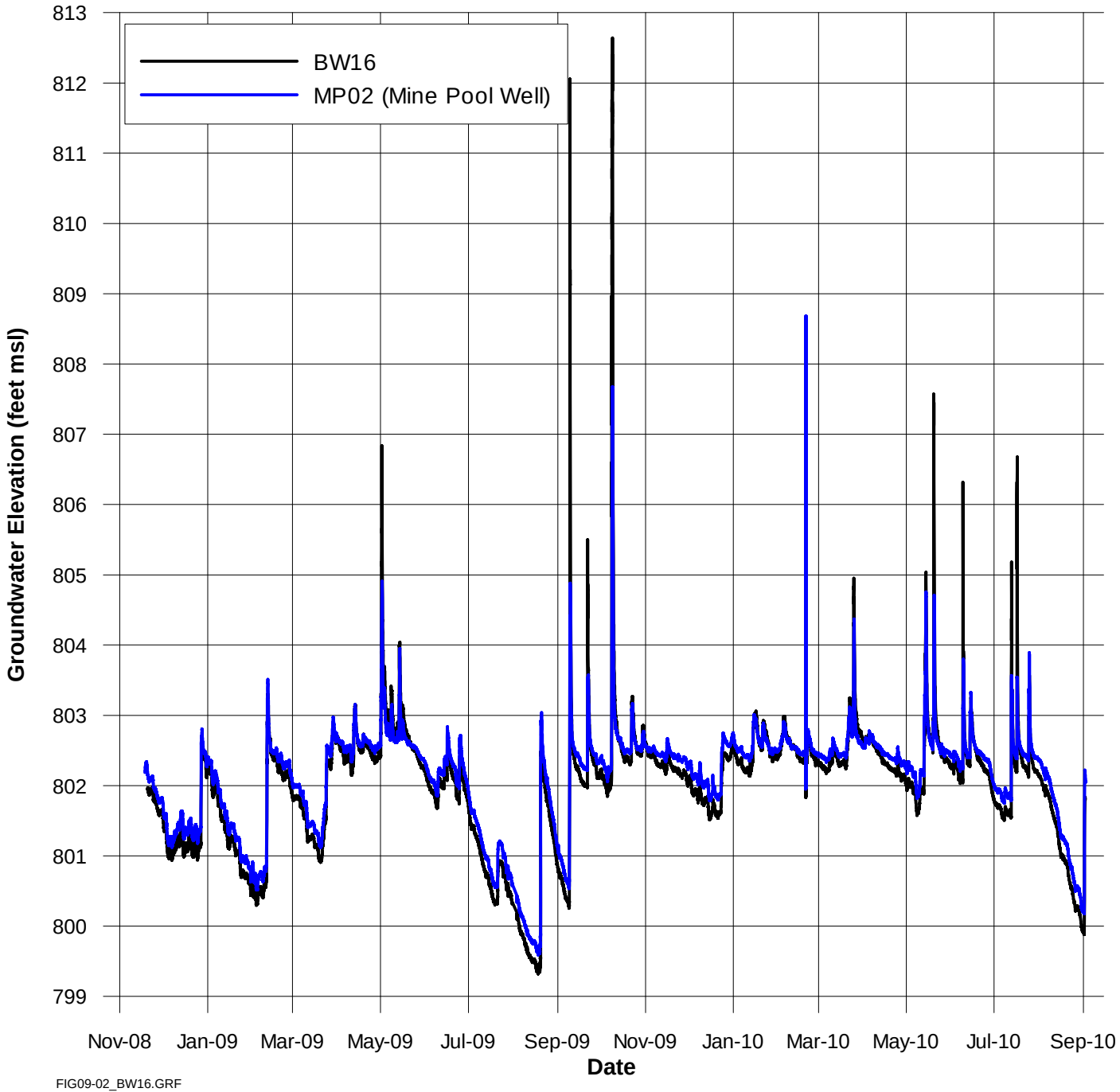
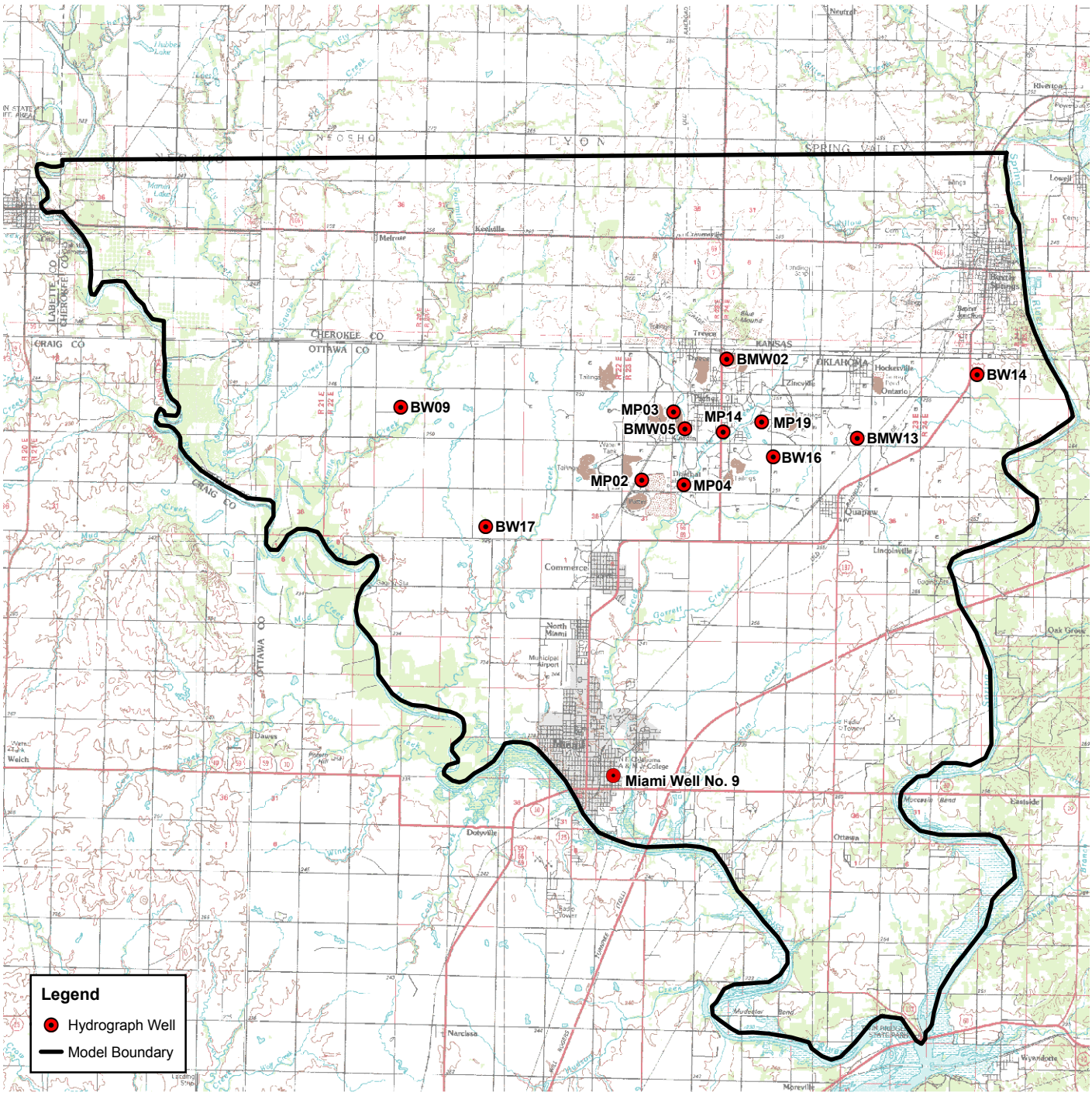



FIG09-02_BW16.GRF

FIGURE 9-2
Groundwater Elevations in Boone Aquifer Monitoring Well BW16
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




N

0 3 6 Miles

**FIGURE 9-3**
Location of Hydrograph Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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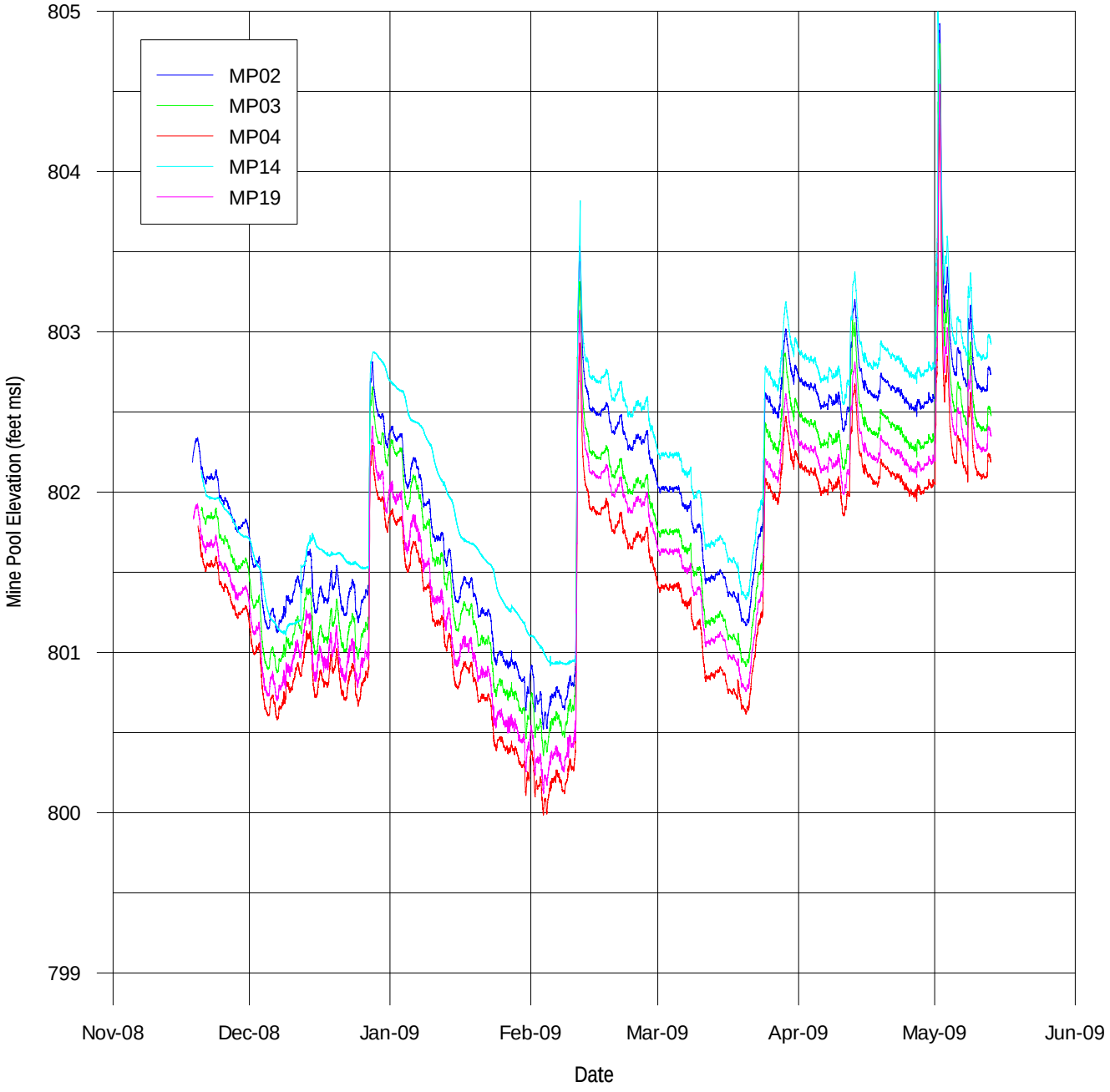



FIGURE 9-4
Mine Pool Water Levels
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

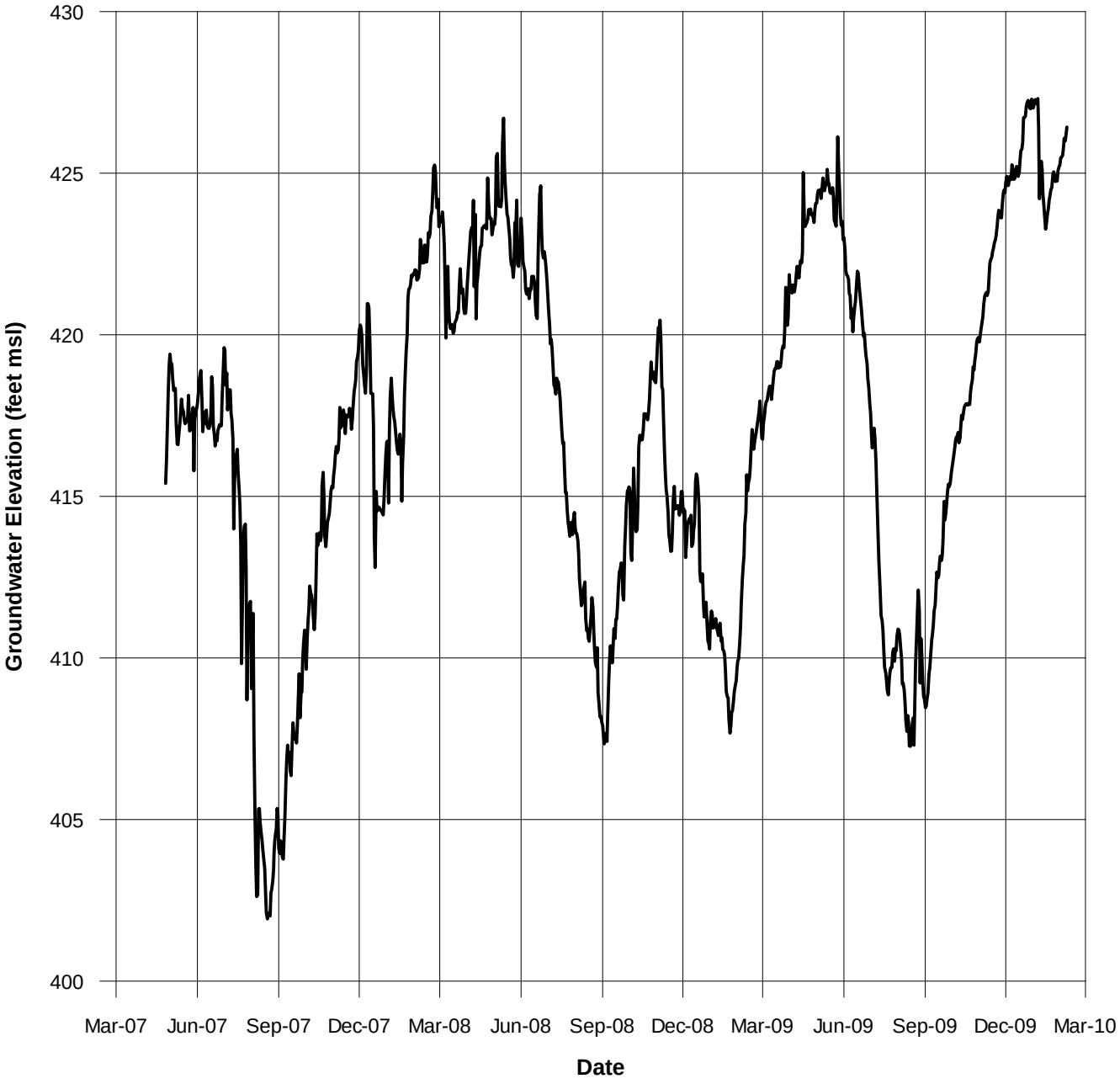
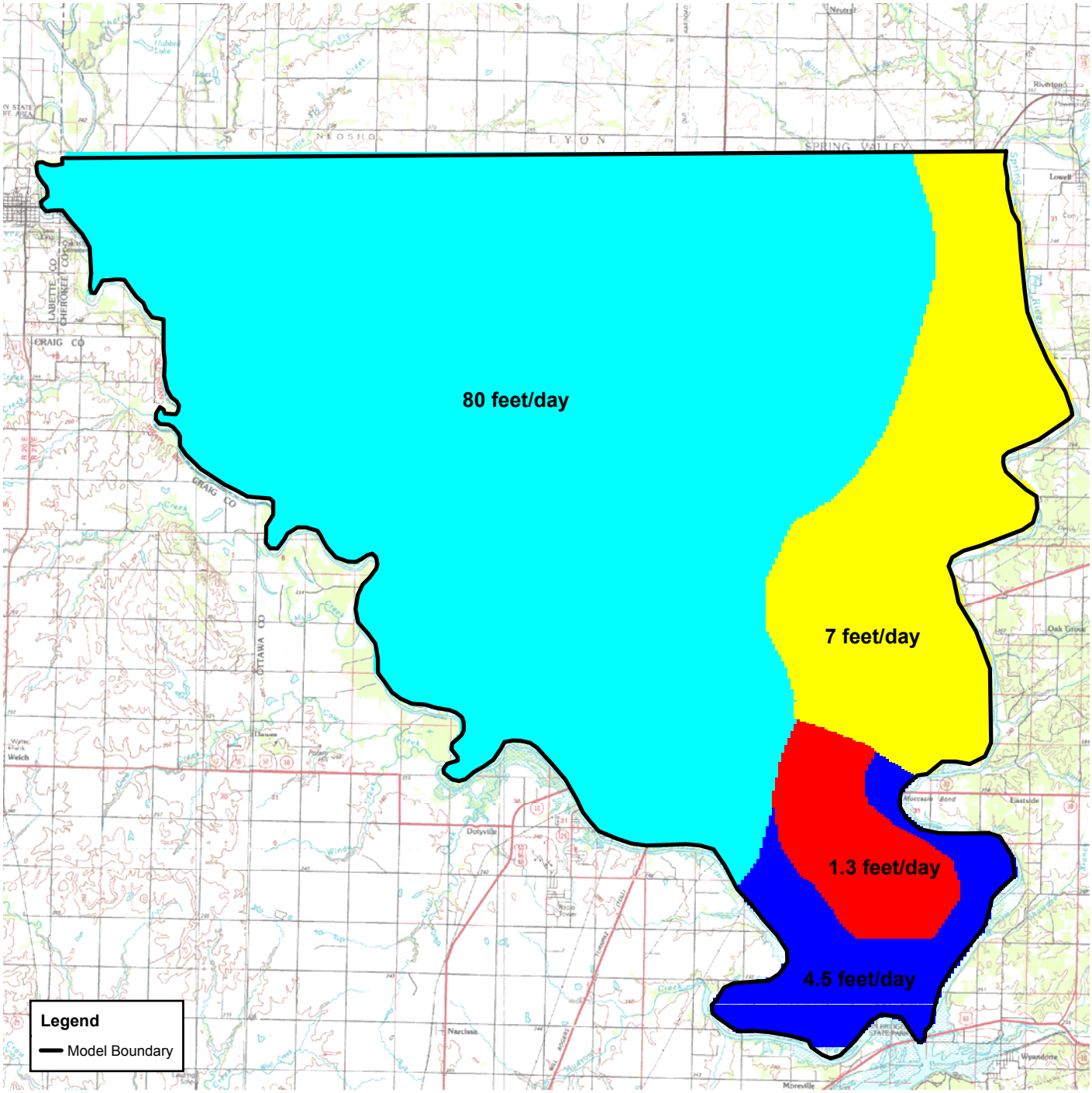


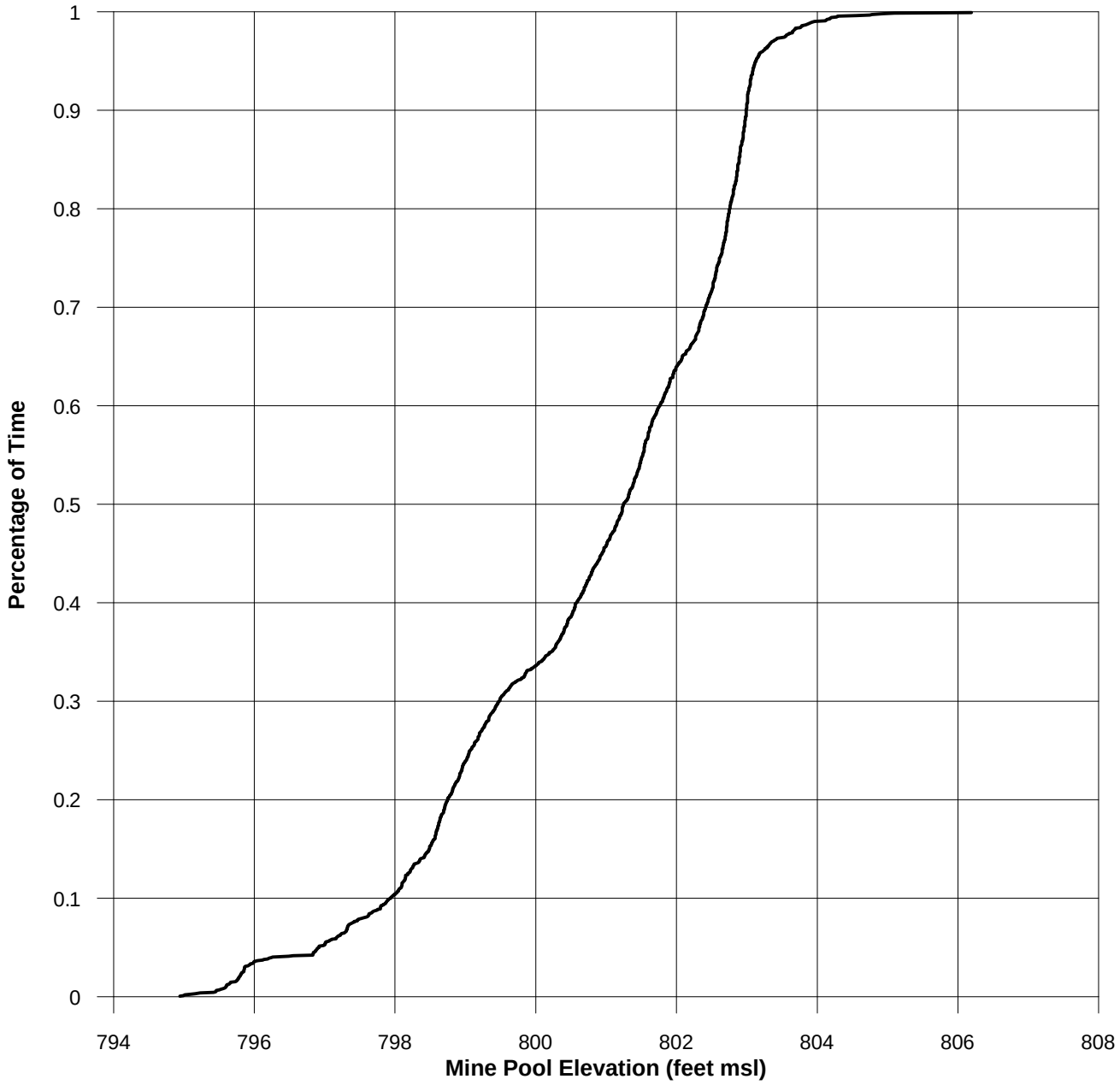

FIGURE 9-5
Groundwater Elevations in Roubidoux Aquifer
Miami Well No. 9
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




N

0 3 6 Miles

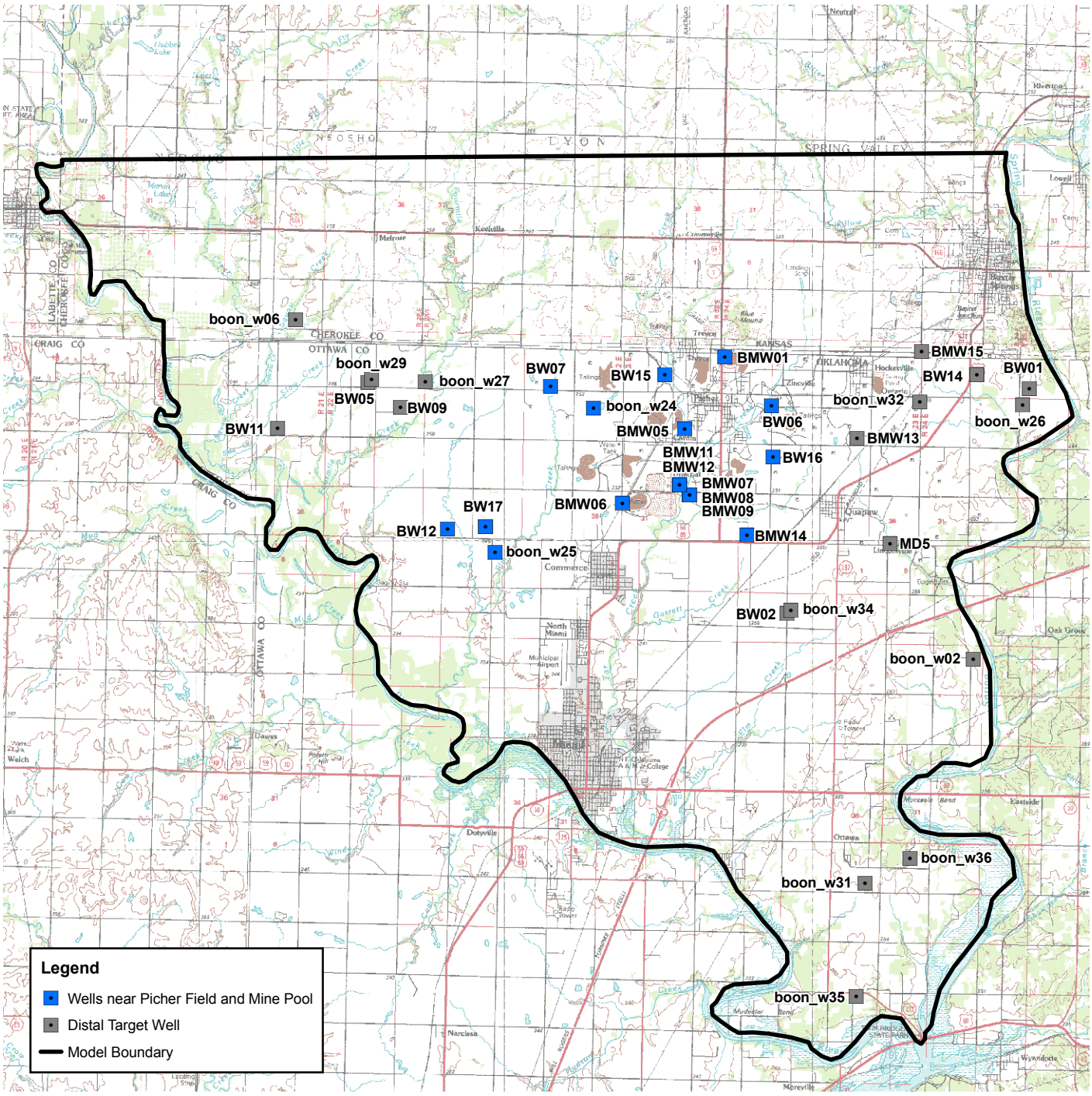
**FIGURE 9-6**
Simulated Hydraulic Conductivity of the Boone Aquifer
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




Note:

Nine-tenths of the time, the Mine Pool elevation is less that 803 feet msl.

FIGURE 9-7
Mine Pool Elevation Frequency Curve
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*



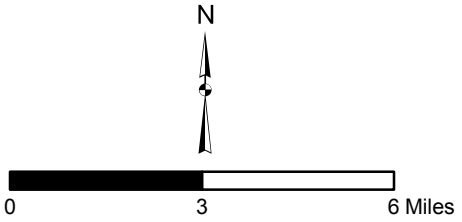




**FIGURE 9-8**
Location of Calibration Target Wells
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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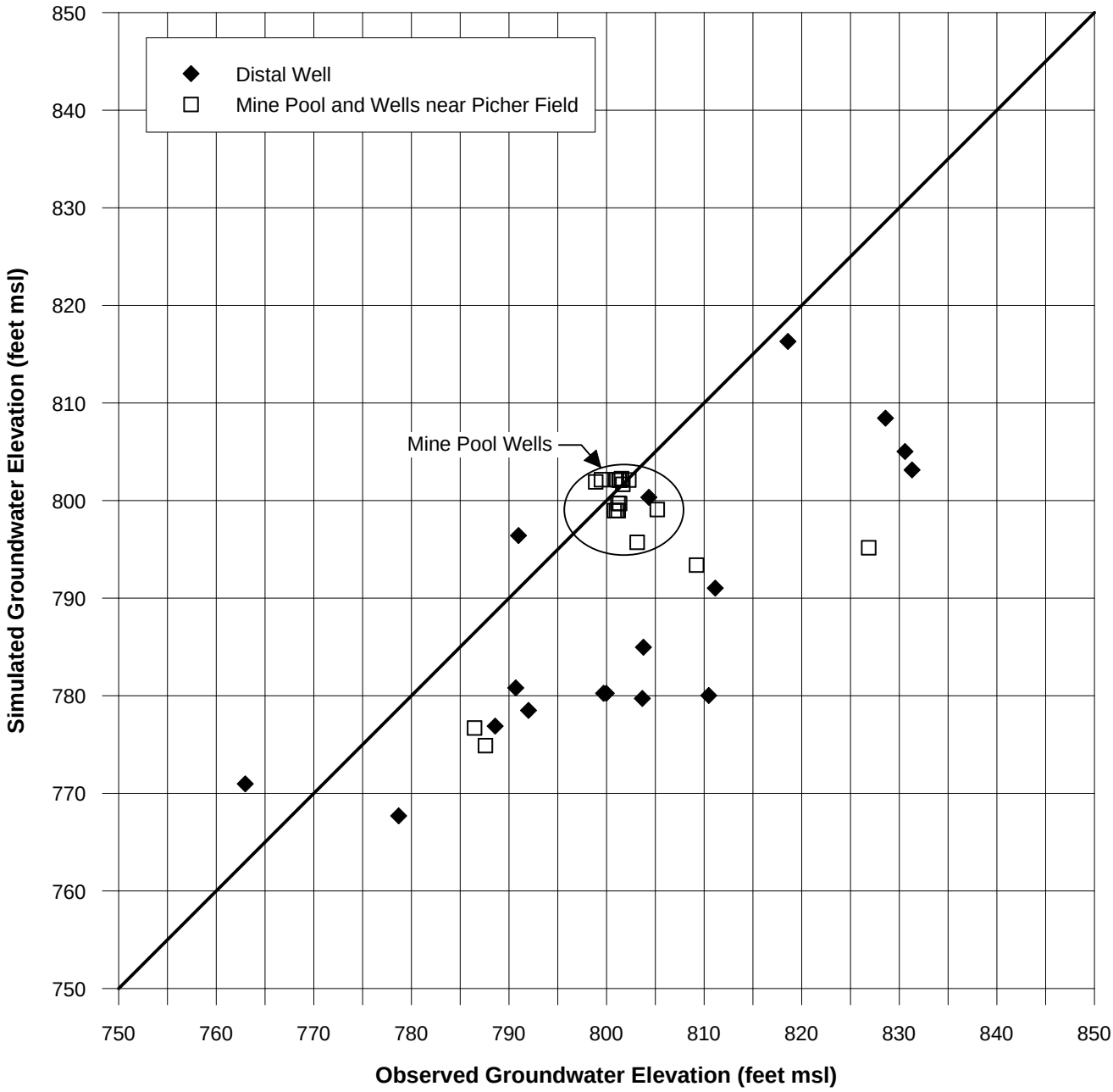



Note:

Observed groundwater elevations represent April 2009 and 2004 USGS data.

FIGURE 9-9
Simulated Versus Observed Groundwater Elevations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

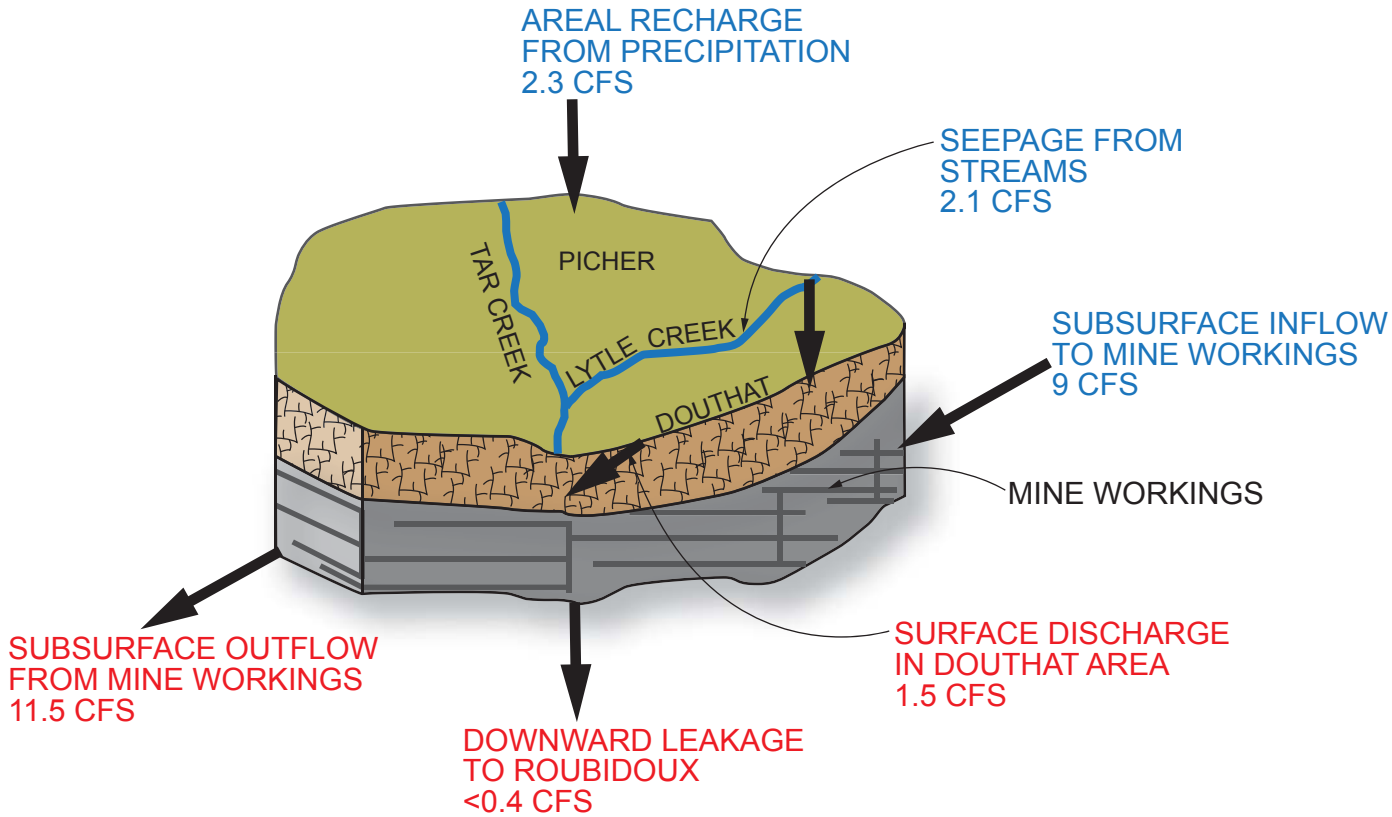
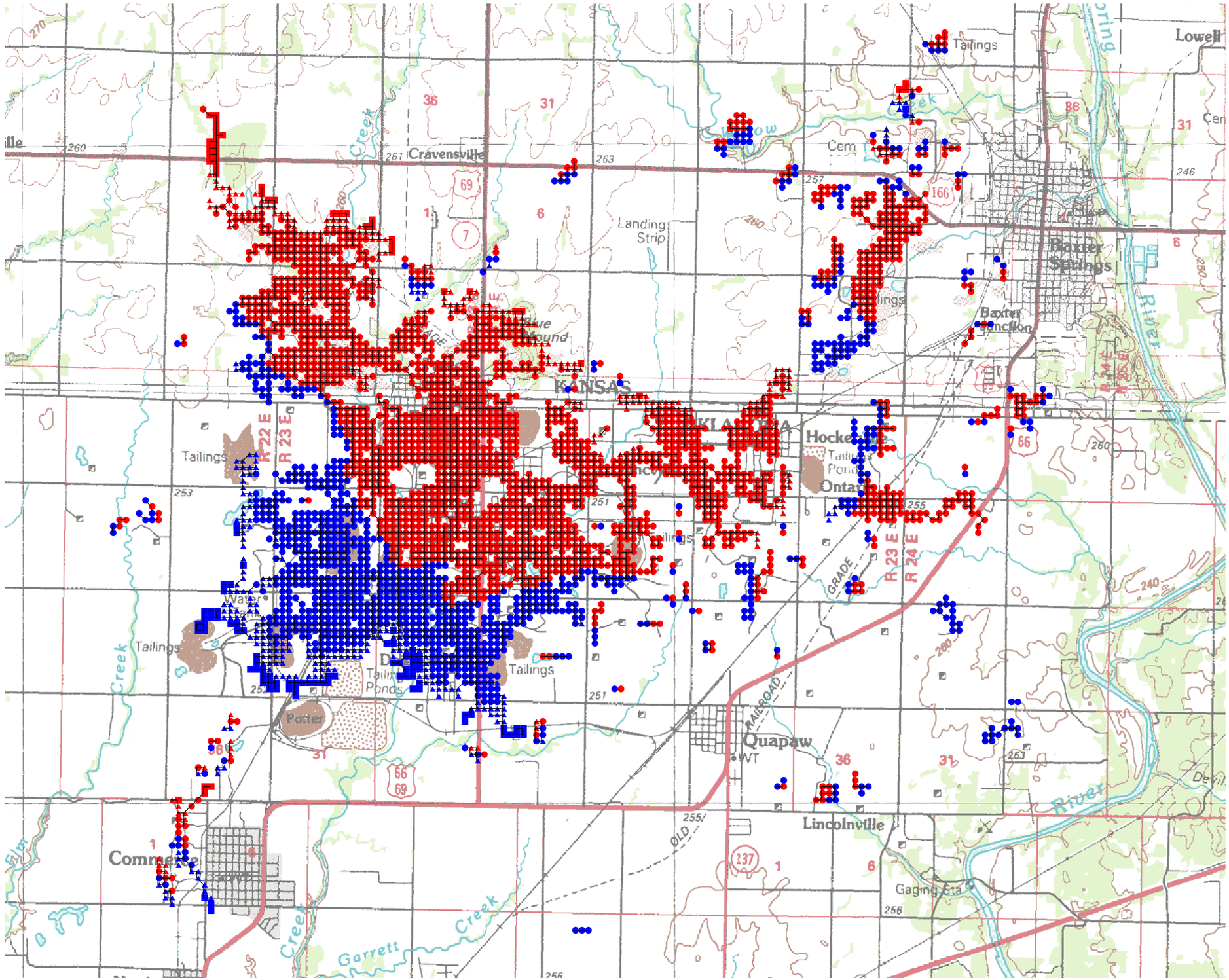



**FIGURE 9-10**
Simulated Mine Pool Water Budget Components
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




**Legend**

**Exchange Flow from Aquifer to Mine Pool (gpm)**

- -74 to -15
- -15 to -5
- -5 to 0
- 0 to 5
- 5 to 15
- 15 to 71
- CFP Pipe Network

Notes:

Negative value indicates discharge from Mine Pool to aquifer.

Positive value indicates discharge from Boone Aquifer into Mine Pool.

CFP = Conduit Flow Process.

N

0 5,000 10,000 Feet

**FIGURE 9-11**
Simulated Exchange Flows Between the Mine Workings and the Boone Aquifer
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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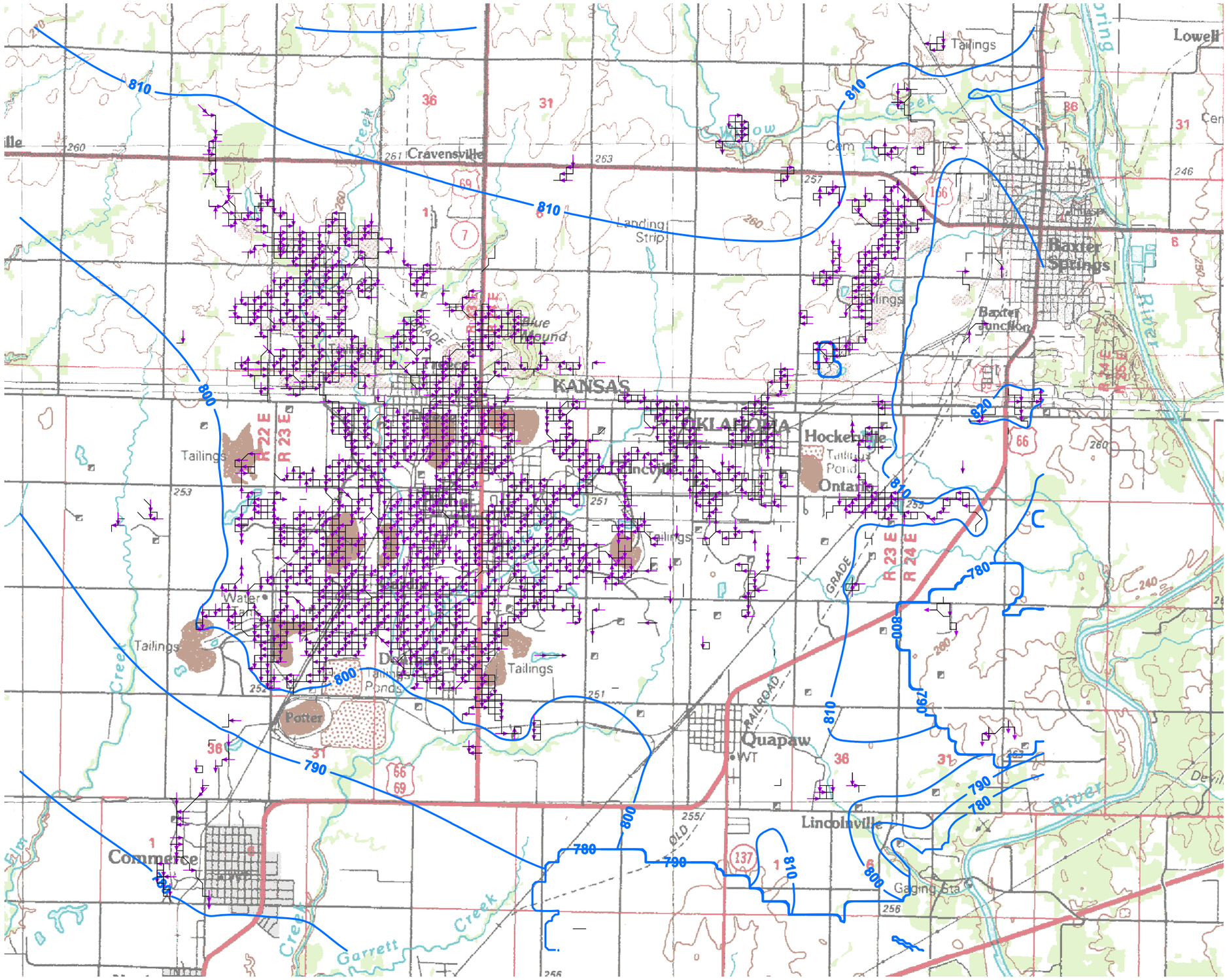


**Legend**

- Simulated Groundwater Flow Direction
- Simulated Groundwater Elevation Contour (feet msl)
- CFP Pipe Network

Note:

CFP = Conduit Flow Process.

N

0 5,000 10,000 Feet

**FIGURE 9-12**
Simulated Flow Direction in the Mine Workings
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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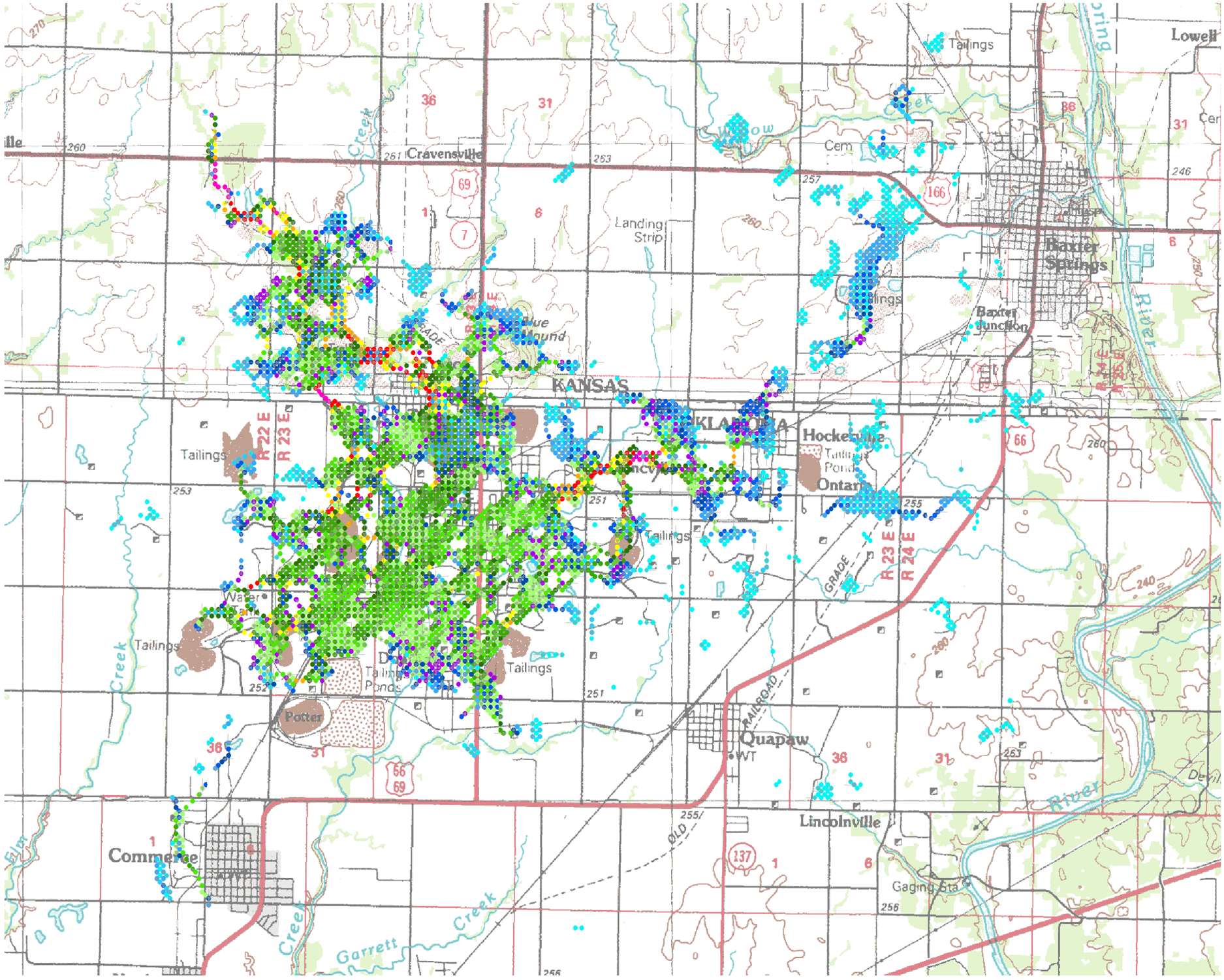


FIGURE 9-13
Simulated Flow Rates in the Mine Workings
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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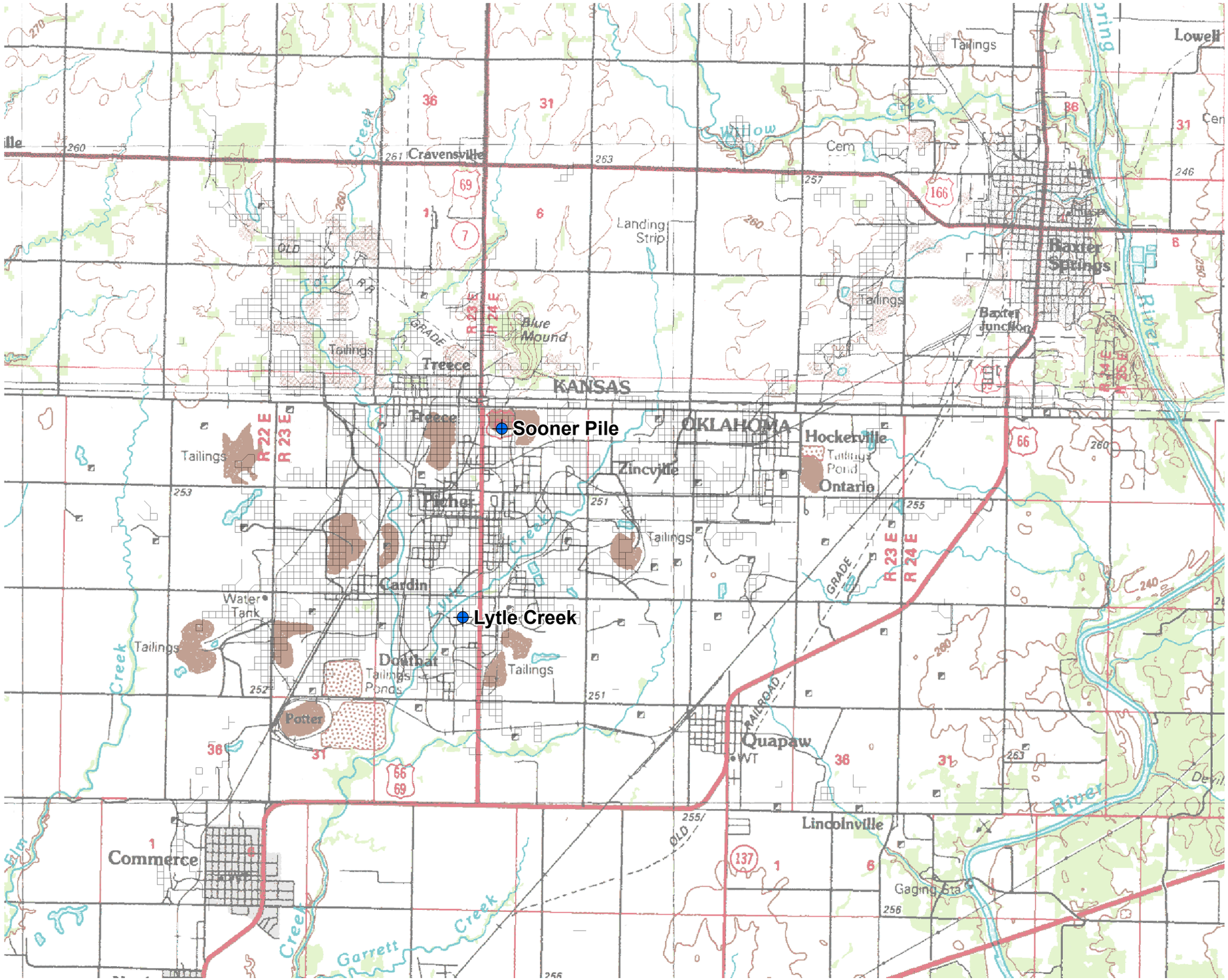


**Legend**

Injection Point

CFP Pipe Network

Note:

CFP = Conduit Flow Process.

N

0 5,000 10,000 Feet

**FIGURE 9-14**
Assumed Source Locations for Post-Injection Solute Transport Simulations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

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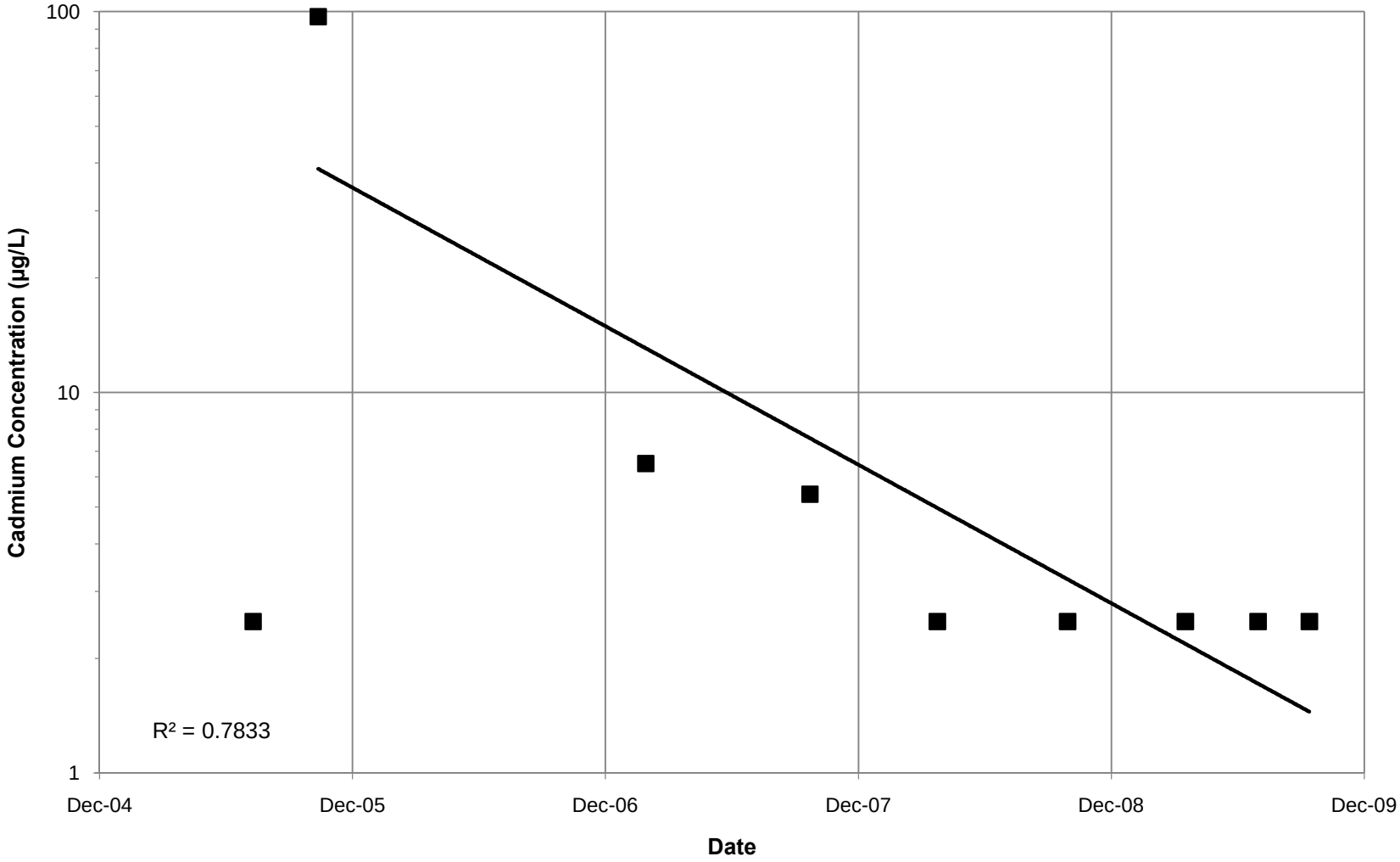



FIGURE 9-15
Craig Mine Post-Injection Cadmium Concentrations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

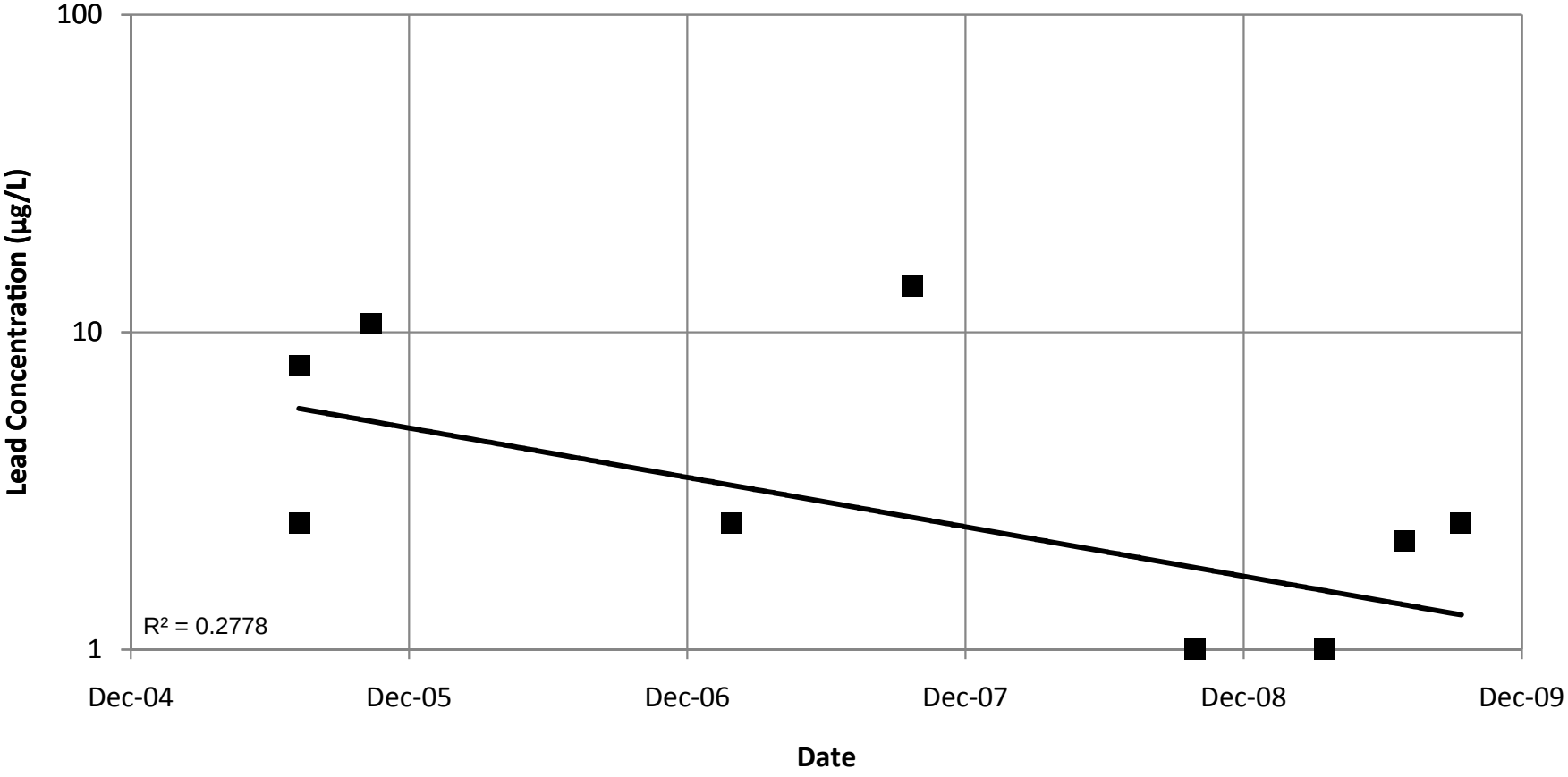



FIGURE 9-16
Craig Mine Post-Injection Lead Concentrations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

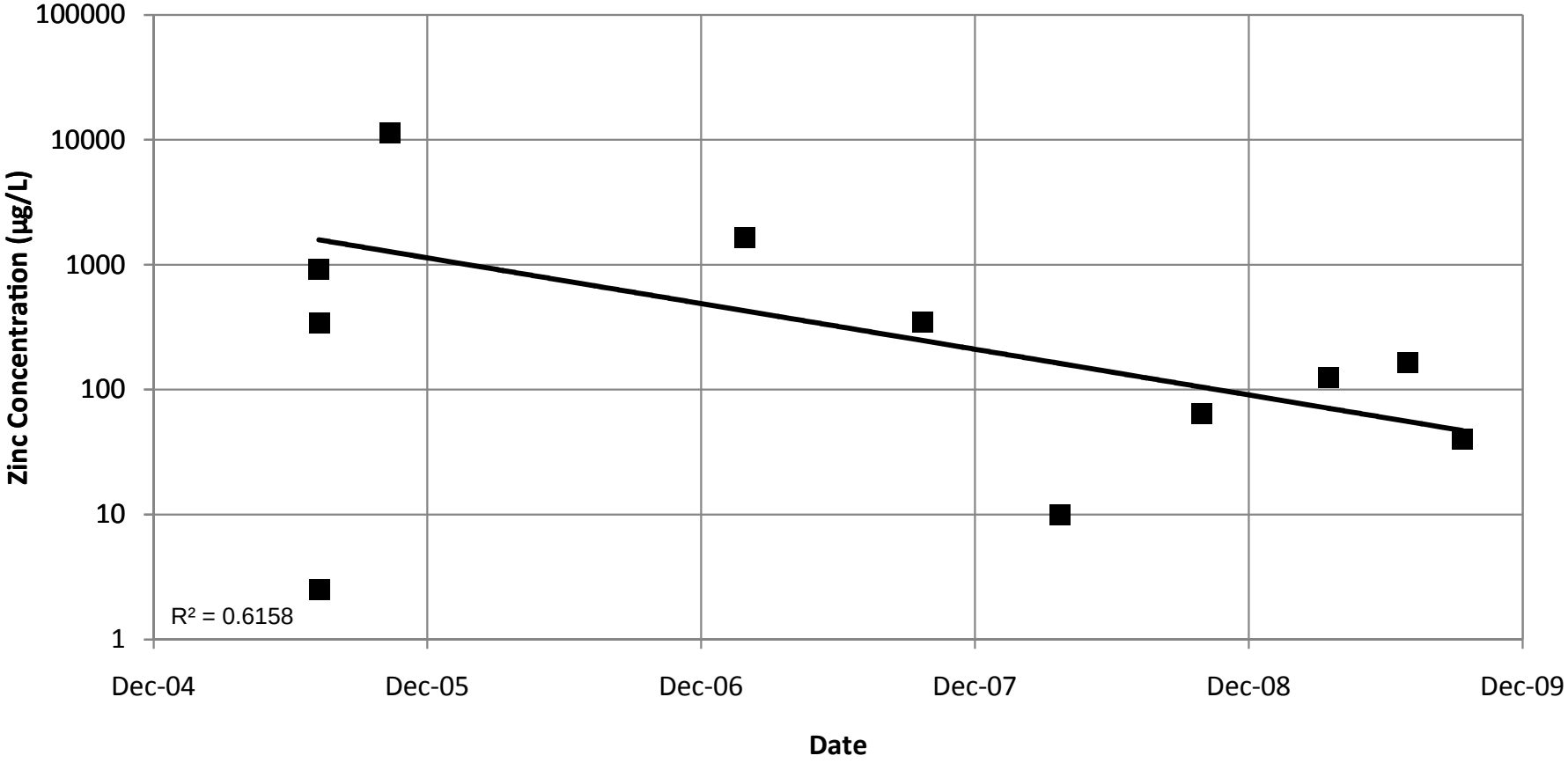



FIGURE 9-17
Craig Mine Post-Injection Zinc Concentrations
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

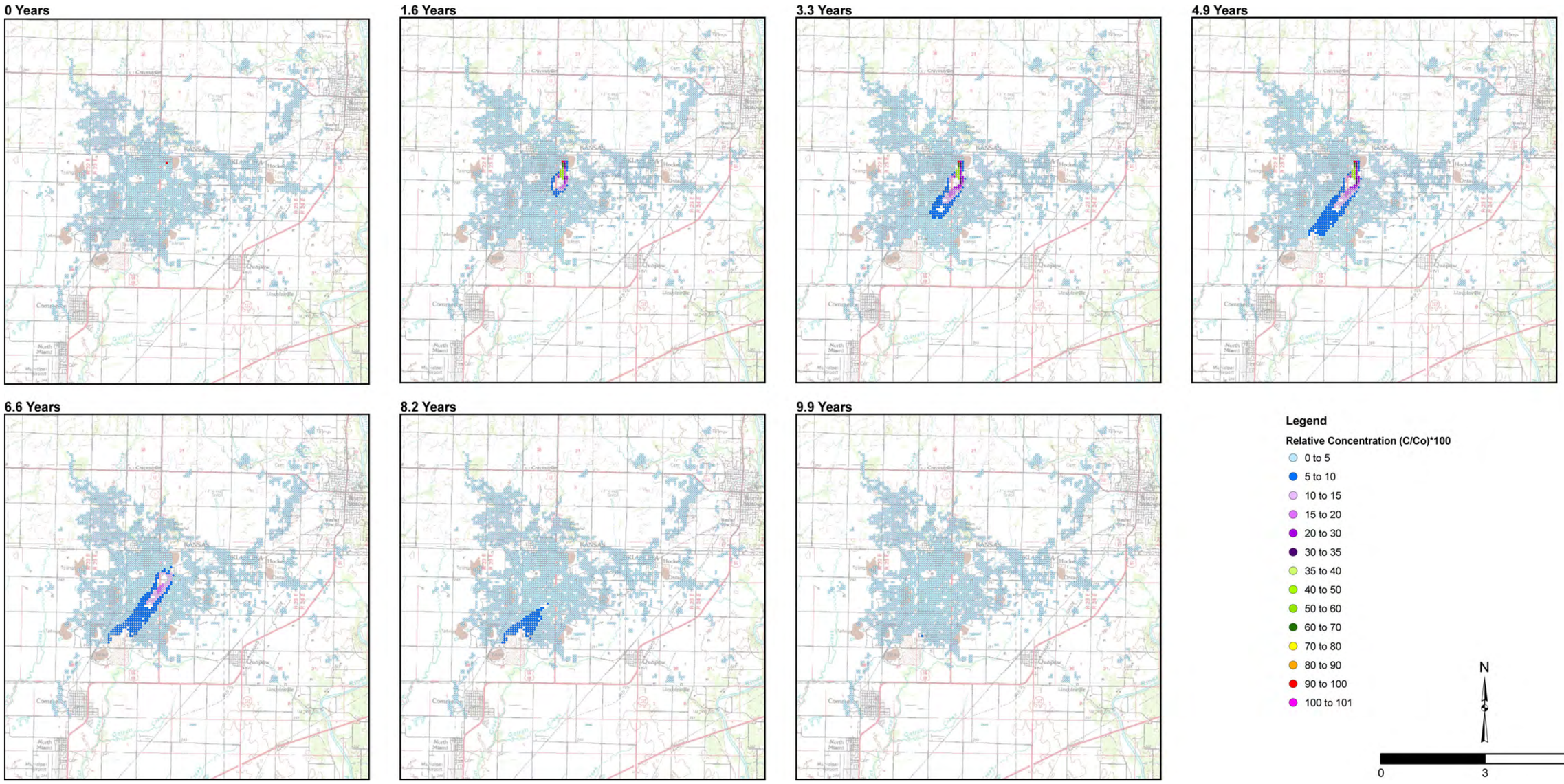



FIGURE 9-18
Forecasted Solute Transport Resulting from Sooner Pile Injection
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

FIGURE 9-19
Forecasted Solute Transport Resulting from Lytle Creek Pile Injection
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

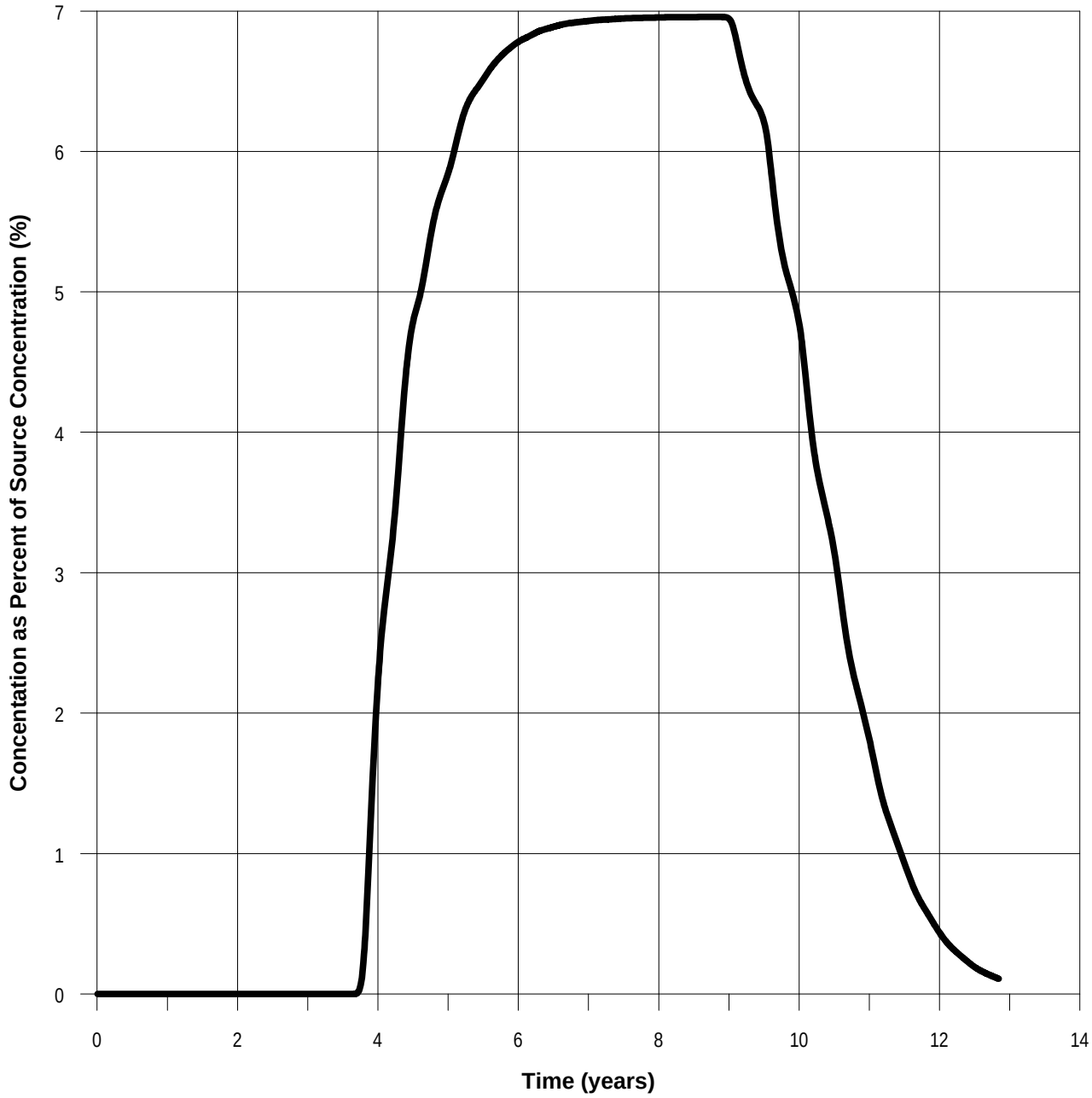



FIGURE 9-20
Model Forecasts of Dilution Percentages at the Downgradient Edge of the Picher Mine Pool Following Sooner Pile Chat Injection
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

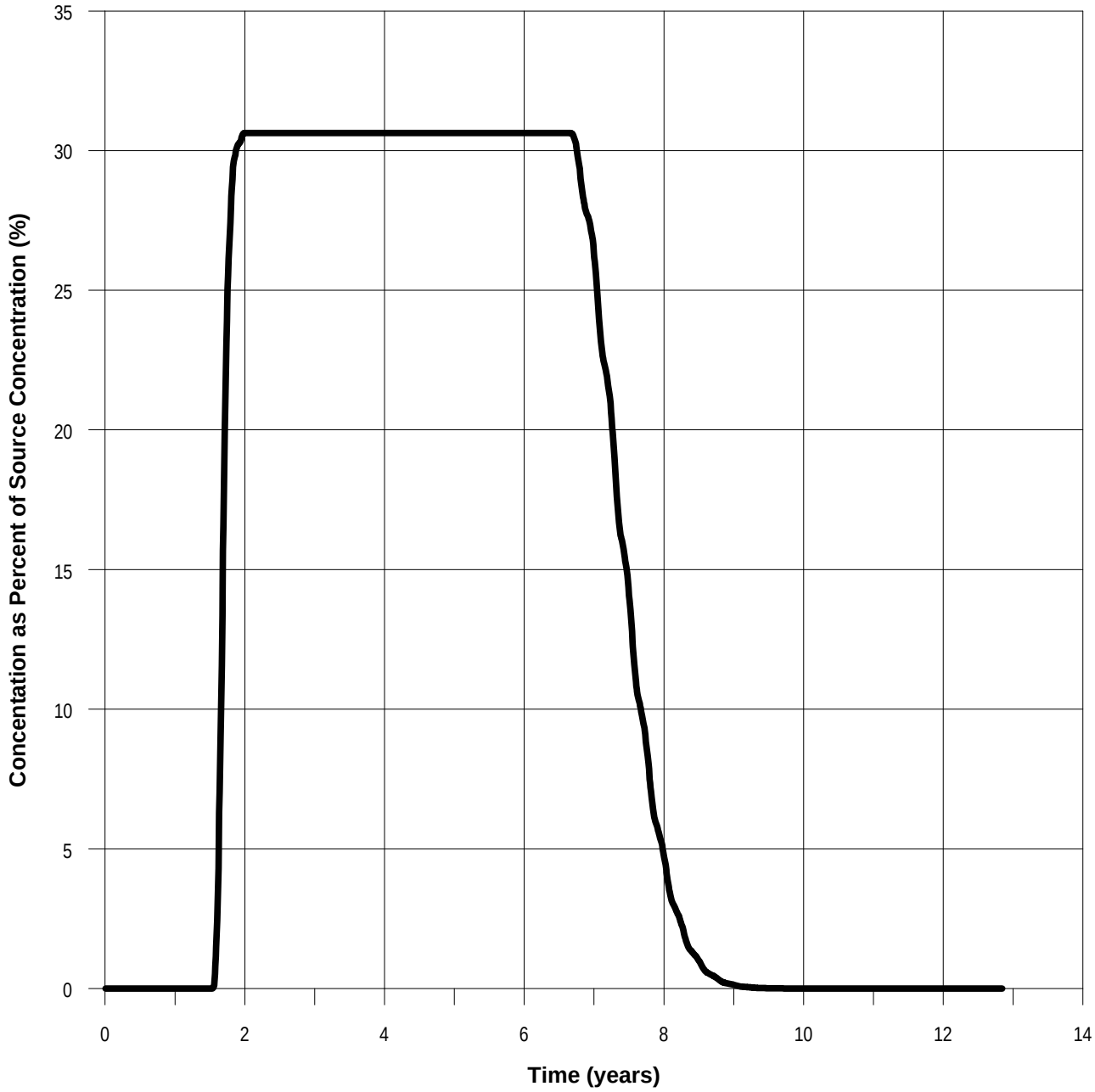



FIGURE 9-21
Model Forecasts of Dilution Percentages at the Downgradient Edge of the Picher Mine Pool Following Lytle Creek Pile Chat Injections
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

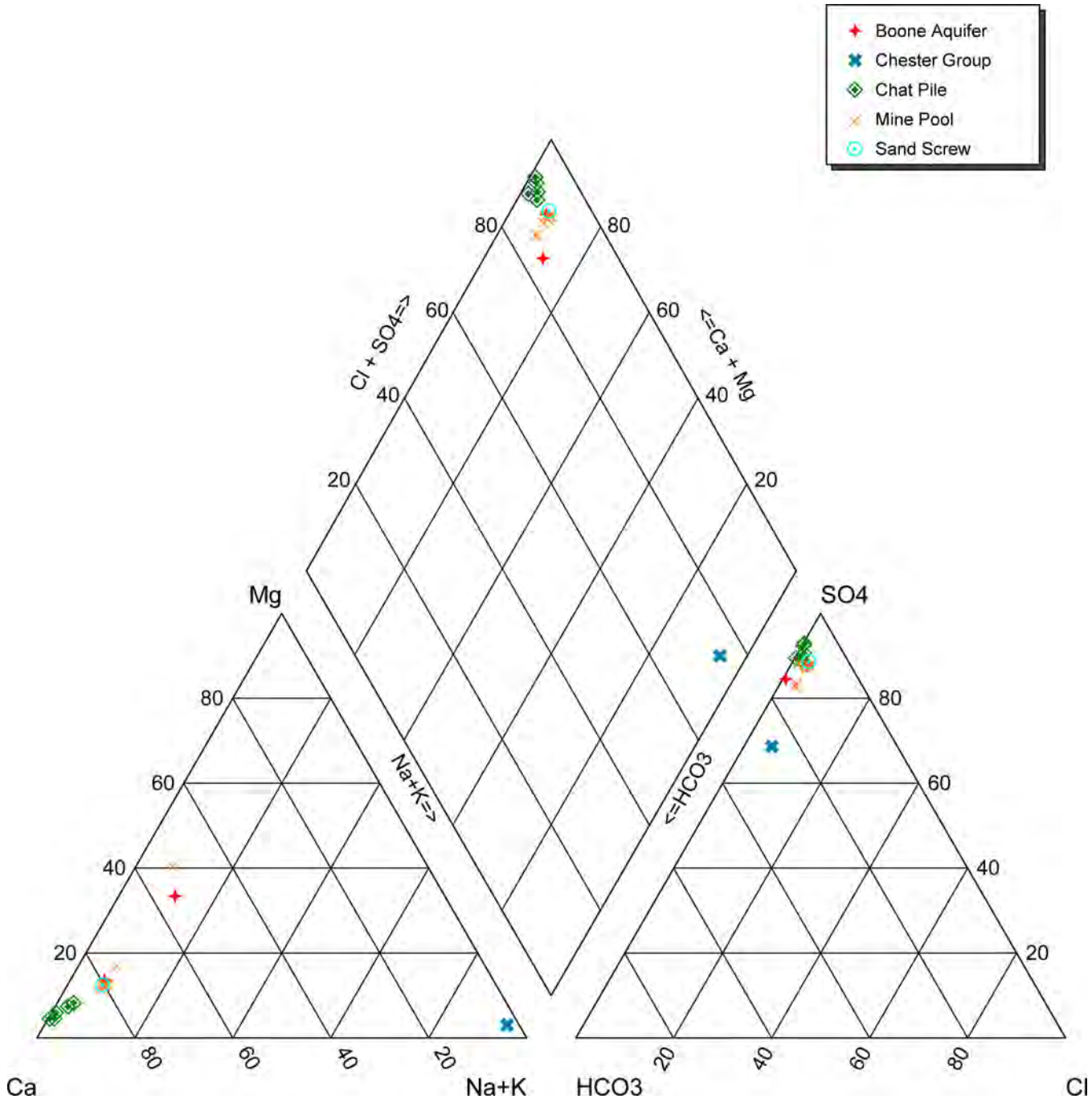
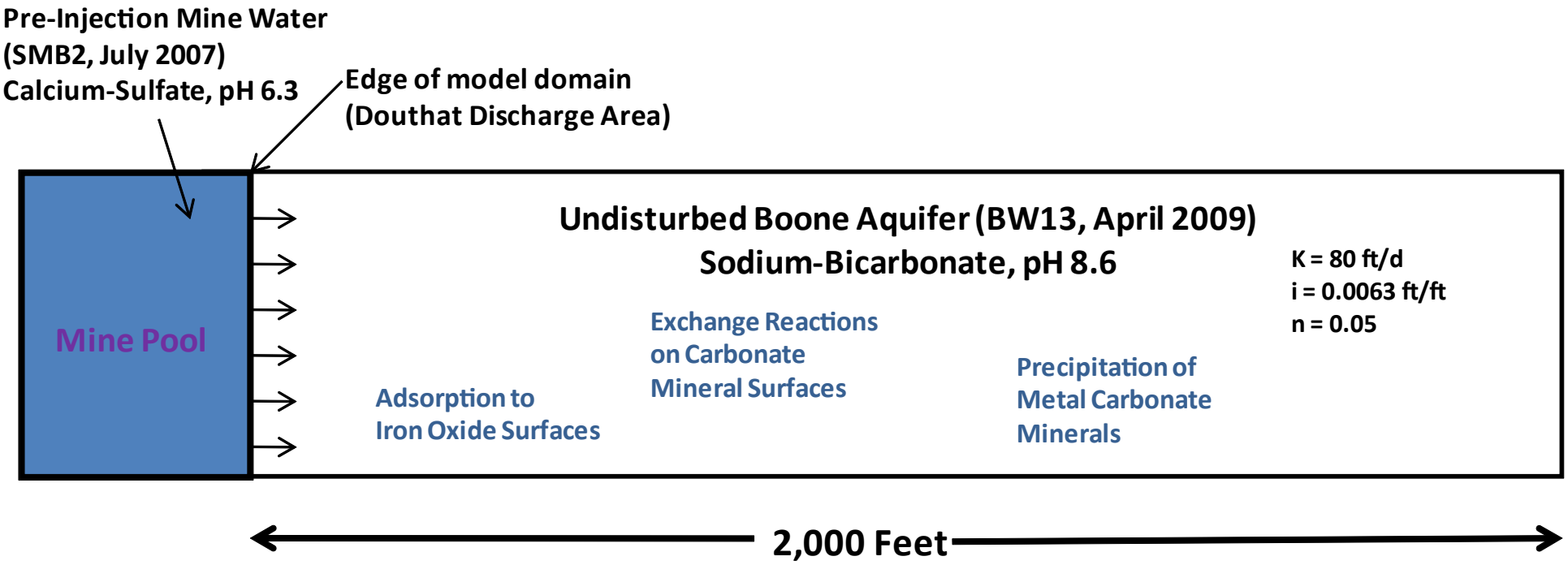
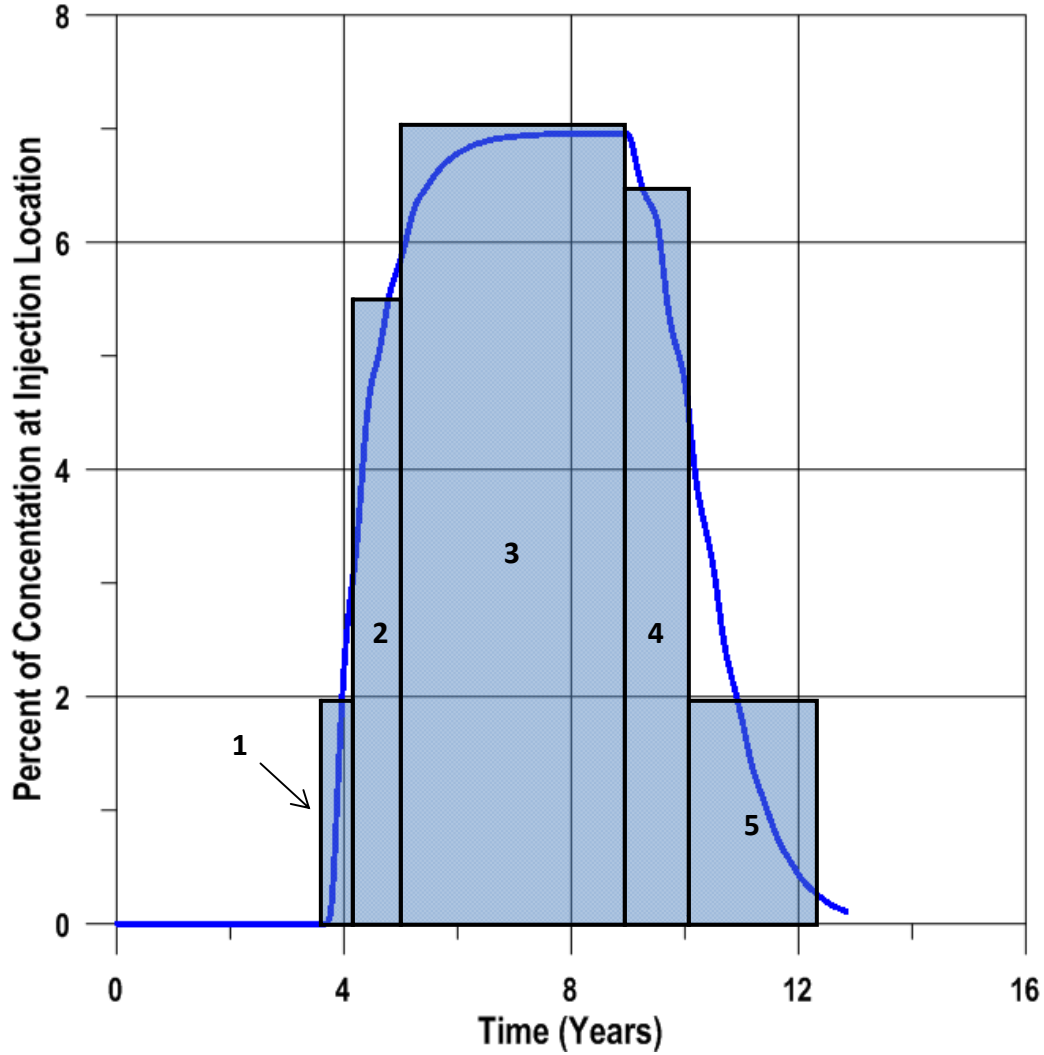



FIGURE 10-1
Piper Diagram from Sooner Pile Pilot Study
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




**Model Aquifer Parameters**
K = Hydraulic Conductivity
i = Groundwater Gradient
n = effective porosity

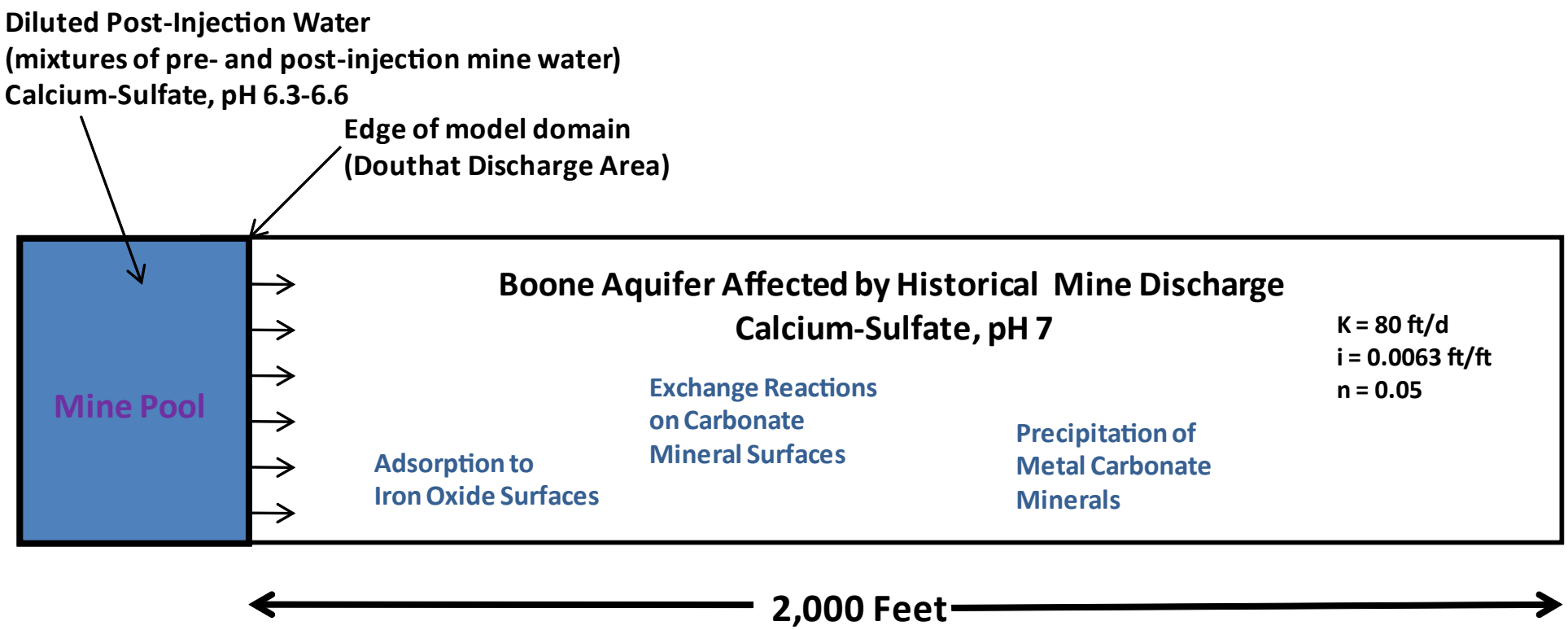
FIGURE 10-2
Conceptual Design of PHAST Model: Stage 1
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




**Water Representation**
**Pre-Injection: SMB2 July 2007**
**Post-Injection: SMB3 October 2009**

**Mine Pool Water Mixtures**
**1: 1.9% Post-Injection, 98.1% Pre-Injection; 0.6 years**
**2: 5.5% Post-Injection, 94.5% Pre-Injection; 1.2 years**
**3: 7.0% Post-Injection, 93.0% Pre-Injection; 3.5 years**
**4: 6.2% Post-Injection, 93.8% Pre-Injection; 0.9 years**
**5: 1.9% Post-Injection, 98.1% Pre-Injection; 2.6 years**

**FIGURE 10-3**
Division of Simulated Sooner Diluted Water Curve into Fixed Solution Compositions for PHAST Modeling
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*




**Model Aquifer Parameters**
K = Hydraulic Conductivity
i = Groundwater Gradient
n = effective porosity

FIGURE 10-4
Conceptual Design of PHAST Model: Stage 2
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

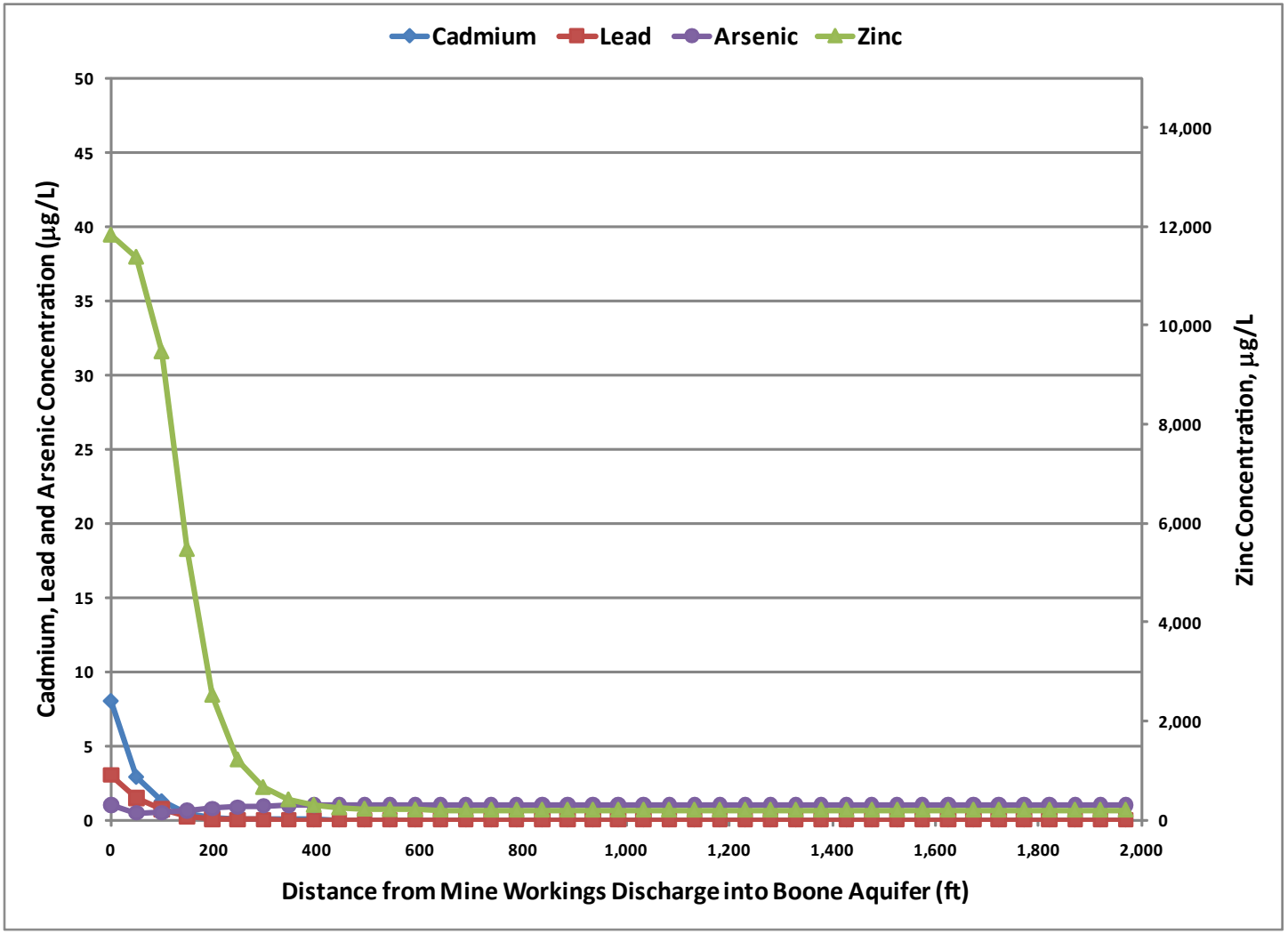



FIGURE 10-5
Stage 1: Simulated Trace Metal Concentrations: 10 Years
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

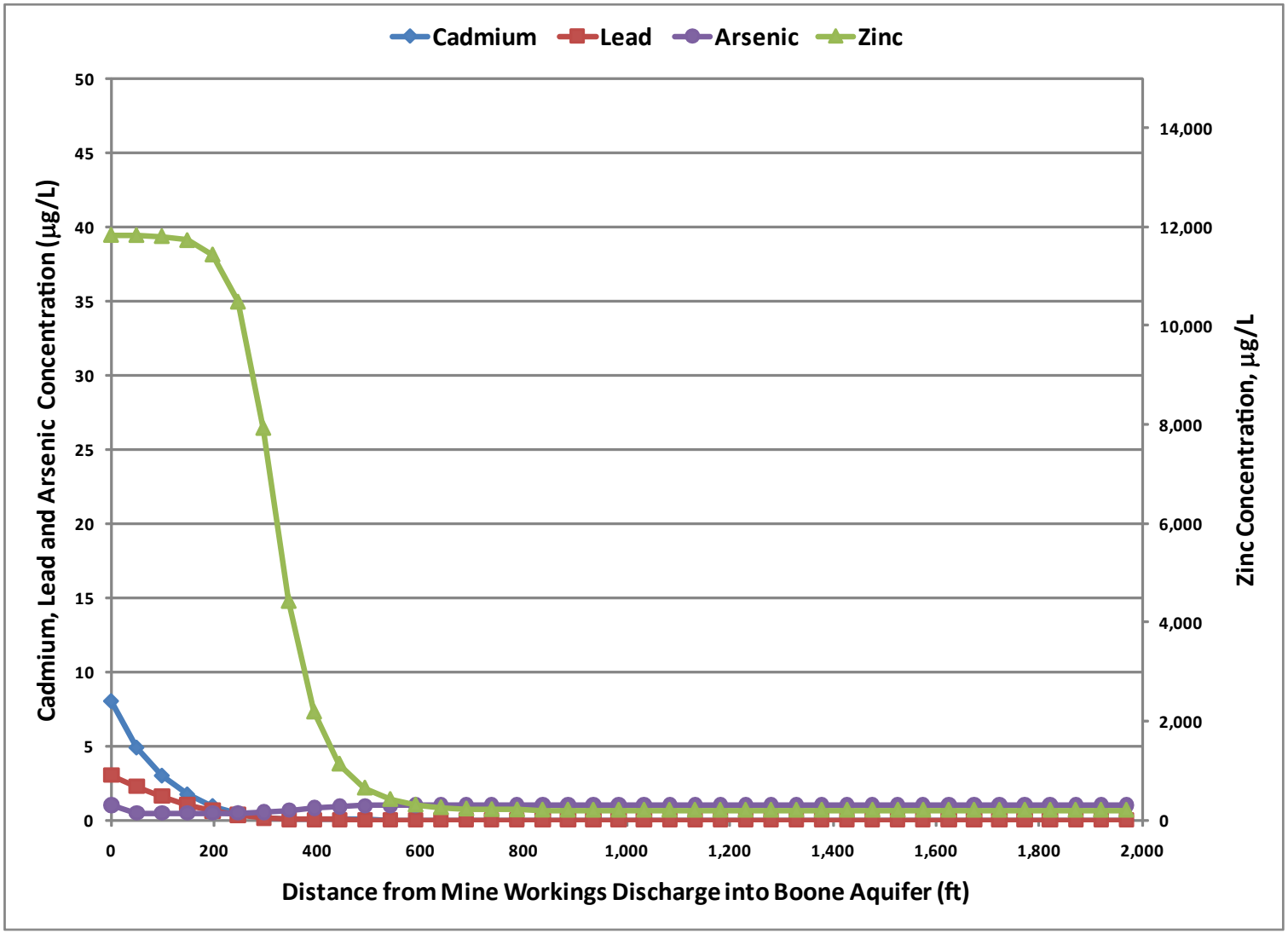



FIGURE 10-6
Stage 1: Simulated Trace Metal Concentrations: 20 Years
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

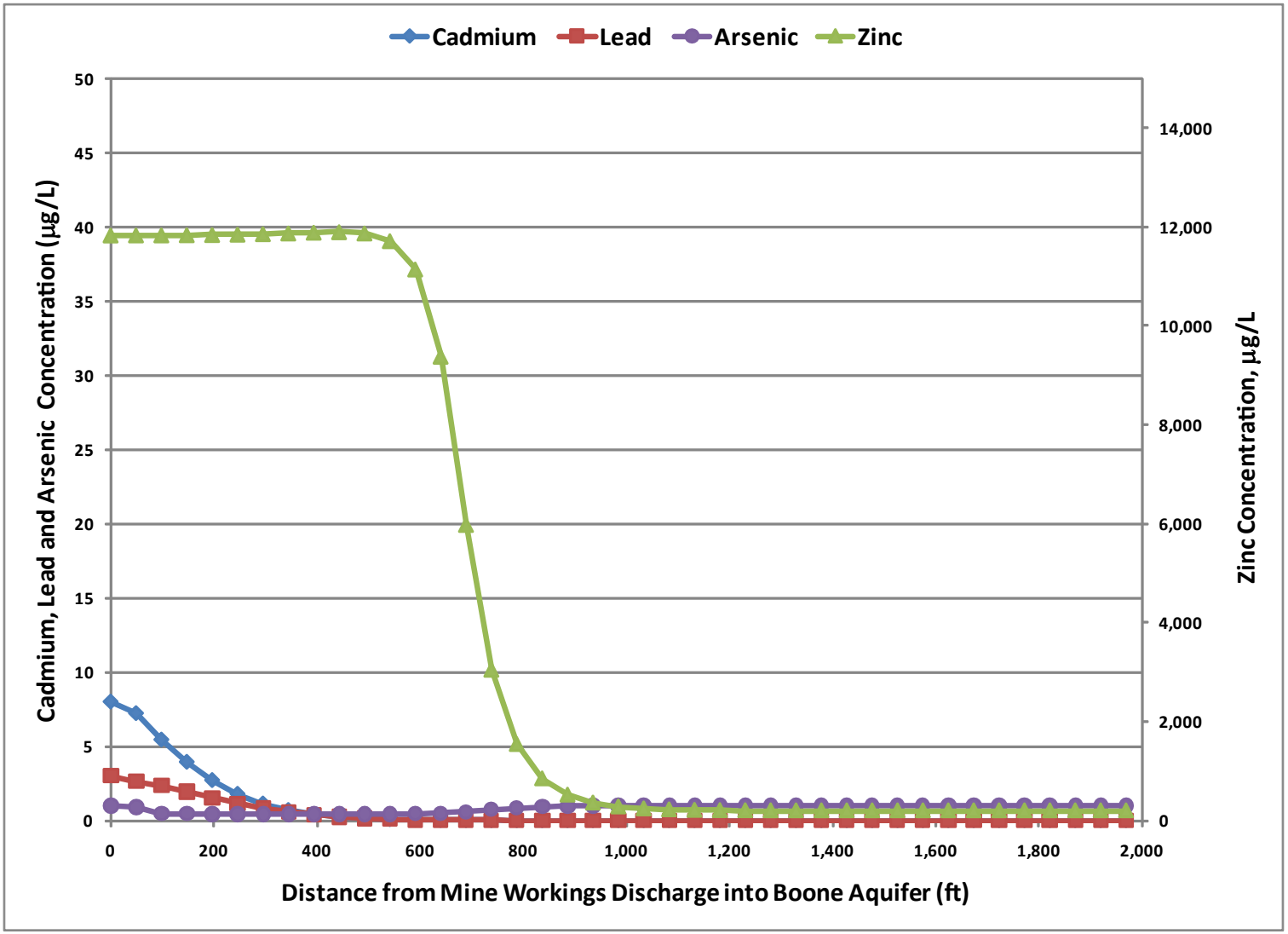



FIGURE 10-7
Stage 1: Simulated Trace Metal Concentrations: 40 Years (Present Day)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

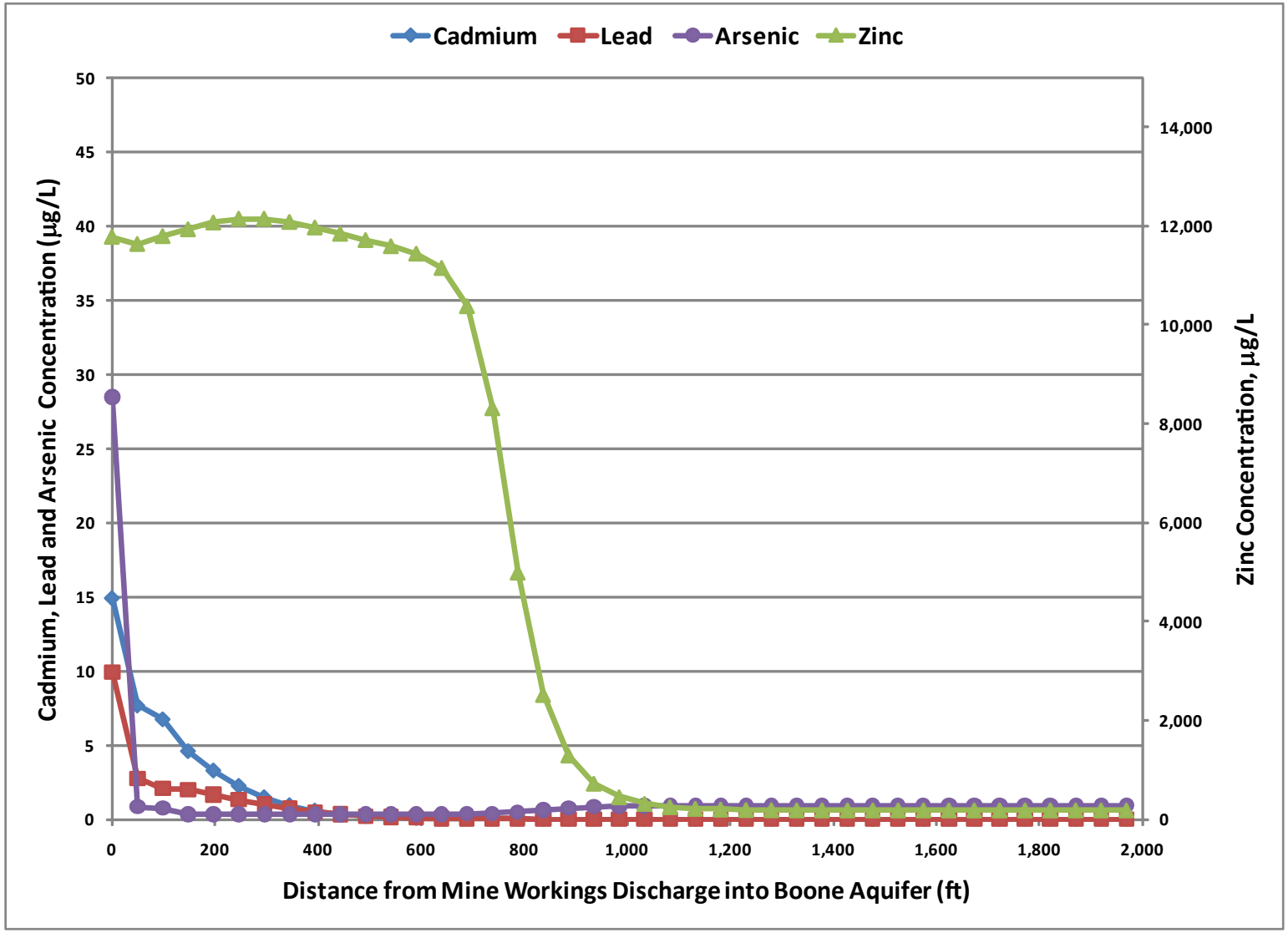



FIGURE 10-8
Stage 2 (Sooner Source): Simulated Trace Metal Concentrations (End of 5-Year Simulated Chat Fines Injection)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

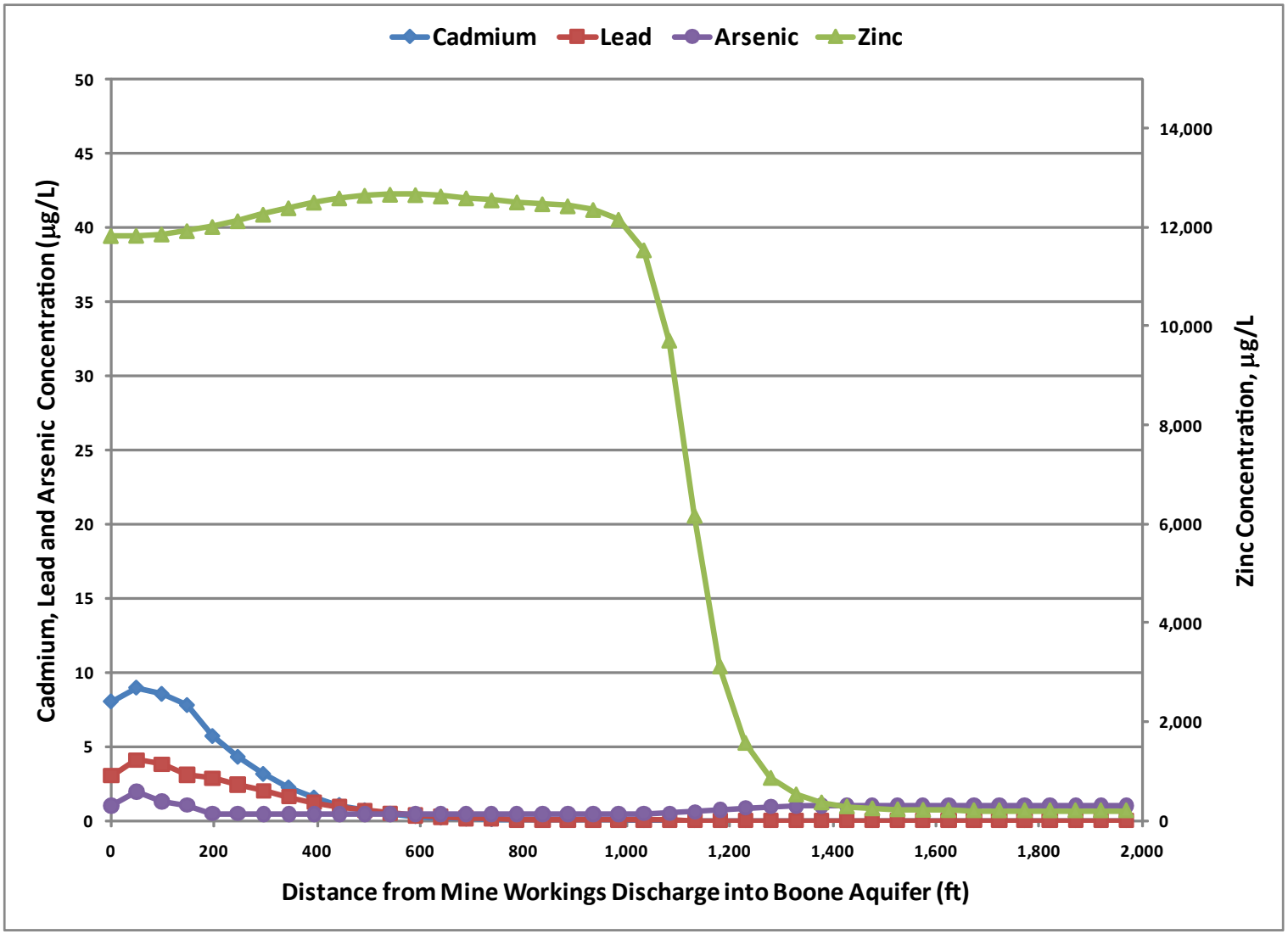



FIGURE 10-9
Stage 2 (Sooner Source): Simulated Trace Metal Concentrations (20 Years After End of Chat Fines Injection)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

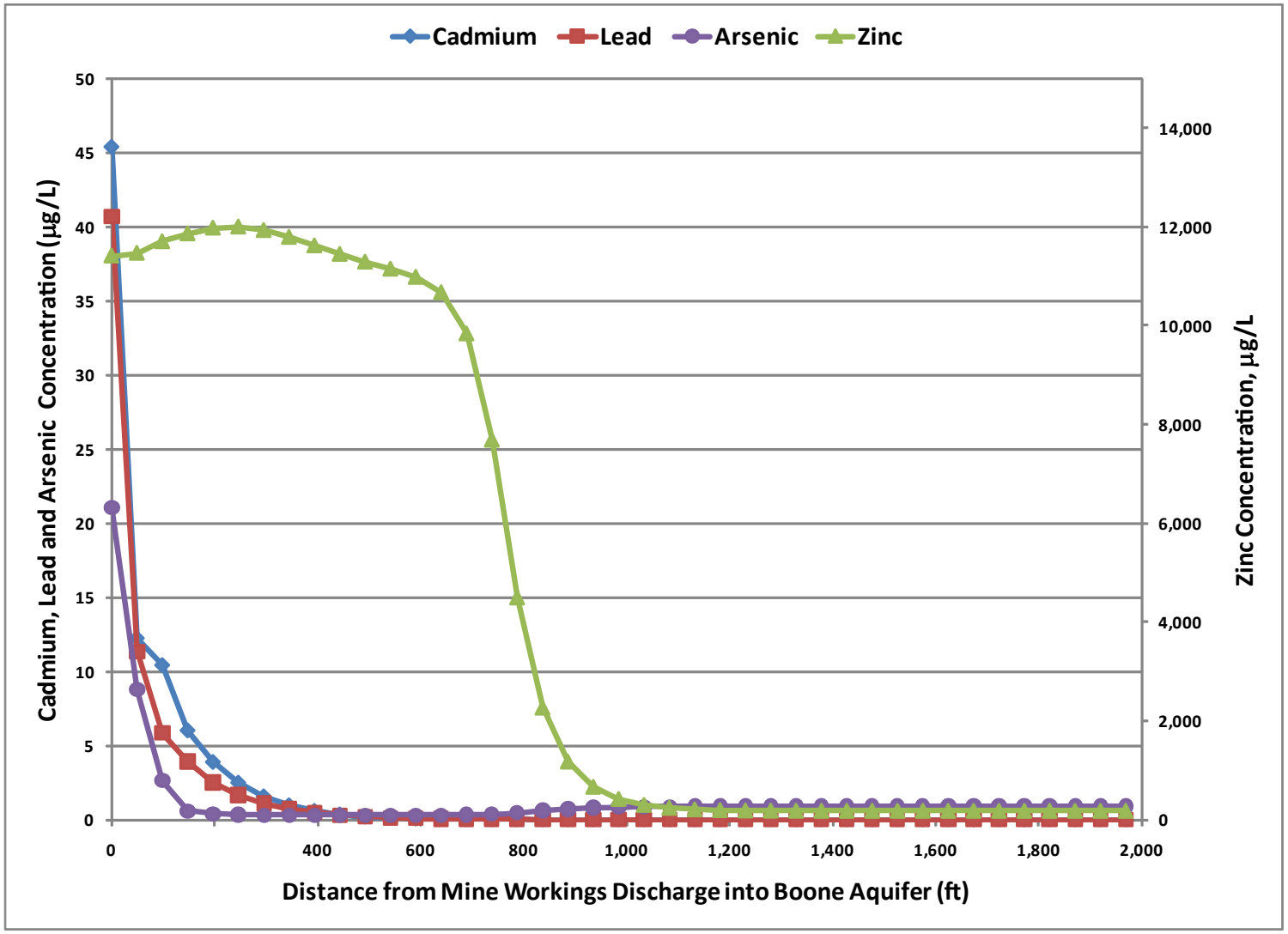



FIGURE 10-10
Stage 2 (Lytle Source): Simulated Trace Metal Concentrations
(End of 5-Year Simulated Chat Fines Injection)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*

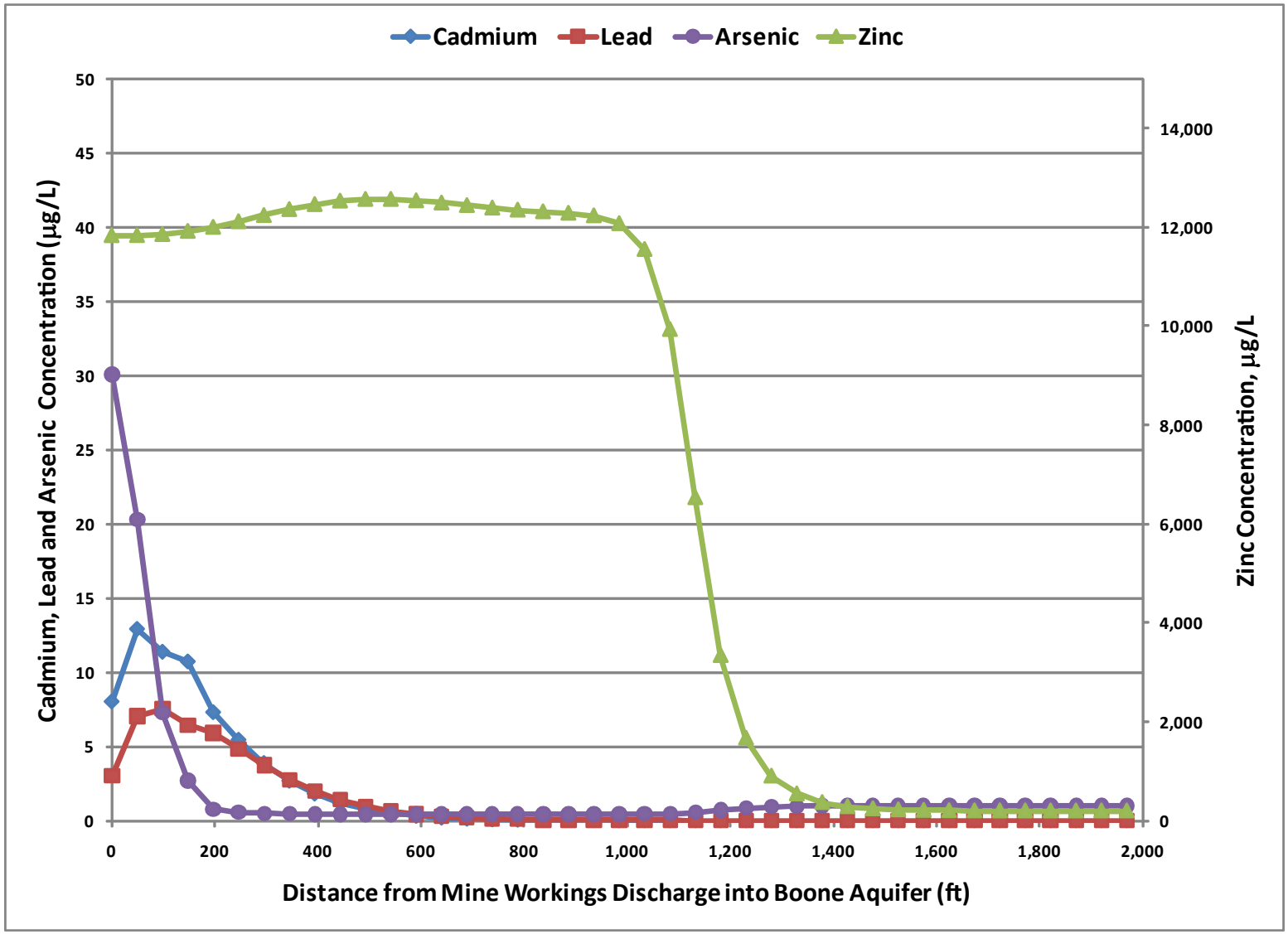



FIGURE 10-11
Stage 2 (Lytle Source): Simulated Trace Metal Concentrations
(20 Years After End of Chat Fines Injection)
*Tar Creek Superfund Site, Operable Unit 4*
*Ottawa County, Oklahoma*