FIVE YEAR REVIEW

TAR CREEK SUPERFUND SITE

OTTAWA COUNTY, OKLAHOMA

APRIL 1994

U.S. ENVIRONMENTAL PROTECTION AGENCY

REGION 6

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
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JAN 18 1995

MEMORANDUM

SUBJECT: Documentation of the Approval of Five-Year Review Report for the Tar Creek Superfund Site

FROM: Allyn M. Davis, Director
Hazardous Waste Management Division (6H)

TO: Superfund Files

The purpose of this memorandum is to document the approval of the Five-year Review report for the Tar Creek Superfund site, Ottawa County, Oklahoma. When the Five-Year Review report for the Tar Creek Superfund site was issued in April 1994, the Environmental Protection Agency (EPA) had no requirement that the report be signed by an approving official. Formal signature by the approving official was a later requirement of the Supplemental Five-Year Review Guidance issued July 26, 1994. The draft Five-Year Review report was reviewed by the Hazardous Site Control Division in Headquarters. Review comments were incorporated into the final report. My staff briefed me on the Five-Year Review report and I approved the report prior to issuance by the Region in April 1994.

TABLE OF CONTENTS

FIGURES

* - FIGURES FROM PREVIOUSLY PUBLISHED EPA/ODEQ/OWRB/OSDH DOCUMENTS
** - FIGURE FROM U.S. GEOLOGICAL SURVEY

APPENDICES

EXECUTIVE SUMMARY

I. BACKGROUND

The Tar Creek Superfund Site is located in the northeastern portion of Ottawa County, Oklahoma. The site is a former lead and zinc mining area and is the Oklahoma portion of the Tri-State mining district of northeastern Oklahoma, southeastern Kansas and southwestern Missouri. Mining began in Ottawa County in the early 1900's and continued until the 1960s. The Boone Formation was the source of the metal ore and was also an aquifer. As such, the mining operations pumped large volumes of water from the mine workings until mining ceased, at which time the aquifer, and hence the mines, began refilling. As water filled the mines, the native sulfide minerals, which had been oxidized by exposure to air, dissolved, creating acid mine water. By 1979, water levels had increased to the point that the acid mine water began discharging at the surface from several locations, severely impacting Tar Creek.

In 1980 the Governor of the State of Oklahoma established the Tar Creek Task Force to investigate the discharges; the Oklahoma Water Resources Board (OWRB) was designated as the lead State agency. In 1981, the site was proposed to the National Priorities List (NPL). The Environmental Protection Agency (EPA) provided funding to the State of Oklahoma to conduct a Remedial Investigation and Feasibility Study (RI/FS) through a Cooperative Assistance Agreement with the Oklahoma State Department of Health (OSDH), the lead State Superfund Agency. OSDH contracted with OWRB to perform the investigations. The site was listed on the NPL in 1983.

EPA signed a Record of Decision (ROD) for the site on June 6, 1984. The ROD addressed two concerns: 1) the surface water degradation by the discharge of acid mine water; and 2) the threat of contamination of the Roubidoux Aquifer, the regional water supply, by downward migration of acid mine water from the overlying Boone Aquifer through abandoned wells connecting the two.

The remedy provided for the elimination or reduction of the discharge of acid mine water by preventing recharge of the Boone Aquifer. This would presumably lower the water levels as discharge continued, eventually eliminating the discharge. Recharge was to be prevented by utilizing diking and diversion structures to stop surface water from entering the two collapsed mine shafts which were identified as the main inflow points. Additionally, the remedy called for preventing the downward migration of acid mine water into the Roubidoux Aquifer by plugging 66 abandoned wells. During remediation, an additional 17 wells were identified and plugged, bringing the total to 83 wells. Construction activities as described in the ROD were concluded on December 22, 1986.

II. **SUMMARY**

A. Surface Water

Although the diking and diversion structures are operating as designed, after-action monitoring has shown that the discharges of acid mine water continued unabated after construction of the diking and diversion structures. The water level in the Boone Aquifer is not statistically different than before the remedy was constructed, indicating that the volume of acid mine water discharged to Tar Creek has not been reduced. The concentrations of metals in the acid mine water discharge appears to be reducing, probably due to natural remediation. However, stream water quality continues to be severely impacted.

The State of Oklahoma has concluded the impacts to Tar Creek, i.e. water chemistry and habitat which are not adequate to support a "Warm Water Aquatic Community" and are suitable only for secondary contact recreation (e.g. boating), are because of irreversible man-made conditions. The State of Oklahoma has adopted Water Quality Standards for Tar Creek which reflect this conclusion. EPA concurs with the State’s conclusion that the surface water conditions are irreversible. EPA also concludes that this portion of the remedy is protective of human health, as the revised designated beneficial uses of the stream do not permit use for water supply, fishery, primary contact recreation, or agricultural uses. EPA recommends no further action to remediate the surface water.

B. Ground Water

All public water supply wells tested in the area continue to meet primary drinking water standards and are protective of human health. However, monitoring of twenty-one wells in the area producing water from the Roubidoux Aquifer supports the conclusion that five of the wells show some impact of acid mine water contamination. The five impacted wells fail the secondary drinking water standard for iron, and one of the five also fails the secondary standard for sulfate. Secondary drinking water standards are not health based, but rather are a function of aesthetics, taste and odor. Secondary drinking water standards are not enforceable, and neither iron or sulfate are hazardous substances addressable by CERCLA. EPA and the State of Oklahoma are conducting further investigations to determine whether the contamination in these five wells is due to inadequate well integrity (allowing contaminated water from the Boone Aquifer to enter the well) or whether this represents direct contamination of the Roubidoux Aquifer. EPA will evaluate the need to continue to plug abandoned wells based upon the results on the discrete sampling efforts. Public water supply program monitoring requirements should be adequate to determine future protectiveness of the remedy. Should the Roubidoux Aquifer be found to no longer be capable of meeting primary drinking water standards, the need for additional corrective action will be reevaluated.

C. Mining Wastes

Additional information on mining wastes on the land surface has been provided by EPA Region 7. Investigations of the Cherokee County Superfund Site, which represents the Kansas portion of the Tri-State mining district, indicate that mining wastes in Kansas contain elevated levels of lead and cadmium as high as 13,000 ppm and 540 ppm, respectively. These types of wastes were not significantly investigated during the Tar Creek Remedial Investigation, as the focus at that time was on water quality.

The U.S. Public Health Service's Indian Health Service has recently informed EPA that 34% of 192 Native American children tested had blood lead levels in excess of the 10 μg/dl standard.

An investigation should be conducted to evaluate the impact of mining wastes, i.e., chat piles and floatation ponds, on human health and the environment and whether additional remedial action is warranted. Suggested actions include:

A. Designation of a second operable unit at this site for mining wastes.

B. Initiation of a blood lead study in the area on Native American and other children.

C. Concurrent environmental sampling in high access areas (e.g. school yards, daycares, playgrounds, to assess potential sources of exposure to lead.

D. Mapping of all mine wastes (i.e., chat piles, excavated chat piles, and floatation ponds) by the use of aerial photographs or other remote sensing techniques.

E. Classification of surface mine wastes utilizing a field portable x-ray florescence unit.

F. Field sampling of a representative portion (approximately 10%) of mine wastes and affected media to confirm x-ray florescence unit performance.

F. Sampling of leachate from mine wastes.

G. Sampling of airborne particulates near mine wastes.

I. INTRODUCTION

A. Purpose

The Environmental Protection Agency (EPA) conducts Five Year Reviews of a remedial action at Superfund sites pursuant to Section 121 (c) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The purpose of the Five Year Review is to evaluate the effectiveness of remedies at sites in protecting human health and the environment. Specifically, the review is intended to confirm that the remedial objectives of the Record of Decision have been met, that the remedy is performing as designed and that the initial goals of the remedy remain protective. The Five Year Review for the Tar Creek Superfund Site is considered a "policy Review". Policy reviews are conducted at sites where a remedy was selected prior to October 17, 1986. The Record of Decision for Tar Creek was signed on June 6, 1984.

B. Authority

Authority for conducting Five Year Reviews is contained in section 121(c) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, and section 300.430(f) (4) (ii) of the National Contingency Plan. Guidance for planning and conducting these reviews is provided in OSWER Directive 9355.7-02, dated May 23, 1991.

II. BACKGROUND

A. Tar Creek Task Force Investigations

Surface discharges of acid mine water into the Tar Creek watershed from flooded underground lead and zinc mines of the Picher Field in Ottawa County, Oklahoma began in 1979. In June 1980, the Governor of Oklahoma formed the Tar Creek Task Force, comprised of 24 local, state, and federal agencies to address the contamination problems at Tar Creek. The Task Force investigated the problem initially in 1980 and 1981. The Task Force utilized Hittman Associates, Inc., to perform studies at the site on the effects of the acid mine contamination on the area surface and ground water. Hittman Associates submitted final reports in October 1981. The sampling and analysis data developed during the preparation of the reports was used to prepare the Hazardous Ranking System (HRS) score for the Tar Creek site for possible inclusion on the National Priorities List (NPL). The primary threat identified at the site was the potential for contamination of the Roubidoux Aquifer, which is the primary drinking water supply in the area. The Hazard Ranking Score (HRS) calculated for the site was 58.15. The site was proposed to the NPL on July 27, 1981, and listed on the NPL on

September 8, 1983. The Record of Decision (ROD) was signed on June 6, 1984.

Response actions at Tar Creek were conducted as a State-lead project, with the Environmental Protection Agency (EPA) acting as the support agency. Until July 1, 1993, the lead State technical agency for the Tar Creek site was the Oklahoma Water Resources Board (OWRB). However, the Oklahoma State Department of Health (OSDH) had been designated as the lead State agency for all State-lead Superfund response actions in Oklahoma. OSDH therefore acted as the lead agency for administrative oversight of the project, with both agencies jointly responsible for implementation of the project. On July 1, 1993, State responsibility for all aspects of this project were consolidated when the project was transferred to the newly created Oklahoma Department of Environmental Quality (ODEQ). ODEQ is presently the lead agency for the activities at the Tar Creek site.

A Cooperative Assistance Agreement between EPA and OSDH to conduct a Remedial Investigation/Feasibility Study (RI/FS) was signed on June 16, 1982. The scope of work for the RI included investigating the following items:

a. Potential for migration of contaminated water from the Boone Aquifer to the Roubidoux Aquifer.
b. Surface water contamination.
c. Water quality from sampling Boone Aquifer wells.
d. Inventory milling waste (tailings) piles.
e. Leachate and fugitive dust from chat piles.

The scope of work for the FS consisted of identifying and evaluating remedial alternatives. Under an interagency agreement, OSDH subcontracted with the OWRB to conduct the RI/FS, which was completed in December 1983. Many of the reports produced by the Tar Creek Task Force were incorporated into the RI/FS. The Task Force remained involved with project oversight through the construction phase, which was completed December 22, 1986.

B. <u>Site Location and Description</u>

The Tar Creek Superfund Site is a former lead and zinc mining area located in far northeastern Oklahoma. The area is part of the Tri-State Mining District located at the juncture of Oklahoma, Kansas and Missouri. Although the site has no distinct boundaries, it represents the Ottawa County, Oklahoma, portion of the Picher Field mining region and is approximately 40 square miles. The Picher Field also extends north into Cherokee County, Kansas. The principal communities within the Ottawa County mining area are Picker, Cardin, Quapaw, and Commerce, as shown on Figure 1. Figure 2 shows the mine workings in the main part of the Picher Field.

Figure 1

Tar Creek Drainage Basin

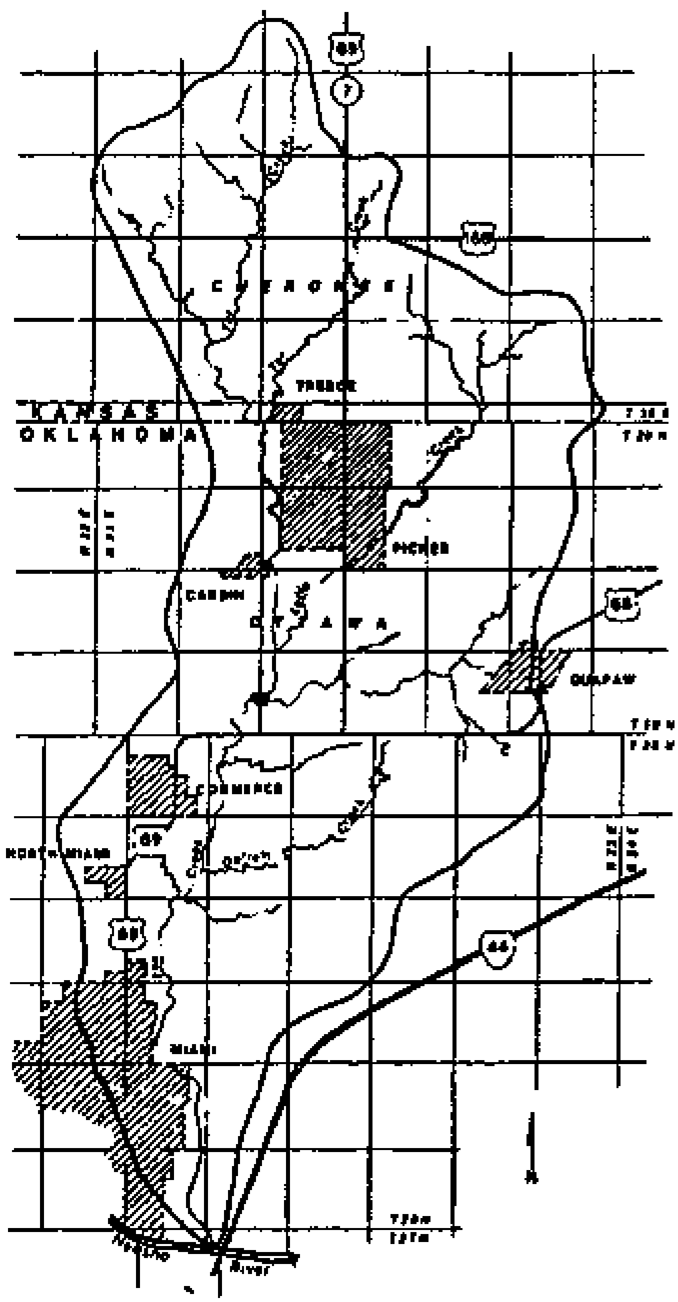
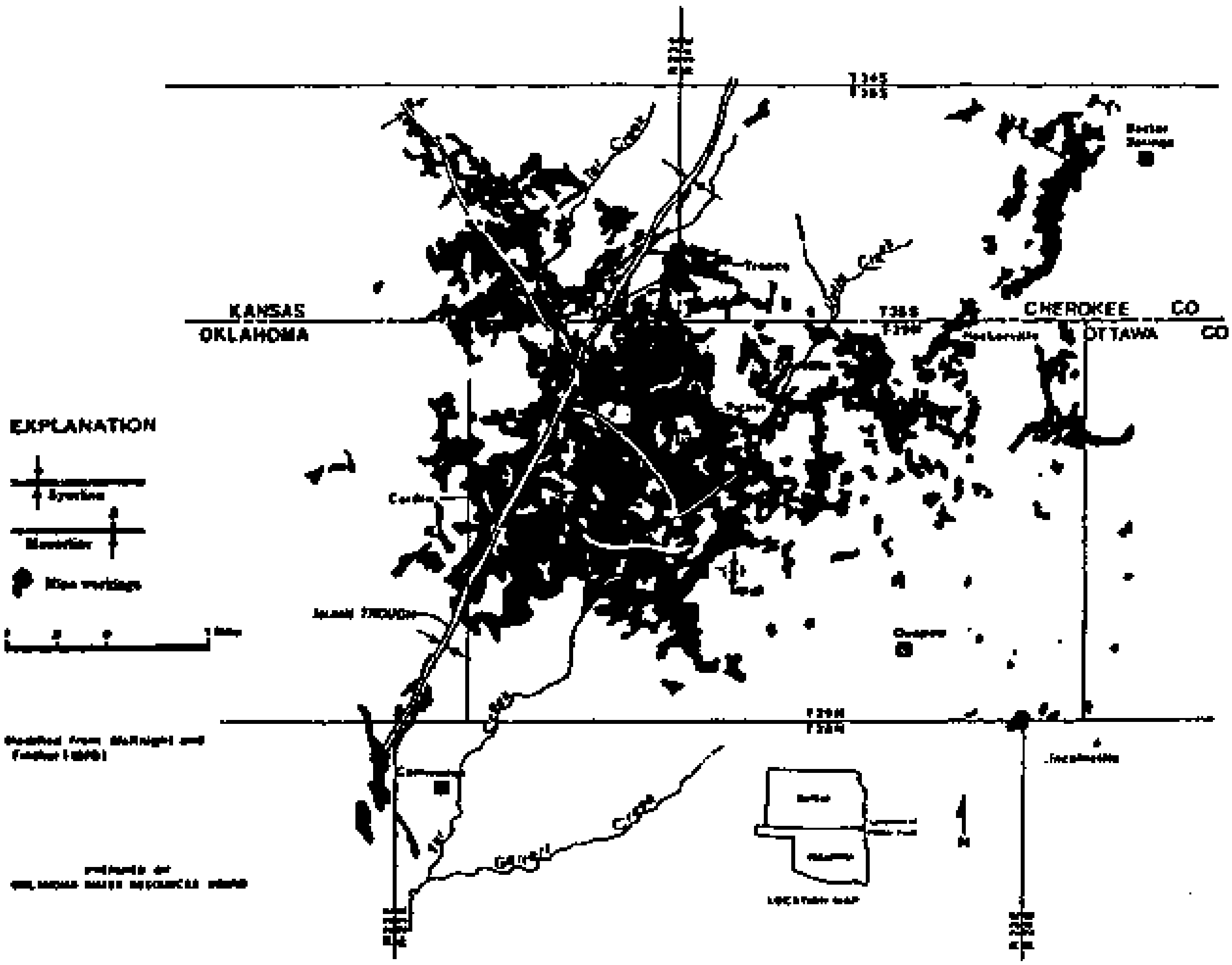


Figure 2

Location of Underground Mine Works



Generalized location of the underground mine workings in the Picher Field, Oklahoma and Kansas.

Tar Creek is the principal drainage system for the Picher Field area, and is a small ephemeral stream characterized by standing pools. With its headwaters in Cherokee County, Kansas, Tar Creek flows southerly between Picher and Cardin, passes to the east of Commerce and Miami, and on to its confluence with the Neosho River, one of the two major rivers in northeastern Oklahoma. Along with its major tributary Lytle Creek, Tar Creek drains approximately 53 square miles of area.

C. Mining History

Lead and zinc mining first began in 1904 and reached its peak in 1925. Many mills were established in the area to process the ore. During peak production, maximum annual output for lead and zinc concentrates were 130,410 tons and 749,254 tons, respectively. Large scale mining activities ended in the mid 1960's. The ore bearing strata were primarily located within a 50 – 150 feet thick zone of the Boone Formation, with maximum depths of mining reaching 385 feet below the ground surface (BGS). Mining was accomplished using room and pillar techniques. Large rooms, with ceilings up to 100 feet high, were connected by drifts (horizontal tunnels). The drifts contained more than 100 miles of roads.

When mining ceased, underground cavities approaching a volume of 100,000 acre feet (161,000,000 cubic yards) had been created. An estimated 100,000 boreholes were located in the entire Picher Field (most in Oklahoma), and 1,064 mine shafts (typically 5' x 7' or 6' x 6') existed in the Oklahoma portion of the mining district. Also, numerous water wells, drilled for milling operations, have been abandoned.

The years of mining activities also resulted in the accumulation on the ground surface of a large volume of tailings and other mining wastes. The tailings, locally known as chat, were accumulated and stored in giant piles, the majority of which are located around the former mining towns of Picher and Cardin. An unknown quantity of finer sediments in abandoned floatation ponds (i.e. sediment settling basins) are also present at many locations.

D. Source of Problem

The Boone Formation is an aquifer, which in areas where the Boone is overlain by the Krebs group, acts as a confined or artesian aquifer, with sufficient potentiometric pressure such that wells tapping the formation would flow at the ground surface. During mining operations, inflows of ground water into the mine workings were removed by large scale pumping, creating a large cone of depression which dewatered the Boone Aquifer. The exposed sulfide minerals (primarily marcasite and pyrite, both FeS_2) in the mine cavities became oxidized from being in contact with moist air. Upon cessation of mining activities (and hence, pumping), drifts and shafts of the abandoned workings began to flood. The oxidized minerals were much more soluble than the original form and dissolved, producing acid mine water. The acid water reacted with the surrounding rock, leaching many of the other metals present. Thus, the acid mine water contains high concentrations of zinc, lead, cadmium, sulfate and iron.

The majority of the mine workings were flooded by 1979 due to ground water infiltration and surface water inflow. As the potentiometric level exceeded the ground surface elevation in low lying areas along Tar Creek in the far southern portions of the Picher Field (near Commerce), acid mine water discharged to the surface through abandoned mine shaft openings and boreholes. This process is shown schematically in Figure 3.

At least three types of mining wastes are present at the site. “Development” rock, or “waste” rock, is large (4" - 2') diameter rock removed during the opening of the shaft or drifts (tunnels) and generally is not considered to be a problem.

“Chat” is mine tailings from the milling process and is a mixture of gravel (typically 3/8ths of an inch in diameter) and finer-grained materials. The numerous chat piles in the area contain approximately 48 million cubic yards of waste. The chat piles have been utilized for many years as a source of materials for the concrete and asphalt industry, as well as directly as gravel. From a comparison of historical aerial photographs conducted in the early 1980's, it was estimated that less than 50 percent of the original volume of chat produced still remains in the area. The sale of chat materials has been a significant source of income in the local area.

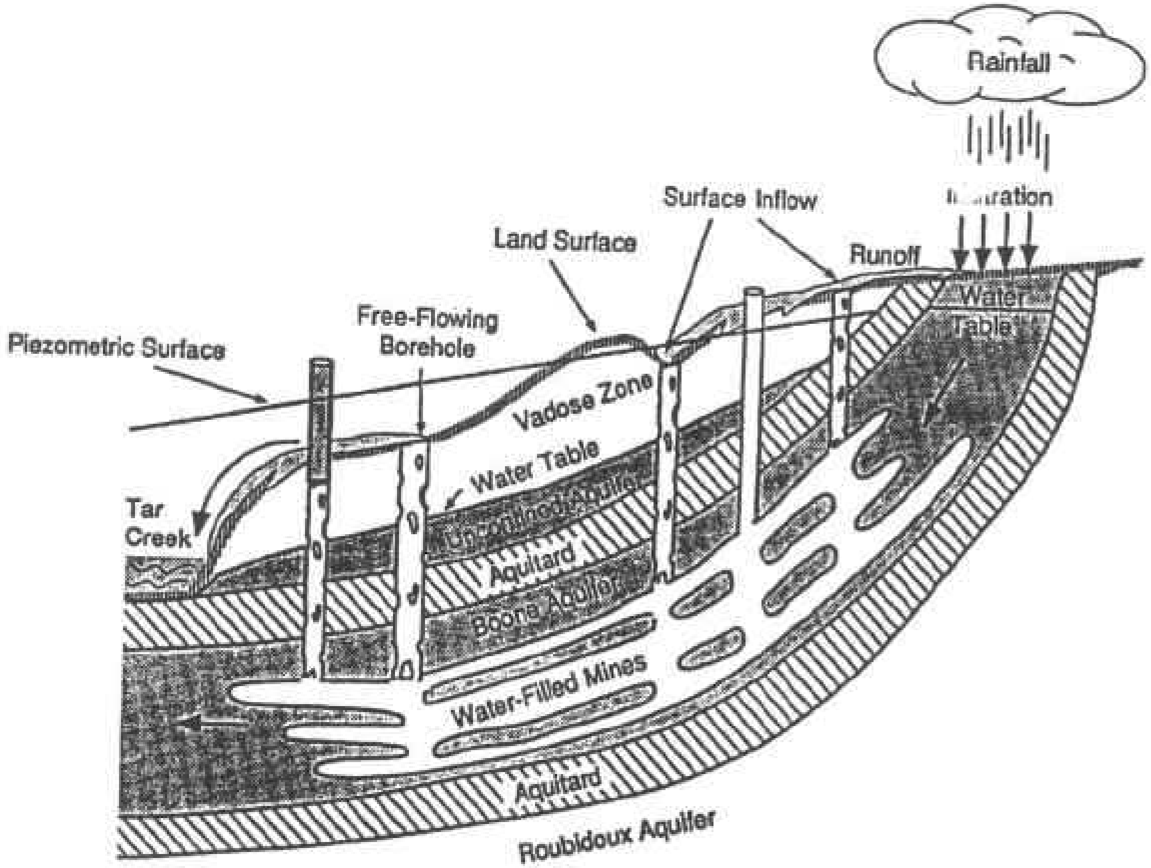
Floatation pond sediments, sometimes referred to as “tailings”, are fine grained sediments which originated in the gravity separation process and were disposed of in settling basins. The Oklahoma Geological Survey estimated that at least 16 major floatation ponds cover approximately 800 acres. Smaller tailings ponds were not inventoried.

E. Site Characterization

The geological strata of interest at the Tar Creek site are those of Ordovician and Mississippian age. The Ordovician sequence, from oldest (and deepest) to youngest (and shallowest), consists of the Roubidoux Formation (105 to 190 feet thick), the Jefferson City Dolomite (270 to 340 feet thick), and the Cotter Dolomite (143 to 183 feet thick). The Roubidoux Formation, also known as the Roubidoux Aquifer, is a cherty limestone with several sandy sequences near the base and is the major source of drinking water in the region. These three formations are similar in appearance and difficult to separate in drilling cuttings.

Figure 3

Creation of Acid Mine Water



Above the Ordovician strata, scattered remnants of the Chattanooga Shale are present, separating the Cotter Formation from the overlying Mississippian age formations.

The Mississippian formation of primary interest is the Boone Formation. The Boone Formation, also known as the Boone Aquifer, ranges in thickness from 329 to 393 feet. Lead and zinc ore mined in the Picher Field was located in various members of the Boone. Within the mining district, the ground water within the Boone is of poor quality, due mainly to acidity and high dissolved metals concentrations. Outside of the mining area, the Boone Aquifer is used as a potable water source.

The most prominent surface features at the site are large chat piles and collapse features, i.e., mine subsidence areas (commonly referred to as sinkholes) and caved-in mine shafts. Topography is generally flat, with a gentle drop to the south.

In areas where the Boone Formation outcrops, the Boone acts as an unconfined aquifer and direct recharge occurs. In some areas west of the Spring River the Boone is overlain by undifferentiated Mississippian and Pennsylvanian strata, including shales, which cause the Boone to act as a confined aquifer. In the southern portion of the mining area, the potentiometric surface of the Boone Aquifer exceeds the land surface elevation and causes the acid mine water to flow out of abandoned wells, boreholes, mine shafts and collapse structures, which then enters Tar Creek.

F. <u>Enforcement</u>

The ROD for the Tar Creek Superfund Site was signed on June 6, 1984. On June 15, 1984, seven companies and eight individuals were sent RD/RA notice letters. All either declined to participate or did not respond. EPA therefore proceeded to conduct the RD/RA and to pursue cost recovery actions. Construction was completed on December 22, 1986.

On December 30, 1987, EPA signed a Department of Justice referral package to implement cost recovery proceedings against seven companies identified as operators. EPA entered into a Consent Decree with six of the potentially responsible parties (PRPs): ASARCO, Inc.; Blue Tee Corporation; Childress Royalty Company; Gold Fields Mining Corporation; NL Industries, Inc.; and St. Joe Minerals Corporation. The Consent Decree was filed June 10, 1991, in the U.S. District Court, Northern District of Oklahoma. The defendants agreed to pay to the Hazardous Substance Superfund the sum of $1.273 million dollars. In consideration of such payment, and subject to the reopener clause and other limitations, such as natural resources damages suits, the United States covenants not to sue or to take administrative action for any costs incurred in connection with the RI/FS, the 1984 ROD, and the emergency response action to replace the Picher public water supply well.

Other PRPs were either found to not be financially viable or were addressed in bankruptcy proceedings.

III. PUBLIC HEALTH AND ENVIRONMENTAL PROBLEMS

A. General

The principal public health threat identified at the Tar Creek site in the HRS package and the RI/FS was the potential for the contamination of the public water supply wells producing from the Roubidoux Aquifer. The RI/FS did not address possible human health risk associated with direct exposure to mine waste materials, although limited air sampling was conducted. No significant health problem associated with the air pathway was found. The principal environmental concern has been the environmental degradation of Tar Creek.

Public health and environmental data were generated through the monitoring program conducted through the Tar Creek Task Force and Superfund. The Health Effects Subcommittee of the Tar Creek Task Force evaluated data with respect to adverse human health problems and submitted a final report in March 1983. The area investigated included the Grand Lake system (Tar Creek drainage system, Neosho River, Spring River, and Grand Lake), wells in the mining area, and selected mines. Air monitoring was also performed. The Environmental Effects Subcommittee of the Tar Creek Task Force investigated the short term and long term environmental effects of acid mine drainage on the Grand Lake System and submitted a final report in April 1983. However, it should be noted that a formal baseline risk assessment, consisting of a human health evaluation and a ecological assessment, was not conducted for the Tar Creek site. Final EPA guidance on conducting risk assessments had not been issued at the time the Tar Creek studies were conducted. The following discussion of the major public health and environmental effects at the Tar Creek site is based on the findings by the Task Force and subsequent monitoring activities.

B. Potential Contamination of the Roubidoux Wells

There are three potential pathways for contamination of the Roubidoux public water supply wells from mine water. The first is from mine water actually migrating downward through the intervening strata and contaminating the Roubidoux aquifer. The second is from flow through abandoned wells or boreholes which penetrate to the Roubidoux. The third potential pathway is from mine water directly entering the wells through failed or inadequate casing, without actually migrating down into the Roubidoux Aquifer. These three pathways of contamination are discussed below:

1. Migration through intervening strata. Acid mine water could reach the Roubidoux Aquifer from the Boone Aquifer by migrating through the intervening Cotter and Jefferson City Dolomites. Hydraulic conductivity studies conducted on core sections revealed very low values of 3.1E-7 cm/sec and 9.6E-9 cm/sec, for the Cotter and Jefferson City dolomites, respectively. However, these low permeabilities may be misleading, as evidence of fracturing is clearly present in much of the excavated rock. This is probably offset by natural secondary mineralization, which is also clearly present. This may be supplemented by a self plugging mechanism caused by chemical precipitation of insoluble metal hydroxides as the acid mine water reacts with the dolomite and limestone in these formations. The resultant neutralization of pH causes precipitation of insoluble minerals, possibly plugging the openings and preventing further migration. There would be some potential for flow of mine water downward if fractures are interconnected from the Boone down through the Cotter and Jefferson City formations and into the Roubidoux. However, the Task Force concluded it is unlikely that any interconnection spans the entire 300-400 feet distance between the Boone and the Roubidoux Aquifers. EPA does not believe the evidence is conclusive on this issue. However, because of the great difference in potentiometric elevations between the two aquifers, EPA concludes any hydraulic connection between the two is minor.

2. Abandoned wells and boreholes. The most likely route by which the acid mine water could reach the Roubidoux Aquifer is by direct access through abandoned deep wells and boreholes. The U.S. Geological Survey (USGS) conducted studies in March 1981 on two of the abandoned wells and showed that water was flowing downward. As a part of the remedial action, 83 wells have been plugged. Since the end of construction approximately 15 more Roubidoux wells have been identified that may need to be plugged. It is unknown how many more of these wells may exist.

3. Inadequate well casings. Most of the documented cases of contamination of Roubidoux water supply wells have been from failed or inadequate well casings. Corroded/deteriorated casings have allowed poor quality mine water from the Boone to infiltrate the wells. When the casings were repaired or replaced, the quality of the water being pumped was restored. Also, in some instances mine water was entering the wells below the bottom of the casing. This can occur from migration of water behind and under the casing, or by migration into the Cotter Dolomite and then laterally into the uncased portion of the well. When sufficiently deep casings were installed, the water quality of the wells was restored.

The current monitoring project, which is being conducted by the State of Oklahoma, is attempting to determine whether the poor water quality of some of the public water supply wells in the mining area is due to direct impacts on the Roubidoux Aquifer or inadequate well integrity.

Wellhead samples were collected from eleven public water supply wells in the mining area each month from August 1992 through January 1993. Additionally, ten wells outside the mining area were sampled in January 1993 to determine background water quality in the Roubidoux Aquifer. Results indicated that all twenty-one wells are meeting primary drinking water standards, but five wells in the mining area are impacted by acid mine water constituents, specifically, iron and sulfate.

ODEQ and EPA are developing additional investigations, which will disassemble the impacted wells and collect water quality samples directly from the Roubidoux Aquifer. This should determine whether the Roubidoux Aquifer is itself impacted, or whether poor well integrity is resulting in poor water quality. This project is further discussed later in this report.

C. Exposure to Mine Wastes

The large quantities of mine waste materials in chat piles, floatation ponds, and other areas represent a potential health risk due to direct exposure. Contaminants of concern are lead, cadmium, and, potentially, other metals. The RI/FS for Tar Creek did not address health effects due to direct exposure to mine wastes, however the air pathway was addressed. Air samples were collected near the chat piles at Picher, Oklahoma. The Health Effects Sub-Committee of the Tar Creek Task Force concluded that the observed concentrations of toxic metals in airborne particulates were not significant and should not pose a significant health problem for people living in the area.

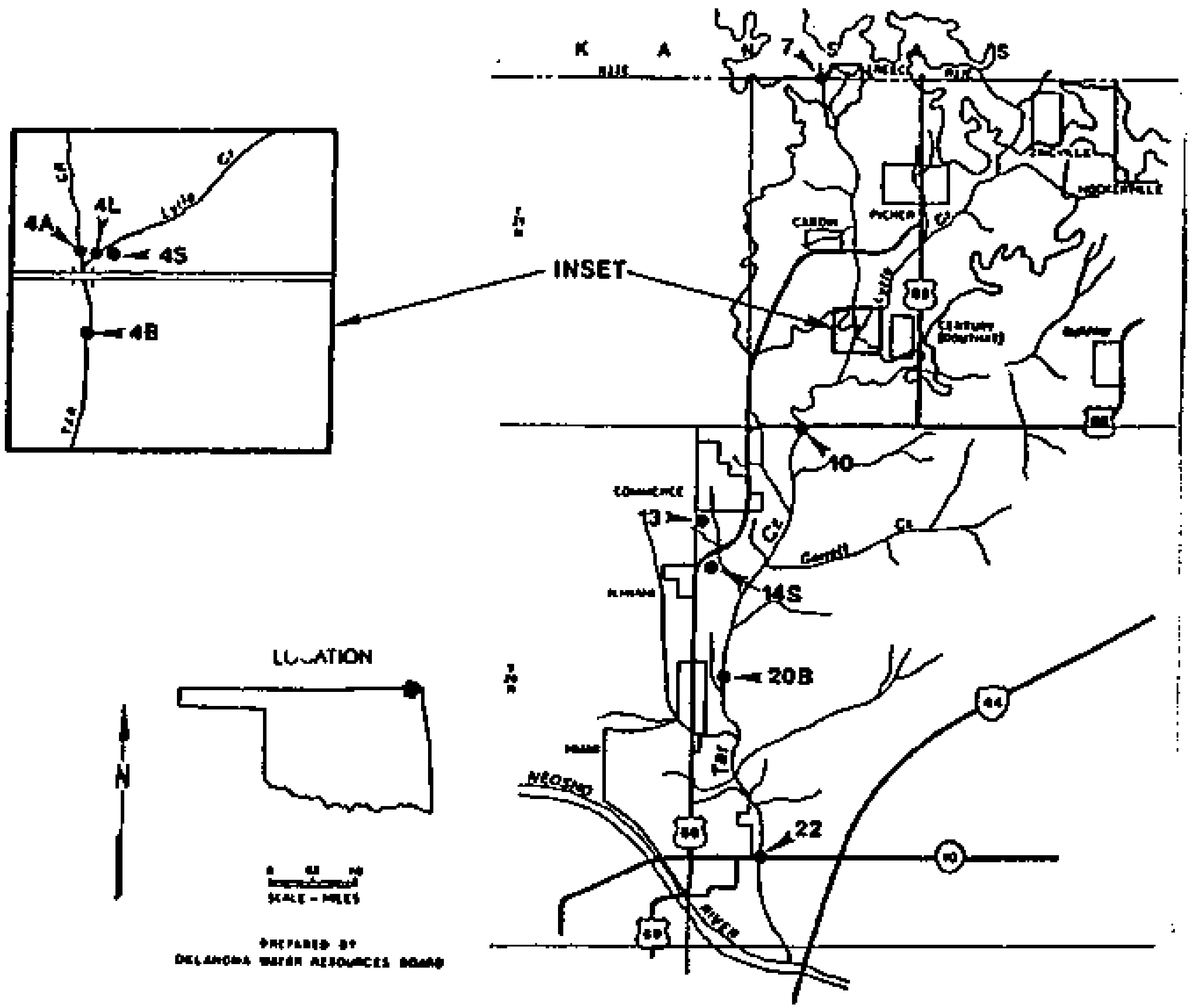
EPA Region 7 is responsible for other Superfund Sites in the Kansas and Missouri portions of the Tri-State Mining District. Similar mine wastes in Kansas have been evaluated for risks associated with direct exposure. Some materials, primarily flotation pond sediments and surface sediments in areas of excavated chat piles, were found to contain high levels of lead and cadmium. Some existing chat piles with high levels of lead and located in areas of high accessibility are being excavated and disposed of in subsidence features. More specific details of Region 7's activities are found in Section X., “Finding of EPA Region 7”.

D. Environmental Degradation of Tar Creek

The primary known discharge points for acid mine water into the Tar Creek watershed are sites 4s and 14 (Figure 4. Site 14 is

Figure 4

Location of Monitoring Sites



identified as site 14s on this map). Flow at site 4s is intermittent with an average discharge rate of 1.04 cubic feet per second (cfs) when flowing, with a pH ranging from 4.4 to 5.5. Site 14 discharges all year long at an average flow of 0.31 cfs and a pH ranging from 5.0 to 6.7. Typical average concentrations of heavy metals discharging from the mines based on 1987 through 1989 data are as follows:

Table 1. Concentrations of Metals Discharging From Mines Based on 1987 - 1989 Data

	Average Concentration in μg/l	
Constituent	Site 4s	Site 14
Iron	170,033	288,300
Zinc	62,161	19,072
Cadmium	19	13
Lead	65	57

Another source of contamination of Tar Creek is leachate from the tailing piles. Water quality standards are routinely violated as a result of the acid mine drainage and the leachate from the tailings piles. Leachate from the tailings piles was determined by the Tar Creek Task Force report to be insignificant in comparison to the acid mine water discharges. However, this may not be true, as only 15% of the loading to Tar Creek has been accounted for in the measured discharges. Also, leachate may have a much more pronounced effect on Tar Creek above the point where acid mine water discharges.

The State of Oklahoma Water Quality Standards identify Tar Creek as having the designated beneficial uses of 1) a habitat limited aquatic community, and 2) secondary body contact recreation. The habitat limited aquatic community designation is applied to waters which will not support a warm water aquatic community. The Oklahoma Water Resources Board has stated in correspondence that these designations are due to the irreversible man-made damages incurred at the site. These designations comply with the Oklahoma Water Quality Standards (Oklahoma Administrative Code, Chapter 45, Subchapter 5, Section 785:45-5-12(b)(3)), which state a habitat limited aquatic community may be designated when “human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place”.

The numeric Water Quality Standards (WQSs) applicable to Tar Creek are presented in Table 2.

Table 2. Water Quality Standards for Tar Creek

Parameter	Acute Toxicity* Maximum Allowable Concentration, μg/l	Chronic Toxicity** Maximum Allowable Concentration μg/l
Cadmium	55.23	1.6
Lead	143	5.56
Zinc	169	153.4
	April 1-June 15	June 16-March 31
Dissolved Oxygen (DO)	4.0 mg/l	3.0 mg/l

* - Acute Toxicity MAC refers to the maximum level which aquatic organisms can safely be exposed to for short durations.

** - Chronic Toxicity MAC refers to the maximum level which aquatic organisms can safely be exposed to indefinitely.

The pH standard states values shall be between 6.5 and 9.0 for waters designated for fish and wildlife propagation unless due to natural conditions. However, as Tar Creek is not designated for fish and wildlife propagation, the pH standard does not apply.

Tar Creek can best be characterized as having high metals concentrations, high hardness, and low pH. The dissolved oxygen standard is sometimes violated due to consumption of oxygen by the oxidation process. Because of the low flow rate for Tar Creek most of the year and its low buffering capacity, the environmental impact from the acid mine discharges is readily apparent. The Tar Creek Field Investigation Report (Task I.1) reported the mine drainage has had a severe impact on Tar Creek since 1979. Soon after discharge commenced, most of the downstream biota in the creek were killed, the banks and bottom of the creek turned red due to ferric hydroxide deposition, and red stains appeared on bridge abutments and cliffs in the Neosho River, downstream from its confluence with Tar Creek. The sediments in Tar Creek contain lead, zinc, cadmium, and iron.

The current designated beneficial use for Tar Creek as a habitat limited aquatic community is applied to waters which will not support a warm water aquatic community and recognizes the effects of acid mine drainage on Tar Creek as being irreversible. Despite this, aquatic biota sampling in Tar Creek in October 1989 did confirm that a restricted aquatic community is present and increases in quality as the stream approaches the confluence with the Neosho River. Additionally, sampling at the Oklahoma-Kansas state boundary, above the known discharges of acid mine water, indicated a normal assemblage of fishes.

E. Impacts on Neosho River, Spring River, and Grand Lake

The Health Effects Sub-Committee of the Tar Creek Task Force concluded that the Neosho River, Spring River, and Grand Lake can be safely used as a raw water source for public water supplies. Fish sample studies were also conducted, and it was concluded that fish from the areas sampled from these water bodies are safe for human consumption. Most of the metals present in the acid mine water are precipitated out of the water and into the Tar Creek stream sediments before the confluence of Tar Creek and the Neosho River. Although the acid mine water discharges to Tar Creek provide a concentrated source of metals, the head waters of the Neosho River, and especially the upper reaches of the Spring River, also contribute large quantities of metals. Comparison of metals concentrations in stream sediments above and below the confluence of Tar Creek and the Neosho River show no significant increase, except for zinc. The Spring River is fed by tributaries that flow through the Galena, Kansas, area. Extensive lead and zinc mining also occurred there.

It was concluded by the Tar Creek Task Force Environmental Effects Sub-Committee that the sediments provide an effective long-term sink for metals and should effectively remove them from most biological processes. Therefore, these sediments do not represent a health risk. The Neosho River has received little impact from the acid mine drainage into Tar Creek other than aesthetic alteration at the Tar Creek confluence.

IV. REMEDIAL OBJECTIVES

A. Summary

A Record of Decision (ROD) for the site was signed June 6, 1984. The remedial objectives were to mitigate the potential threat to public health and the environment by preventing contamination of the Roubidoux Aquifer and by minimizing damage to Tar Creek from acid mine drainage. The scope of the 1984 ROD did not address public health concerns related to direct exposure to the mining waste on the ground surface. The States of Oklahoma and Kansas agreed with the selected alternative, which included diversion of surface flows at three sites and plugging of 66 Roubidoux wells (later increased to 83), followed by a monitoring plan to assess the effectiveness of the well plugging and the surface diversion and diking. The total cost of the remedial actions to date has been $5.5 million. The cost of operation and maintenance has been $7,200. Construction activities at the site were completed on December 22, 1986. Following construction, surface water and ground water monitoring was conducted for a period of two years. A second ground water monitoring program was begun in 1991 and is currently between the wellhead monitoring and discrete sampling phases.

B. The Selected Remedial Action and Costs

The selected remedial action consisted of the following activities:

1. Plugging Abandoned Roubidoux Wells. Well plugging at the site consisted of clearing the well holes of obstructions and setting an acid resistant cement plug from bottom to top. For the 83 abandoned Roubidoux wells in Kansas and Oklahoma, the average cost of construction per well varied depending upon the difficulty in clearing each well. The actual cost of the well plugging, including remedial design costs and State matching funds, was $2,698,711. This represents an average cost per well of approximately $32,515.

2. Surface Diversion. Surface water diversion and diking structures were constructed to prevent surface drainage into mine shafts, subsidence areas, and open boreholes. The action targeted three major inflow areas identified as the Muncie, Big John, and Admiralty mines, that, combined, represented approximately 75 percent of the yearly surface inflows into the mine workings. The Admiralty site was an outflow point but it was projected that after the water level in the mines was lowered (as a result of the remediation) it would become a major inflow point. It was projected that reducing the surface water inflow into the mines by 75 percent (3,800 acre-feet) would eliminate or reduce by a significant amount the 1,000 acre-feet of surface discharges of acid mine water, and also cause the ground water levels in the mines to drop by a significant amount. However, no numerical target cleanup goals, reductions in acid mine discharges, or reductions in the ground water level in the mines were stated in the ROD. The actual cost of the surface diversion and diking program, including remedial design costs and State matching funds, was $1,576,531.

   Completion of these two activities (well plugging and surface diversions) constituted the completion of the construction phase of the project.

3. Monitoring of Surface Water and Ground water. A two-year monitoring and surveillance program was called for to assess the effectiveness of the remedial actions in mitigating contamination of Tar Creek and preventing degradation of the Roubidoux Aquifer. Monitoring was conducted from 1987-1988. For surface water, flow measurements were made and water quality data was collected to determine if the pollutant loading to Tar Creek was reduced after construction of the diversion and diking structures. Also, water levels in the Blue Goose Mine, which are considered indicative of the potentiometric surface of the Boone aquifer, and thus indicative of discharge volumes of acid mine water into Tar

Creek, were monitored. For the Roubidoux Aquifer, water quality data was collected from public water supply wells to assess water quality following the well plugging activities. Details of the monitoring program are presented in the “Tar Creek After Action Monitoring Report” prepared and submitted in April 1991 by the Oklahoma Water Resources Board (OWRB) and included as Appendix C. The report concluded that:

1. Concentrations of most constituents in the acid mine water discharges are decreasing. Although it is not possible to identify the cause of this decrease, it is likely that the decrease is a naturally occurring phenomenon.

2. The volume of the acid mine water discharged to Tar Creek was not significantly impacted by the remedial action.

3. Surface water quality was not significantly improved, and the diking and diversion remedial action was at best only partially effective.

4. Although some public water supply wells in the Roubidoux aquifer are impacted by acid mine water, insufficient data exists to evaluate the effectiveness of the well plugging operations.

EPA concurred with these conclusions.

In 1991, development of a second ground water monitoring program was begun to assess the status of the Roubidoux Aquifer and whether the well plugging operations had succeeded in preventing its contamination. A two phased approach was developed which would begin with wellhead monitoring and conclude with discrete sampling of the Roubidoux Aquifer itself. This program is currently between phases and is discussed at Section IX, “Present Activities”.

C. Other Alternatives Evaluated in the Feasibility Study.

A summary of the other alternatives evaluated in the FS and their associated costs is as follows:

No Action

Insitu Treatment of Mine Water

Pumpage and Treatment of Acid Mine Water

Treatment of Acid Mine Water Discharges

Treatment of Roubidoux Water Supplies

Alternative Drinking Water Supplies

1. No Action. The no action alternative was evaluated for the purpose of assessing the potential for passive remediation with no outside influence. Studies indicated that it would take 60-100 years to flush the mines of contaminated water. Studies also indicated that abandoned Roubidoux wells were potentially major pathways allowing significant quantities of mine water to contaminate the Roubidoux in a relatively short period of time. The no action alternative was rejected based on the conclusion that no action would result in continued environmental damage to Tar Creek and would allow contamination of the Roubidoux Aquifer.

2. Insitu Treatment of Mine Water. Insitu treatment consists of treating the source of contamination in Tar Creek, i.e., the contaminated water in the mines. The insitu treatment technology evaluated in the FS consisted of pumping the mine water to the surface and slurrying with alkaline materials. The slurried alkaline material would be pressure pumped back into the flooded mine shafts at such intervals and volumes to provide maximum mixing and treatment of the contaminated mine water within the drifts. Introducing the alkaline slurry materials would result in the elevation of the pH of the mine water and cause the dissolved metals to precipitate as insoluble metal hydroxides. The major disadvantages of insitu treatment were as follows: the high cost of the enormous quantities of neutralizing materials required due to the low pH of the mine water; technical concerns about achieving adequate mixing of the neutralizing agents and acid mine water; concerns about mine collapse and subsidence from pumping large volumes of water. Based on cost and potential technical problems it was concluded that treating such a large volume (26 billion gallons) of mine water was not feasible.

3. Pumping and Treatment of Acid Mine Water. As envisioned by the FS, pumping and treating would consist of the following components: plugging/sealing all known point discharges; surface diversion to reduce periodic inflows of surface water into the underground workings; a collection well system; and construction of a chemical treatment plant to precipitate the heavy metals from the mine water. This alternative was designed to treat all the acid mine water in a relatively short period of time compared to the time required for natural restoration. The major disadvantages that resulted in rejection of this alternative were: high capital and operation and maintenance costs; over pumping of mine waters for treatment could result in mine subsidence; large volumes to be treated resulting in production of large quantities of sludge, which may be a RCRA characteristic hazardous waste.

4. Treatment of Acid Mine Water Discharges. The treatment of acid mine discharges alternative consisted of collecting and

pumping acid mine discharges to a centralized treatment plant (or plants) for treatment and discharge of treated effluent to surface waters. Chemical precipitation of the heavy metals was the preferred treatment technology. The major disadvantages that resulted in the rejection of this alternative were as follows: only the larger point discharges would be practical to collect and treat (collecting smaller and more diffuse springs, and other outflows would be impractical); high capital, operation, and maintenance costs; long treatment period; and poor quality water would remain in the Boone formation until mines are flushed by natural processes.

5. Treatment of Roubidoux Water Supplies. This alternative, to be implemented if the Roubidoux became contaminated, consisted of treating the Roubidoux water supplies by lime softening to remove heavy metals prior to distribution for consumption. The major disadvantages of this alternative were as follow: high capital, operation, and maintenance costs; and it does not restore the aquifer to drinking water quality. However, in the event that the Roubidoux Aquifer became contaminated, treatment of water produced from Roubidoux wells prior to distribution was considered to be a feasible alternative.

6. Alternative Drinking Water Supplies. This alternative consisted of the provision of an alternative water supply in the event that widespread contamination of the Roubidoux Aquifer were to occur. The FS evaluated pumping water from Grand Lake to Commerce, Oklahoma. After treatment water would be distributed for consumption. The disadvantages of this alternative are as follows: high capital, operation, and maintenance costs; does not restore the Roubidoux Aquifer to drinking water quality.

V. APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

One of the purposes of the 5 Year Review is analyze applicable or relevant and appropriate requirements (ARARs), including newly promulgated ARARs, to determine if they have a bearing on the protectiveness of the remedy. ARARs currently identified for the Tar Creek remedial action are listed and discussed below:

1. Oklahoma Water Quality Standards, Oklahoma Water Resources Board, OWQS/Section 300 - Any waste waters that are treated on-site and discharged to Tar Creek must meet the water quality standards as set by the State of Oklahoma. These standards specify numerical and narrative criteria assigned to protect each beneficial use for surface water and are based on the designated uses of the receiving water. The present discharges of acid mine water are unregulated discharges and do not represent a violation, although water quality standards are exceeded. However, in the future, if the acid mine discharges are treated on-site, the OWQS will be used to set treated effluent discharge requirements.

2. Water Quality Criteria, Clean Water Act, CWA/40 CFR 131 - These regulations set water quality criteria for the discharge of wastewater to surface waters. The present discharges of acid mine water are unregulated and do not represent a violation.

3. National Primary Drinking Water Standards, Safe Drinking Water Act, SDWA/40 CFR 141 - These regulations set drinking water quality standards, including maximum contaminant levels (MCLs), for protection of public health. These standards are applicable to ground water that is a current or potential source of drinking water. Lead is one of the contaminants of concern at Tar Creek and the cleanup level for lead in ground water has been of particular interest. The previous MCL for lead was 50 parts per billion (ppb). In May 1991, EPA replaced the MCL for lead with a treatment standard. The goal of the new standard is for at least 90 percent of monitored household drinking water taps to have lead levels of 15 ppb or less. EPA's Office of Emergency and Remedial Response is also currently recommending that a final cleanup level of 15 ppb for lead in ground water usable for drinking water is protective.

4. National Secondary Drinking Water Standards, Safe Drinking Water Act, SDWA/40 CFR 143 - These regulations set drinking water quality standards based on taste, odor and aesthetic acceptability, rather than health-based concerns. Secondary MCLs are recommended maximum levels and are not enforceable standards. At Tar Creek the secondary drinking water parameters of concerns are iron and sulfate. However, iron and sulfate are not hazardous substances and Superfund has no authority to address these contaminants.

VI. SUMMARY OF SITE VISITS

A. General.

A site visit was made to Tar Creek on September 1, 1993, by representatives of ODEQ, EPA and the Agency for Toxic Substances and Disease Registry (ATSDR). The purposes of the site visit were to inspect the completed remedial action and review the effectiveness of on-site response actions. The trip report of the site visit is included as Appendix A. The ATSDR report, "Site Review and Update", is included as Appendix D. A second site visit was conducted on January 10-11, 1994, to review the site in preparation for this report. Attendees included EPA Regions 6 and 7, ODEQ, ITEC, the Bureau of Indian Affairs, the Indian Health Service, representatives of the Quapaw, Peoria, and Wyandotte tribes, as well as others. The trip report and list of attendees for this site visit is also included in Appendix A.

B. Summary.

September 1, 1993. - Participants inspected the diversion structures at the K-1 (Muncie Mine) and O-3 (Admiralty Mine) sites. Both were in good shape and appeared to be functioning as designed. Participants also observed outflow of acid mine water at site 4 (near the confluence of Tar Creek and the old Lytle Creek channel) and site 13 (a collapsed mine structure near Commerce High School). Although several chat piles were observed to be actively quarried for gravel, much chat remains in the area. The active chat quarrying operations are known to wash at least some of the material they excavate to remove the fine materials. Fine particles in chat have been identified as containing high levels of metals. Access to chat piles is uncontrolled and tracks of people and off-road vehicles were abundant in some areas. Chat piles are frequently located near populated areas. A baseball field in the city of Picher is surrounded by chat piles. No observations were made of any plugged wells.

January 10-11, 1993. - Participants toured the Oronogo-Duenweg Superfund Site in Jasper County, Missouri, and the Cherokee County Superfund Site in Kansas. Site conditions were similar to those in Tar Creek. Remedial activities were being conducted at the Galena (Kansas) subsite, with onsite disposal of chat into dry mine shafts and collapse features. Recontouring of the ground surface was being conducted to divert drainage away from other collapse features. At Tar Creek, all of the site locations mentioned in the above paragraph were re-visited, with additional visits to the Eagle-Picher Central Mill and numerous collapse features and floatation ponds. Local concern centered around direct exposure to mining wastes and illegal disposal of solid wastes. However, the representative of the Indian Health Service indicated that routine blood testing of Native American children participating in the U.S. Department of Agriculture's WIC program indicated a significant percentage exceeded the 10 µg/dl benchmark for blood lead concentration. EPA later requested a copy of this data and was denied.

VII. PAST SURFACE AND GROUND WATER MONITORING

A. General

Construction of the diversion and diking structures was completed on December 22, 1986, and was followed by after action monitoring in 1987 and 1988. The purposes of the monitoring activities were to determine: 1) if the pollution of Tar Creek caused by the acid mine drainage had been reduced since the diversion and diking structures were completed, and 2) to determine the effectiveness of the well plugging in reducing the potential for contamination of the Roubidoux Aquifer. To monitor surface water, flow measurements were made and surface water quality samples were collected and analyzed to determine if the pollutant loading to Tar Creek had decreased since construction. To monitor ground water, water quality samples were collected from municipal wells and analyzed to see if water quality in the Roubidoux Aquifer had improved. The available surface and ground water monitoring data collected during the monitoring period was reviewed and analyzed by Robert S. Kerr Environmental Research Laboratory (RSKERL). The resulting report by RSKERL entitled “Report on the Effectiveness of Remediation on the Tar Creek Superfund Site”, dated September 1989, is included as Appendix B. A summary report by OWRB of the results of the monitoring, entitled “Tar Creek After Action Monitoring Report” (AAR), received April 5, 1991, is included as Appendix C. Data from the AAR are summarized below. However, EPA has recalculated the percent change for each constituent at each monitoring location according to the following formula:

$$\frac{(Y - X)}{X} \times 100 = \%\ \text{change}$$

where: X = 1980-1982 (beginning) mean concentration
Y = 1987-1989 (end) mean concentration

Average percent change at each monitoring station was also recalculated by using the following formula:

$$\frac{(\%\ change_{constituent\ 1} + .. + \%\ change_{constituent\ n})}{n} \times 100 = \text{Average \% Change}$$

where: n = the number of constituents analyzed at the monitoring station.

B. <u>Surface Water Monitoring Program</u>

Surface water monitoring stations were first installed on Tar Creek in 1979. The monitoring program was expanded in 1980. These sampling sites are shown on Figure 4. Some of the sites in Figure 4 are located on Tar Creek, while others are located where acid mine water discharges at the surface. A summary of the results of the surface water monitoring from each of the surface water monitoring sites is presented below. The individual constituent concentrations in the summary tables are the means of data collected before construction (1980-1982) and after construction (1987-1989). The dissolved oxygen, pH, and conductivity calculations are averages of readings measured in the field during the 1980's.

1. Sites Located on Tar Creek:

Site 7 is located on the Oklahoma-Kansas state line, well above the known outflow points. Average concentrations during the period 1987-89, reflected in Table 3 below, were generally lower than the period 1980-82, except for lead where the concentration increased. At site 7, WQSs for cadmium, lead, and zinc were exceeded. It is assumed that the elevated concentrations are due to leachate from tailings piles.

Table 3. Water Quality at Site 7

	Mean Concentration, µg/l		
	1980-82	1987-89	% Change
Cadmium	21.2	16.9	- 20
Fluoride	0.29	0.19	- 34
Iron	5663	799	- 86
Lead	58	107	+ 84
Sulfate	626	341	- 46
Zinc	5870	3523	- 40
	Average % Change		- 24
Average pH		7.0 SU	
Average DO*		9.0 mg/l	
Average Conductivity		825 µmhos/cm	

* - dissolved oxygen

Site 4a is located directly upstream from the area where a majority of the acid mine discharge enters Tar Creek, so it may be assumed that a majority of the elevated concentrations observed at this site are due to tailing pile leachate. The concentrations of cadmium, lead and zinc exceed WQSs. The average concentrations during the period 1987-89, reflected in Table 4 below, was generally lower than the period 1980-82, except that the concentrations of lead and cadmium increased.

Table 4. Water Quality at Site 4a

	Mean Concentration, µg/l		
	1980-82	1987-89	% Change
Cadmium	23	27	+ 17
Fluoride	0.9	0.4	- 56
Iron	11,433	1011	- 91
Lead	23	38	+ 65
Sulfate	679	522	- 23
Zinc	26,270	7620	- 71
	Average % Change		- 27
Average pH		6.6 SU	
Average DO		8.3 mg/l	
Average conductivity		1350 µmhos/cm	

Site 4b is located within the area where a majority of the acid mine discharge enters Tar Creek. Concentrations at site 4b are affected by both the tailing pile leachate from upstream, as well as acid mine drainage. The concentrations of most contaminants, reflected in Table 5, increased somewhat, except for cadmium which decreased significantly. The average concentrations of cadmium, lead, and zinc violate WQSs.

Table 5. Water Quality at Site 4b

	Mean Concentration, µg/l		
	1980-82	1987-89	% Change
Cadmium	48	17	- 65
Fluoride	1.6	1.7	+ 6
Iron	NA	73,112	NA
Lead	31	37	+ 19
Sulfate	1,105	1,281	+ 16
Zinc	26,371	31,259	+ 19
	Average % Change		- 1
Average pH		5.9 SU	
Average DO		6.3 mg/l	
Average Conductivity		2022 µmhos/cm	

Site 10 is located below the area where a majority of the acid mine discharge enters Tar Creek. With the exception of iron and sulfate, all concentrations decreased at site 10. The average concentrations of cadmium, lead, and zinc violate WQSs. See Table 6.

Table 6. Water Quality at Site 10

	Mean Concentration, µg/l 1980-82	1987-89	% Change
Cadmium	32	16	- 50
Fluoride	2.9	1.6	- 45
Iron	27,139	45,882	+ 69
Lead	92	37	- 60
Sulfate	954	1,274	+ 34
Zinc	37,246	28,823	- 23
		Average % Change	- 13
Average pH		5.7 SU	
Average DO		6.6 mg/l	
Average Conductivity		2087 µmhos/cm	

Site 20 is located downstream from all known acid mine discharges. Concentrations of some parameters (iron, lead, and sulfate) increased, while the concentrations of other parameters (cadmium and fluoride) decreased. The net effect is a relatively low increase in overall contamination. The average concentrations of cadmium, lead, and zinc violate WQSs. See Table 7.

Table 7. Water Quality at Site 20

	Mean Concentration, µg/l 1980-82	1987-89	% Change
Cadmium	19	13	- 32
Fluoride	2.2	1.2	- 45
Iron	8,853	20,034	+126
Lead	33	37	+ 12
Sulfate	619	1,186	+ 92
Zinc	21,333	21,408	0
		Average % Change	+ 18
Average pH		5.2 SU	
Average DO		6.1 mg/l	
Average Conductivity		1606 µmhos/cm	

Site 22 is located farthest downstream and monitors recovery of Tar Creek from acid mine drainage. Discharge from the Miami sewage treatment plant helps buffer the acidity of the mine water at this point. Concentrations of all the parameters at site 22 increased, as reflected in Table 8,

although in general the concentrations at site 22 are less than the concentrations at site 20, which is upstream. The concentrations of cadmium, lead, and zinc at site 22 violate WQSs.

Table 8. Water Quality at Site 22

	Mean Concentration, µg/l 1980-82	1987-89	% Change
Cadmium	5	9	+ 80
Fluoride	0.6	1.0	+ 67
Iron	1,260	10,928	+767
Lead	20	38	+ 90
Sulfate	152	969	+538
Zinc	6,083	15,149	+149
		Average % Change	+282
Average pH		6.6 SU	
Average DO		9.8 mg/l	
Average Conductivity		1606 µmhos/cm	

In summary, OWRB concluded the available monitoring data indicates that contaminant concentration in Tar Creek due to acid mine drainage and tailing pile leachate may be decreasing. EPA notes, however, water quality at downstream locations sites 20 and 22 indicate average constituent concentrations of many metals have increased. This may indicate an increased volume of discharge or dissolution of metals into the water column from stream bed sediments. Further, it is difficult to explain why some constituents are decreasing while others are increasing. EPA concluded the data was not sufficient for statistical analysis, in part because of the short period of post-construction monitoring OWRB concluded additional monitoring is required to adequately establish trends.

2. Sites Monitoring Acid Mine Discharges:

Concentrations of measured parameters in the acid mine discharges are much higher than in Tar Creek, as would be expected, and greatly exceed WQSs.

Acid mine discharge **site 4s** is a weir which measures discharges from springs south of Lytle Creek. As shown in Table 9,concentrations at 4s decreased for every parameter.

Table 9. Water Quality at Site 4s

	Mean Concentration, μg/l 1980-82	1987-89	% Change
Cadmium	130	19	-85
Fluoride	13	4	-69
Iron	353,048	170,033	-52
Lead	68	65	-4
Sulfate	3,096	2,184	-29
Zinc	231,814	62,161	-73
		Average % Change	-52

Acid mine discharge **site 4L** is a weir set in the old Lytle Creek channel. No changes in concentration are available for this site, since no observations were made before construction. Table 10 contains post-remediation data.

Table 10. Water Quality at Site 4L

	Mean Concentration, μg/l 1980-82	1987-89	% Change
Cadmium		12	
Fluoride		2.3	
Iron		64,840	
Lead		60	
Sulfate		2,145	
Zinc		49,625	

Acid mine discharge **site 13** is a weir designed to measure flow from a collapsed mine shaft. There was a decrease in all parameters measured, as reflected in Table 11.

Table 11. Water Quality at Site 13

	Mean Concentration, μg/l 1980-82	1987-89	% Change
Cadmium	239	29	-88
Fluoride	6	1	-83
Iron	168,700	100,985	-40
Lead	97	60	-41
Sulfate	1,900	1,843	-3
Zinc	86,250	17,645	-80
		Average % Change	-56

Acid mine discharge **site 14** is a spring which is the southern-most known acid mine discharge. The values in Table 12 reflect there was a decrease in all the measured parameters at this site, except for lead.

Table 12. Water Quality at Site 14

	Mean Concentration, µg/l		
	1980-82	1987-89	% Change
Cadmium	13	13	0
Fluoride	5	2	-60
Iron	500,827	288,300	-42
Lead	33	57	+73
Sulfate	2,892	2,438	-12
Zinc	125,214	19,072	-85
		Average % Change	-21

In summary, the available monitoring data indicates that overall the contaminant concentrations in the acid mine discharges have decreased since completion of the remedial action.

3. Tar Creek Pollutant Loading:

Pollutant loading for Tar Creek is expressed as tons/year. Data is available for loading comparisons only at sites 4s and 14. The percent change in tons of total loading has also been calculated.

The data from **site 4s,** presented in Table 13, indicates a decrease in loading for all parameters. A comparison of Table 9 and 13 indicates that the percent decrease in loading is about the same as the percent decrease in concentration. This is because the flow at site 4s did not change significantly during the monitoring period.

Table 13. Loading at Site 4s

	Loading, tons/ year		
	1980-82	1987-89	% Change
Cadmium	0.142	0.019	-87
Iron	383.7	169	-56
Lead	0.074	0.065	-12
Sulfate	3,374.6	2,169	-36
Zinc	252.7	61.7	-76
Total Tons	4,011.216	2,399.784	
	Average % Change		-53
	Loading (Tons) % Change		-40

Pollutant loading for **site 14** is presented in Table 1.. A comparison with Table 12 indicates the change in loading at site 14, unlike that at site 4s, was not proportional to the change in concentration. While concentrations at site 14 generally decreased, the loading increased for some of the parameters because of a substantial increase in flow.

Table 14. Loading at Site 14

	Loading, tons/year 1980-82	1987-89	% Change
Cadmium	0.004	0.005	+25
Iron	172.3	122.0	-29
Lead	0.011	0.024	+118
Sulfate	994.8	1,031.2	+4
Zinc	43.07	8.1	-81
Total Tons	1,210.185	1,161.329	
	Average % Change		+7
	Loading (Tons) % Change		-4

Pollutant loading for **site 20** is presented in Table 15. Site 20, located downstream from all known acid mine discharges, shows the total loading to Tar Creek from the Picher field.

Table 15. Loading at Site 20

	Loading, tons/year
Cadmium	1.02
Iron	924
Lead	2.24
Sulfate	170,560
Zinc	1,368

In summary, the mines have been discharging to Tar Creek for about 12 years. During this period more than 12 tons of cadmium, 11,000 tons of iron, 26 tons of lead, 2,000,000 tons of sulfate and 16,000 tons of zinc have flowed down Tar Creek. The loading may be decreasing, as some evidence indicates concentrations in some discharges are decreasing.

4. Tar Creek Sediment Contamination.

The average concentrations of selected metals in Tar Creek sediments for pre- and post-construction periods are given in Table 16.

Table 16. Sediment Concentrations (mg/kg)

	Period 1980-1982			Period 1987-1989		
Site	Iron	Lead	Zinc	Iron	Lead	Zinc
7	3,267	101	2,267	3,155	526	8,420
4a	7,878	289	5,083	4,673	562	5,075
4b	123,950	967	13,850	20,629	388	31,258
10	30,000	320	5,100	86,557	888	19,907
20	118,333	246	6,950	65,534	245	4,457
22	19,000	53	5,675	77,935	290	6,117

From the data it is observed that iron concentrations increased by an order of magnitude downstream from acid mine discharges. Above the discharges, the average iron concentration in the sediment is 4,743 mg/kg. Below the discharges, the average concentration is 67,742 mg/kg. However, the data is erratic, and it is difficult to draw any conclusions as to the effects of the remediation. The Tar Creek Task Force had previously concluded the sediments provide an effective long-term sink for metals and should effectively remove them from most biological processes.

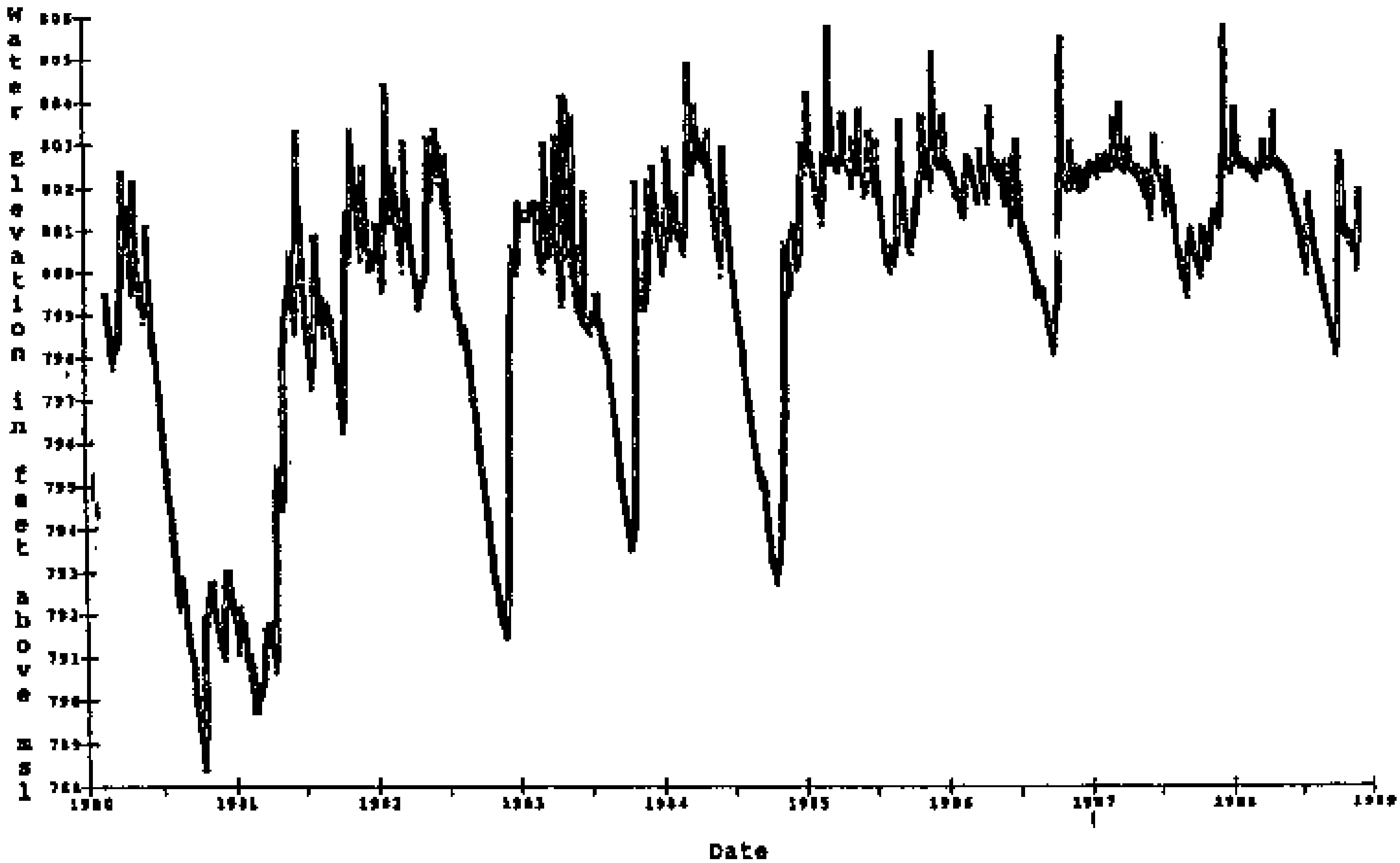
C. Water Levels in Blue Goose Mine

The intent of the diversion and diking was to reduce surface inflow into the mines, thereby reducing acid mine discharges. The established linear relationship between the measured water level in the Blue Goose mine and the measured acid mine water discharge rate at site 4s allows the use of the mine water elevation as an indicator of acid mine discharge, i.e., the discharge flow rate is dependent on the hydraulic head differential between the water elevation in the mines and the surface discharge outlet elevation. A graph of water elevation in the Blue Goose mine versus time is shown on Figure 5. Based on the data collected at the Blue Goose mine, EPA concluded that the average water level after construction was not statistically different from the average water level before construction. This indicates that the discharge of acid mine water was not significantly reduced after construction.

During the monitoring period shown on Figure 5, water levels fluctuated from 788 feet to 806 feet (MSL). RSKERL analyzed the relationship between rainfall events and water level responses in the mines before and after diversion. It was assumed that water level increases in the mines, for a given rainfall, would be less after diversion than before diversion. The amount of rise (in feet) was calculated for each rainfall (inches). There were 42 data points before and 33 points after diversion. These observations were normally distributed with a mean of 0.45 feet/inch before the diversion and 0.29 feet/inch after the diversion, a decrease of 36 %. A normality plot (RSKERL, 1989)of the pre- and post-diversion mine water level rises is shown on Figure 6. The total contribution of surface inflow into the mines from inflow sites K-1 and K-2, located in Kansas, was estimated to be 72%. If it is assumed that the water level/rainfall response is proportional to the effectiveness of the diversion, then the mean after remediation should have been 0.13 feet/inch, since 72% of the inflow was to be diverted. It is noted that there

Figure 5

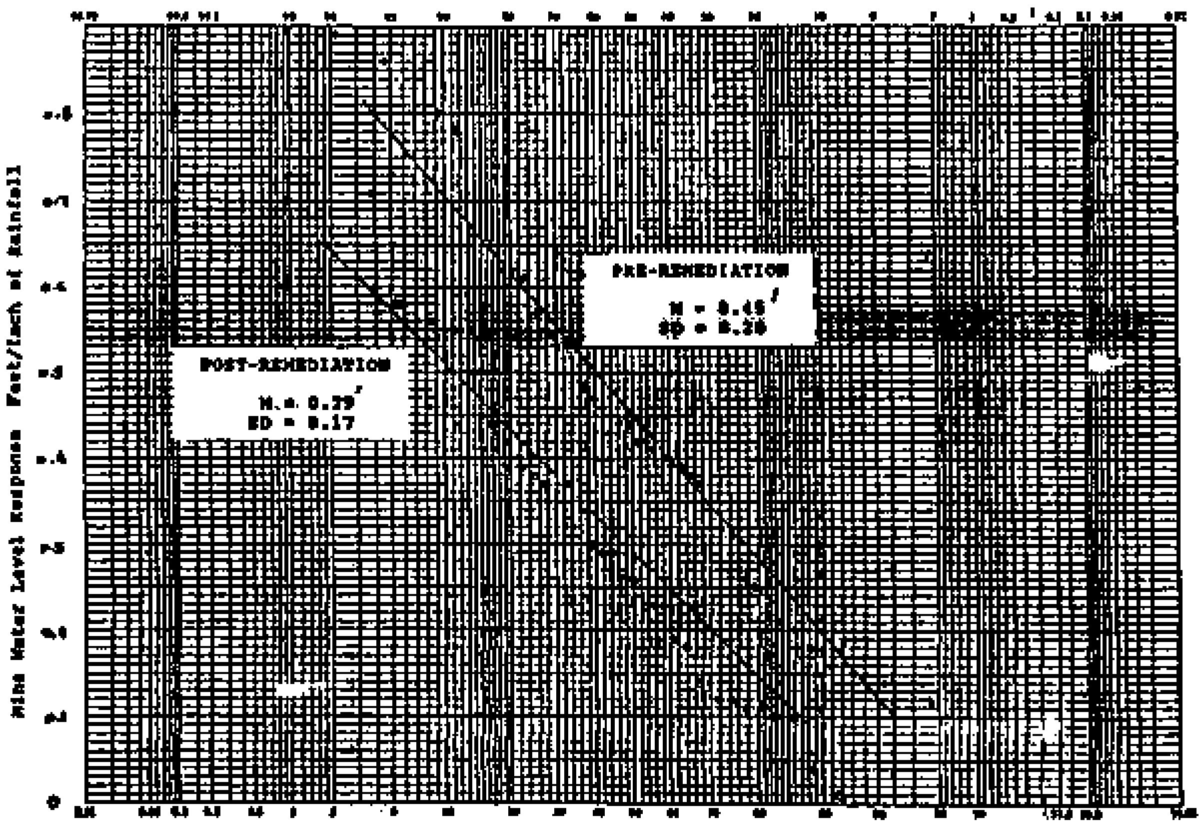
Water Levels in the Blue Goose Mine



DAILY WATER ELEVATIONS IN THE BLUE GOOSE MINE 2/21/80 TO 11/14/88

Figure 6

Water Levels Rises vs Rainfall Events



NORMALITY PLOTS OF PRE- AND POST-DIVERSION MINE WATER LEVEL RISE

are limitations in the rainfall and water level data upon which the analysis is based. Additionally, the natural variation in rainfall patterns within the watershed influence the observations.

EPA concludes that although the diversion structures are effectively preventing the surface water inflow, the original remedial goal of decreasing the discharge of acid mine water was at best only partially achieved. EPA also concludes that although the diversion structures have been successful in reducing the rise in water levels in response to a given precipitation event, because the long term water level average in the Boone has not been significantly reduced it is apparent that many other sources of recharge must be present. Other potential sources of recharge include other surface water inflow points; natural recharge of the aquifer; and recharge from the ground water in the unconsolidated surficial sediments via the tens of thousands of exploration boreholes

D. Ground Water Monitoring

After the well plugging remediation, the after action monitoring in 1987 - 1988 obtained water quality data from the sampling of public water supply wells producing from the Roubidoux Aquifer. The resulting data was analyzed by RSKERL. RSKERL noted the following limitations in the data:

1. Monitoring period after remediation too short.
2. Discrepancies in identification of sampled wells.
3. No depth of sampling notations.
4. Nonuniform collection and analysis procedures.

Due to limitations of the data, RSKERL was unable to assign data to individual wells. In order to analyze the data, the wells were grouped together by municipality. A comparison of water quality means among selected communities in the area using the entire database from January 1980 through October 1988 is shown in Table 17 (RSKERL, 1989).

Table 17. Comparison of Mean Water Quality Parameters

Parameter	Miami	Commerce	Pitcher	Quapaw
Spec. Cond. 0 uS/cm	477	333	493	518
Tot. Hard. - mg/L	140	140	245	264
Fe -µg/L	105	284	847	932
Mn -µg/L	26	15	20	23
pH	7.6	7.5	7.3	7.2
SO_4 - mg/L	18	30	118	128
Zn -µg/L	45	33	316	78

RSKERL concluded that the water quality of the Roubidoux wells at Picher and Quapaw is of significantly poorer quality than at Miami, Commerce, and Cardin with respect to total hardness, iron, sulfate and zinc. The mean concentration of iron exceeds the secondary drinking water standard (Fe - 300 µg/l) at Pitcher and Quapaw. However, due to the limitations associated with the data, EPA concluded that the effectiveness of the well plugging operations could not be established. EPA and the State of Oklahoma have been performing additional monitoring activities to resolve this issue.

VIII. POST REMEDIAL ACTION STATUS

A. Surface Water

The objective in the ROD was that the diversion and diking would reduce surface inflows into the mines by about 3,800 acre-feet/year (75 percent), resulting in elimination of the acid mine water discharges (which were estimated at 1,000 acre-feet/year. Based on the monitoring data, EPA concluded that the volume of acid mine discharges has not been significantly reduced. However, contaminant concentrations in the discharges of acid mine water have decreased. Additionally, the diversion structures have been successful in preventing the surface water inflow into the mines, thus keeping more water in the creek itself. The reduction in the concentrations of the discharges may be related to the remediation activities; however, these are more likely due to natural remediation processes. OWRB speculated in the After Action Report (AAR) that as long as significant acid mine discharges continue, surface water quality will not improve in the foreseeable future to the level that water quality standards are not violated. However, since there has only been two years of after action monitoring, there is not sufficient data to predict water quality trends. RSKERL and the U. S. Bureau of Reclamation (USBOR) reviewed the available surface water monitoring data and recommended that additional monitoring was needed to predict water quality trends. The USBOR’s review, entitled "Review of After Action Report for Tar Creek Superfund Site", is included as Appendix D.

EPA also notes the AAR reported that only 15% of the total metals loading to Tar Creek was calculated to be contributed by the known major discharges. EPA concludes that if 85% of metals loading to Tar Creek is from unidentifiable sources it would not significantly improve water quality to collect and treat the known discharges.

B. Ground Water

Potential pathways of contamination of Roubidoux water supply wells from acid mine water are inflow through deteriorated casings, inflow underneath shallow casings, migration through intervening strata, or migration from nearby abandoned wells or boreholes which have not been plugged. The Tar Creek Feasibility Study (Task II. 1. B. d.) reported the cities of Cardin, Commerce and Picher were able to alleviate water quality problems after replacing corroded well casings. The purpose of the past well plugging operations was to prevent mine water from migrating into and contaminating the Roubidoux Aquifer through abandoned wells or boreholes. Presently, secondary drinking water standards for iron and sulfate are being violated in several of the Roubidoux wells due to contamination from mine water. Secondary standards are not health based and are not enforceable. The most current data indicates that all wells sampled in the area are in compliance with the primary drinking water standards. However, previous data was inconsistent and inconclusive. In 1989, RSKERL reviewed all available Roubidoux water supply data through 1988 and concluded that, due to deficiencies in the existing data and the short period of post-remediation sampling, the effectiveness of the well plugging remedy could not be established. EPA and the State of Oklahoma are currently developing further investigations to determine the water quality of the Roubidoux aquifer. Details of these monitoring efforts are presented in the next section.

IX. PRESENT ACTIVITIES

After a review of the existing Roubidoux Aquifer data by the agencies involved, it was concluded that the monitoring data is inadequate to determine the adequacy of the selected remedy. Regarding the protection of the Roubidoux Aquifer, a revised monitoring program was developed by EPA, OWRB, OSDH and USGS to provide reliable and statistically sound data that can be used to determine whether acid mine water has contaminated the public water supply obtained from the Roubidoux Aquifer. The monitoring program is also designed to provide a supportable baseline to predict future changes in Roubidoux water quality. The monitoring program consists of two parts:

1. Wellhead sampling of municipal water supply wells; and
2. Discrete sampling of the Roubidoux Aquifer.

The field activities of the wellhead sampling portion of this monitoring program were completed by the USGS under the technical direction of the OWRB. However, as previously mentioned, control of this project was transferred to the ODEQ on July 1, 1993. ODEQ developed the Technical Memorandum on the results of the wellhead sampling and will direct the discrete sampling portion of this monitoring program.

A. Wellhead Sampling

The wellhead sampling portion of the program has been completed. Twenty-one public water supply wells located in Ottawa County and producing from the Roubidoux Aquifer were sampled. ODEQ's report, "Technical Memorandum - Sampling Results of Public Water Wells, August, 1992 to January 1993, Tar Creek Superfund Site", is attached as Appendix E. Ten wells inside the mining area and one well considered to represent background conditions were sampled once a month for each of the six months from August 1992 through January 1993. See Figure 7. Additionally, in January 1993, ten wells outside the mining area were sampled to increase the data set for background Roubidoux Aquifer water quality. Two sets of filtered (dissolved constituents) and raw (non-filtered; total (dissolved + suspended) constituents) samples were collected by the USGS and analyzed by RSKERL and various laboratories participating in EPA's Contract Laboratory Program (CLP). Samples were analyzed for the following constituents: alkalinity, aluminum, antimony, arsenic, barium, beryllium, bi-carborate, boron, cadmium, calcium, chloride, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, pH, potassium, selenium, silver, sodium, specific conductivity, strontium, sulfate, temperature, thallium, titanium, vanadium, and zinc. Zinc, iron and sulfate were chosen as the most reliable indicators of acid mine water contamination of the Roubidoux due to the large differences in the levels of these constituents when comparing mine water quality to background Roubidoux water quality. The water quality information reflected in Table 18 is taken from ODEQ's Technical Memorandum.

Table 18. Comparison of Roubidoux Water and Mine Water

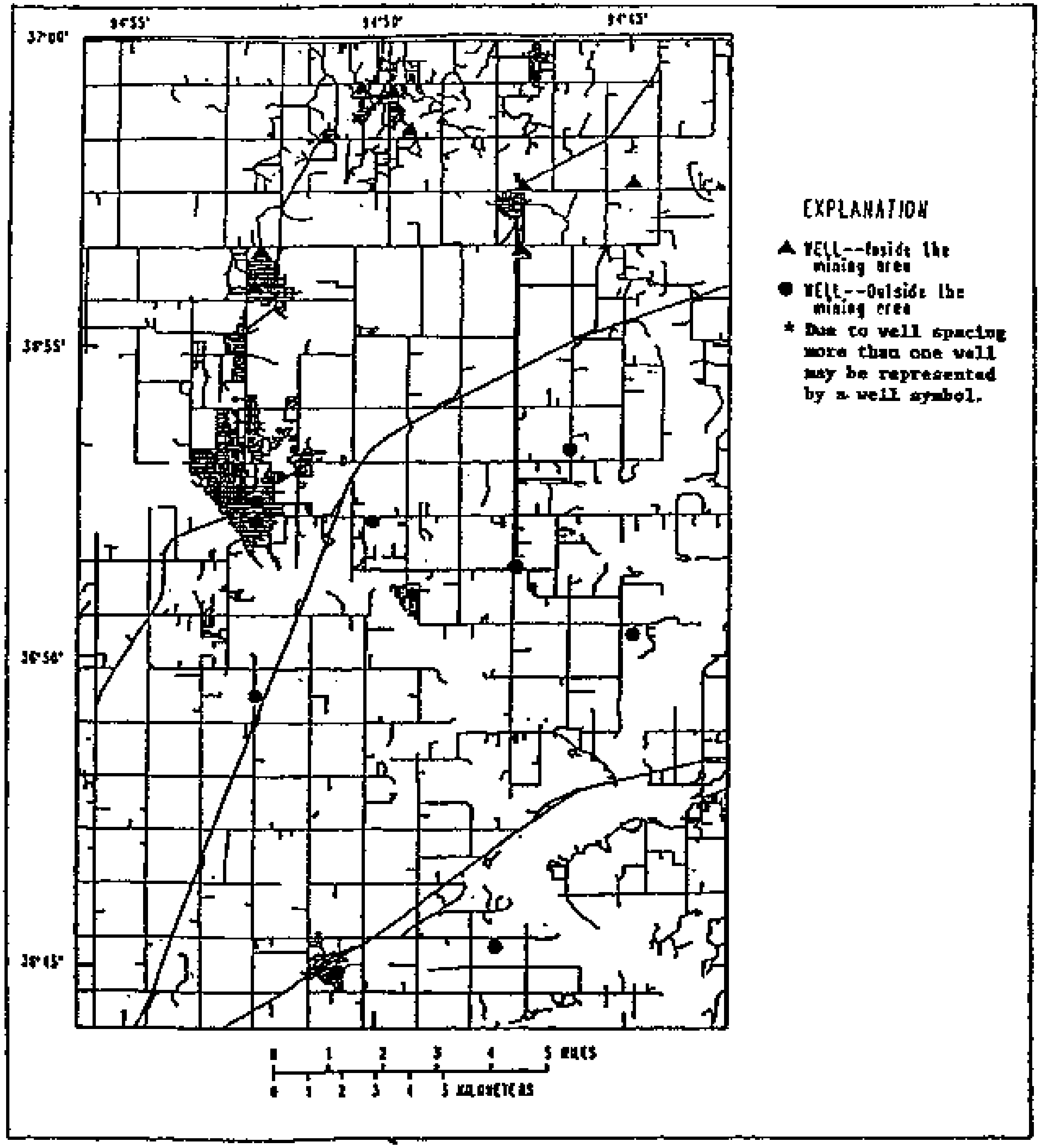
	Roubidoux Water* µg/l	Mine Water** µg/l
Total Zinc	6	108,000
Total Iron	43	110,000
Sulfate	17	1,950

* - mean of sample results from ten wells outside the mining area.
** - Mean of concentrations of mine water.

Results indicated that all twenty-one of the public water supply wells tested are currently in compliance with all primary drinking water standards examined. However, five

Figure 7

Wellhead Monitoring Locations



wells (Picher #2, #3, and #4, as well as Quapaw #2 and Commerce #3) failed the secondary drinking water standard (SDWS) for iron, and the Picher #4 well also failed the SDWS for sulfate. (The Picher #4 well was installed by EPA in a removal action in 1985.) These five wells, while protective of human health, are considered to be impacted by acid mine water from the Boone. What has not been demonstrated is whether these water quality problems are a well integrity problem, or represent more widespread contamination of the Roubidoux Aquifer. The memorandum concluded that additional investigations to determine the actual water quality of the Roubidoux Aquifer by direct sampling are required to determine this information.

B. Discrete Sampling

This project has not yet begun field activities. ODEQ and EPA are currently evaluating the best course of action to accomplish the goals of the project, i.e., how to determine the actual water quality of the Roubidoux Aquifer. The workplan for this project is currently being developed.

ODEQ and EPA have agreed the general procedure will be to disassemble public water supply wells and remove the pumping equipment from the well; insert a pump to the level of the Roubidoux Aquifer and isolate the aquifer by installing an inflatable packer to seal off the borehole above the Roubidoux, thus preventing the potential inflow of acid mine water; then, after sufficient purging to ensure production of water representative of the Roubidoux Aquifer, to collect and analyze water quality samples. Additional testing may be performed to assess casing location and condition.

EPA and ODEQ have agreed the priority wells to be examined are those five which have exhibited an impact by the acid mine water. Additional wells in the mining area may, or may not, be investigated if funds are sufficient to continue investigations. Discrete sampling will determine whether the Roubidoux Aquifer is producing contaminated water, or if inadequate well integrity is allowing production of a mixture of clean water from the Roubidoux Aquifer and acid mine water from the Boone Aquifer.

C. Anticipated Results

Two possible results are anticipated to be determined by the discrete sampling activities: 1) the Roubidoux Aquifer’s water quality is good and water quality problems are the result of poor well integrity; or 2) well integrity is good and the water quality of the Roubidoux Aquifer has been degraded by inflow of the acid mine water.

Should the water quality problems be due to well integrity problems, it should be possible to either rehabilitate those wells, or to plug and abandon them in favor of drilling new wells.

Should it be shown that the Roubidoux Aquifer has been directly impacted by acid mine water contamination, it may become necessary, if the wells fail to meet primary drinking water standards at some undetermined time in the future, to provide a water treatment system or an alternate water supply. EPA emphasizes that all wells tested are currently meeting primary drinking water standards. Further, the secondary drinking water standards violations for iron and sulfate do not represent a health risk, and these constituents are not hazardous substances addressable under CERCLA's authorities.

X. FINDINGS OF EPA REGION 7

As previously mentioned, the Tar Creek Superfund Site is located in the Tri-State Mining District. The environmental problems associated with Tar Creek are in large part duplicated at the Cherokee County and Oronogo-Duenweg Superfund Sites. These sites are administered by EPA's Region 7 office, located in Kansas City, Kansas. Investigations of these sites were conducted after the remedy was implemented at Tar Creek. These later investigations were in many ways more comprehensive than the investigations at Tar Creek. A short summary of these two sites follows.

A. Cherokee County Superfund Site

The Cherokee County Superfund Site, located in southeast Kansas, was proposed to the NPL in 1982 and promulgated in 1983. The site is subdivided into 6 subsites: Badger Area, Baxter Springs, Galena, Lawton Area, Treece Area, and the Waco Area.

Galena Subsite

Region 7 began investigations at the Galena subsite in 1985 and signed the ROD for the alternative water supply operable unit on December 21, 1987. The ROD provided an alternate water supply to approximately 1,050 people who had been utilizing domestic wells producing water from the contaminated Boone Aquifer as their primary drinking water supply. These wells exceeded MCL's for several metals. The Galena municipal water supply system was expanded to provide water to approximately 418 homes, businesses and farms outside the normal distribution area.

A second ROD was signed for the ground water/surface water operable unit at the Galena subsite on September 18, 1989. Major components of this ROD were:

1. Removal and selective placement of mining wastes into subsidence features;

2. Diversion and channelization of surface streams;

3. Recontouring and vegetation of filled subsidence features; and

4. Investigation and remediation, as necessary, of Roubidoux Aquifer wells.

Mine wastes (which include waste rock and tailings (chat) piles) were determined to represent an unacceptable risk to human health and the environment, with exposure occurring through direct contact, incidental ingestion, and inhalation. A cleanup level of 1000 ppm for lead, 25 ppm for cadmium, and 10,000 ppm for zinc was established in the ROD. Maximum levels of these constituents detected during the RI are identified in Table 19.

Table 19. Maximum Levels in Mine Wastes/Soils

	Maximum Concentration detected (mg/kg (ppm) dry weight)		Action
	Soil	Mine Wastes	Level*
Cadmium	12	79	25
Lead	510	3,880	1,000
Zinc	1,100	15,731	10,000

* - As established in the ROD.

Although Region 7 would prefer to place all mine wastes above the water table, this may not be possible. If not, wastes will be separated into materials greater or less than 2 inches. Only material which is more than two inches in diameter will be placed below the water table. This material has been determined to be less reactive. All other materials will be placed above the water table. To date (January 1994), all material which has been relocated has been placed above the water table.

Chat below the action levels will be used as fill material to bring the level of mine wastes to grade. Also, chat will be mixed with clean fill soil to reduce infiltration and facilitate revegetation of the surface while reducing costs for soil.

Abandoned wells and boreholes extending to the Roubidoux were grouted, if possible, to prevent downward migration of acid mine water.

One municipal water supply well in the city of Galena was rehabilitated to prevent inflow of contaminated mine water into the well.

Baxter Springs and Treece Subsites

In 1990, Region 7 entered into an Administrative order on Consent (AOC) with the PRP's at the site to conduct the RI/FS. Region 7 received the RI Report in January 1993 and approved it that spring. Region 7 is currently evaluating the FS Report. Region 7 is also developing a Proposed Plan, which is anticipated to be released in the early spring of 1994.

Table 20 provides the concentrations for cadmium, lead and zinc, at these subsites, as identified in the RI/FS.

Table 20. Concentrations of Metals in Chat and Floatation Pond Sediments

	Bulk Chat		Floatation Pond Sediments	
	Range	Average	Range	Average
Cadmium	13 - 89	46	13 - 540	124
Lead	100 - 1,660	750	56 - 13,000	3,800
Zinc	3,100 - 13,000	8,300	6,400 -52,0000	21,600

All constituents are in mg/kg (ppm) dry weight

Badger Area, Lawton Area, and Waco Area

Investigations have not yet begun in these areas.

B. Oronogo-Duenweg Superfund Site

This site is located in Jasper County in southwest Missouri. The site has been subdivided into ten areas. No RODs have been issued for this site. However, Region 7 has entered into an AOC with the PRPs at seven of these sites to conduct a PRP-lead RI/FS. Region 7 is concurrently conducting an RI/FS on the three other areas of this site. Both EPA's and the PRP's RI/FS initial reports are expected to be completed by October 1994. It has not been determined yet whether a second phase of investigations will be necessary. Initial data analyses indicate the levels of contamination are similar to those in the Baxter Springs and Treece subsites of the Cherokee County site.

In November 1993, Region 7 was informed that approximately 25 households of the Jasper County site were confirmed to be utilizing wells completed in the Boone Aquifer as a domestic water supply source, and that these wells were exceeding primary drinking water standards (MCLs). An additional 270 households in the area are also potentially utilizing this same source as their water supply. Region 7 has entered into an agreement with the PRPs to:

1. Provide bottled water to the 25 households with known contamination;

2. Conduct confirmation sampling at the tap of these 25 residences;

3. Locate and sample the 270 other potentially affected households; and

4. Provide Region 7 a report by January 30, 1994, documenting the results of these investigations.

Upon receipt of this report, Region 7 will evaluate the need for further action at that time.

XI. SUMMARY

Based on the 5 Year Review of the Tar Creek Superfund site the following conclusions are made:

A. Diversion and Diking

The inspection of the diversion and diking structures indicate that they are functioning as designed and are adequately maintained. Operation and maintenance costs have been reasonable. No deficiencies were noted.

The goal of the diversion and diking remedy was to reduce surface inflow into the mines by approximately 75 percent, thereby eliminating or reducing acid mine discharges by a significant amount. Available monitoring data indicates that although the diversion and diking remedy was successful in preventing surface water inflow at these two locations, the remedy did not significantly reduce the surface discharges of acid mine water and has at best only partially achieved the intended goal.

One possible reason for the failure of the remedy to eliminate or reduce the discharge of acid mine water is that the initial evaluation of the sources of recharge for the Boone Aquifer grossly under estimated the sources other than the two inflow points of Tar Creek into the subsidence features which EPA diked. Other sources of recharge are apparently capable of sustaining the water level in the Boone Aquifer and the discharge of acid mine water.

One estimate indicates up to 100,000 open boreholes into the Boone Formation may be present in Ottawa County. Those boreholes in which the potentiometric surface of the Boone Aquifer is below the top of the Boone Formation are probably acting as a source of recharge, either from direct infiltration of rainwater or through the presence of an unconfined aquifer in the unconsolidated surficial sediments. Similarly, for those boreholes which are located in areas where the potentiometric surface of the Boone Aquifer is higher than the top of the Boone Formation, contaminated mine water is probably moving upward and into the unconsolidated surficial sediments. This water may then move laterally through the sediments and discharge into Tar Creek. This flow probably establishes a portion of the base flow in Tar Creek.

B. Water Quality in Tar Creek

Data from the two year monitoring program established by the ROD indicates that the contaminant concentration in the acid mine discharges, and subsequently in Tar Creek, may be decreasing. However, surface water monitoring to date has been insufficient to adequately establish trends. Monitoring data has been erratic, with increases and decreases occurring with no apparent pattern. The general reduction in the concentration of the discharges from the mines may be related to the diversion and diking activities, although this has not been confirmed. Alternatively, a natural remediation process, whereby the material available for leaching may become depleted, may be occurring.

The After Action Report states that only 15% of the total metals loading to Tar Creek was calculated to be contributed by the known major discharges, and that 85% of metals loading to Tar Creek is from unidentified sources. EPA concludes it would not significantly improve water quality to collect and treat the known discharges.

The State of Oklahoma has established in the Water Quality Standards for Tar Creek the designated beneficial uses of 1) a limited aquatic habitat, and 2) secondary contact recreation. Statewide water quality standards for cadmium, lead and zinc, applicable to all waters of the state, including Tar Creek, are not being met; however, the Oklahoma Water Resources Board has stated the basis for these designated beneficial uses was the State’s conclusion that the water quality conditions are "...due to irreversible man-made damages incurred."

The Tar Creek Task Force had previously concluded the sediments provide an effective long-term sink for metals and should effectively remove them from most biological processes. EPA believes these sediments do not pose an increased environmental threat in Tar Creek. Concentrations of metals in sediments in the Neosho River are essentially unchanged above and below its confluence with Tar Creek.

C. Roubidoux Well Pluggings

Analysis of the data collected to date is insufficient to determine the well plugging remedial action's effectiveness and/or success at this time. However, the current monitoring clearly indicates all twenty-one of the public water supply wells sampled are producing water which complies with primary drinking water standards and is protective of human health. The monitoring data supports the conclusion that five wells are impacted by acid mine water and are not meeting secondary drinking water standards for iron, and one of these wells also fails the secondary standard for sulfate. However, these standards are not health based standards and are not enforceable. Further, the source of this contamination has not been established. Additional ground water monitoring is required to evaluate the effectiveness of the well plugging remedy, and to establish water quality trends in the Roubidoux Aquifer. The current monitoring program is designed to determine whether the source of contamination in the impacted public water supply wells is the Roubidoux Aquifer or poor well integrity.

D. Mining Wastes

Based on information collected at Superfund sites in Kansas and Missouri Region 7 has determined the levels of lead, cadmium, and zinc present in some mining wastes (i.e. waste rock, development rock, bulk chat and floatation pond sediments) present a significant risk to human health and the environment. Region 7 has issued one ROD for the Galena Subsite of the Cherokee County Superfund Site which establishes cleanup levels of 1,000 ppm lead, 25 ppm cadmium, and 10,000 ppm zinc. The RI/FS for the Baxter Springs and Treece Subsites at the Cherokee County Superfund Site, which are adjacent to the Oklahoma/Kansas state boundary and contiguous to the Tar Creek Superfund Site, indicates that the average concentration of cadmium in bulk chat (46 ppm) exceeds the Galena Subsite cleanup level. However, Region 7 may or may not select this cleanup level for the Baxter Springs and Treece Subsites. The average lead (750 ppm) and zinc (8,300 ppm) concentrations in bulk chat at these subsites do not exceed Galena's cleanup levels. In floatation pond sediments, the average concentrations of lead (3,800 ppm), cadmium (124 ppm) and zinc (21,600 ppm) all exceed these cleanup levels. While it is not known if concentrations of metals in the mining wastes at the Tar Creek site are similar to those at Baxter Springs and Treece, the proximity of the wastes and their contemporaneous origin suggest they would be similar.

The studies upon which the Tar Creek ROD were based did not include a risk assessment to examine the potential for direct exposure to and ingestion of hazardous substances from mining wastes. Air monitoring of fugitive dust emissions was conducted and results indicated that ambient air quality did not pose a risk to human health. Risk assessment guidance had not been developed at that time and emphasis at this site centered on surface and ground water contamination. Potential exposure scenarios and risks have not been calculated for the Tar Creek site. Further investigations would be required to determine an acceptable level of metals concentrations in mining wastes and to assess whether wastes are present which pose an unacceptable risk to human health and the environment.

XII. PROTECTIVENESS OF REMEDY

Based on the available post remediation monitoring data and the 5 Year Review, it cannot be concluded that the goals in the ROD have been met. The reasons for this statement are:

1. Of the twenty-one municipal water supply wells tested producing from the Roubidoux Aquifer, five of these wells, while currently meeting primary drinking water standards, appear to be clearly impacted by acid mine water. Although EPA and ODEQ feel the probable source of contamination is inadequate well integrity, the source of this contamination has not been determined.

2. The surface water in Tar Creek continues to be severely impacted. Acid mine water discharges have not been abated. However, the State of Oklahoma’s Water Quality Standards state that the water quality conditions in Tar Creek are irreversible. Additionally, the concentration of metals in the acid mine water discharge appear to be decreasing, resulting in water quality improvements.

While the remedy may not have met the goals in the ROD, it is protective of human health because the primary route of exposure addressed by the ROD, i.e., drinking water from the Roubidoux Aquifer, is meeting all health based primary drinking water standards. Additionally, the State of Oklahoma Water Quality Standards recognize the nature of the water quality degradation in Tar Creek as being irreversible and have selected designated beneficial uses to reflect this condition.

However, the 1984 ROD did not address exposure to mining wastes. The following recent information indicates further action may be warranted at the site to be protective of human health:

1. The risks associated with direct exposure to mining wastes in Oklahoma have not been determined, but EPA Region 7 approved a PRP produced RI Report in 1993 which examined similar wastes in Kansas and determined they pose an unacceptable risk to human health and the environment. Mining wastes in Kansas contain lead concentrations as high as 13,000 ppm, and cadmium levels as high as 540 ppm.

2. The Indian Health Service has indicated that 34% (66) of 192 children routinely tested due to their participation in the USDA WIC program have blood lead levels elevated above 10 µg/dl (letter dated January 21, 1994). This letter is included as Appendix F.

XIII. RECOMMENDATIONS

Based on the 5 Year Review of the Tar Creek Superfund site, the following recommendations are made:

1. A revision and extension of the post remediation ground water monitoring program is recommended to evaluate the success of the well pluggings in preventing contamination of the Roubidoux Aquifer. This recommendation is in the process of being implemented through the discrete sampling of the Roubidoux Aquifer being conducted by ODEQ and EPA. Upon conclusion of this project, the long term monitoring of the Roubidoux Aquifer will be conducted under the requirements of the public water supply program. Should the Roubidoux Aquifer be found to no longer be capable of meeting primary drinking water standards, the need for additional corrective action will be reevaluated.

2. The ROD envisioned that additional abandoned Roubidoux wells and boreholes would be located and need to be plugged. OWRB has located approximately 15 additional wells that may require plugging. EPA will evaluate the need to continue to plug abandoned wells based upon the results on the discrete sampling efforts.

3. The State of Oklahoma has concluded the damages to Tar Creek are irreversible, and has addressed this situation in the State's Water Quality Standards. No further remedial action or monitoring is recommended for Tar Creek. EPA may need to amend the ROD.

4. An investigation should be conducted to evaluate the impact of chat piles and floatation ponds on human health and the environment and whether additional remedial action is warranted. Suggested actions include:

A. Designation of a second operable unit at this site for mining wastes.

B. Initiation of a blood lead study in the area on Native American and other children.

C. Concurrent environmental sampling in high access areas (e.g. school yards, daycares, playgrounds) to assess potential sources of exposure to lead.

D. Mapping of all mine wastes (i.e., chat piles, excavated chat piles, and floatation ponds) by the use of aerial photographs or other remote sensing techniques.

E. Classification of surface mine wastes utilizing a field portable x-ray florescence unit.

F. Field sampling of a representative portion (approximately 10%) of mine wastes and affected media to confirm x-ray florescence unit performance.

F. Sampling of leachate from mine wastes.

G. Sampling of airborne particulates near mine wastes.

APPENDIX A

SITE INSPECTION REPORTS

AUTHOR: MICHAEL OVERBAY, RPM
U.S. EPA

DATE: SEPTEMBER 1, 1993, and JANUARY 14, 1993

RECORD OF COMMUNICATION	
FROM: Michael Overbay, RPM	TO: Tar Creek Files
DATE: 9/1/93 TIME:	TYPE: Trip Report
SUBJECT: Multi-Agency Site Inspection	

SUMMARY: On September 1, 1993, a site inspection was conducted at the Tar Creek site. Dennis Hrebec (ODEQ), Jennifer Lyke and Steve Richardson (ATSDR) accompanied me to the K-1 (Muncie) and O-3 (Admiralty) diversion structures. Both were observed to be in good physical condition and operating as designed. No maintenance appeared to be required, as both had been effectively vegetated and showed no signs of erosions. Discharges of acid mine water were observed to be active near the juncture of Tar Creek and Lytle Creek at site 4s as well as near the Commerce High School near site 13. No biota was observed in Tar Creek below the discharge locations. Sediments in the streambed were orange, indicative of metals (primarily iron) precipitation.

No attempt was made to observe any plugged wells, other discharge locations, or the diversion structure at location K-2 (Big John).

Many chat piles and abandoned floatation ponds were observed. Access is unrestricted in almost every location. Physical evidence of trespass was abundant. Some chat piles are actively being quarried for aggregate material. In some cases, the chat is washed to remove fines (which are highest in metals concentrations) before use. This wash water could potentially fail RCRA’s TCLP test.

CONCLUSIONS: The diversion structures were functioning as designed and did not appear to require any maintenance at this time.

ACTIONS TAKEN OR REQUIRED:

COPIES TO:

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION 6
1445 ROSS AVENUE, SUITE 1200
DALLAS, TEXAS 75202-2733

January 14, 1994

MEMORANDUM

SUBJECT: Trip Report, Tar Creek Superfund Site

FROM: Michael Overbay, RPM
OK/TX Remedial (6H-SR)

TO: Tar Creek Superfund Site Files

Carl Edlund, Chief, Superfund Programs Branch (6H-H) and I traveled to Ottawa County, Oklahoma, on Monday and Tuesday, January 10-11, 1994. The purpose of the trip was to review the status of the Tar Creek site in the context of the Five Year Review, and to coordinate activities. Other attendees were:

Bob Morby and Mark Doolan (Region 7);
Dennis Hrebec and David Cohenour (ODEQ);
Dwayne Beavers and Kent Curtis (ITEC);
John Dalgarn (BIA);
Teresa Provine and Don Moomaw (BoRec);
Don Ackerman (Indian Health Service);
Carrol Jackson (Quapaw Tribe);
John Froman (Peoria Tribe); and
Charles Hoffman (Landowner).

Additionally, State Senator Rick Littlefield met us Monday morning.

Monday, January 10, 1994

The group traveled to the Oronogo-Dunweg Superfund Site in Joplin, Missouri, and the Galena Subsite of the Cherokee County (Kansas) Superfund Site. Region 7 reviewed the results of the RI/FSs conducted on these sites and showed us the construction activities at the Galena Subsite. Under a 1989 ROD, a rural water supply system has been completed. This was necessary because about individual households were utilizing private water wells producing water from the contaminated Boone aquifer. Also, a second ROD is currently being implemented to dispose of chat (mine tailings) with lead concentrations above 500 ppm in mine shafts and sink holes. Approximately 3 million cubic yards of chat are being disposed of, and the land surface recontoured and vegetated, at a cost of approximately $9 million. Region 7 also has recently approved the PRP’s RI/FS for the Baxter Springs/Treece Subsites. This report documents that abandoned floatation ponds and excavated chat pile locations present significant threats to human health and the environment. **Concentrations as high as 13,000 ppm lead and 900 ppm cadmium have been identified.** Region 7 anticipates issuing a Proposed Plan by the end of January which will propose capping in place of the floatation ponds and institutional controls (zoning restrictions) on the excavated chat pile locations.

Tuesday, January 11, 1994

The group visited the diversion structures which Region 6 constructed in 1986. These were in good shape and functioning as designed. We also observed discharge locations near the juncture of Lytle Creek and Tar Creek, as well as near the Commerce High School. Many abandoned floatation ponds were observed, as well as numerous houses which appeared to be built on excavated chat piles or next to existing chat piles. A Little League baseball park was observed in Picher which was surrounded by chat piles. Also, ODEQ felt the site may be a former sedimentation pond.

The Indian Health Service representative, Don Ackerman, indicated the IHS has tested approximately 200 small children in the USDA WIC (Women, Infants and Children) Program and that **67 (33%) have had elevated blood lead levels. 30 (15%) of those had blood lead levels above 20 µg/dl.** This was the first time EPA has become aware of any actual data concerning elevated blood levels in this area. Copies of this data have been requested.

The Hockerville smelter site was also visited. Little evidence was seen of any major smelting activities.

Conclusions

The past investigations of mining wastes (chat piles, floatation ponds, and excavated chat piles) in Oklahoma have been very limited, as efforts have focused on contamination of Tar Creek and ground water. These mining wastes have been determined to represent an unacceptable health risk in Region 7 and similar wastes are clearly present in Oklahoma. The presence of a large portion of the population with elevated blood lead levels indicates the need for addition remediations should be evaluated. EPA should proceed with the recommendations in the draft Five Year Review of conducting a new RI/FS on the mining wastes and their impact on human health.

APPENDIX B

REPORT ON THE EFFECTIVENESS OF REMEDIATION ON THE TAR CREEK SUPERFUND SITE

AUTHOR: BERT E. BLEDSOE
ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
U.S. EPA

DATE: SEPTEMBER 6, 1989

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
P.O. BOX 1198
ADA, OKLAHOMA 74820

September 6, 1989

MEMORANDUM

SUBJECT: Report on the Effectiveness of Remediation on the Tar Creek Superfund Site

FROM: Bert E. Bledsoe, Research Chemist BEB
Applications and Assistance Branch
RSKERL

TO: Carl E. Edlund, Chief
Superfund Programs Branch (6H-S)
U.S. EPA, Region VI

THRU: Dick Scalf, Chief
Applications and Assistance Branch
RSKERL

The attached report entitled "Tar Creek - The Effectiveness of Remediation" is in reply to your technical assistance request of March 16, 1989, to aid the Oklahoma Water Resources Board in the review and analysis of data collected during the site's post construction monitoring period.

There was considerable delay in the finding and copulation of the data required for the evaluation of the effectiveness of the remedial action. Ground water quality, mine water levels, rainfall, and mine discharge data were gathered by the Oklahoma Department of Health, Oklahoma Water Resources Board, and the United States Geological Survey. Each of these agencies had sampled, analyzed, and collected data in the vicinity of the site prior to and/or subsequent to December 1986.

A statistical approach was used to determine the effectiveness of the remediation as no additional samples were taken or new data generated.

The report represents the combined effort of myself, Randall Ross, and the Dynamac support staff. If you have any questions or need further assistance, please contact me at (FTS) 743-2324.

Attachment

cc: Paul Sieminski, RPM Region VI
Dave Dillon, Oklahoma Water Resources Board
Rich Steimle, OSWER

TAR CREEK

The Effectiveness of Remediation

Superfund Technology Support Center
Robert S. Kerr Environmental Research Laboratory
Environmental Protection Agency
Ada, Oklahoma

September 6, 1989

INTRODUCTION

On March 16, 1989, the U.S. EPA's Region 6, at the behest of the Oklahoma Water Resources Board (OWRB), requested the Robert S. Kerr Environmental Research Laboratory (RSKERL) to assess the effectiveness of remediation activities at the Tar Creek Superfund Site. It is a former lead and zinc mining area in the Tri-State Mining District of Kansas, Oklahoma and Missouri. RSKERL, which is EPA's center for ground-water research, maintains a Ground-Water Technology Support Center, sponsored by the Office of Research and Development and the Office of Solid Waste and Emergency Response, to provide technical assistance to those involved with Superfund activities at hazardous waste sites.

Acid water from the Picher mine field is discharged into Tar Creek, which passes through several communities in northeastern Oklahoma and then empties into the Neosho River. The mine water also has the potential to migrate downward through abandoned wells into the area's major water supply, the Roubidoux aquifer.

Remediation at Tar Creek and the Picher mine field consisted of principally two activities. One was the diversion of surface runoff which was flowing into collapsed mines, and the other was the plugging of abandoned deep wells which provided possible communications between the Boone formation and the underlying Roubidoux aquifer. Remediation was completed by December, 1986, and was followed by post-remediation monitoring.

The Laboratory compiled data from a variety of sources and the report is based entirely on a review and analysis of those data and reports. The conclusions are, in large measure, based on a statistical evaluation of this data: in some cases conditions before and after remediation; and in others, trends after remediation. The recommendations are based on the statistical confidence afforded by existing data.

BACKGROUND

Regional water supplies are from the deep Roubidoux and the shallow Boone aquifers. Recharge areas are generally east of the Spring River in Oklahoma, Kansas and Missouri. Westward the ground water is confined, but along Tar Creek the Boone confining layer has been disrupted by erosion, collapsed mine features, and thousands of exploration holes associated with lead and zinc mining.

Long term pumping created a cone of depression into which mine shafts up to 300 feet could be excavated. With cessation of mining the pumping stopped, water rose in the mines, and by 1979 the discharge of mine water began from open holes whose elevations were below the potentiometric surface in the mines.

The mine workings, shafts, drifts; the numerous drill and core holes; and the geologic fractures, joints and breccias combine to make a system of extremely high transmissivity of underground water. Water entering the mines, either from the Boone or from the surface, results in rapid fluctuations of water in the mines and corresponding down gradient discharges to the Tar Creek area.

A. Site Visit

Early in this investigation a visit was made to the Tar Creek site to gain firsthand knowledge of the problem, the steps taken in remediation, and the geology and hydrogeology of the system.

The complexity of the mining operation, as well as its relationship with both surface and subsurface waters is apparent. Key observations were: 1) the tailings or chat piles have an undetermined but possibly important role in the overall hydrologic balance, 2) additional boreholes might exist and serve as points of mine water discharge, and 3) the complex surface and subsurface features make it very difficult to design and monitor a program of remediation in such a large hydrologic system.

The observation was also made that, at the time of the visit, the piezometric head in the mine was only a few feet higher than land surface. This was demonstrated by the standpipe at 4S.

B. Data Collection

Data was collected from several sources to evaluate the effectiveness of the well plugging operations in preventing or reducing contamination in the Roubidoux aquifer, and stream diversions to lower the amount of runoff inflow, and subsequent mine water discharges. Water quality, mine water level, rainfall, and mine discharge data were gathered by the OSDH, OWRB, and the USGS. Each of these agencies has sampled and analyzed in the vicinity of the site prior to and/or subsequent to December 1986. The data were received in either disk, tape, printout, or report form.

C. Well Plugging

Water quality data were merged for the cities of Commerce, Miami, Picher-Cardin and Quapaw, and sorted by date (Appendix A). Wells within a one mile radius of each city were grouped with other water quality data from that city. Discrepancies in well identification or numbering schemes among the different governmental agencies affect the sorting and analysis.

A statistical approach was used to determine whether the plugging of Roubidoux wells has significantly improved the water quality in municipal wells. A proper statistical evaluation depends on both the quantity and quality of appropriate data. The analysis was influenced by data limitations. These are:

1. Data for the period after December, 1986, when well plugging operations were completed, are very limited. For example, there are no more than six data points for a well after remediation.

2. Discrepancies in the identification of sampled wells among the agencies resulted in the need to group wells by city thereby preventing an analysis of individual wells.

3. Samples generally lack depth notations. There are, however, significant variations in water quality as a function of sampling depth.

4. Procedures were not uniform among the groups involved in collection and analysis.

The various limitations and concerns regarding the available data are reflected in the difficulties encountered in its analysis and interpretation (Appendix B). In spite of these difficulties, most of the data was considered to be real and analyzed accordingly. The analyses are fully described in Appendix C.

D. Surface Flow Diversion

Diversion data included information on daily rainfall at Picher, water levels in the Blue Goose mine, and mine discharges. Rainfall records date back to February, 1981, while the earliest water level data were recorded in February, 1980. Mine discharges were based on mine water levels. This information was sorted by date and merged into a single data set (Appendix D).

Water elevations in the mines respond to significant rainfall events within 24 hours. Unlike true ground-water hydrology, this rapid response to runoff allows the problem to be handled as a surface rather than a subsurface water problem.

The flooded mines and the Boone aquifer have a rather unusual hydrologic relationship. When water in the mine is high, it serves to recharge the local Boone formation. After periods of prolonged drought, release from storage in the Boone tends to maintain water in the mine and sustain a base flow to Tar Creek.

Water levels at the Blue Goose mine since February, 1980 have fluctuated from 788’ to 806’ (Figure 1). During the four-year period, November, 1984, through. November, 1988, almost all recordings of the water elevation were above 800 feet and the average water levels before and after diversion were not statistically different. Observations prior to November 1, 1984 were not used in the analysis because any difference in water elevations due to diking would be obscured by the large variability of the early data. The investigation used only four years of rainfall and mine water level response data; i.e., two years before and after the diversion remediation was completed.

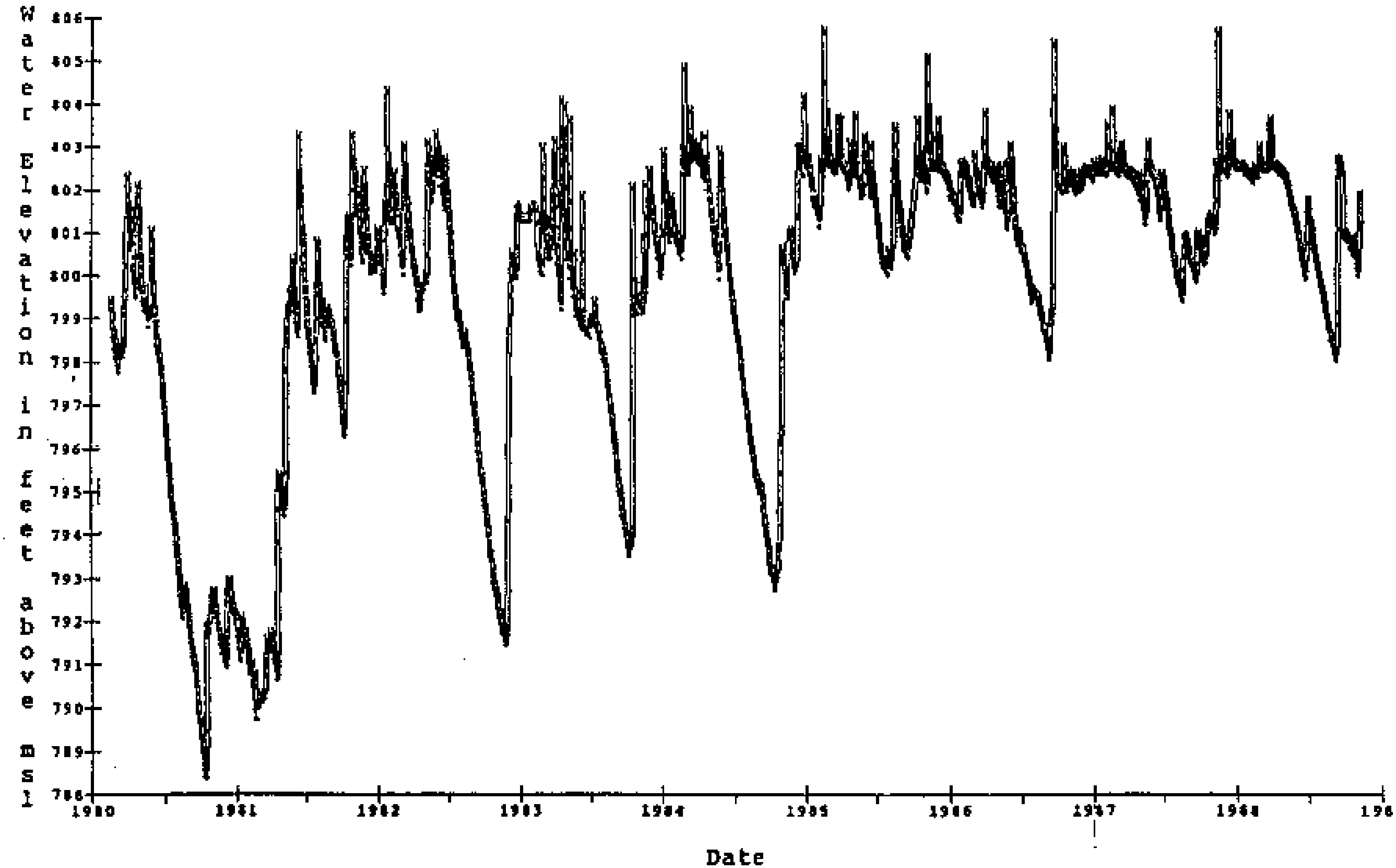


FIGURE 1. DAILY WATER ELEVATIONS IN THE BLUE GOOSE MINE 2/21/80 TO 11/14/88

APPROACH AND FINDINGS

A. Well Plugging

A number of statistical tests were made in an attempt to determine if water quality changes, in municipal wells, had occurred after the completion of well-plugging activities. A summary of possible changes is given in Table 1.

Table 1. Possible Improvements In Water Quality Since the Completion Of Well Plugging.

Roubidoux Water Quality Analysis

City	Parameter	Units	Transformation	Well Plugging Before	After
Commerce	Tot. Hard.	mg/l	None	146	124
Miami	Spec. Cond.	µS/cm*	NP	500	295
Miami	Tot. Hard.	mg/l	None	144	115
Miami	pH	Stnd.	None	7.7	7.3

* Values are based on the medians of the ranked data.
NP = Nonparametric
Note: All differences are significant at the 0.05 level.

Statistical comparisons for a number of parameters could not be performed due to a lack of data. Nevertheless, the water quality at Miami and Commerce appears to be slightly higher, with regard to a few parameters, since well plugging was completed. It is likely that these apparent changes are due to bias associated with comparing many pre-remediation values with a relatively few post-remediation observations.

An analysis of the data also suggests that water quality from Roubidoux wells differs from one area to another. For example, it appears that water in the Picher-Quapaw area is of significantly lower quality than that in the Commerce-Miami area with respect to some parameters. Table 2 provides a comparison of water quality means for these communities using the entire data base from January, 1980.

Table 2. Comparison of Mean Water Quality Parameters

Comparison Of Community Water Supplies				
	Miami	Commerce	Pitcher	Quapaw
Spec. Cond. - µS/cm	477	333	493	518
Tot. Hard. - mg/l	140	140	245	264
Fe - µg/l	105	284	847	932
Mn - µg/l	26	15	20	23
pH	7.6	7.5	7.3	7.2
SO_4 - mg/l	18	30	118	128
Zn - µg/l	45	33	316	78

It can be seen that differences in water quality are most pronounced with respect to total hardness, iron, sulfate, and zinc. A better understanding of these apparent differences could be made by additional comparisons with other municipalities taking water from the Roubidoux and removed from the mining area.

B. Surface Flow Diversion

The approach selected for this study is to develop a relationship between rainfall events and water level responses in the mines. The technique assumes that changes in water levels in the mine will differ after diversion because, for any given rainfall, less runoff will be available to enter the mine and alter the elevation. For example, if the water level in the mine rose about a foot after a 2 inch rain on the watershed (about 200 acre-feet of runoff) before the K-1 and K-2 diversions, it would be expected to rise less given the same rainfall after the diversion. The amount would be proportional to the effectiveness of the remediation.

Limitations in the data prevent other analyses. Total discharge volume measurements from the mines were not available. They would, admittedly, have been difficult to obtain as there are a large number of known discharge points, and other discharge points may not yet have been identified.

The relationship between rainfall events at Picher and water levels in the Blue Goose mine after October, 1984, is presented in Appendix E. In most instances a rise in the water table could be correlated with the amount of rain. In some cases no rise is observed despite a rainfall event, while in others a rise occurs when no rainfall was recorded. These situations probably result because rainfall at Picher is not always representative of rainfall on the watershed of K-1 and K-2. On still other occasions the rainfall was recorded halfway or at the end of a rise, or there was a series of small rains, making it difficult to determine the amount of rain responsible for the subsequent rise. In any case, it should be noted that this analysis could not account for rainfall intensity, time of day for sampling, and antecedent moisture content.

For those cases when the rainfall is simultaneous with the rise in mine water level, the amount of rise (in feet) was calculated for each rainfall (in inches). There are 42 data points before and 33 points after the diversion. These observations are normally distributed with a mean of 0.45 feet/inch before the diversion and 0.29 feet/inch after the diversion (Figure 2). According to the Record of Decision, 72% of the surface inflow was at sites K-1 and K-2 prior to diversion. If so the post-diversion water level responses should have a mean of 0.13 feet/inch.

The success of this test is affected by the nature of the rainfall data. Specifically, the rainfall data do not provide intensity information or the time when a rainfall event occurred. The data report only the total amount of daily rainfall. In addition, rainfall is collected at one station in Picher and often may not be representative of rainfall over the entire area contributing runoff to the mines.

In much the same way, this investigation is affected by water level measurements at the Blue Goose mine. These also are reported on a daily basis, resulting in the inability to establish a closer relationship between rainfall and water level responses.

It is important to note that the data limitations mentioned prevent the use of this information in any meaningful quantitative way. Rather, it can only be concluded that, based on two years of events before and after the diversion, the remediation was at best only partially effective in reducing surface runoff into the mines.

C. Standpipe Installation

During the site visit it was observed that the piezometric surface of the aquifer-mine hydrologic system was only a few feet above land surface. Therefore, a new proposal to control discharges from the mines is suggested.

A fundamental principle of ground-water hydrology is that any well open to the atmosphere and below the piezometric surface of a confined aquifer will be a free-flowing artesian well. As shown in Figure 3, if the discharge point of an open well is above the piezometric surface it will not flow.

Only eight boreholes in the Tar Creek area have been identified as free flowing: they are, by necessity, below the piezometric surface of water in the mines. Discharges from the boreholes are only a fraction of the total volume of water in the mines and the Boone aquifer. The cessation of these flows would, therefore, have an insignificant effect on water levels in the hydrologic system.

All identified free-flowing boreholes are less than four feet in diameter and most are less than two feet. If a corrosion-resistant pipe were driven into each borehole and sealed, so that the pipe extended above the piezometric surface of the mines, surface discharges at these points would cease.

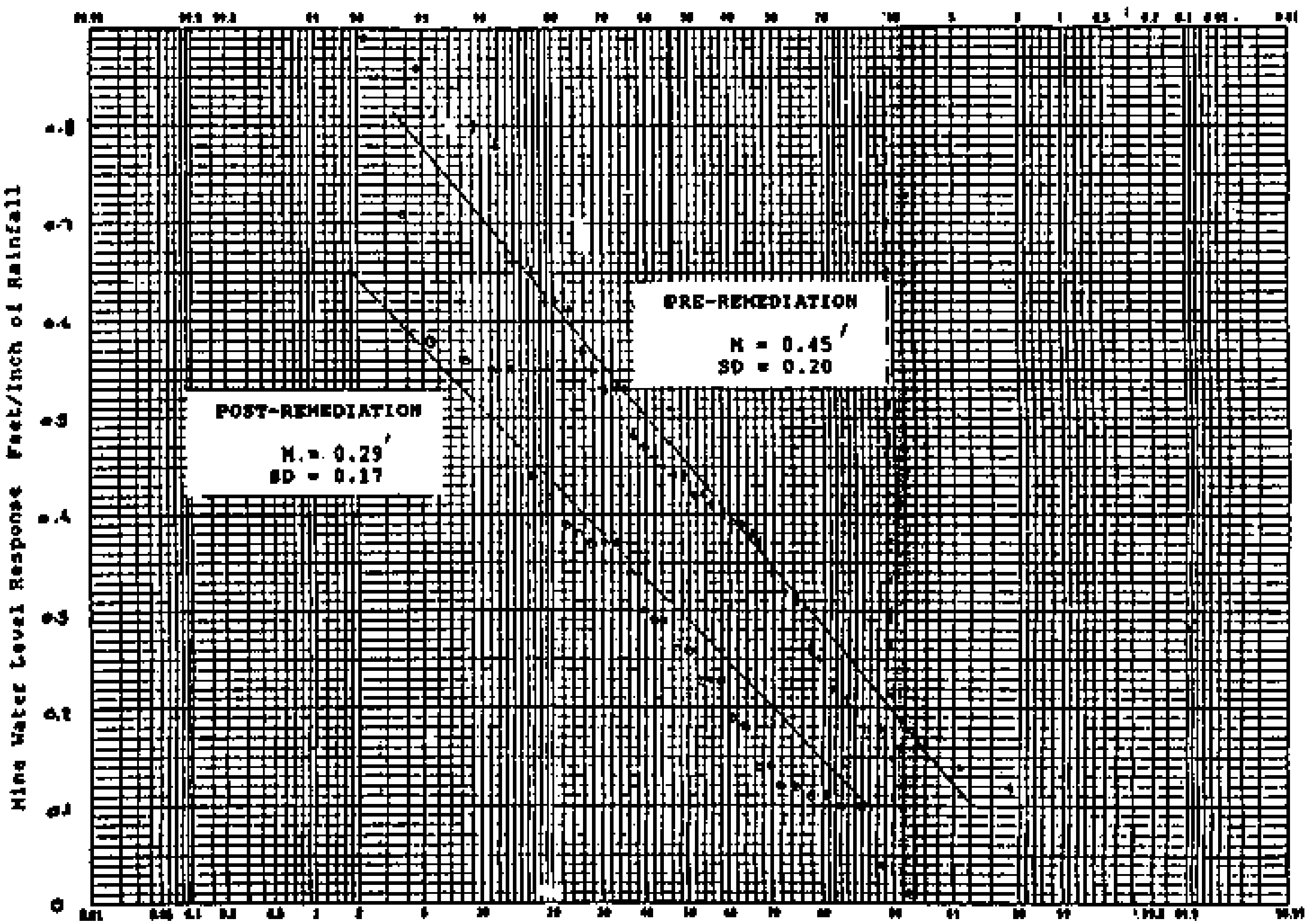


FIGURE 2. NORMALITY PLOTS OF PRE- AND POST-DIVERSION MINE WATER LEVEL RISE

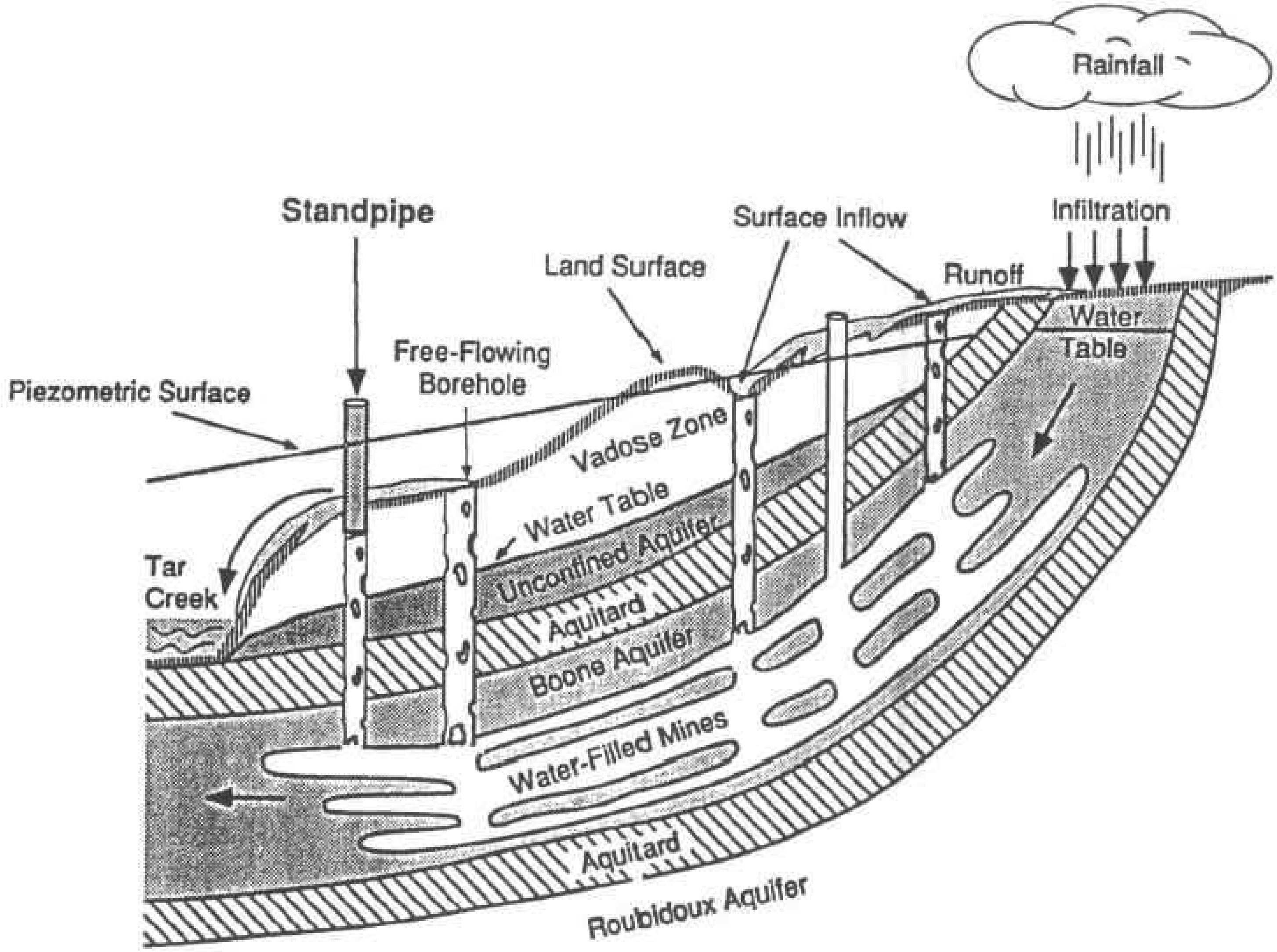


FIGURE 3. SCHEMATIC OF THE STANDPIPE PROPOSAL FOR THE CONTAINMENT OF SURFACE CONTAMINATION FROM ABANDONED LEAD-ZINC MINES IN THE TAR CREEK AREA.

The piezometric surface rarely exceeds a height of 806 feet above mean sea level. If standpipes were installed into each discharge point to a height of 807 feet, all known surface discharges from mines in the Blue Goose area would cease. The removal of these flows would also assist in locating other possible points of discharge.

It is suggested that a feasibility study for such a plan be made and, if favorable, a test project implemented.

CONCLUSIONS

Based on the analyses of this investigation, the following conclusions are made:

1. Monitoring data has been collected for a long period before remediation and only a short period after. This results in an unbalanced data set making statistical analyses of doubtful value except to illustrate possible trends.

2. An analysis of the water quality of mine discharges before and after the diversion of surface runoff into the mines is not useful in determining the effectiveness of the remediation.

3. Due to deficiencies in the existing data and the short period of post-remediation sampling, the effectiveness of well plugging cannot be established at this time.

4. Water quality in the Roubidoux at Picher and Quapaw is significantly inferior to that at Miami, Commerce, and Cardin with respect to total hardness, iron, sulfate, and zinc.

5. The diversion of surface flows at sites K-1 and K-2 are at best only partially effective in reducing inflow to the mines.

6. Discharges at 4S have a linear relationship with water levels at the Blue Goose mine and are assumed to be representative for the mine field. Mine water levels for a two year period prior to and a similar period after diversion of surface runoff have the same average. The discharge volumes for the two periods are therefore the same and the effect of diversions cannot be precisely determined.

RECOMMENDATIONS

Desirable objectives for remediation activities at Tar Creek are: (a) to protect and/or improve the Roubidoux aquifer's water quality, and (b) to reduce or stop the discharge of acid mine water into Tar Creek. To this end, and based on the conclusions of this investigation, the following recommendations are offered as guidance for additional post-remediation activities at Tar Creek:

1. Monitoring is an essential part of any remediation for it is necessary to understand baseline as well as changes in critical parameters. A monitoring plan must evolve to effectively and efficiently evaluate the effectiveness of the remediation. It is not necessary to sample frequently or analyze for every contaminant; it is, however, necessary to identify critical elements, such as sampling techniques, frequencies, and quality control.

2. EPA's "Practical Guide for Ground-Water Sampling" sets out recommendations for developing a sampling protocol to assure reliable measurements and quality control. It is recommended that the agencies which collect information at Tar Creek coordinate their objectives and methods in accordance with those guidelines. The clear objective should be to produce a data set that will yield reliable statistical information that confirms changes at the Tar Creek site. Some issues to address are:

    a. Single or multiple samples or measurements.
    b. Locations and standardized identifications for measurements and sample sources.
    c. Sampling techniques: frequency, purging, down hole vs discharge point.
    d. Sample collection and preservation.

3. It is recommended that plugging continue at all abandoned deep wells. The Roubidoux water is an important regional asset which should be protected by reasonable measures to prevent contamination. Water in the overlying Boone aquifer is under a higher head than the Roubidoux and therefore will flow downward where possible, carrying contaminants.

4. It is recommended that the monitoring of mine discharges and water quality continue. A larger data set is required to confidently predict the relationships between discharge, mine water levels and mine water level responses to rainfall.

5. An additional data set, which includes rainfall at a second location as well as intensity, has been gathered but not made available to RSKERL. It is recommended that this data be used to more accurately define the relationship between rainfall events and mine level responses. This will allow a more precise approximation of the effect of diversion on runoff inflow to the mines.

6. The USGS, OWRB, and OSDH should agree on a common numbering scheme for the municipal wells involved at the Tar Creek site. If a system could be agreed upon, the ensuing statistical analysis of water quality data could identify defective wells and account for a much higher percentage of the variability associated with the data.

7. It is recommended that down-hole sampling be considered at municipal wells. Preliminary data suggest extremely poor water quality exists at lower depths in these wells. Contamination may be entering the Roubidoux from the Boone that is only noticeable at the lower depths. By sampling only the discharges

of municipal wells, these concentrations are diluted by relatively pristine water in the upper reaches of the well.

8. It is recommended that in the future--quarterly, and if possible, monthly--sampling be conducted for given wells to provide the necessary data base from which to conduct a more valid statistical analysis.

9. It is recommended that a feasibility study be conducted to determine if surface discharges from the mines can be contained by installing standpipes at points of discharge with their tops being above the maximum elevation of the piezometric surface of the aquifer-mine hydrologic system. If such a study proves favorable, a test project should be implemented.

APPENDIX C

TAR CREEK AFTER ACTION MONITORING REPORT

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OKLAHOMA WATER RESOURCES BOARD

DATE: APRIL 5, 1991

TAR CREEK AFTER ACTION MONITORING REPORT

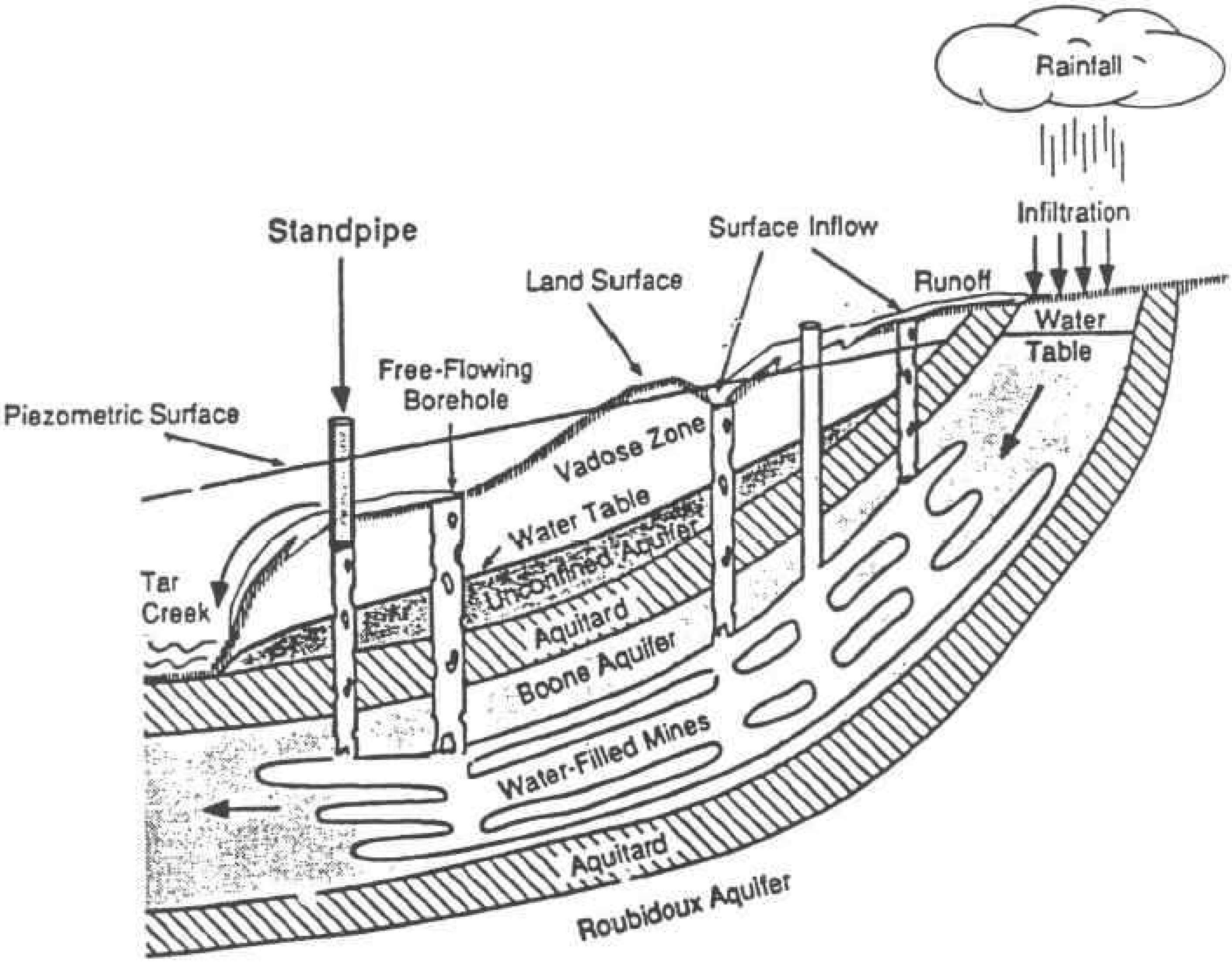
INTRODUCTION

The Picher field, located in Ottawa County, Oklahoma and Cherokee County, Kansas, is one of the lead-zinc subregions comprising the tri-state mining region of Oklahoma, Kansas and Missouri. As the Picher field was mined, starting in 1904, depths to 385 feet were reached and a cavity approaching 100,000 acre feet was created.

By 1979, a majority of the mine workings were flooded due to ground water infiltration and surface water inflow. As the piezometric surface exceeded the land elevation in low lying areas along Tar Creek in Oklahoma, acid mine water discharged to the surface through abandoned mine shaft openings and boreholes. Tar Creek has since experienced significant degradation due to these surface discharges. Figure 1 provides a schematic view of this process.

The mines are contained within the Boone Aquifer, which overlies the Roubidoux formation, a major source of drinking water for communities in the area. (See Figure 1) It is theorized that the Roubidoux is being contaminated by downward migration of the acid mine water through vertical fractures in the interlying formations or through

Figure 1. Schematic of the Acid Mine Water Pollution Process



the numerous abandoned wells, connecting the Boone and Roubidoux formations.

Both state and federal agencies have performed numerous activities in response to the acid mine water contamination, culminating in the remedial actions directed by the Record of Decision (ROD). A ROD was required since the Picher field was made a Super Fund site and received federal funding under CERCLA.

The remedial action dictated by the ROD to mitigate surface discharge involved diking and diversion of surface runoff flowing into collapsed mine shafts and bore holes which were still connected to the mine works. To mitigate Roubidoux aquifer contamination, abandoned deep wells which provided possible access between the Boone and Roubidoux formations were plugged.

Remediation was completed by December, 1986, and was followed by post-remediation monitoring. The purpose of this monitoring is to determine if the pollution caused by the acid mine drainage has abated since the remediation activities were completed. Therefore, ground water quality data was collected from municipal wells, to see if water quality in the Roubidoux had improved. Flow measurements were made and surface water quality data was collected to determine if the pollutant loading to Tar Creek had decreased since remediation.

This report will discuss the three mechanisms by which pollution from the Picher Field could have been abated during the 1980’s. They are:

1. Concentrations in acid mine discharges decrease as contaminants are leached from the mine works and flushed, leaving less material available for leaching.

2. Loading to Tar Creek decreases as the flow of acid mine drainage is reduced due to decreased surface inflow through the diking and diversion accomplished by the remedial action.

3. Loading to the Roubidoux aquifer decreases through decreased migration of groundwater from the Boone aquifer to the Roubidoux due to the well plugging accomplished by the remedial action.

The effectiveness of the remedial actions was analyzed by the Superfund Technology Support Center, at the Robert S. Kerr Environmental Research Laboratory. Therefore the majority of this report will deal with the first mechanism listed above, and the Lab’s findings concerning the remaining mechanisms will be summarized.

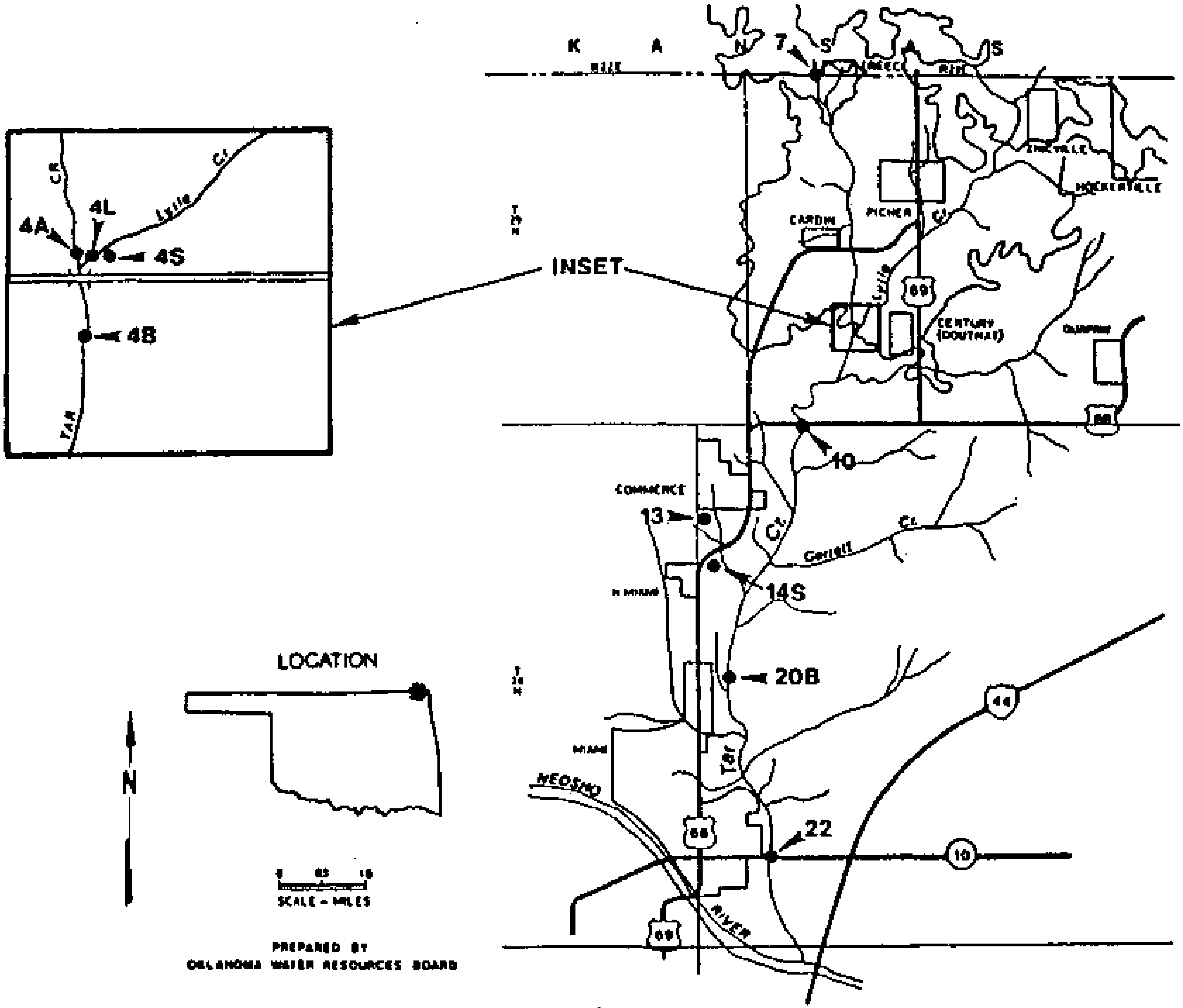
The impact of acid mine drainage is twofold. It pollutes both Tar Creek and the Roubidoux aquifer. Surface water samples are taken to determine the effect of acid mine drainage on Tar Creek, and groundwater samples show the effect on the Roubidoux aquifer. Therefore, surface and groundwater sampling will be treated separately.

SURFACE WATER MONITORING SITES

Initial surface water monitoring efforts were conducted by the OWRB with the assistance of the U.S.G.S. Monitoring stations were installed on Tar Creek in 1979 using federal funds from EPA. The monitoring program was expanded in 1980, under the direction of the Governor’s Tar Creek Task Force. The sampling sites which are used in this study are shown in Figure 2. Some of the sites in Figure 2 are located on Tar Creek, while others are at locations where acid mine water discharges to the surface.

Sites located on Tar Creek will be discussed first. Site 7 is located on the state line, well above the known inflow points. Site 4a is just upstream from the first identified discharge but below the new confluence with Lytle Creek created as part of the remedial action. Lytle Creek was diverted around Site 4L. This is not shown in Figure 2. Runoff from large tailing piles enters Tar Creek above site 4a. Site 4b is immediately downstream from major acid mine discharges monitored at 4s and 4L. Site 10 is located a few miles downstream from unmonitored acid mine discharges which enter Tar Creek below site 4b. Site 20b is below all known discharges of acid mine water. This site location changed in 1984 due to a relocation of the USGS stream monitoring gage. Water quality monitoring at this site is tied to the USGS gage so that stream loading may be estimated. Site 22 is the furthest downstream. It is situated so that it can detect any recovery of water quality in Tar Creek before it enters the Neosho (Grand) River.

Figure 2. Sampling sites on Tar Creek.



Four sites monitor acid mine water discharges (Figure 2). Site 4L is at a wier set in the old Lytle Creek channel. Since Lytle Creek was diverted from its channel to enter Tar Creek above site 4a, the flow measured at the wier is almost totally mine discharge. Site 4s is a wier which measures discharge from springs south of Lytle Creek. However, several springs in this area are not monitored. Site 13 is a wier designed to measure flow from a collapsed mine shaft. Site 14 is a spring which is the southern-most known acid mine discharge. It was the first discharge from the Picher field, in 1979, and the first to receive a wier. The wiers at 14 and 4s were installed before remedial action was undertaken, while the wiers at 4L and 13 were installed after remediation.

TAR CREEK WATER QUALITY

Tar Creek is adversely impacted by several substances in the acid mine water discharges. To determine what these substances are, a series of samples for various substances were taken between 02/05/80 and 12/23/82. The parameters analyzed included alkalinity, aluminum in sediment, dissolved aluminum, total aluminum, arsenic, dissolved cadmium, cadmium in sediment, total cadmium, chemical oxygen demand, dissolved chromium, chromium in sediment, total chromium, copper in sediment, dissolved copper, total copper, dissolved oxygen, total fluoride, total hardness, iron in sediment, dissolved iron, total iron, lead in sediment, dissolved lead, total lead, manganese in sediment, dissolved manganese, total manganese, mercury in sediment, dissolved mercury, total mercury, nickel in sediment, dissolved nickel, total nickel pH, suspended solids, total solids, dissolved solids, specific conductance, sulfate, water temperature, zinc in sediment, dissolved zinc, and total zinc. The raw data is available at the offices of the Oklahoma Water Resources Board.

Three water samples were taken at each site. One sample was filtered in the field, using a manual vacuum pump with a .45 micron filter. This sample and another were preserved with acid for metal analysis. The remaining sample was preserved on ice. Sampling was accomplished using standard procedures. Analysis was performed by the Oklahoma State Department of Health laboratory, following Standard Methods.

The results from these samples showed elevated levels of several parameters. They established a baseline of water quality in Tar Creek during the early years of acid mine drainage. Obviously, the acid mine waters were leaching heavy metals from the mine works. During residence in the mines, and after discharge to Tar Creek, chemical reactions were taking place which affected other parameters, such as dissolved oxygen and pH.

After remedial action, the chemical quality of Tar Creek was again assessed. Although no remediation to improve water quality was undertaken, it was theorized that as time went on water quality should improve, because less material was available for leaching. Quarterly samples were taken between 01/27/87 and 02/02/89. Because several parameters did not show elevated levels they were eliminated from this round of sampling. During this period, dissolved cadmium, total cadmium, dissolved oxygen, total fluoride, iron in sediment, dissolved iron, total iron, lead in sediment, dissolved lead, total lead, pH, specific conductance, sulfate, sulfate in sediment, water temperature, zinc in sediment, dissolved zinc and total zinc were analyzed on a quarterly basis.

WATER QUALITY TABLES

Tables summarizing water quality data are presented below. The concentrations in the tables are the means of the data collected in 1980-82 and of the data collected in 1987-89. For each period, about three to ten concentrations of a specific substance are used to compute the average.

In some cases, data have been deleted, because it is obviously erroneous. Questionable data has been included. This occasionally results in dissolved concentrations which are greater than total concentrations. Concentrations of heavy metals are measured as ug/L, while fluoride and sulfate are measured as mg/L.

To determine if water quality is changing over time, the percent change in concentration is computed using

$$\% \text{ change} = \frac{a-b}{C} \times 100,$$

where a = mean concentration for the period 1987-89, b = mean concentration for the period 1980-82, and c is the smaller of a or b. This method to compute concentration changes over time was chosen because the data are not ammenable to trend analysis.

WATER QUALITY AT SITE 7

Since site 7 is upstream from any known acid mine discharge it is assumed that elevated concentrations are due to leachate from tailing piles. Table 1 shows mean concentrations of selected parameters at site 7.

Table 1. Concentrations of selected substances at site 7.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 Total	87-89 dissolved total	% change
Cadmium				21.3	16.9	- 26
Fluoride				.29	.19	- 53
Iron	1063			5663	799	-609
Lead	27.7	36	+ 31	58	107	+ 84
Sulfate				626	341	- 84
Zinc	9055	3241	-181	5870	3523	- 67

Average % change - 113

EPA’s human health criterion (Gold Book) for cadmium is 10 mg/L. The average cadmium concentration exceeds this criterion. The water quality standards to protect fish and wildlife propagation from lead is 24.6 mg/L. The average lead concentration exceeds this value. The water quality standards to protect fish and wildlife propagation from zinc is 414 mg/L. The average zinc concentration exceeds this criterion by nearly an order of magnitude. The water quality standard for sulfate is 96 mg/L. The average concentration exceeds this criterion.

The average concentration during the period 1980-82 was generally higher than the period 87-89. While lead concentrations appear to have increased, concentrations of the other substances appear to have decreased. In general, concentrations at this site have decreased throughout the decade, but still violate water quality standards and a human health criterion.

WATER QUALITY AT SITE 4a

Site 4a is directly upstream from the area where a majority of the acid mine discharge enters Tar Creek, so it may be assumed that a majority of the elevated concentrations observed at this site is due to tailing pile leachate. Table 2 shows mean concentrations of selected parameters at site 4a.

Table 2. Concentrations of selected substances at site 4a.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	%change
Cadmium	30	26	- 31	23	27	+ 19
Fluoride				0.9	0.4	- 125
Iron	13,604	889	-1430	11,433	1011	-1031
Lead	20	36	+ 77	23	38	+ 63
Sulfate				679	522	- 30
Zinc	20,584	7,786	- 164	26,270	7620	- 245

average % change = -290

Note that in general concentrations are higher at site 4a than at site 7. There are several major tailing piles between the two sites.

The average cadmium concentration exceeds EPA's human health criterion. The water quality standards for lead, sulfate and zinc are violated at site 4a. The criterion for zinc is exceeded by more than an order of magnitude.

The average concentration during the period 1980-82 was generally higher than the period 87-89. Concentration of iron decreased by an order of magnitude during the decade. However, lead concentrations increased. Summarizing the concentration observations at both sites 7 and 4a, it appears that in general, concentrations in Tar Creek due to tailing pile leachate are generally decreasing, but still cause a violation of water quality standards and a human health criterion in Tar Creek. Concentrations of lead due to tailing pile leachate appear to be increasing.

Lead, which increased in concentration at the upper stations during the decade, decreased at site 10. With the exception of iron and sulfate, all concentrations decreased at this site.

WATER QUALITY AT SITE 20

Site 20 is downstream from all known acid mine discharges. Table 5 shows mean concentrations of selected parameters at site 20.

Table 5. Concentrations of selected substances at site 20.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	% change
Cadmium	29	12	-145	19	13	- 39
Fluoride				2.2	1.2	- 83
Iron	4,615	17,691	+283	8,853	20,034	+126
Lead	26	36	+ 37	33	37	+ 11
Sulfate				619	1,186	+ 92
Zinc	20,711	20,268	- 2	21,333	21,408	0

Average % change = +28

A comparison of table 5 and table 2 shows that concentrations above and below the discharge areas are about the same. However, the flow in Tar Creek has increased considerably between the two sites. Therefore, the loading (mass/time) is much greater at site 20 than at site 4a. This indicates that a majority of the pollution of Tar Creek is caused by the acid mine discharges.

The average cadmium concentration exceeds EPA's human health criterion at site 20. The water quality standard for lead is routinely violated, and the criteria for sulfate and zinc are generally exceeded by more than an order of magnitude.

While concentrations of some substances increased during the 1980's concentrations of other substances decreased, so that the net effect was little change in overall concentrations. In general, concentrations at this site may be considered to be relatively stable throughout the decade.

WATER QUALITY AT SITE 22

Water quality at site 22 represents the recovery of Tar Creek from acid mine drainage. This site is the farthest downstream. Discharge from the Miami POTW helps buffer the acidity of the mine water at this point. Table 6 shows mean concentrations of selected parameters at site 22.

Table 6. Concentrations of selected substances at site 22.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	% change
Cadmium	2.7	8.9	+229	5	9	+ 80
Fluoride				.6	1.0	+ 67
Iron	200			1,260	10,928	+ 767
Lead	20	36	+ 80	20	38	+ 90
Sulfate				152	969	+ 538
Zinc	1,083	16,403	+810	6,083	15,149	+ 149

Average % change = +312%

A comparison with table 5 shows that concentrations have decreased between sites 20 and 22. Cadmium does not usually violate the human health criterion at this site. However, water quality standards for lead, sulfate and zinc are still violated.

Concentrations at site 22 increased markedly during the 1980’s. The concentration of every substance listed in Table 6 appears to have increased. However, it is assumed that if the decreases in concentration observed upstream continue, then eventually concentrations at site 22 will decrease, since there are no known sources of acid mine water in the downstream portion of Tar Creek.

SUMMARY OF TAR CREEK WATER QUALITY

While the data by no means provides conclusive evidence, it is perceived that concentrations in Tar Creek due to acid mine drainage and tailing pile leachate are decreasing slightly. Further monitoring will be required to determine if this perception is correct.

ACID MINE DISCHARGE WATER QUALITY

Discharge water quality was observed at four locations in the Picker field. The springs at sites 4s and 14, as well as the cave-in at site 13 were monitored for water quality over the same periods as sites on Tar Creek. However, the water quality at 4L was only observed after remedial action was completed. Parameters analyzed were the same as for

Tar Creek. Tables summarizing the quality of the mine discharges are presented below. The format for these tables are the same as those summarizing sites on Tar Creek.

WATER QUALITY AT SITE 4s

Table 7 shows mean concentrations of selected parameters at site 4s.

Table 7. Concentrations of selected substances at site 4s.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	% change
Cadmium	154	19	- 717	130	19	- 592
Fluoride				13	4	- 258
Iron	367,500	165,960	- 121	352,048	170,033	- 107
Lead	46	33	- 40	68	65	- 4
Sulfate				3,096	2,184	- 42
Zinc	227,942	59,786	- 281	231,814	62,161	- 273

Average % change = -244

Concentrations in the discharge are much higher than in Tar Creek. A comparison of Tables 7 and 2 show that fluoride, iron, zinc and sulfate concentrations are an order of magnitude larger in the discharge than in the stream. However, concentrations at 4s decreased for every parameter during the 1980’s.

WATER QUALITY SITE 4L

Table 8 shows mean concentrations of selected parameters at site 4L.

Table 8. Concentrations of selected substances at site 4L.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	% change
Cadmium		9			12	
Fluoride					2.3	
Iron		88,444			64,840	
Lead		36			60	
Sulfate					2,145	
Zinc		48,282			49,625	

Average % change =

No changes in concentration can be produced for this site, since no observations were made before remediation was undertaken. A comparison of tables 7 and 8 shows that the concentrations at 4s were generally higher than at 4L. Since 4s and 4L are within a few hundred feet of each other, the mine water which feeds both discharges must be of the same quality. The differences are probably due to the differing natures of the sampling points. Samples at 4s were taken as the water bubbled up from the ground. Samples at 4L were taken at the wier, after water had overflowed from cave-ins and flowed an appreciable distance down the old Lytle Creek channel.

WATER QUALITY AT SITE 13

Samples were taken at the wier after the acid mine water was discharged from a cave-in. Table 9 shows mean concentrations of selected parameters at site 13. All concentrations decreased during the 1980’s at this site.

Table 9. Concentrations of selected substances at site 13.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	% change
Cadmium	263	25	- 962	239	29	-910
Fluoride				6	1	-470
Iron	108,530	95,452	- 14	168,700	100,985	- 67
Lead	45	36	- 24	97	60	- 60
Sulfate				1900	1843	- 3
Zinc	32,177	17,430	- 84	86,250	17,645	-389

Average % change = -298

WATER QUALITY AT SITE 14

Samples were taken as the water bubbled out of the spring at this site. Table 10 shows mean concentrations of selected parameters.

Table 10. Concentrations of selected substances at site 14.

	Period					
	80-82 dissolved	87-89 dissolved	% change	80-82 total	87-89 total	% change
Cadmium		11		13	13	- 3
Fluoride				5	2	- 94
Iron	520,333	286,080	- 82	500,827	288,300	- 74
Lead	24	33	+ 40	+ 33	57	+ 73
Sulfate				2892	2,438	- 19
Zinc	119,415	19,050	-527	125,214	19,072	-557

Average % change = -124

Since sites 13 and 14 are close together, water quality at these two discharges should be about the same. However, the spring at site 14 discharges a very large amount of iron. Iron concentrations at this site were the highest observed in the Picher field.

SUMMARY OF ACID MINE DRAINAGE WATER QUALITY

Concentrations of some constituents are much higher in the discharges than in Tar Creek. This is particularly true for iron and zinc.

While changes in concentration during the 1980’s in Tar Creek are not clear cut, the trend in concentrations in the discharges is unambiguous. Concentrations of all substances decreased at all discharge points, except for lead at site 14. As theorized, less material available for leaching in the mines results in lower concentrations in the discharge. As concentrations in the discharge continue to decrease, a substantial decrease in concentrations in Tar Creek will likely be the result. However, it may still be a long time before water quality standards are not violated, if no further remedial action is undertaken.

HYDROLAB MEASUREMENTS

Temperature, pH, conductivity and dissolved oxygen (D.O.) were measured in the field using a hydrolab. These measurements were made on a frequent basis, resulting in more than two hundred records per parameter during the 1980's at some sites. The average pH, D.O. and conductivity are provided in Table 11.

Table 11. Hydrolab Data

Site	pH(S.U.)	D.O. (Mg/L)	Conductivity(umhos/cm)
7	7.0	9.0	825
4a	6.6	8.3	1350
4b	5.9	6.3	2022
10	5.7	6.6	2087
20	5.2	6.1	1606
22	6.6	9.8	1602

At site 7, upstream from the acid mine discharges, the pH and D.O. are high with relatively low conductivity. At site 20, below the acid mine discharges, the pH and D.O. are low, with high conductivity. The minimum pH recorded at site 20 was 2.7, while the minimum pH at site 7 was 4.9. The acidity of the stream increased dramatically due to the acid mine water.

The water quality standard to protect fish and wildlife propagation from acidity is pH greater than 6.5. This standard is routinely violated at sites 4b, 10 and 20. At site 22, where the water quality is improving, pH and D.O. have increased considerably compared to site 20. Site 22 is the only station where water quality standards violations for D.O. were not observed. On Tar Creek, the D.O. standard is 3 mg/L, except between April 1 and June 15, when it is 4 mg/L.

AESTHETICS

According to the Oklahoma Water Quality Standards, the state's waters must be free from floating materials and suspended substances that produce objectionable color and turbidity. The oxidation of the iron in the acid mine discharge causes Tar Creek to run red at sites 4b, 10 and 20. Unsightly stains are left on bridge abutments and trees. If the acid mine discharges stop, this standards violation will be abated immediately.

FLOW COMPARISONS

Data for flow computations were taken at five locations; the four wiers and site 20, where a USGS flow measuring station is located. The Cipoletti wier crests are four feet wide at sites 4s and 4L, three feet wide at site 13, and one foot wide at site 14. Flow at the wiers is computed using depth of water flowing over the wier crest, which was measured at the times the hydrolab readings were taken (generally on a weekly basis, but with some sizable data gaps).

To obtain the flow at the wiers, the average depth over the crest was used. The relationship between depth and flow for a Cipoletti wier is given by

$$Q = 3.367LH^{3/2},$$

where:

Q = flow rate in cubic feet per second
L = length of wier crest in feet
H = depth of water overcrest in feet.

The mean flow for Tar Creek at site 20 was estimated using the data available to the OWRB after the gauging station was relocated.

LOADING COMPARISONS

Loading is simply concentration times flow. Because loading in Tar Creek is so high, it will be expressed here as tons/year. Temporal loading comparisons can only be accomplished at sites 4s and 14, because these are the only sites at which flow records are available during both periods when concentration data was collected. Loading before and after remediation is shown in Tables 12 and 13.

Table 12 Loading at Site 4s
(tons/year)

Substance	1980-82	1987-89	% change
Cadmium	.142	.019	- 659
Iron	383.7	169	- 127
Lead	.074	.065	- 14
Sulfate	3374.6	2169	- 56
Zinc	252.7	61.7	- 310
Average			- 233

A comparison of tables 7 and 12 shows that the percent changes are about the same for both concentration and loading. This is because the flow at site 4s didn't change much during the 1980's.

The change in loading at site 14, unlike that at site 4s, was not proportional to the change in concentration.

Table 13. Loading at Site 14
(tons/year)

Substance	1980-82	1987-89	% change
Cadmium	.004	.005	+ 19
Iron	172.3	122.0	- 41
Lead	.011	.024	+ 118
Sulfate	994.8	1031.2	+ 4
Zinc	43.07	8.1	- 434
Average			- 67

A comparison of Tables 13 and 10 shows that the absolute percent change is less for loading than for concentration. While concentrations generally decreased after remediation (although not because of remediation), flow at site 14 increased substantially.

Table 14 shows loading at sites 13 and 14L after remediation. Loadings before remediation could not be computed because the wiers were not yet in place. Note that the loading from site 14 is greater than at site 13.

Table 14. Loading at Sites 13 and 4L
(tons/year)

Substance	Suite 13	Site 4L
Cadmium	.013	.015
Iron	45.7	81.1
Lead	.027	.075
Sulfate	835	2,682
Zinc	8	62

The loading at site 20, on Tar Creek downstream from all known acid mine discharges, may be computed using flow data from the USGS station. It is used to show the total loading to Tar Creek from the Picher field, and to estimate the fraction of the loading monitored at the four wiers. Consider Table 15.

Table 15. Loading at Site 20 and Total Wier Loading (tons/year)

Substance	Site 20	Total Wiers	Fraction
Cadmium	1.02	.052	.05
Iron	924	418	.45
Lead	2.24	.191	.09
Sulfate	170,560	67,167	.04
Zinc	1,368	140	.10

The mines have been discharging to the surface for about 10 years. Therefore, since the discharge started, more than 10 tons of cadmium, 9,000 tons of iron, 22 tons of lead, 1,700,000 tons of sulfate and 13,000 tons of zinc have flowed down Tar Creek.

It was estimated that about half the acid mine discharge to Tar Creek was monitored. However, Table 15 shows that only about 15% of the loading is accounted for at the wiers. Either there are many unknown discharges of acid mine water, or much of the loading is due to surface sources (such as tailing pile leachate or resuspension).

SEDIMENT DATA

Sediment samples were taken at the stream monitoring sites. Data for selected substances are displayed in Table 16 for pre-and post-remedial action periods.

Table 16. Sediment Concentrations (mg/kg)

Site	80-82 Iron	80-82 Lead	80-82 Zinc	87-89 Iron	87-89 Lead	87-89 Zinc
7	3,267	101	2,267	3,155	526	8,420
4a	7,878	289	5,083	4,673	562	5,075
4b	123,950	967	13,850	20,629	388	31,258
10	30,000	320	5,100	86,557	888	19,907
20	118,333	246	6,950	65,534	245	4,457
22	19,000	53	5,675	77,935	290	6,117

The iron concentration increases by an order of magnitude in stream sediments downstream from acid mine discharges. Above the discharges, average iron concentration in sediment is about 4,743 mg/kg. Below the discharges the average concentration is around 67,742 mg/kg.

Due to the lead concentration in the sediment, it must be examined as a hazardous waste before it can be removed from the streambed. A concentration above 100 mg/kg is likely to produce a hazardous waste, so all of the sediment in Tar Creek has this potential. The average concentrations, shown in Table 16 for each site, exceeds 100 mg/kg for lead. The maximum concentrations observed were 1084 mg/kg at site 7, 1958 at 4a, 1780 at 4b, 3208 at site 10, 380 at site 20 and 572 mg/kg at site 22. The maximum concentrations exceeded 100 mg/kg by an order of magnitude at all sites except 20 and 22. The lead concentrations in Tar Creek sediment may be increasing with time. The average lead concentration in the sediment in the early 80's was about 329 mg/kg, but current concentrations appear to be around 483 mg/kg.

SUMMARY OF CONCENTRATION AND FLOW DATA

Loading to Tar Creek has been high throughout this decade, causing water quality standards and human health criterion violations on a continuous basis. Zinc concentrations sometimes violate water quality standards by two orders of magnitude, and the lowest pH recorded in the creek was 2.7.

Only about 15% of the load in Tar Creek is monitored at the wiers. This could indicate that a majority of the load is due to surface sources, rather than acid mine discharge. Surface sources could include tailing pile runoff or resuspension. Resuspension might be indicated by the increase in concentration recorded at site 22, near the Neosho River, during the 1980's. Since concentrations in the region of Tar Creek where a majority of the sources of heavy metals exist has generally decreased, it is difficult to find another explanation for increased concentration at site 22.

One heavy metal concentration has not generally decreased in the Picher field. The data indicates that lead concentration may have increased, on the average. Since lead is less soluble than, for example, zinc; it may be that the amount of lead available for leaching does not decrease as rapidly as for more soluble metals. Therefore, lead concentrations in Tar Creek may remain stable for a considerable time if no further remediation work is undertaken.

Cleanup is complicated by the possibility that Tar Creek sediment may have to be considered a hazardous waste, due to high lead concentrations, if it is removed from the streambed. Since lead concentrations do not appear to be decreasing in Tar Creek sediment, the potential for the sediment being a hazardous waste will not diminish rapidly with time.

Because the data is sparse, many factors affecting concentration in the water column and sediment could not be examined. Therefore, conclusions based upon the available data must be viewed as tentative.

TAR CREEK BIOTA

Sampling for fish and benthic macroinvertebrates was conducted in Tar Creek in October, 1989. Three sites were sampled; 7, 20 and 22 (see Figure 1).

Fish were sampled through electrofishing and seining. The electrofishing unit consists of a 220 v generator and a VVP-15 coffelt unit in a small boat, pulled behind employees in chest waders with hand-held electrodes. This is a very efficient capture mechanism when the water is not too deep. A ten foot minnow sein was also employed. Each site was sampled for 30 minutes by a a three man team. All fish collected were preserved in the field with a 10% formalin solution, and identified in the laboratory.

Benthic macroinvertebrates were sampled following the Rapid Bioassessment Protocol II. Organisms were then sorted and preserved in 70% Ethanol for laboratory identification. The paucity of benthic organisms precluded analysis at sites 7 and 20.

BIOTA AT SITE 7

At site 7, 3 warmouth, 3 mosquito fish, 2 largemouth bass, 11 green sunfish, 5 bluegill sunfish and 8 blackspotted topminnows were collected. This may not be representative of the biota at the site, which consisted of a large pool that was too deep for efficient sampling with the equipment used. The assemblage of fishes in this pool cannot be considered to be limited by the pollution revealed by the chemical analyses. Criteria to protect fish and wildlife propagation were normally exceeded for lead, and often by an order of magnitude for zinc, at this site.

BIOTA AT SITE 20

The fish population at this site is restricted by water chemistry. Although conditions for shocking are excellent, the majority of the fish collected were in an area where relatively unpolluted water entered the stream. In addition to lead and zinc criteria, the pH criterion was routinely violated at this site. One warmouth, 8 green sunfish, 1 bluegill sunfish, 1 hybred sunfish, 9 blackspotted topminnows and 2 mosquitofish were collected at site 20. The large warmouth was taken at midstream. Warmouth are regarded as relatively intolerant to pollution.

BIOTA AT SITE 22

The biota at this site had recovered significantly from the acid mine drainage, even though fish and wildlife criterion for lead and zinc are routinely violated (zinc by an order of magnitude). The relatively shallow pools and riffles were effectively sampled. The fishes collected included 1 largemouth bass, 2 warmouth, 1 channel catfish, 8 green sunfish, 29 bluegill sunfish, 1 slough darter, 11 mosquitofish, 2 slim minnows, 10 redfin shiners and 81 red shiners. This assemblage covers the range from tolerant to intolerant. The benthic macroinvertebrates collected included fresh water shrimp, damselfly larvae, dragonfly larvae, whirligigs, hellgrammites and water striders. Because of the site's proximity to the Neosho River, a portion of this assemblage may be transient.

CHANGES IN ACID MINE DISCHARGE DUE TO REMEDIATION

As we have seen, pollution caused by acid mine discharge is decreasing somewhat because concentrations in the discharge are decreasing. Another way pollution caused by acid mine discharge can be mitigated is by reducing the flow of acid mine water from the mines. This is what diking and diversion was supposed to accomplish. By keeping water from going into the mines, it was assumed that less water would be discharged. The Superfund Technology Support Center at the Robert S. Kerr Environmental Research Laboratory, in Ada, Oklahoma, reported on the validity of this assumption in "Tar Creek, The Effectiveness of Remediation."

Because a majority of the acid mine drainage is not monitored (only about 15% of the loading in Tar Creek is produced by the monitored discharges), Kerr Lab used the mine water elevation as an indicator of acid mine discharge. It was shown that a linear relationship exists between water elevation at the Blue Goose mine and the discharge at site 4s. The two year mean elevation after remediation was essentially unchanged from the two year mean elevation before remediation. Therefore, it may be assumed that discharge of acid mine water did not decrease after remediation. Kerr Lab showed that diking and diversion had an effect on the response of mine water level elevations to rainfall. It was concluded that it is important to note that the data limitations mentioned prevent the use of this information in any meaningful quantitative way. Rather, it can only be concluded that ".....the remediation was at best only partially effective in reducing surface runoff into the mines."

It cannot be concluded that pollution of Tar Creek was abated significantly by the diking and diversion. There is still a great deal of surface water running into the mines. Kerr Lab showed that the inflow was reduced by much less than the expected seventy-five percent. This, combined with the potential for groundwater inflow, has kept the acid mine discharges flowing at a relatively uniform rate.

FURTHER REMEDIAL ACTIONS TO REDUCE ACID MINE DISCHARGE

Kerr lab has suggested that surface drainage can be mitigated by raising the elevation of the discharges above the piezometric surface of the mines. “If a corrosion-resistant pipe were driven into each borehole and sealed, so that the pipe extended above the piezometric surface of the mines, surface discharges at these points would cease.”

Unfortunately, not all surface discharges are bore holes, but it is probably possible to sufficiently raise the elevation of all the current discharge points. The piezometric head in the mines is usually only a few feet above the land surface (See Figure 1). In some cases, ring dikes around discharging cave-ins will be required. The question arises, however, that if the current discharges are stopped, will not the piezometric surface of the mines increase and new discharges occur? Does the mine water elevation data suggest that large amplitude fluctuations in water level will occur if discharge elevations are increased? It appears that it depends upon whether the mines may be considered as a surface or a subsurface system. Kerr Lab addresses this in their report. “Water elevations in the mines respond to significant rainfall within 24 hours. Unlike true ground-water hydrology, this rapid response to runoff allows the problem to be handled as a surface rather than a subsurface water probe.”

OWRB personnel have observed that new discharge points appear when the peizometric surface increases. Therefore, raising the elevation of the current discharge points will not stop surface drainage, especially during wet periods, unless surface inflow is stopped. To stop surface inflow an aggressive diking and diversion program which diverts runoff from all inflow points is required.

The feasibility of raising the elevations of current and potential discharge points combined with diking and diversion of inflow areas should be studied. The benefits of reducing discharge of acid mine drainage include mitigation of one of the most polluted areas in the U.S., and protection of downstream waterbodies, particularly Grand Lake. There are several problems which must be considered. Most importantly, Tar Creek sediment will probably have to be treated as a hazardous waste. This may restrict areas where earth may be moved. The Picher Field functions as a stormwater detention basin for Tar Creek. Runoff which would otherwise increase flooding in Tar Creek is detained in the mine works. If diking and diversion is effective, a stormwater detention basin will have to be built, so that the flooding currently experienced by the city of Miami is not increased.

The no action alternative should be dismissed. Although concentrations in the mine discharges appear to be diminishing with time, resulting in decreasing concentrations in Tar Creek, this decrease is not great enough to result in concentrations meeting the water quality standards in the forseeable future. Furthermore, lead concentrations in Tar Creek water and sediment do not appear to be decreasing.

Substantial funds have already been spent on mitigating acid mine drainage to Tar Creek. Accepting the no action alternative is tantamount to an admission that these funds were wasted.

GROUND WATER MONITORING SITES

Municipal wells were sampled to determine trends in water quality in the Roubidoux aquifer. The resulting concentrations were compiled and analyzed by the Superfund Technology Support Center at the Robert S. Kerr Environmental Research Laboratory. Kerr Lab was not able to assign data to individual wells. “Discrepancies in the identification of sampled wells among the agencies resulted in the need to group wells by city, thereby preventing an analysis of individual wells.” Therefore, data were merged to obtain estimates of water quality in the Roubidoux at Commerce, Miami, Picher-Cardin and Quapaw.

ANALYSIS OF GROUNDWATER QUALITY

Kerr lab used a statistical approach to determine whether the plugging of abandoned Roubidoux wells had significantly improved water quality in municipal wells. However, the analysis was impeded by the following data limitations:

1. Paucity of data after well plugging operations were completed.
2. Significant variations in water quality as a function of sampling depth require consistent sampling procedures.
3. Collection and analysis of samples were not performed in a uniform manner.

Kerr Lab found “Water quality in the Roubidoux at Picher and Quapaw is significantly inferior to that at Miami, Commerce, and Cardin with respect to total hardness, iron, sulfate and zinc.” The mean concentration of iron exceeds the secondary drinking water standard at Pitcher and Quapaw. Some of the local residents in the Picher area are convinced that their water is getting worse, and will soon become unpotable. However, Kerr Lab concludes “Due to deficiencies in the existing data and the short period of post-remediation sampling, the effectiveness of well plugging cannot be established at this time.”

RECOMMENDATIONS FOR FUTURE ROUBIDOUX AQUIFER REMEDIATION EFFORTS

Kerr lab made several recommendation concerning remedial actions for the Roubidoux aquifer. They are summarized below:

1. A monitoring plan must evolve to evaluate the effectiveness of the remediation.
2. The agencies which collect information at Tar Creek should coordinate their objectives and methods in accordance with EPA’s “Practical Guide for Groundwater Sampling.”
3. It is recommended that plugging of all abandoned deep wells continue.
4. The USGS, OWRB and OSDH should agree on a common numbering scheme for the municipal wells involved at the Tar Creek site.
5. Down-hole sampling should be considered at municipal wells. Contamination may be entering the Roubidoux that is only noticeable at lower depths.
6. Quarterly, and if possible, monthly sampling should be conducted for given wells to provide the necessary data base from which to conduct a more valid statistical analysis.

Kerr Lab's recommendations concern remedial action. There are other aspects of Roubidoux pollution which also must be dealt with. The monitoring plan must not only address the effectiveness of remediation, but also the extent of pollution of the Roubidoux. If a portion of the Roubidoux is lost as a water supply, ample warning to obtain an alternative source must be given. The most feasible alternative source may depend upon the aerial extent of pollution in the Roubidoux.

In the recommended alternatives (p13), of the ROD, EPA Region VI, Oklahoma and Kansas agreed that the well plugging and diking and diversion programs met the National Contingency Plan criteria. These criteria deal with the appropriate extent of remedy. As part of the well plugging remedy "The State will undertake a long-term ground water monitoring program of the Roubidoux to assure the safety of the Roubidoux." Therefore, three goals are proposed in the ROD; diking and diversion, well plugging and Roubidoux monitoring.

The goal to abate pollution of Tar Creek by acid mine drainage was to be accomplished by a seventy five percent reduction in inflow to the mine works through diking and diversion. Analysis of the after action monitoring data shows that the diking and diversion remedial action did not significantly abate pollution of Tar Creek because the surface inflow was not decreased by 75%. The only abatement of Tar Creek pollution observed was due to decreases in concentrations in the acid mine discharges. These decreases were most likely not the result of remedial action.

The goal to monitor the groundwater quality of the Roubidoux aquifer to detect contamination before it becomes a significant problem was not accomplished. As Kerr Lab discovered, the groundwater monitoring program was inadequate for use in any meaningful quantitative way. Therefore, it cannot be used to observe or predict trends in Roubidoux water quality.

The goal to prevent contamination of the Roubidoux aquifer through plugging of abandoned wells cannot be assessed. Kerr Lab determined that groundwater monitoring data was not sufficient to assess the effectiveness of well plugging.

It cannot be shown that any of the goals directed by the Record of Decision, Remedial Alternative Selection, has been fulfilled. Therefore, further remedial action will be required. As discussed above, this action should consist of diking and diversion of all inflows combined with raising the elevation of surface discharges, plugging of remaining abandoned Roubidoux wells, and initiation of a viable groundwater monitoring program.

APPENDIX D

SITE REVIEW AND UPDATE

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DATE: DECEMBER 16, 1993

Site Review And Update

TAR CREEK (OTTAWA COUNTY)

MIAMI, OTTAWA COUNTY, OKLAHOMA

CERCLIS NO. OKD980629844

SEPTEMBER 30, 1993

REVISED

December 16, 1993

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

REVISED SITE REVIEW AND UPDATE

TAR CREEK (OTTAWA COUNTY)

MIAMI, OTTAWA COUNTY, OKLAHOMA

CERCLIS NO. OKD980629844

Prepared by

Remedial Programs Branch
Division of Health Assessment and Consultation
Agency for Toxic Substances and Disease Registry

SUMMARY OF BACKGROUND AND HISTORY

The Tar Creek site covers a 40-square mile portion of the Picher Field mining district in Ottawa County, Oklahoma. The Picher Field, located in Ottawa County, Oklahoma, and Cherokee County, Kansas, is a part of the Tri-State mining region of the Oklahoma, Kansas, and Missouri. Lead and zinc ores were mined from the Picher Field from 1904 through the mid 1960s. During the active mining period, the Boone formation was dewatered through extensive pumping by the mining companies. Dewatering of the formation caused native iron and lead sulfides within the mines to be oxidized by exposure to air. After mining operations ceased, groundwater accumulated in the mines and reacted with the oxidized sulfides to form acid mine water. The acid water in-turn dissolved metals remaining in the formation, resulting in high concentrations of zinc, lead, cadmium, and iron, as well as sulfate, in the mine water.

By 1979, water levels in the Boone formation had risen to sufficient levels to allow acid mine water to discharge at the surface from boreholes and abandoned mine shafts. This acid mine drainage, containing high levels of dissolved metals, then began flowing into Tar Creek resulting in severe water quality degradation. In addition, because the hydrostatic level in the Boone Formation is higher than in the underlying Roubidoux Formation, acid mine water tends to flow into the Roubidoux (through boreholes, abandoned wells, and corroded well casings). Contamination of the Roubidoux by acid mine water is potentially a major threat to the area’s drinking water since this aquifer is the area’s principal water supply source. However, at the present time, all area drinking water systems are reported to be meeting primary drinking water standards.

Another source of surface water contamination is a drainage from tailings (“chat”) piles which were generated by the ore mining and processing operations. Large piles of the gravel-like chat, which contain metals such as cadmium, lead, and zinc, are scattered throughout the site area.

The surface water and potential groundwater problems associated with acid mine water prompted the U.S. Geological Survey (USGS) and the State of Oklahoma to investigate the site. In June 1980, at the request of the governor of Oklahoma, a Tar Creek Task Force was formed to address the growing concern regarding surface water and groundwater contamination by acid mine water in the Tar Creek area. This task force published a report entitled “An Environmental Health Evaluation of the Tar Creek Area” in March 1983, which was based on a study of current environmental conditions in the area. Major findings of the report included the following: 1) no adverse health effects (e.g., cancer) would be expected from exposure to site-related contaminants; 2) drinking water supplied by area public and rural waters systems is safe; 3) Tar Creek and portions of the Boone aquifer contaminated by acid mine water should not be used for private or public drinking water supplies; and 5) fish from area surface waters were safe to eat; 6) no significant concentrations of metals were found in particulate air samples collected near chat piles; and 7) no significant air, soil, or external gamma radiation were detected in the area. The report recommended continuing monitoring of public water supplies in the Tar Creek area. The Center for Disease Control’s (CDC’s) Superfund Implementation Group, the predecessor of the Agency for Toxic Substances and Disease Registry (ATSDR), reviewed the task force’s preliminary report at the time it was issued. The results of CDC’s review are discussed later in this document.

In October 1981, EPA proposed the site for inclusion on the National Priorities List (NPL). The site was officially added to the NPL in September 1983.

In June 1982, the Oklahoma State Department of Health (OSDH) entered into a cooperative agreement with EPA to conduct a Remedial Investigation/Feasibility Study (RI/FS) of the site. The RI/FS, which was conducted by the Oklahoma Water Resources Board (OWRB) under contract to the OSDH, was completed in December 1983. In June 1984, EPA issued a record of decision (ROD) for the site which selected remedial actions to address site contamination. The selected remedy for the site consisted of 1) diverting Tar Creek away from mine shaft openings and diking the openings to prevent surface water from entering the mines; and 2) plugging known abandoned wells to prevent contamination of the area’s drinking water supply. These remedial activities were completed in December 1986.

In 1985, the OWRB notified EPA of elevated levels of metals in the Town of Picher water supply well. As a result, EPA’s Removal Program established an alternative water supply by drilling a new supply well and connecting it to the Picher water system.

Post-remediation surface water and groundwater monitoring was conducted by OWRB and the USGS in 1987 and 1988 to determine if the completed remedial activities were effective in reducing the acid mine water problems. The monitoring results indicated that the previous diking and diversion actions were ineffective at reducing the flow of acid mine drainage into Tar Creek. However, the groundwater data were not adequate to determine the effectiveness of past well plugging activities.

In August 1992, OWRB began a groundwater sampling program to determine the effectiveness of the previous well plugging actions. The monitoring program was to include sampling of area water supply wells and direct sampling of the water supply (Roubidoux) aquifer. From August 1992 through January 1993, ten water supply wells were sampled on a monthly basis. Cadmium was found in two samples slightly in excess of EPA’s Maximum Contaminant Level (MCL), while lead was detected in two samples but not above the EPA action level. In October 1993, EPA and ODEQ agreed to begin direct testing of the water supply aquifer, which may provide information regarding the extent of aquifer contamination and the integrity of existing water supply wells.

A five-year review of the site is currently being conducted by EPA to evaluate whether the completed remedial actions are effectively protecting public health and the environment. However, as previously discussed, available information suggests that the previous remedial actions have not significantly reduced impacts associated with acid mine discharges in the Tar Creek area.

In May 1983 and January 1984, respectively, CDC’s Superfund Implementation Group reviewed the following two documents: 1) “Feasibility Study of Lung Cancer and Other Diseases in the Tri-State Mining District of Kansas, Missouri, and Oklahoma,” by Dr. John S. Neuberger, University of Kansas, and Dr. Joseph G. Hollowell et al., Kansas Department of Health and Environment; and 2) “Preliminary Environmental Health Evaluation of the Tar Creek Area,” by the Tar Creek Task Force Health Effects Subcommittee. The results of these two reviews, which together comprised ATSDR’s January 20, 1984 health assessment for the Tar Creek site, are discussed below.

In the May 1983 review, CDC noted several deficiencies in the Tar Creek Task Force report, including 1) inaccurate dietary exposure estimates for cadmium and lead, 2) omission of fish sampling information such as fish size and number of filets per sample, 3) lack of sensitivity in cadmium and lead analyses, 4) inaccuracies in derivation/application of “no action levels”, and 5) lack of fish data for metals such as arsenic, selenium, and mercury. Based on the limited data reviewed, CDC concluded that there was no significant health risk associated with the levels of chromium, copper, and zinc reported in the fish samples. However, CDC stated that a more extensive survey may be required in order to better characterize heavy metal contamination (especially cadmium and lead) of fish from the Tar Creek area and possible adverse health effects associated with consumption of such fish.

In the January 1984 review, CDC evaluated a proposal by Neuberger, Hollowell, and colleagues to perform a feasibility study related to health effects reported in the tri-state mining district (which includes the Tar Creek area). The reported health effects included 1) excesses in lung cancer mortality rates among white men and women in the three tri-state lead-zinc mining counties: Cherokee County, KS; Jasper County, MO; and Ottawa County, OK; 2) elevated lung cancer death rates among males in Cherokee County, KS; and 3) elevated death rates for some non-malignant causes in Cherokee County. As a result of its review, CDC recommended that the proposed feasibility study not be funded. However, CDC did find sufficient reason to recommend that the authors consider a case-control study of lung cancer deaths and a descriptive mortality analyses of non-malignant causes of death. In addition, CDC noted that the increased lung cancer mortality rates were not likely due to non-occupational (i.e., non-mining), environmental causes, and therefore, suggested that the authors submit protocols for studying miners to the National Institute for Occupational Safety and Health (NIOSH) or the U.S. Bureau of mines.

CURRENT CONDITIONS OF SITE

On September 1, 1993, Steve Richardson and Jennifer Lyke of ATSDR visited the site area with the EPA remedial project manager (RPM), and representatives from the Oklahoma Department of Environmental Quality (ODEQ) (previously part of the OSDH) and the Ottawa County Health Dept. During the site visit, the major problems associated with the site were found to involve acid mine drainage which has contaminated the shallow aquifer and area surface waters (primarily Tar Creek) and possibly the deep aquifer as well. The mine drainage is bright orange-red because of high levels of iron. The iron is dissolved by low pH water in the mines and then precipitates out when the oxygen content and pH of the water are increased by mixing with surface waters.

Other problems observed in the site area included cave-ins from old mining activities and open mine shafts which may present physical/safety hazards to persons in the area. In addition, numerous large piles of old mine tailings or chat, which contain various metals (e.g., cadmium, lead), were noted throughout the area. The chat is widespread in the area since it is used for a variety of purposes such as manufacturing asphalt and cement and for roadbeds and gravel driveways. Also, the chat piles are used for climbing and riding dirt bikes, as evidenced by footprint and motorcycle tracks on the piles. In the town of Picher, OK, the local baseball field is surrounded by several large chat piles.

CURRENT ISSUES

In order to determine whether members of the surrounding community had health concerns related to the site, ATSDR contacted representatives of the Ottawa County Health Department and ODEQ. State and county officials reported that area residents are concerned about the quality of their drinking water, primarily in regard to taste and odor problems and staining of sinks, tubs, clothes, etc. caused by the water’s high iron levels. In addition, there is a perceived increased incidence of cancer and lung disease in area communities. The state and county officials are concerned about the potential for acid mine water in the shallow Boone aquifer to contaminate the deep Roubidoux aquifer, which is used by several local municipalities as a drinking water source. These officials are also concerned about potential human exposure to metals from the numerous, widespread chat piles located throughout the area (see previous discussion).

CONCLUSIONS

Based on ATSDR’s review of available information, it appears that the past remedial actions, such as stream diversion and mine shaft diking, have not significantly reduced the effects of acid mine drainage on Tar Creek. (The effect of acid mine drainage on heavy metal levels in area fish cannot be determined since CDC’s previous recommendation concerning fish sampling was never implemented.) In addition, despite the past well plugging activities, acid mine water 1) has impacted some drinking water wells (likely due to poor well integrity), and 2) may be entering the Roubidoux aquifer, thereby threatening the area’s primary drinking water source. However, at present, it is not known whether acid mine water has actually contaminated the Roubidoux.

Open mine shafts and caved-in areas present a physical hazard especially to children who may accidentally fall in them.

Available information is insufficient to determine whether chat piles in the site area represent a significant source of human exposure to heavy metals.

RECOMMENDATIONS

1. Wherever possible, restrict access to any known open mine shafts and cave-ins in the site area.

2. Proceed as planned with direct sampling of the Roubidoux to determine if the aquifer is being significantly contaminated by acid mine water.

3. Continue monitoring of area drinking water wells, especially public water supply wells, for site-related contaminants. If monitoring data show contaminant levels above established drinking water standards, alternative water supplies should be provided.

4. Continue periodic sampling of water and sediments in Tar Creek and other area surface waters. Also, consider sampling of fish from area surface waters impacted by acid mine drainage.

5. Conduct a sampling investigation of area chat piles and soils near the piles (including soil from residential yards and the Picher little-league field) to determine if metals (e.g., cadmium, lead) are present at levels of health concern.

6. ATSDR should review the results of any sampling activities conducted in accordance with the above recommendations to determine whether further actions by ATSDR are needed.

DOCUMENTS REVIEWED

1. Agency for Toxic Substance and Disease Registry. Health Assessment for Tar Creek, Miami, Ottawa, County, Oklahoma. Atlanta: ATSDR, January 20, 1984.

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3. Oklahoma Water Resources Board. Governor’s Tar Creek Task Force: Data Summary of Surface and Groundwater from Abandoned Lead and Zinc Mines of Ottawa County, Oklahoma, December 1980 to July 1981.

4. Oklahoma Water Resources Board. Tar Creek After Action Monitoring Report.

5. Oklahoma Water Resources Board. Tar Creek Feasibility Investigation, Task II.1.A, Identification and Assessment of Potential Remedial Alternatives. 1983.

6. Tar Creek Task Force, Health Effects Sub-Committee. An Environmental Health Evaluation of the Tar Creek Area. March 1983.

7. U.S. Environmental Protection Agency, Region VI. Briefing Paper, Tar Creek Superfund Site. 1993

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10. U.S. Environmental Protection Agency, Region VI. Progress at Superfund Sites in Oklahoma. Fall 1992.

PREPARER OF SITE REVIEW AND UPDATE

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APPENDIX E

TECHNICAL MEMORANDUM, SAMPLING RESULTS OF PUBLIC WATER SUPPLY WELLS, AUGUST 1992 THROUGH JANUARY 1993, TAR CREEK SUPERFUND SITE

AUTHOR: DAVID H. COHENOUR
OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

DATE: DECEMBER 10, 1993

TECHNICAL MEMORANDUM

Sampling Results of Public Water Wells

August, 1992 to January, 1993

Tar Creek Superfund Site

Prepared By

David H. Cohenour

State of Oklahoma

Department of Environmental Quality

Superfund Program

December 10, 1993

Technical Memorandum
Sampling Results of Public Water Wells
August, 1992 to January, 1993
Tar Creek Superfund Site

Introduction

Mining of zinc and lead ore deposits in northeast Oklahoma, southeast Kansas, and southwest Missouri, commonly known as the Tri-state area, began in 1891. Significant ore production ceased in 1970, but minor amounts of zinc and lead concentrates were produced until 1981 (Luza, 1986). Figure 1 shows the location of the Tar Creek drainage basin in the Tri-state area. The host rock for most of the ore deposits is the Mississippian age Boone Formation, which is composed of limestone and chert and has a thickness of 350 to 400 feet in the mining area (McKnight and Fischer, 1970).

During active mining, large capacity pumps were used to de-water the mines. This exposed iron, zinc, and lead sulfides to a moist oxygen rich atmosphere, causing the sulfides to oxidize. When the mines were abandoned, the pumps used to de-water the mines were shut off, and ground water began seeping back into the mines. The ground water reacted with the oxidized metallic sulfides resulting in the formation of sulfuric acid and the dissolution of iron, zinc, lead, nickel, and cadmium. The resulting acid mine waters contain high concentrations of sulfate, iron, lead, cadmium, and nickel. In 1979, the water table in the mines became higher than the ground surface and acid mine water began discharging into Tar Creek.

The United States Environmental Protection Agency (EPA) began studying the environmental impacts of the acid mine drainage in 1979. With the passage of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, the Tar Creek area was proposed to the National Priorities List (NPL) in 1981, and added to the NPL in 1983. Remedial activities taken in the past to mitigate acid mine impacts to surface and ground water have included the diversion of surface water from entering abandoned mines and the plugging of abandoned water wells in the Tar Creek area. The EPA and the State of Oklahoma Department of Environmental Quality (DEQ) are currently conducting after action monitoring of the site to determine if the remedial actions have effectively reduced the environmental impacts and if more remedial actions are warranted.

Hydrogeology and Ground Water Impacts

Geologic Setting

Topography of the area is generally a relatively flat prairie. Elevations range from approximately 775 to 900 feet above mean sea level. The region is drained by Tar Creek

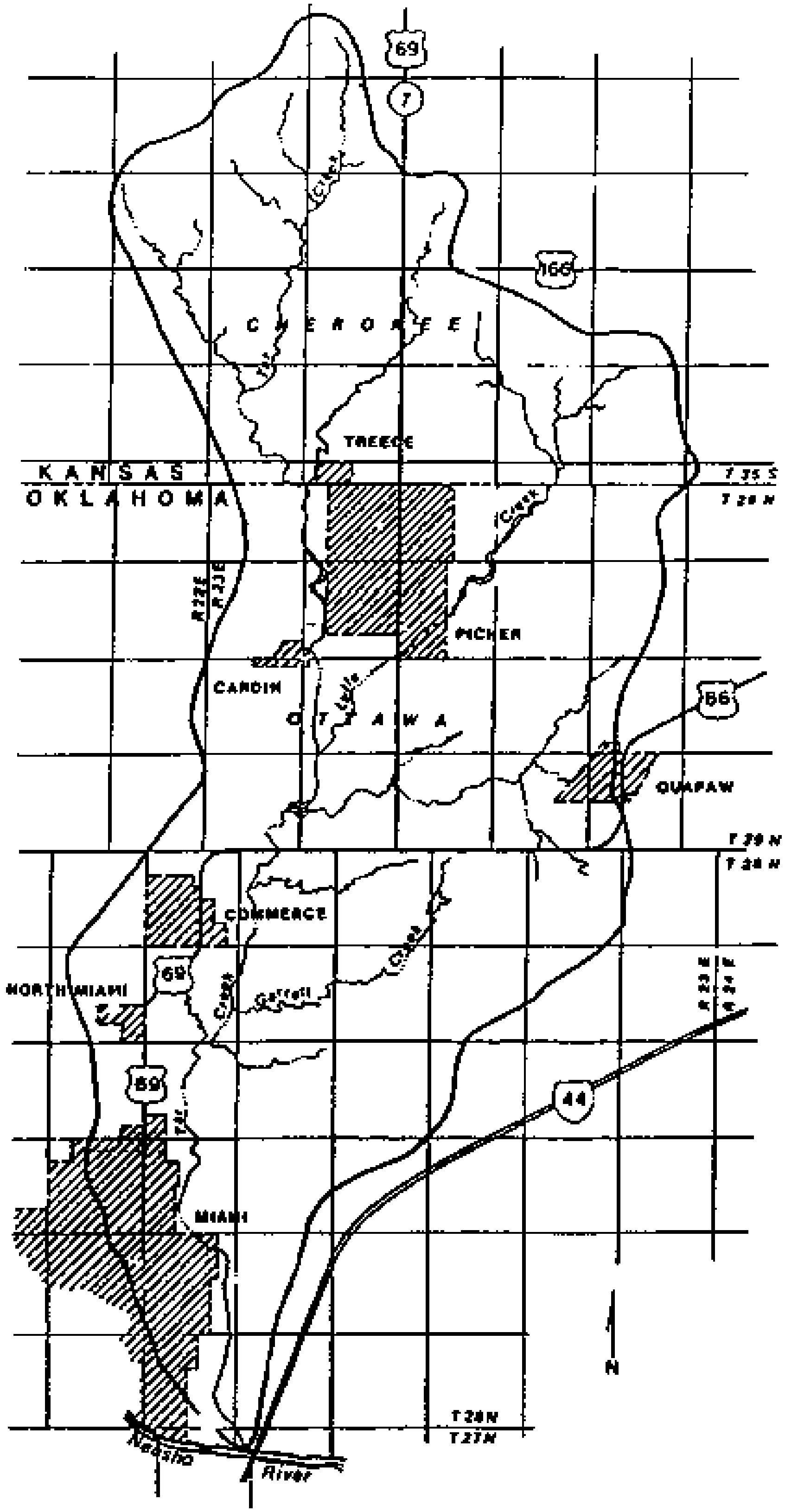

Figure 1. Tar Creek drainage basin.

Source: OWRB, 1983.

and Lytle Creek, which combine and flow into the Neosho River. Bedrock in the Tar Creek area dip to the northwest at 15 to 20 feet per mile, with abrupt local variations caused by folding and faulting. In descending order the stratigraphy of the Tar Creek area and hydrogeologic significance (modified after McKnight and Fischer, 1970; and Reed, Schoff, and Branson, 1955), is as follows:

Pennsylvanian age Strata

Krebs Group: Zero to 200 feet of gray to black fissile shale with some thin coal and sandstones. Present in the western and northwestern parts of Ottawa County, missing in the eastern portion of the County. Forms a probable aquitard over the underlying Boone aquifer where present.

Mississippian age Strata

Boone Formation: Consists of 350 to 400 feet of bluish gray to light gray limestone and gray to white chert. The Boone Formation is also known as the Keokuk and Reed Springs Formations. The Oklahoma State Department of Health (OSDH) has mapped the Keokuk and Reed Springs Formations as a principle bedrock ground water resource in northeastern Oklahoma (Johnson, 1983). Ground water movement in the Boone Formation is primarily through fractures and solution cavities.

Devonian and Mississippian age Strata

Chattanooga Shale: Zero to 50 feet of black shale near the boundary between Devonian and Mississippian Periods. Absent in most of the mining area. A probable aquitard restricting ground water movement between the overlying Boone aquifer and underlying Ordovician Strata where present. Deep wells in the area are usually uncased below the Chattanooga Shale.

Ordovician age Strata

Cotter Dolomite: Approximately 165 feet of dolomite and dolomitic limestones with oolitic, opalescent chert lenses and very fine grained sandy zones. The Cotter may contribute some water to deep wells, but it’s yield is unknown.

Jefferson City Dolomite: 270 to 340 feet of dolomite with 10 to 50 % brown chert. The rate at which ground water can be produced from the Jefferson City Dolomite is unknown.

Roubidoux Formation: 105 to 180 feet of cherty dolomite with two or three 15 to 30 feet thick layers of sandstone. The Roubidoux Formation is a major producer of ground water in the area with yields up to 600 gallons per minute.

Gasconade Dolomite and Van Buren Formation: Approximately 240 feet of cherty dolomite. At the base of the Van Buren Formation is the 60 foot thick Gunter sandstone member, which yields moderate amounts of water to one well located at Quapaw.

Cambrian age Strata

Eminence Dolomite: 105 to 140 feet of dolomite with chert, pyrite, shale fragments. Yield of the Eminence Formation is unknown.

- The Roubidoux, Gasconade, and Eminence Formations are mapped by the OSDH as a principal ground water resource in northeastern Oklahoma (Johnson, 1983).

Ground Water Impacts

Ground water in the Boone aquifer has been contaminated by mining activities in the Tar Creek area. However, public water supply wells in the Tar Creek area are completed such that they produce water from the deeper Roubidoux Formation, also known as the Roubidoux aquifer. Usually steel casing is installed in deep wells to at least the top of the Cotter Dolomite to prevent contaminated ground water in the Boone aquifer from being produced with good quality ground water from the Roubidoux aquifer. However, several public wells have been plugged due to poor quality water, which was apparently caused by the inflow of acid mine water through corroded well casing (OWRB, 1983). A subsequent study also reported that water supply wells that produced poor quality water had poor well integrities, and contamination of the Roubidoux aquifer was not evident (Christenson, Parkhurst, and Fairchild, 1990). Since the Boone aquifer's potentiometric surface is hundreds of feet higher than the Roubidoux aquifer's potentiometric surface, the possibility of downward movement of acid mine water into the Roubidoux aquifer through unplugged ore exploration drill holes, abandoned water wells, or intervening strata is a potential threat to public water supplies. Where the Chattanooga Shale is missing in the mining area, ground water impacts may be present in the Cotter Dolomite, and poor quality water may be produced from a well that has casing extending only to the top of the Cotter Dolomite. Due to the factors listed above, the Oklahoma State Department of Health (now the DEQ), through a cooperative agreement with the EPA, subcontracted with the Oklahoma Water Resources Board (OWRB), which retained the United States Geological Survey (USGS) to develop and implement a public water supply monitoring program to determine if acid mine waters are impacting public water supplies in the Tar Creek area.

Public Water Supply Water Quality Monitoring

Twenty-one public water supply wells in the Tar Creek area were sampled by the USGS over a six month period between August 12, 1992, and January 28, 1993. Eleven of these wells are located inside the mining area and were each sampled six times. The remaining ten wells are located outside of the mining area and were sampled once. Figure 2 shows the locations of the wells sampled during the monitoring period.

Ground water samples from the public supply wells were analyzed for the following constituents: alkalinity, aluminum, antimony, arsenic, barium, beryllium, bi-carbonate, boron, cadmium, calcium, chloride, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, pH, potassium, selenium, silver, sodium, specific conductivity, strontium, sulfate, temperature, thallium, titanium, vanadium, and zinc.

Water Supply Well Sampling Methods

Ground water samples were collected after each water supply well was purged. Each well was purged for a minimum of one hour, until at least three casing volumes of water were removed from the well, and field measurements of specific conductance, temperature, and pH measurements had stabilized to the following criteria:

Specific conductance:	Five percent of value for 3 consecutive readings, 5 minutes apart.
Temperature:	Within 0.5 degree Celsius for 3 consecutive readings, five minutes apart.
pH:	Within 0.1 standard pH unit for 3 consecutive readings, five minutes apart.

Raw (unfiltered) and filtered ground water samples were collected for total and dissolved metals analysis and preserved in the field with nitric acid until the pH of the sample was 2 or less (standard units). All samples collected were placed in a cooler with ice and delivered to the analytical laboratory within 24 hours. Sequential duplicate samples of each well (samples collected a few minutes apart from the same well) were analyzed by EPA’s Robert S. Kerr Environmental Research Laboratory (RSKERL) located in Ada, Oklahoma and laboratories in the EPA Contract Laboratory Program (CLP). Sampling results from RSKERL and CLP laboratories are summarized in tables contained in Appendix A.

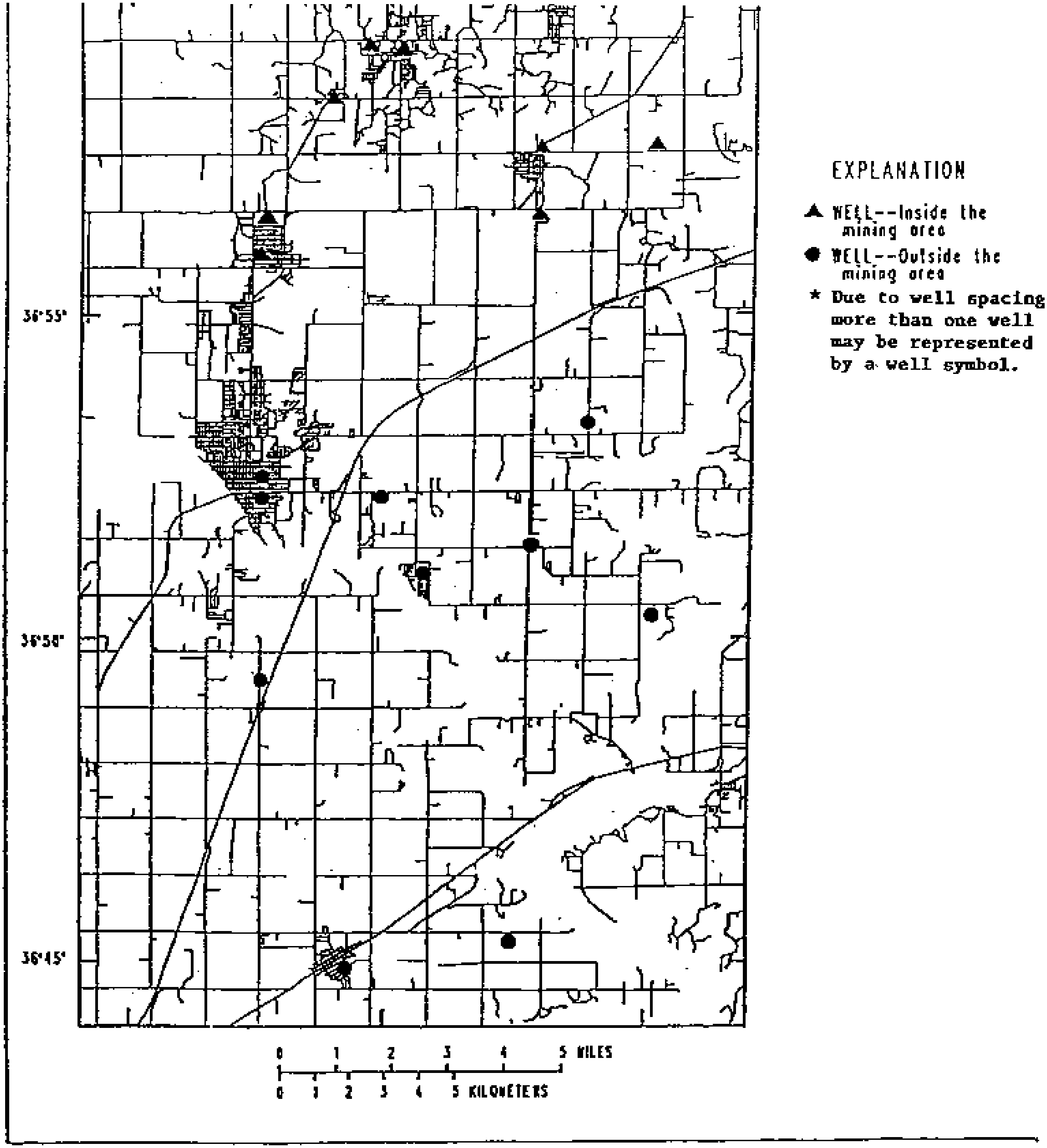

Figure 2.
Source: Scott Christenson, written communication, USGS, 1992.

Public Water Supply Monitoring Results

Primary Drinking Water Standards

The Safe Drinking Water Act (SDWA) requires the EPA to set Maximum Contaminant Limits (MCLs), also known as primary drinking water standards, for contaminants found in public water supplies. A MCL is the enforceable maximum permissible concentration of a contaminant in water delivered to any user of a public water supply system. The State of Oklahoma primary drinking water standards are called Maximum Allowable Levels (MALs) and must be at least as stringent as federal MCLs. Since all MALs discussed in this report are equivalent to MCLs, this report uses MCLs when referring to primary drinking water standards.

Some samples analyzed for lead by RSKERL were reported with detection limits that are higher, up to 26 ug/l (parts per billion), than the EPA action level of 15 ug/l for lead. In general, RSKERL reported higher concentrations of heavy metals in sequential duplicate samples, with higher detection limits, than the CLP laboratories.

One sample analyzed by RSKERL was reported to have a dissolved lead concentration of 237 ug/l. This result is considered anomalous because of the following reasons: (1) the sequential duplicate total lead sample collected from this well was reported by RSKERL below the detection limit of <26 ug/l; (2) 237 ug/l is a higher lead concentration than the mean dissolved lead concentration of 135 ug/l in acid mine water (Playton, Davis, and McClaflin, 1980); and (3) 20 other total and dissolved lead analyses by RSKERL and CLP laboratories of samples from this well had reported lead concentrations from below the detection limit to 2.1 ug/l (detection limits of <1.0 to <22 ug/l). Therefore, this result is not representative of actual water quality from the well sampled. Rejecting the reported lead concentration of 237 ug/l, the reported total and dissolved lead concentrations in the remaining samples for all wells ranged from below detection limit to 25.0 ug/l (detection limits of <1.0 to <26.0 ug/l). The only sample to exceed the current EPA action level of 15 ug/l for lead was collected on 12/15/92 from Rural Water District 4, well #4, and reported by RSKERL to have a total lead concentration of 25 ug/l. However, a sample collected from the same well, on the same day, three minutes earlier, was reported by the CLP laboratory to have a total lead concentration of 1.7 ug/l. Therefore, the RSKERL reported concentration of 25 ug/l for this sample is also questionable. The next highest lead concentration was reported by RSKERL at 12.8 ug/l (total lead) from a sample collected from the Miami #3 well on 1/27/93. Again, the CLP laboratory reported a total lead concentration of <1.4 ug/l (the detection limit) for the sequential duplicate sample.

Only one sample had a reported total mercury concentration in excess of the MCL of 2 ug/l. Total mercury was reported at a concentration of 2.9 ug/l from a sample collected from the Pitcher #3 well on 9/22/92. Five other samples from this well had reported concentrations of mercury of <0.2 ug/l (the detection limit). Total mercury was reported for all other samples at concentrations ranging from below the detection limit to 0.61 ug/l (detection limits < 0.1 to < 0.2 ug/l).

Total cadmium was detected by the CLP Laboratory at a concentration of 5.1 ug/l, which is slightly above the MCL of 5.0 ug/l, in a sample collected from the Pitcher #4 well on 10/20/92. Total cadmium was also detected by the CLP laboratory at a concentration of 5.1 ug/l in a sample collected from the Pitcher #3 well on 10/20/92. All other samples analyzed for total and dissolved cadmium were reported at concentrations below the MCL of 5 ug/l for cadmium.

The following parameters were reported at concentrations below MCLs:

> Total and dissolved arsenic was reported at concentrations ranging from below the detection limit to 25 ug/l (MCL 50 ug/l, detection limits from < 1 to <39 ug/l).
>
> Total and dissolved barium was reported at concentrations ranging from below the detection limit to 250 ug/l (MCL 2,000 ug/l, detection limit of <49 ug/l).
>
> Total and dissolved chromium was reported at concentrations ranging from below the detection limit to 16 ug/l (MCL 100 ug/l, detection limits from <0.8 to < 8 ug/l).
>
> Total and dissolved nickel was reported at concentrations ranging from below the detection limit to 31.1 ug/l (MCL 100 ug/l, detection limits from < 2.6 to < 14.5 ug/l).
>
> Total and dissolved selenium was reported at concentrations ranging from below the detection limit to 28 ug/l (MCL 50 ug/l, detection limits of < 0.9 to < 26 ug/l). It was noted that results for selenium from RSKERL were reported at concentrations of approximately an order of magnitude higher than selenium concentrations from CLP laboratories.

The EPA has proposed MCLs for sulfate at two concentrations, 400 and 500 mg/l (parts per million). None of the samples analyzed had reported concentration of sulfate in excess of the lowest proposed MCL of 400 mg/l.

Compliance with Primary Drinking Water Standards

Except for mercury, at least eighteen samples were collected from each of the eleven wells located inside the mining area (seven samples were collected from these wells for mercury analysis because the RSKERL did not analyze for mercury). Usually three samples were collected a few minutes apart from the same well (sequential duplicates). If one sequential duplicate sample was reported in excess of a MCL (or action level), while the other sequential duplicate samples and all other samples taken from the same well were reported below the MCL, the reported sampling result in excess of the MCL was thought to be an artifact of the sampling results and not representative of actual water quality from the well sampled.

Sampling points for public water supply systems are at the points of entry to the water supply distribution system. Assuming that a well head is a distribution system's point of entry (most conservative assumption), the sampling results can be used for determining compliance with primary drinking water standards. If samples are taken more frequently than annually, compliance with MCLs is determined by calculating the running average of sample results from a well over the year. Even if artifacts of a individual wells sampling results are included, all wells sampled are in compliance with MCLs for cadmium, and mercury. The action level for lead is exceeded if the 90th percentile of samples collected during any six month monitoring period is greater than 15 ug/1. Including artifacts of individual well sampling results, the 90th percentile samples for all wells sampled were below the action level sampled for the six month monitoring period (OSDH, 1992). Therefore, all of the wells sampled complied with primary drinking water standards and do not constitute a public health threat.

Secondary Drinking Water Standards

Secondary drinking water standards (SDWSs) are non-enforceable drinking water standards for certain chemicals that do not pose a health risk. The EPA recommends that SDWSs are met to insure that aesthetic qualities of the water supply, such as taste, odor, and clarity are acceptable to the population.

Concentrations of total and dissolved iron were reported ranging from the detection limit of < 6.1 to 1,320 ug/l. The SDWS of 300 ug/l for iron was exceeded in all samples taken from the Pitcher #2 well and the Quapaw #2 well. All samples, except one sample from each well, were reported above the iron SDWS for the following wells: Commerce #3, Pitcher #3, and Pitcher #4. One sample collected from Quapaw well #4 had a reported concentration of total iron of 1120 ug/l. However, the other 17 samples collected from this well had reported concentrations of total and dissolved iron ranging from below the detection limit to 65 ug/l (detection limits of < 6.1 to < 99 ug/l).

Sulfate was detected in samples at concentrations ranging from 4 to 301 mg/l. The SDWS of 250 mg/l for sulfate was exceeded in all samples collected from the Picher #4 well. Samples collected from the Picher # 3 well show a trend of increasing sulfate concentration with time over the sampling period. Sequential duplicate samples collected on the 1/25/93 from the Picher #3 well, the last sampling event for this well, were in excess of the SDWS for sulfate with reported concentrations of 256, 263, and 264 mg/l. No other violations of SDWSs were reported by the CLP laboratories or the RSKERL.

Indicators of Acid Mine Water Contamination

All water supply wells sampled complied with MCLs for hazardous constituents. However, in order to predict if water supplies will be contaminated by mine water, indicators of mine water contamination must be developed. Indicators of acid mine water contamination can be determined by comparing the quality of mine water to the quality of water produced from Roubidoux wells located outside the mining area (background wells).

Table 1 compares mine and Roubidoux water quality for three general water quality parameters. In general, the larger the concentration difference of the parameters listed in Table 1, the better the parameter can be used as an indicator of mine water contamination. Since the mean concentrations of total zinc, total iron, and sulfate are orders of magnitude higher in mine water than in Roubidoux water (from wells outside the mining area), total zinc, total iron, and sulfate are excellent indicators of mine water contamination.

Table 1
Comparison of Roubidoux Water and Mine Water Quality

Parameter	Roubidoux water*	Mine water**
Total Zinc (ug/l)	6	108,000
Total Iron (ug/l)	43	110,000
Sulfate (mg/l)	17	1,950

* Mean of sample results from 10 wells outside mining area.
** Mean concentrations of mine water (Playton, Davis and McClaflin, 1980).

Statistical Analysis

A statistical analysis of the sampling results was performed to determine if acid mine water is impacting drinking water supplies in the Roubidoux aquifer. Upper tolerance limits were calculated for the indicator parameters in Table 1 using the sampling results from wells located outside the mining area (background data). In order to calculate tolerance limits for the background data, it must be determined if the background sampling results are normally distributed. A data set is normally distributed if the ratio of the sample standard deviation (S) to the sample mean (X), defined as the coefficient of variance (CV), is less than one.

$$\mathbf{CV = S/X} \qquad (1)$$

If the coefficient of variance is greater than one, the data may be log normally distributed. The data was transformed by taking the natural logarithm (ln) of individual sample results. If the coefficient of variance of the transformed data is less than one, the data is log normally distributed. Table 2 shows the number of samples (n), mean (x), mean of the transformed data (ln X), standard deviation (S), standard deviation of the transformed data (ln S), coefficient of variance, and coefficient of variance of the transformed data calculated for zinc, iron, and sulfate from the background sampling results. Total zinc, Total iron, and sulfate background sampling results and transformed data, with calculated means and standard deviations are tabulated in Appendix B.

Table 2

Parameter	n	X	ln X	S	ln S	CV	ln CV
Total Zinc (ug/l)	21	9	1.73	11	0.86	1.22	0.50
Total Iron (ug/l)	19	62	NA	60	NA	0.97	NA
Sulfate (mg/l) *	31	25	2.82	35	0.72	1.38	0.26

NA = not applicable

When sample results were reported below the detection limit, the detection limit was used to calculate X and S. This approach is not appropriate for regulatory compliance monitoring because the actual concentration represented by a non-detect is between zero and the detection limit. This resulted in a slightly higher mean and a slightly lower standard deviation for background indicator parameter concentrations. However, the goal of the statistical analysis is to determine at what concentrations the general water quality parameters zinc, iron, and sulfate indicate contamination by mine water and not the enforcement of a primary drinking water standard. Since detection limits for iron and zinc ranged from 3.2 to 11 ug/l (sulfate was always reported above the detection limit), tolerance limits for zinc and iron are biased by less than ten parts per billion.

Several outliers were found in the background data sets. However, only outliers caused by analytical or sampling errors can be removed from the background data. Sequential duplicate sample results reported total iron at concentrations of 1320 and 355 ug/l for one background well were thrown out of the iron background data because the well was inactive before it was sampled (personal communication Scott Christenson, USGS) and the high iron results were caused by rust or sediment inside the well. No other outliers in the background data sets were found to be caused by sampling or analytical error.

The iron background data is normally distributed since the coefficient of variance for background iron data is less than one. The coefficient of variance for zinc and sulfate background data is greater than one. Therefore, the zinc and sulfate background data sets are not normally distributed. However, the zinc and sulfate background data sets have log normal distributions because coefficients of variance of transformed zinc and sulfate data are less than one.

Tolerance intervals establish a concentration range that is constructed to contain a specified proportion (P%) of the population with a specified confidence coefficient (Y). The proportion of the population included (P) is referred to as the coverage. The probability that the tolerance interval includes the proportion P% of the population is referred to as the tolerance coefficient. A 95% coverage and 95% tolerance coefficient is recommended (EPA, 1989). With a 95% coverage, random observations from the same distribution as the background well data would exceed the upper tolerance limit less than 5% of the time. With a 95% tolerance coefficient, one has confidence level of 95% that the upper 95% tolerance limit will contain at least 95% of the distribution of the observations from the background well data. Since the goal is to determine at what concentrations zinc, iron and sulfate indicate mine water contamination, a one-sided tolerance interval or an upper, tolerance limit is desired.

Upper tolerance limits (TL) were calculated for total zinc, total iron and sulfate by using the following equation:

$$\mathbf{TL = X + (KS)} \qquad (2)$$

Where: X is the sample mean
S is the sample standard deviation
K is the one sided normal tolerance factor (from table in Appendix B)

Statistically significant evidence of mine water impacts exists if sampling results from wells inside the mining area exceed the tolerance limits for total zinc, total iron, and sulfate. Inverse natural logarithms of total zinc and sulfate transformed tolerance limits yield tolerance limits that can be compared to sampling results from wells inside the mining area (EPA, 1989). Table 3 shows the tolerance limits calculated for the indicator parameters total zinc, total iron, and sulfate.

Table 3

Indicator Parameter	Upper Tolerance Limit *
Total Zinc	43 ug/l *
Total Iron	207 ug/l
Sulfate	82 mg/l *

* Inverse natural log of results from equation 2.

It should be noted that zinc, iron, and sulfate occur naturally in ground water from geologic sources. Background concentrations of zinc, iron, and sulfate in the Roubidoux aquifer are variable because of changes in the lithology of the Roubidoux Formation. Since the Roubidoux Formation is not geochemically homogenous and isotropic, the ground water contained in it will have some chemical variability. Also, excessive iron in water may be temporarily produced from a Roubidoux well that has not been actively pumped (from rusty casing and tubing). However, it is highly unlikely that all three indicator parameters (zinc, iron, and sulfate) are naturally elevated significantly above background averages.

The mean concentrations of individual well sampling results for total zinc, total iron, and sulfate were in excess of tolerance limits for all three constituents for the following wells: Picher #2, Picher #3, Picher #4, Quapaw #2, and Commerce #3. The mean concentrations of total zinc, total iron, and sulfate for all samples taken from an individual well are shown in Table 4. Statistically significant evidence exists that these wells have been impacted by acid mine water.

Table 4

Mean Concentration of Indicator Parameters in Impacted Wells

Well	Total Zinc ug/l	Total Iron ug/l	Sulfate mg/l
Tolerance Limit	43	207	82
Picher #2	150.3	441.1	122.0
Picher #3	64.5	407.4	201.7
Picher #4	129.2	893.8	289.2
Quapaw #2	44.8	931.6	186.6
Commerce #3	50.5	396.3	122.2

Summary and Conclusions

Statistical analysis of the sampling results shows that there is evidence of mine water impacts to the five of the eleven public wells sampled inside the mining area. The analysis does not reveal whether the impacted wells have poor well integrity, are not cased deep enough, if the Roubidoux aquifer is impacted by mine water, or a combination of the three are impacting water quality. Further investigations of impacted wells are required to determine if the contamination is caused by well integrity, well completion, or contamination of the Roubidoux aquifer.

All water supply wells sampled inside the mining area produce water that meet EPA and State primary drinking water standards. Therefore, the mine water impacted public wells presently do not pose a health threat. However, the secondary drinking water standard for iron was exceeded by five wells inside the mining area and the secondary drinking water standard for sulfate was exceeded by one well inside the mining area.

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Appendix A

Sampling Results

OWNER	DATES	TIMES	STAID	SAMPL	STYPE	QATYPE	AGYANAL	AUK	AL	SB	AS
Cardin	08-18-92	1050	365823094510701	99203930	Raw		CLP	132	<42	<32.2	<2.6
Cardin	08-18-92	1053	365823094510701	99200067	Raw		RSKERL	132	<52	—	<39
Cardin	08-18-92	1054	365823094510701	99203932	Filtered		RSKERL	132	<52	—	<39
Cardin	09-22-92	0900	365823094510701	99204048	Raw		CLP	140	<21.4	<16.9	<1.9
Cardin	09-22-92	0901	365823094510701	99200071	Raw	Duplicate	CLP	140	<21.4	<16.9	<1.9
Cardin	09-22-92	0903	365823094510701	99200072	Raw		RSKERL	140	<76	—	<5.9
Cardin	09-22-92	0904	365823094510701	99204077	Filtered		RSKERL	140	<76	—	<5.9
Cardin	10-21-92	0900	365823094510701	99300043	Raw		CLP	136	<25	<32	1.1
Cardin	10-21-92	0903	365823094510701	99300010	Raw		RSKERL	136	<37	—	<12
Cardin	10-21-92	0904	365823094510701	99300044	Filtered		RSKERL	136	<37	—	<12
Cardin	11-17-92	1050	365823094510701	99300151	Raw		CLP	133	<61	<31	<4
Cardin	11-17-92	1053	365823094510701	99300035	Raw		RSKERL	133	<26	—	<10
Cardin	11-17-92	1054	365823094510701	99300152	Filtered		RSKERL	133	69	—	<10
Cardin	12-14-92	0920	365823094510701	99300266	Raw		CLP	134	<25	<32	<1
Cardin	12-14-92	0921	365823094510701	99300067	Raw	Duplicate	CLP	134	<25	<32	<1
Cardin	12-14-92	0923	365823094510701	99300054	Raw		RSKERL	134	<67	—	24
Cardin	12-14-92	0924	365823094510701	99300267	Filtered		RSKERL	134	<67	—	<23
Cardin	01-25-93	0920	365823094510701	99300388	Raw		CLP	138	<30.8	<24.3	<1.5
Cardin	01-25-93	0921	365823094510701	99300098	Raw	Duplicate	CLP	138	<30.8	<24.3	<1.5
Cardin	01-25-93	0923	365823094510701	99300089	Raw		RSKERL	138	6	—	<18
Cardin	01-25-93	0924	365823094510701	99300389	Filtered		RSKERL	138	72	—	<18
Commerce 1	08-17-92	0930	365600094523001	99203909	Raw		CLP	136	<42	<32.2	<2.6
Commerce 1	08-17-92	0931	365600094523001	99200054	Raw	Duplicate	CLP	136	<42	<32.2	<2.6
Commerce 1	08-17-92	0933	365600094523001	99200060	Raw		RSKERL	136	<52	—	<39
Commerce 1	08-17-92	0934	365600094523001	99203911	Filtered		RSKERL	136	<52	—	<39
Commerce 1	09-23-92	1050	365600094523001	99204090	Raw		CLP	130	<21.4	<16.9	<1.9
Commerce 1	09-23-92	1053	365600094523001	99200079	Raw		RSKERL	130	<76	—	<5.9
Commerce 1	09-23-92	1054	365600094523001	99204091	Filtered		RSKERL	130	<76	—	<5.9
Commerce 1	10-21-92	1140	365600094523001	99300047	Raw		CLP	136	<25	<32	2
Commerce 1	10-21-92	1143	365600094523001	99300013	Raw		RSKERL	136	<37	—	<12
Commerce 1	10-21-92	1144	365600094523001	99300048	Filtered		RSKERL	136	<37	—	<12
Commerce 1	11-17-92	1200	365600094523001	99300154	Raw		CLP	138	<61	<31	<4
Commerce 1	11-17-92	1203	365600094523001	99300037	Raw		RSKERL	138	<26	—	<10
Commerce 1	11-17-92	1204	365600094523001	99300153	Filtered		RSKERL	138	<32	—	<10
Commerce 1	12-14-92	1120	365600094523001	99300268	Raw		CLP	136	<25	<32	<1
Commerce 1	12-14-92	1123	365600094523001	99300056	Raw		RSKERL	136	<67	—	<23
Commerce 1	12-14-92	1124	365600094523001	99300269	Filtered		RSKERL	136	<67	—	<23
Commerce 1	01-26-93	1050	365600094523001	99300370	Raw		CLP	134	<30.8	24.6	<1.5
Commerce 1	01-26-93	1053	365600094523001	99300090	Raw		RSKERL	134	<59	—	<16
Commerce 1	01-26-93	1054	36560009452300	99300372	Filtered		RSKERL	134	<59	—	<16
Commerce 2	08-17-92	1100	365557094522701	99203912	Raw		CLP	128	<42	<32.2	<2.6
Commerce 2	08-17-92	1103	365557094522701	99200061	Raw		RSKERL	128	<52	—	<39
Commerce 2	08-17-92	1104	365557094522701	99203914	Filtered		RSKERL	128	<52	—	<39
Commerce 2	09-23-92	1150	365557094522701	99204092	Raw		CLP	123	<21.4	<16.9	<1.9
Commerce 2	09-23-92	1153	365557094522701	99200080	Raw		RSKERL	123	<76	—	<5.8
Commerce 2	09-23-92	1154	365557094522701	99204093	Filtered		RSKERL	123	<76	—	<5.8
Commerce 2	10-21-92	1030	365557094522701	99300045	Raw		CLP	124	<25	<32	<1
Commerce 2	10-21-92	1031	365557094522701	99300011	Raw	Duplicate	CLP	124	29.9	<32	<1
Commerce 2	10-21-92	1033	365557094522701	99300012	Raw		RSKERL	124	<37	—	<12
Commerce 2	10-21-92	1034	365557094522701	99300046	Filtered		RSKERL	124	<37	—	18
Commerce 2	11-17-92	1250	365557094522701	99300155	Raw		CLP	126	<61	<31	<4

OWNER	DATES	TIMES	STAID	SAMPL	STYPE	QATYPE	AGYANAL	ALK	AL	SB	AS
Commerce 2	11-17-92	1253	365557094522701	99300039	Raw		RSKERL	126	<32	—	<10
Commerce 2	11-17-92	1254	365557094522701	99300156	Filtered		RSKERL	126	<26	—	<10
Commerce 2	12-14-92	1310	365557094522701	99300271	Raw		CLP	122	27.3	<32	<1
Commerce 2	12-14-92	1313	365557094522701	99300057	Raw		RSKERL	122	<67	—	<23
Commerce 2	12-14-92	1314	365557094522701	99300270	Filtered		RSKERL	122	106	—	<23
Commerce 2	01-26-93	1130	365557094522701	99300367	Raw		CLP	124	<30.8	<24.3	<1.5
Commerce 2	01-26-93	1133	365557094522701	99300089	Raw		RSKERL	124	<59	—	<18
Commerce 2	01-26-93	1134	365557094522701	99300368	Filtered		RSKERL	124	<59	—	<18
Commerce 3	08-17-92	1340	365627094522201	99203915	Raw		CLP	156	<44	<32.2	<2.6
Commerce 3	08-17-92	1343	365627094522201	99200062	Raw		RSKERL	156	<52	—	<39
Commerce 3	08-17-92	1344	365627094522201	99203917	Filtered		RSKERL	156	<52	—	<39
Commerce 3	09-23-92	1350	365627094522201	99204094	Raw		CLP	144	<21.4	<16.9	<1.9
Commerce 3	09-23-92	1353	365627094522201	99200081	Raw		RSKERL	144	<76	—	<5.9
Commerce 3	09-23-92	1354	365627094522201	99204095	Filtered		RSKERL	144	<76	—	<5.9
Commerce 3	10-21-92	1520	365627094522201	99300051	Raw		CLP	168	<25	<32	1.6
Commerce 3	10-21-92	1523	365627094522201	99300016	Raw		RSKERL	168	<37	—	<12
Commerce 3	10-21-92	1524	365627094522201	99300052	Filtered		RSKERL	168	<37	—	25
Commerce 3	11-17-92	1440	365627094522201	99300158	Raw		CLP	159	<61	<31	<4
Commerce 3	11-17-92	1443	365627094522201	99300041	Raw		RSKERL	159	<26	—	14
Commerce 3	11-17-92	1444	365627094522201	99300157	Filtered		RSKERL	159	<26	—	17
Commerce 3	12-14-92	1410	365627094522201	99300272	Raw		CLP	160	<25	<32	<1
Commerce 3	12-14-92	1413	365627094522201	99300058	Raw		RSKERL	160	<67	—	<23
Commerce 3	12-14-92	1414	365627094522201	99300273	Filtered		RSKERL	160	<67	—	<23
Commerce 3	01-26-93	1400	365627094522201	99300365	Raw		CLP	158	<30.8	<24.3	<1.5
Commerce 3	01-26-93	1401	365627094522201	99300088	Raw	Duplicate	CLP	158	<30.8	<24.3	<1.5
Commerce 3	01-26-93	1403	365627094522201	99300087	Raw		RSKERL	158	61	—	<18
Commerce 3	01-26-93	1404	365627094522201	99300366	Filtered		RSKERL	158	<59	—	<18
Commerce 4	08-17-92	1430	365627094522101	99203918	Raw		CLP	118	<42	<32.2	<2.6
Commerce 4	08-17-92	1433	365627094522101	99200063	Raw		RSKERL	118	<52	—	<39
Commerce 4	08-17-92	1434	365627094522101	99203920	Filtered		RSKERL	118	<52	—	<39
Commerce 4	09-23-92	1510	365627094522101	99204097	Raw		CLP	116	<21.4	<16.9	<1.9
Commerce 4	09-23-92	1513	365627094522101	99200082	Raw		RSKERL	116	<76	—	<5.8
Commerce 4	09-23-92	1514	365627094522101	99204096	Filtered		RSKERL	116	<76	—	<5.8
Commerce 4	10-21-92	1340	365627094522101	99300049	Raw		CLP	120	<25	<32	2
Commerce 4	10-21-92	1343	365627094522101	99300014	Raw		RSKERL	120	<37	—	<12
Commerce 4	10-21-92	1344	365627094522101	99300050	Filtered		RSKERL	120	<37	—	21
Commerce 4	11-17-92	1550	365627094522101	99300159	Raw		CLP	126	<61	<31	<4
Commerce 4	11-17-92	1551	365627094522101	99300049	Raw	Duplicate	CLP	126	<61	<31	<4
Commerce 4	11-17-92	1553	365627094522101	99300043	Raw		RSKERL	126	<26	—	<10
Commerce 4	11-17-92	1554	365627094522101	99300160	Filtered		RSKERL	126	<26	—	<10
Commerce 4	12-14-92	1500	365627094522101	99300274	Raw		CLP	120	<25	<32	<1
Commerce 4	12-14-92	1503	365627094522101	99300059	Raw		RSKERL	120	<67	—	<23
Commerce 4	12-14-92	1504	365627094522101	99300275	Filtered		RSKERL	120	<67	—	<23
Commerce 4	01-26-93	1440	365627094522101	99300363	Raw		CLP	122	<30.8	<24.3	<1.5
Commerce 4	01-26-93	1443	365627094522101	99300085	Raw		RSKERL	122	<59	—	<18
Commerce 4	01-26-93	1444	365627094522101	99300364	Filtered		RSKERL	122	<59	—	<18
Cook, Joe	01-27-93	1750	365018094451101	99300349	Raw		CLP	238	<30.8	<24.3	<1.5
Cook, Joe	01-27-93	1753	365018094451101	99300076	Raw		RSKERL	238	<59	—	<18
Cook, Joe	01-27-93	1754	365018094451101	99300350	Filtered		RSKERL	238	60	—	<18

OWNER	DATES	TIMES	STAID	SAMPL	STYPE	QATYPE	AGYANAL	ALK	AL	SB	AS
Fairland 2	01-26-93	0910	364454094504401	99300373	Raw		CLP	134	<30.8	<24.3	<1.5
Fairland 2	01-26-93	0913	364454094504401	99300091	Raw		RSKERL	134	<59	—	<18
Fairland 2	01-26-93	0914	364454094504401	99300374	Filtered		RSKERL	134	73	—	<18
Grand Lake Shores	01-27-93	1430	365100094491701	99300353	Raw		CLP	134	<30.8	<24.3	<1.5
Grand Lake Shores	01-27-93	1431	365100094491701	99300103	Raw	Duplicate	CLP	134	<30.8	<24.3	<1.5
Grand Lake Shores	01-27-93	1433	365100094491701	99300078	Raw		RSKERL	134	<59	—	<18
Grand Lake Shores	01-27-93	1434	365100094491701	99300354	Filtered		RSKERL	134	<59	—	<18
Miami 6	01-27-93	0910	365213094500701	99300347	Raw		CLP	118	47.3	<24.3	<1.5
Miami 6	01-27-83	0913	365213094500701	99300075	Raw		RSKERL	118	<59	—	<18
Miami 6	01-27-93	0914	365213094500701	99300348	Filtered		RSKERL	118	<59	—	<18
Miami 1	01-27-93	1040	365229094522101	99300345	Raw		CLP	120	<30.8	<24.3	<1.5
Miami 1	01-27-93	1043	365229094522101	99300074	Raw		RSKERL	120	64	—	<18
Miami 1	01-27-93	1044	365229094522101	99300346	Filtered		RSKERL	120	<59	—	<18
Miami 3	01-27-93	1230	365206094522201	99300355	Raw		CLP	126	<30.8	66.5	<1.5
Miami 3	01-27-93	1233	365206094522201	99300080	Raw		RSKERL	126	106	—	<18
Miami 3	01-27-93	1234	365206094522201	99300356	Filtered		RSKERL	126	<59	—	<18
Ogeechee Farms	01-27-93	1620	364516094473501	99300351	Raw		CLP	128	<30.8	<24.3	<1.5
Ogeechee Farms	01-27-93	1623	364516094473501	99300077	Raw		RSKERL	128	<59	—	<18
Ogeechee Farms	01-27-93	1624	364516094473501	99300352	Filtered		RSKERL	128	64	—	<18
Picher 2	08-17-92	1540	365905094494602	99203921	Raw		CLP	136	<42	<32.2	<2.6
Picher 2	08-17-92	1543	365905094494602	99200064	Raw		RSKERL	136	<52	—	<39
Picher 2	08-17-92	1544	365905094494602	99203923	Filtered		RSKERL	136	<52	—	<39
Picher 2	09-22-92	1600	365905094494602	99204084	Raw		CLP	138	<21.4	<16.9	2.9
Picher 2	09-22-92	1603	365905094494602	99200076	Raw		RSKERL	138	<76	—	<5.9
Picher 2	09-22-92	1604	365905094494602	99204085	Filtered		RSKERL	138	<76	—	<5.9
Picher 2	10-20-92	0940	365905094494602	99300031	Raw		CLP	136	<25	<32	<1
Picher 2	10-20-92	0941	365905094494602	99300001	Raw	Duplicate	CLP	136	<25	<32	<1
Picher 2	10-20-92	0943	365905094494602	99300003	Raw		RSKERL	136	45	—	15
Picher 2	10-20-92	0944	365905094494602	99300032	Filtered		RSKERL	136	<37	—	<12
Picher 2	11-16-92	1610	365905094494602	99300145	Raw		CLP	158	<61	<31	<4
Picher 2	11-16-92	1613	365905094494602	99300029	Raw		RSKERL	158	<26	—	20
Picher 2	11-16-92	1614	365905094494602	99300146	Filtered		RSKERL	158	<26	—	16
Picher 2	12-15-92	0850	365905094494602	99300281	Raw		CLP	138	<25	<32	1.2
Picher 2	12-15-92	0853	365905094494602	99300062	Raw		RSKERL	138	<67	—	<23
Picher 2	12-15-92	0854	365905094494602	99300280	Filtered		RSKERL	138	73	—	<23
Picher 2	01-25-93	1120	365905094494602	99300387	Raw		CLP	138	<30.8	<24.3	<1.5
Picher 2	01-25-93	1123	365905094494602	99300097	Raw		RSKERL	138	112	—	<18
Picher 2	01-25-93	1124	365905094494602	99300386	Filtered		RSKERL	138	87	—	<18
Picher 3	08-17-92	1610	365905094494603	99203924	Raw		CLP	156	<42	<32.2	<2.6
Picher 3	08-17-92	1611	365905094494603	99200057	Raw	Duplicate	CLP	156	<42	<32.2	<2.6
Picher 3	08-17-92	1613	365905094494603	99200065	Raw		RSKERL	156	<52	—	<39
Picher 3	08-17-92	1614	365905094494603	99203926	Filtered		RSKERL	156	<5.2	—	<39
Picher 3	09-22-92	1700	365905094494603	99204086	Raw		CLP	151	<21.4	<16.9	<1.9
Picher 3	09-22-92	1703	365905094494603	99200077	Raw		RSKERL	151	<76	—	<5.9
Picher 3	09-22-92	1704	365905094494603	99204087	Filtered		RSKERL	151	<76	—	<5.9
Picher 3	10-20-92	1050	365905094494603	99300033	Raw		CLP	156	<25	<32	<1

OWNER	DATES	TIMES	STAID	SAMPL	STYPE	QATYPE	AGYANAL	ALK	AL	SB	AS
Picher 3	10-20-92	1053	365905094494603	99300005	Raw		RSKERL	156	<37	—	14
Picher 3	10-20-92	1054	365905094494603	99300034	Filtered		RSKERL	156	<37	—	<12
Picher 3	11-16-92	1710	365905094494603	99300147	Raw		CLP	151	<61	<31	<4
Picher 3	11-16-92	1713	365905094494603	99300031	Raw		RSKERL	151	<26	—	<11
Picher 3	11-16-92	1714	365905094494603	99300148	Filtered		RSKERL	151	<26	—	17
Picher 3	12-15-92	0920	365905094494603	99300282	Raw		CLP	160	<25	<32	<1
Picher 3	12-15-92	0923	365905094494603	99300063	Raw		RSKERL	160	<67	—	<23
Picher 3	12-15-92	0924	365905094494603	99300283	Filtered		RSKERL	160	<67	—	<23
Picher 3	01-25-93	1200	365905094494603	99300384	Raw		CLP	178	<30.8	33.3	<1.5
Picher 3	01-25-93	1203	365905094494603	99300096	Raw		RSKERL	178	200	—	<18
Picher 3	01-25-93	1204	365905094494603	99300385	Filtered		RSKERL	178	<59	—	<18
Picher 4	08-18-92	1210	365911094502501	99203933	Raw		CLP	176	<42	<32.2	<2.6
Picher 4	08-18-92	1213	365911094592501	99200068	Raw		RSKERL	176	<52	—	<39
Picher 4	08-18-92	1214	365911094502501	99203935	Filtered		RSKERL	176	<52	—	<39
Picher 4	09-23-92	0910	365911094502501	99204088	Raw		CLP	170	<21.4	<16.9	<1.9
Picher 4	09-23-92	0911	365911094502501	99200088	Raw	Duplicate	CLP	170	<21.4	<16.9	<1.9
Picher 4	09-23-92	0913	365911094502501	99200078	Raw		RSKERL	170	<76	—	<5.9
Picher 4	09-23-92	0914	365911094502501	99204089	Filtered		RSKERL	170	<76	—	<5.9
Picher 4	10-20-92	1250	365911094502501	99300035	Raw		CLP	176	<25	<32	1
Picher 4	10-20-92	1253	365911094502501	99300006	Raw		RSKERL	176	<37	—	<12
Picher 4	10-20-92	1254	365911094502501	99300036	Filtered		RSKERL	176	<37	—	<12
Picher 4	11-17-92	0930	365911094502501	99300150	Raw		CLP	190	<61	<31	<4
Picher 4	11-17-92	0933	365911094502591	99300033	Raw		RSKERL	190	<26	—	16
Picher 4	11-17-92	0934	365911094502501	99300149	Filtered		RSKERL	190	<26	—	12
Picher 4	12-15-92	1010	365911094502501	99300285	Raw		CLP	178	<25	<32	<1
Picher 4	12-15-92	1011	365911094502501	99300069	Raw	Duplicate	CLP	178	27.1	<32	1.1
Picher 4	12-15-92	1013	365911094502591	99300064	Raw		RSKERL	178	<67	—	<23
Picher 4	12-15-92	1014	365911094502591	99300284	Filtered		RSKERL	178	<67	—	<23
Picher 4	01-25-93	1330	365911094502501	99300382	Raw		CLP	177	<30.8	25.2	<1.5
Picher 4	01-25-93	1333	365911094502501	99300095	Raw		RSKERL	177	74	—	<18
Picher 4	01-25-93	1334	365911094502501	99300383	Filtered		RSKERL	177	<9.9	—	<3.6
Quapaw 2	08-18-92	1520	365734094471001	99203936	Raw		CLP	186	<42.2	<32.2	<2.6
Quapaw 2	08-18-92	1523	365734094471001	99200070	Raw		RSKERL	186	<52	—	<39
Quapaw 2	08-18-92	1524	365734094471001	99203938	Filtered		RSKERL	186	<52	—	<39
Quapaw 2	09-22-92	1330	365734094471001	99204080	Raw		CLP	178	22.6	<16.9	<1.9
Quapaw 2	09-22-92	1333	365734094471001	99200074	Raw		RSKERL	178	<76	—	<5.9
Quapaw 2	09-22-92	1334	365734094471001	99204081	Filtered		RSKERL	178	<76	—	<5.9
Quapaw 2	10-20-92	1440	365734094471001	99300037	Raw		CLP	176	<25	<32	<1
Quapaw 2	10-20-92	1443	365734094471001	99300007	Raw		RSKERL	176	<3.7	—	<12
Quapaw 2	10-20-92	1444	365734094471001	99300038	Filtered		RSKERL	176	<37	—	<12
Quapaw 2	11-16-92	1320	365734094471001	99300141	Raw		CLP	175	<61	<31	<4
Quapaw 2	11-16-92	1323	365734094471001	99300025	Raw		RSKERL	175	<26	—	15
Quapaw 2	11-16-92	1324	365734094471001	99300142	Filtered		RSKERL	175	<26	—	<11
Quapaw 2	12-14-92	1610	365734094471001	99300277	Raw		CLP	184	<25	<32	1.1
Quapaw 2	12-14-92	1613	365734094471001	99300060	Raw		RSKERL	184	<67	—	<23
Quapaw 2	12-14-92	1614	365734094471001	99300276	Filtered		RSKERL	184	<67	—	<23
Quapaw 2	01-25-93	1440	365734094471001	99360380	Raw		CLP	180	<30.8	<24.3	<1.5
Quapaw 2	01-25-93	1443	365734094471001	99300094	Raw		RSKERL	180	<59	—	<18
Quapaw 2	01-25-93	1444	365734094471001	99300381	Filtered		RSKERL	180	<59	—	<18
Quapaw 4	08-18-92	1620	365633094471001	99203939	Raw		CLP	120	<42.2	<32.2	<2.6

OWNER	DATES	TIMES	STAID	SAMPL	STYPE	QATYPE	AGYANAL	ALK	AL	SB	AS
Quapaw 4	08-18-92	1623	365633094471001	99200069	Raw		RSKERL	120	<52	—	<39
Quapaw 4	08-18-92	1624	365633094471001	99203941	Filtered		RSKERL	120	<52	—	<39
Quapaw 4	09-22-92	1500	365633094471001	99204082	Raw		CLP	119	<21.4	<16.9	<1.9
Quapaw 4	09-22-92	1503	365633094471001	99200075	Raw		RSKERL	119	<76	—	<5.8
Quapaw 4	09-22-92	1504	365633094471001	99204083	Filtered		RSKERL	119	<80	—	<6.1
Quapaw 4	10-20-92	1540	365633094471001	99300039	Raw		CLP	116	<25	<32	<1
Quapaw 4	10-20-92	1543	365633094471001	99300008	Raw		RSKERL	116	52	—	21
Quapaw 4	10-20-92	1544	365633094471001	99300040	Filtered		RSKERL	116	<37	—	19
Quapaw 4	11-16-92	1450	365633094471001	99300144	Raw		CLP	133	<61	<31	<4
Quapaw 4	11-16-92	1453	365633094471001	99300027	Raw		RSKERL	133	<26	—	<10
Quapaw 4	11-16-92	1454	365633094471001	99300143	Filtered		RSKERL	133	32	—	13
Quapaw 4	12-14-92	1730	365633094471001	99300278	Raw		CLP	120	<25	<32	1.1
Quapaw 4	12-14-92	1733	365633094471001	99300061	Raw		RSKERL	120	83	—	<23
Quapaw 4	12-14-92	1734	365633094471001	99300279	Filtered		RSKERL	120	<67	—	<23
Quapaw 4	01-25-93	1550	365633094471001	99300378	Raw		CLP	122	<30.8	<24.3	<1.5
Quapaw 4	01-25-93	1553	365633094471001	99300093	Raw		RSKERL	122	97	—	<18
Quapaw 4	01-25-93	1554	365633094471001	99300379	Filtered		RSKERL	122	<59	—	<18
RWD 4 Well 2	01-28-93	0830	365128094471301	99300359	Raw		CLP	124	<30.8	<24.3	<1.5
RWD 4 Well 2	01-28-93	0833	365128094471301	99300082	Raw		RSKERL	124	<59	—	<18
RWD 4 Well 2	01-28-93	0834	365128094471301	99300360	Filtered		RSKERL	124	<59	—	<18
RWD 4 Well 3	01-28-93	0930	365319094461101	99300357	Raw		CLP	116	<30.8	<24.3	<1.5
RWD 4 Well 3	01-28-93	0933	365319094461101	99300081	Raw		RSKERL	116	<59	—	<18
RWD 4 Well 3	01-28-93	0934	365319094461101	99300358	Filtered		RSKERL	116	<59	—	<18
RWD 4 Well 4	08-18-92	0930	365738094445601	99203927	Raw		CLP	118	<42	<32.2	<2.6
RWD 4 Well 4	08-18-92	0933	365738094445601	99200066	Raw		RSKERL	118	<52	—	<39
RWD 4 Well 4	08-18-92	0934	365738094445601	99203929	Filtered		RSKERL	118	<52	—	<39
RWD 4 Well 4	09-22-92	1110	365738094445601	99204078	Raw		CLP	118	<21.4	<16.9	<1.9
RWD 4 Well 4	09-22-92	1113	365738094445601	99200073	Raw		RSKERL	118	<76	—	<5.8
RWD 4 Well 4	09-22-92	1114	365738094445601	99204079	Filtered		RSKERL	118	<76	—	<5.8
RWD 4 We11 4	10-20-92	1640	365738094445601	99300041	Raw		CLP	120	<25	<32	<1
RWD 4 Well 4	10-20-92	1643	365738094445601	99300009	Raw		RSKERL	120	<37	—	<12
RWD 4 Well 4	10-20-92	1644	365738094445601	99300042	Filtered		RSKERL	120	<37	—	<12
RWD 4 Well 4	11-16-92	1050	365738094445601	99300139	Raw		CLP	137	<61	<31	<4
RWD 4 Well 4	11-16-92	1051	365738094445601	99300021	Raw	Duplicate	CLP	137	<61	<31	<4
RWD 4 Well 4	11-16-92	1053	365738094445601	99300023	Raw		RSKERL	137	<26	—	<10
RWD 4 Well 4	11-16-92	1054	365738094445601	99300140	Filtered		RSKERL	137	<26	—	<10
RWD 4 Well 4	12-15-92	1130	365738094445601	99300286	Raw		CLP	120	<25	<32	<1
RWD 4 Well 4	12-15-92	1133	36573809444560	99300065	Raw		RSKERL	120	83	—	<23
RWD 4 Well 4	12-15-92	1134	365738094445601	99300287	Filtered		RSKERL	120	<67	—	<23
RWD 4 Well 4	01-25-93	1640	365738094445601	99300375	Raw		CLP	118	<30.8	<24.3	<1.5
RWD 4 Well 4	01-25-93	1643	365738094445601	99300092	Raw		RSKERL	118	89	—	<18
RWD 4 Well 4	01-25-93	1644	365738094445601	99300377	Filtered		RSKERL	118	<59	—	<18
RWD 6 Well 1	01-26-93	1700	364921094522201	99300361	Raw		CLP	124	<30.8	34.1	<1.5
RWD 6 Well 1	01-26-93	1703	364921094522201	99300083	Raw		RSKERL	124	148	—	<18
RWD 6 Well 1	01-26-93	1704	364921094522201	99300362	Filtered		RSKERL	124	<59	—	<18

RESULT OF MODIFY   PAGE 1

OWNER	DATES	TIMES	BA	BE	HC03	B	CD	CA	CL	CR	CO	CU	FE
Cardin	08-18-92	1050	63.1	<1.6	161	—	<3.6	46.2	—	<4.1	< 14	<2.7	173
Cardin	08-18-92	1053	68.2	.3	161	<15	<1.6	51	20.8	<1.9	< 4.3	<50	192
Cardin	08-18-92	1054	66.8	.1	161	<14	<1.6	50.2	21.1	<1.9	< 4.3	<50	184
Cardin	09-22-92	0900	63.3	<.4	171	—	<1	47.2	—	<4.5	< 2.7	<3.5	170
Cardin	09-22-92	0901	59.8	<.4	171	—	<1	44.7	—	<4.5	< 2.7	<3.5	167
Cardin	09-22-92	0903	68.6	<.9	171	<28	<2.3	48.3	21.7	<2.4	< 3.5	<51	<94
Cardin	09-22-92	0904	68.8	<.9	171	<28	<2.3	48.1	21.4	<2.4	< 3.5	<51	124
Cardin	10-21-92	0900	62.1	<1	166	—	<4	45.9	—	<3	< 5	<4	145
Cardin	10-21-92	0903	68.9	<.2	166	37.5	<1.7	48.2	19.9	2.2	< 1.8	<4.8	150
Cardin	10-21-92	0904	66.8	<.2	166	41.4	<1.7	46.7	21.2	<.8	< 1.8	<4.8	152
Cardin	11-17-92	1050	66.1	<1	162	—	<3	47.1	—	<8	< 7	8.2	164
Cardin	11-17-92	1053	67.1	<5	162	36.1	<2.1	48.3	22.7	2.1	< 2.7	<20	170
Cardin	11-17-92	1054	66.1	<5	162	36.9	<2.1	47.5	22.6	16	< 2.7	<20	238
Cardin	12-14-92	0920	71.3	<1	163	—	<4	47	23.3	<3	< 5	<4	143
Cardin	12-14-92	0921	69.5	<1	163	—	<4	46.7	23.1	<3	< 5	<4	143
Cardin	12-14-92	0923	65.3	.2	163	<50	3.8	47.6	23.3	2.5	1.8	<15	125
Cardin	12-14-92	0924	65.6	<.2	163	<50	<2.6	48.1	37.9	<1.4	< 1.7	<15	121
Cardin	01-25-93	0920	66.4	<1.7	168	—	<2.3	48.5	20.4	<5.7	< 10.6	2.8	172
Cardin	01-25-93	0921	64.8	<1.7	168	—	<2.3	46.8	20.4	<5.7	< 10.6	<2.6	167
Cardin	01-25-93	0923	67.2	<5	168	28	<1.6	48.6	21.2	<2.3	< 8.2	<38	140
Cardin	01-25-93	0924	63.8	.1	168	34	1.8	45.9	20.8	3.3	< 8.2	<38	173
Commerce 1	08-17-92	0930	46.7	<1.6	166	—	<3.6	45	—	<4.1	< 14	3.5	255
Commerce 1	08-17-92	0931	46.4	<1.6	166	—	<3.6	44.7	—	<4.1	< 14	<2.7	208
Commerce 1	08-17-92	0933	48.6	<5	156	<12	<1.6	48	34.7	<1.9	< 4.3	<50	109
Commerce 1	08-17-92	0934	<49.6	<5	166	<14	<1.6	47	35.1	<1.9	< 4.3	<50	225
Commerce 1	09-23-92	1050	46.9	<.4	159	—	<1	43.8	—	<4.5	< 2.7	<3.5	251
Commerce 1	09-23-92	1053	52.2	<.9	159	<25	<2.3	46	35.6	<2.4	< 3.5	<51	188
Commerce 1	09-23-92	1054	52.2	<.9	159	<25	<2.3	45.2	35.5	<2.4	4.2	<51	189
Commerce 1	10-21-92	1140	52.3	<1	166	—	<4	46.7	—	<3	< 5	<4	206
Commerce 1	10-21-92	1143	56	<.2	166	79.8	<1.7	48.1	35.3	1.2	< 1.8	<4.8	223
Commerce 1	10-21-92	1144	56.3	<.2	166	80.3	<1.7	47.5	35.3	<.8	< 1.8	<4.8	197
Commerce 1	11-17-92	1200	52.5	<1	168	—	<3	46.8	—	<8	< 7	9	297
Commerce 1	11-17-92	1203	50.3	<5	168	64.4	<2.1	47.3	35.3	<1.6	< 2.7	<20	198
Commerce 1	11-17-92	1204	50.3	<.5	168	77	<1.3	45.4	35.1	<2.9	< 7.1	<26	192
Commerce 1	12-14-92	1120	52	<1	166	—	<4	44.7	35.4	<3	< 5	50.9	227
Commerce 1	12-14-92	1123	50.6	<.2	166	70	<2.6	46.8	34.6	<1.4	< 1.7	<15	246
Commerce 1	12-14-92	1124	51.4	<.2	166	73	<2.6	46	34.9	<1.4	< 1.7	<15	164
Commerce 1	01-26-93	1050	49.9	<1.7	163	—	<2.3	45	31	<5.7	< 10.6	<2.6	189
Commerce 1	01-26-93	1053	49.6	.2	163	58	<1.6	45	32.8	<2.3	< 8.2	<38	168
Commerce 1	01-26-93	1054	50.5	.1	163	66	<1.6	44.9	32.6	<2.3	< 8.2	<38	163
Commerce 2	08-17-92	1100	33.7	<1.6	156	—	<3.6	34.2	—	<4.1	< 14	<2.7	131
Commerce 2	08-17-92	1103	36.3	<5	156	<12	<1.6	35.8	12.9	<1.9	< 4.3	<50	150
Commerce 2	08-17-92	1104	34.9	<5	156	<12	<1.6	34.5	12.8	<1.9	< 4.3	<50	107
Commerce 2	09-23-92	1150	34	<.4	150	—	<1	33.5	—	<4.5	< 2.7	<3.5	251
Commerce 2	09-23-92	1153	39.2	<.9	150	<20	<2.3	35	12.1	3.1	< 3.5	<51	<94
Commerce 2	09-23-92	1154	40.4	<.9	150	<20	<2.3	34.4	12.5	<2.4	< 3.5	<51	<94
Commerce 2	10-21-92	1030	36.5	<1	151	—	<4	34.4	—	<3	< 5	5	127
Commerce 2	10-21-92	1031	35.2	<1	151	—	<4	34.3	—	<3	< 5	6.3	122
Commerce 2	10-21-92	1033	38.8	<.2	151	67.3	<1.7	35.2	11.4	1.1	< 1.8	<4.8	160
Commerce 2	10-21-92	1034	39.2	<.2	151	71.9	<1.7	34.4	7.82	1.8	< 1.8	<4.8	124
Commerce 2	11-17-92	1250	36.8	<1	154	—	<3	33.1	—	<8	< 7	9.8	137

OWNER	DATES	TIMES	BA	BE	HCO3	B	CD	CA	CL	CR	CO	CU	FE
Commerce 2	11-17-92	1253	37.3	<.5	154	68.5	<1.3	32.3	11.3	<2.9	<7.1	<26	110
Commerce 2	11-17-92	1254	37	<5	154	68.2	<2.1	34	13.3	<1.6	3.8	<20	108
Commerce 2	12-14-92	1310	39.7	<1	149	—	<4	30.8	13.5	<3	<5	9.5	165
Commerce 2	12-14-92	1313	39.2	<.2	149	63	<2.6	32.7	11.1	<1.4	<1.7	<15	108
Commerce 2	12-14-92	1314	39.7	.3	149	62	3.1	32.3	12.1	1.6	<1.7	<15	126
Commerce 2	01-26-93	1130	45	<1.7	151	—	<2.3	28.3	10.4	<5.7	<10.6	<2.6	118
Commerce 2	01-26-93	1133	45.9	.1	151	109	<1.6	28	10	<2.3	<8.2	<38	73
Commerce 2	01-26-93	1134	47.8	.1	151	102	<1.6	28.6	10	<2.3	<8.2	<38	91
Commerce 3	08-17-92	1340	54.8	<1.6	190	—	<3.6	65.1	—	<4.1	<14	<2.7	447
Commerce 3	08-17-92	1343	58.8	<.1	190	<20	<1.6	69.1	87.2	<1.9	<4.3	<50	436
Commerce 3	08-17-92	1344	59.3	.1	190	<18	<1.6	72.3	85.3	<1.9	<4.3	<50	179
Commerce 3	09-23-92	1350	57.4	<.4	176	—	<1	66.3	—	<4.5	<2.7	<3.5	416
Commerce 3	09-23-92	1353	56.1	<.9	176	<34	<2.3	68	71.2	<2.4	<3.5	<51	347
Commerce 3	09-23-92	1354	56.8	<.9	176	<35	<2.3	68.4	85.1	<2.4	<3.5	<51	363
Commerce 3	10-21-92	1520	57.4	<1	205	—	<4	68.9	—	<3	<5	<4	374
Commerce 3	10-21-92	1523	62.8	<.2	205	127	<1.7	70.8	85.5	1.8	<1.8	<4.8	507
Commerce 3	10-21-92	1524	62.2	<.2	205	133	<1.7	69.4	88.3	1	2.7	<4.8	399
Commerce 3	11-17-92	1440	55.4	<1	194	—	<3	68.7	—	<8	<7	<6	400
Commerce 3	11-17-92	1443	52.9	<5	194	99	<2.1	67.5	72.6	<1.6	<2.7	<20	361
Commerce 3	11-17-92	1444	54	<5	194	105	<2.1	68.2	72.6	<1.6	<2.7	<20	367
Commerce 3	12-14-92	1410	56.2	<1	195	—	<4	68.1	82.7	<3	<5	<4	382
Commerce 3	12-14-92	1413	54	.3	195	105	<2.6	70.1	79.8	<1.4	<1.7	<15	397
Commerce 3	12-14-92	1414	55.1	<.2	195	109	<2.6	70.3	79.7	1.5	<1.7	<15	658
Commerce 3	01-26-93	1400	51.5	<1.7	193	—	<2.3	66.5	73.2	<5.7	<10.6	<2.6	370
Commerce 3	01-26-93	1401	51.9	<1.7	193	—	<2.3	67.1	73.2	<5.7	<10.6	<2.6	372
Commerce 3	01-26-93	1403	56.5	.1	193	97	<1.6	69.9	78.3	<2.3	<8.2	<38	378
Commerce 3	01-26-93	1404	55.6	.1	193	97	<1.6	70.2	77.7	<2.3	<8.2	<38	387
Commerce 4	08-17-92	1430	36.2	<1.6	144	—	<3.6	29.7	—	<4.1	<14	<2.7	226
Commerce 4	08-17-92	1433	38	<5	144	<10	<1.6	31.9	19.3	2.2	<4.3	<50	104
Commerce 4	08-17-92	1434	38.3	<5	144	<10	<1.6	31.4	19.8	<1.9	<4.3	<50	61.9
Commerce 4	09-23-92	1510	35.2	<.4	141	—	<1	29.6	—	<4.5	<2.7	<3.5	94
Commerce 4	09-23-92	1513	38.7	<.9	141	<19	<2.3	30.6	19.5	<2.4	<3.5	<51	<94
Commerce 4	09-23-92	1514	38	<.9	141	<19	<2.3	31	19	<2.4	<3.5	<51	<94
Commerce 4	10-21-92	1340	37.3	<1	146	—	<4	30 2	—	<3	<5	16.3	54.4
Commerce 4	10-21-92	1343	40.3	<.2	146	54.7	<1.7	31.4	19.4	<.8	<1.8	<4.8	59
Commerce 4	10-21-92	1344	39.2	<.2	146	52.8	<1.7	30.2	19.7	1.4	4.9	<4.8	51
Commerce 4	11-17-92	1550	38.5	<1	154	—	<3	30.6	—	<8	<7	<6	63.2
Commerce 4	11-17-92	1551	38.4	<1	154	—	<3	30.5	—	<8	<7	<6	91.4
Commerce 4	11-17-92	1553	38.1	<5	154	56.9	<2.1	30.7	20	2.3	<2.7	<20	47.4
Commerce 4	11-17-92	1554	37.1	<5	154	43.7	<2.1	30.2	19.8	2.5	<2.7	<20	36.8
Commerce 4	12-14-92	1500	36.1	<1	146	—	<4	28.3	19.9	<3	<5	5.9	61.6
Commerce 4	12-14-92	1503	50.9	<.2	146	56	<2.6	30.6	19.3	2.4	1.8	<15	49
Commerce 4	12-14-92	1504	38.4	<.2	146	<50	<2.6	32	19.1	<1.4	<1.7	<15	30
Commerce 4	01-26-93	1440	37.4	<1.7	149	—	<2.3	30.1	19.3	<5.7	<10.6	<2.6	110
Commerce 4	01-26-93	1443	38.9	<5	149	39	<1.6	30.6	20	<2.3	<8.2	<38	57
Commerce 4	01-26-93	1444	38	.1	149	32	<1.6	30.6	20.1	<2.3	<8.2	<38	46
Cook, Joe	01-27-93	1750	250	<1.7	290	—	<2.3	105	4.39	<5.7	<10.6	<2.6	34
Cook, Joe	01-27-93	1753	234	.1	290	<15	<1.6	92.1	12.6	<2.3	<8.2	<38	42
Cook, Joe	01-27-93	1754	231	.1	290	<15	<1.6	91	14	2.9	<8.2	<38	18

OWNER	DATES	TIMES	BA	BE	HCO3	B	CD	CA	CL	CR	CO	CU	FE
Fairland 2	01-26-93	0910	26	<1.7	163	—	<2.3	29.5	82.9	<5.7	<10.6	<2.6	63
Fairland 2	01-26-93	0913	27.6	.1	163	100	<1.6	30.4	88	<2.3	10.4	<38	20
Fairland 2	01-26-93	0914	29	<5	163	102	<1.6	30.7	87	<2.3	<8.2	<38	20
Grand Lake Shores	01-27-93	1430	29.2	<1.7	163	—	<2.3	37	25.5	<5.7	<10.6	<2.6	28
Grand Lake Shores	01-27-93	1431	28	<1.7	163	—	<2.3	36.4	25.1	<5.7	<10.6	<2.6	23.1
Grand Lake Shores	01-27-93	1433	25.4	<.1	163	71	<1.6	33.4	25.1	<2.3	<8.2	<38	<11
Grand Lake Shores	01-27-93	1434	25.1	.2	163	85	<1.6	33.7	26.3	<2.3	<8.2	<38	<11
Miami 6	01-27-93	0910	20.8	<1.7	144	—	<2.3	31.7	111	<5.7	<10.6	<2.6	66.5
Miami 6	01-27-93	0913	20.9	.1	144	91	<1.6	32.1	106	<2.3	<8.2	<38	<11
Miami 6	01-27-93	0914	22.6	.1	144	101	<1.6	32.4	105	<2.3	<8.2	<38	<11
Miami 1	01-27-93	1040	27.6	<1.7	146	—	<2.3	37.1	80.6	<5.7	<10.6	<2.6	71.8
Miami 1	01-27-93	1043	25.8	.1	146	101	<1.6	32.7	84.5	<2.3	<8.2	<38	50
Miami 1	01-27-93	1044	25	.1	146	103	1.8	32.5	83.2	<2.3	<8.2	<38	44
Miami 3	01-27-93	1230	168	<1.7	154	—	<2.3	161	35.5	5.8	<10.6	19.8	1320
Miami 3	01-27-93	1233	30.6	<5	154	148	2.9	29	36.7	<2.3	<8.2	<38	355
Miami 3	01-27-93	1234	30	<.1	154	159	2.6	29.5	37.4	<2.3	<8.2	<38	51
Ogeechee Forms	01-27-93	1620	37.6	<1.7	156	—	<2.3	34.3	72.5	<5.7	<10.6	19.8	73.6
Ogeechee Farms	01-27-93	1623	33.6	.1	156	119	1.6	29.7	75.2	<2.3	<8.2	<38	32
Ogeechee Forms	01-27-93	1624	34.5	<.1	156	123	<1.6	29.9	74.5	2.4	<8.2	<38	30
Picher 2	08-17-92	1540	68.4	<1.6	166	—	<3.6	51.9	—	<4.1	<14	<2.7	384
Picher 2	08-17-92	1543	73.6	.1	166	<16	<1.6	56.5	10.1	<1.9	<4.3	<50	448
Picher 2	08-17-92	1544	71.9	.1	166	<15	<1.6	54.9	11.8	<1.9	<4.3	<50	440
Picher 2	09-22-92	1600	70.3	<.4	168	—	<1	54.6	—	<4.5	<2.7	<3.5	441
Picher 2	09-22-92	1603	77.8	<.9	168	<31	<2.3	56.4	8.42	<2.4	<3.5	<51	555
Picher 2	09-22-92	1604	77.6	<.9	168	<32	<2.3	56.7	8.62	<2.4	<3.5	<51	380
Picher 2	10-20-92	0940	72.1	<1	166	—	<4	54.3	—	<3	<5	<4	446
Picher 2	10-20-92	0941	72.3	<1	166	—	<4	55.6	—	<3	<5	<4	448
Picher 2	10-20-92	0943	76.6	<.2	166	69.5	<1.7	56.5	4.55	1.5	3.9	<4.8	462
Picher 2	10-20-92	0944	79.8	<.2	166	66.6	<1.7	58.7	4.05	<.8	<1.8	<4.8	465
Picher 2	11-16-92	1610	68.5	<1	193	—	<3	53.2	—	<8	<7	10.7	468
Picher 2	11-16-92	1613	68.2	<5	193	56.5	<2.1	54.3	10.5	<1.6	<2.7	<20	440
Picher 2	11-16-92	1614	71.7	<5	193	51.4	<2.1	56.7	10.7	1.6	<2.7	<20	450
Picher 2	12-15-92	0850	68	<1	168	—	<4	52.4	11	<3	<5	<4	432
Picher 2	12-15-92	0853	69.1	.2	168	<50	<2.6	56.6	9.01	<1.4	4.4	<15	448
Picher 2	12-15-92	0854	67.3	<.2	168	<50	<2.6	54.8	9.44	<1.4	<1.7	<15	497
Picher 2	01-25-93	1120	78.1	<1.7	168	—	<2.3	57.3	10.9	<5.7	<10.6	<2.6	395
Picher 2	01-25-93	1123	81.9	.1	168	39	<1.6	58.4	10.1	<2.3	<8.2	<38	401
Picher 2	01-25-93	1124	81.5	.1	168	31	<1.6	58.1	10.1	2.6	<8.2	<38	381
Picher 3	08-17-92	1610	65.2	<1.6	190	—	<3.6	67.2	—	<4.1	<14	<2.7	397
Picher 3	08-17-92	1611	65.4	<1.6	190	—	<3.6	67.7	—	<4.1	<14	<2.7	428
Picher 3	08-17-92	1613	67.2	.1	190	<17	<1.6	69.5	13.7	<1.9	<4.3	<50	459
Picher 3	08-17-92	1614	68.1	.1	190	<18	<1.6	69.9	16.2	<1.9	<4.3	<50	<6.1
Picher 3	09-22-92	1700	57.4	<.4	189	—	<1	76.8	—	<4.5	<2.7	<3.5	358
Picher 3	09-22-92	1703	66	<.9	189	<41	<2.3	81.1	10.9	<2.4	<3.5	<51	278
Picher 3	09-22-92	1704	65	<.9	189	<40	<2.3	79.9	12	<2.4	<3.5	<51	296
Picher 3	10-20-92	1050	64.9	<1	190	—	5.1	83.6	—	<3	<5	<4	324

OWNER	DATES	TIMES	BA	BE	HCO3	B	CD	CA	CL	CR	CO	CU	FE
Picher 3	10-20-92	1053	71.7	<.2	190	65.5	<1.7	84.6	9.67	1.9	3	<4.8	351
Picher 3	10-20-92	1054	72.3	.3	190	70.8	<1.7	85.5	7.71	<.8	3	5.7	377
Picher 3	11-16-92	1710	63.4	<1	184	—	<3	75.6	—	<8	<7	<6	360
Picher 3	11-16-92	1713	63.6	<5	184	56	<2.1	77.5	11	<1.6	<2.7	<20	342
Picher 3	11-16-92	1714	64.9	<5	184	46.1	<2.1	78.8	13.3	<1.6	<2.7	<20	336
Picher 3	12-15-92	0920	65.8	<1	195	—	<4	78.9	14	<3	<5	4.2	348
Picher 3	12-15-92	0923	67.9	<.2	195	55	3.4	56.1	12.5	<1.4	4.8	<15	445
Picher 3	12-15-92	0924	63.9	<.2	195	54	<2.6	81.9	12.7	<1.4	<1.7	<15	342
Picher 3	01-25-93	1200	63.1	<1.7	217	—	<2.3	104	13.4	<5.7	<10.6	<2.6	707
Picher 3	01-25-93	1203	68.1	<.1	217	40	<1.8	109	12.8	2.5	<8.2	<38	824
Picher 3	01-25-93	1204	67.7	.1	217	36	<1.6	109	12.8	2.6	<8.2	<38	762
Picher 4	08-18-92	1210	82.4	<1.6	215	—	<3.6	101	—	<4.1	<14	<2.7	836
Picher 4	08-18-92	1213	87.4	.1	215	<25	<1.6	108	18.4	<1.9	<4.3	<50	976
Picher 4	08-18-92	1214	89.9	.1	215	<26	<1.6	111	18.2	<1.9	<4.3	<50	256
Picher 4	09-23-92	0910	82.1	<.4	207	—	<1	107	—	<4.5	<2.7	3.8	865
Picher 4	09-23-92	0911	82.1	<.4	207	—	<1	103	—	<4.5	<2.7	3.8	830
Picher 4	09-23-92	0913	88.9	<.9	207	<52	<2.3	106	16.8	<2.4	<3.5	<51	772
Picher 4	09-23-92	0914	87.2	<.9	207	<52	<2.3	106	17.1	<2.4	<3.5	<51	748
Picher 4	10-20-92	1250	85.6	1.4	215	—	5.1	110	—	<3	<5	<4	869
Picher 4	10-20-92	1253	96.8	.2	215	83.5	<1.7	112	20.3	<.8	3.4	21.8	928
Picher 4	10-20-92	1254	96.6	<.2	215	77	<1.7	112	14.4	<.8	<1.8	<4.8	941
Picher 4	11-17-92	0930	85.2	<1	231	—	3.5	108	—	<8	<7	8.4	1010
Picher 4	11-17-92	0933	85.5	<5	231	68.6	<2.1	110	19.9	4.2	<2.7	<20	964
Picher 4	11-17-92	0934	86.9	<5	231	67.6	<2.1	111	17.2	<1.6	<2.7	<20	962
Picher 4	12-15-92	1010	85.4	<1	222	—	<4	106	19	<3	<5	31.4	998
Picher 4	12-15-92	1011	87.6	<1	222	—	<4	105	19	<3	<5	<4	1050
Picher 4	12-15-92	1013	62.9	<.2	222	53	<2.6	81.4	36.4	<1.4	<1.7	<15	351
Picher 4	12-15-92	1014	84	<.2	222	56	<2.6	111	36.4	<1.4	<1.7	<15	1110
Picher 4	01-25-93	1330	83.7	<1.7	216	—	<2.3	112	18.4	<5.7	<10.6	<2.6	1110
Picher 4	01-25-93	1333	92.3	.2	216	55	<1.6	120	17.5	<2.3	<8.2	<38	1210
Picher 4	01-25-93	1334	82.3	<.5	216	58	<1	100	17.5	<6	<1.3	38.2	1090
Quapaw 2	08-18-92	1520	31.1	<1.6	227	—	<3.6	79.6	—	<4.1	<14	<2.7	878
Quapaw 2	08-18-92	1523	32.4	.1	227	<22	<1.6	87.3	28.6	<1.9	<4.3	<50	1040
Quapaw 2	08-18-92	1524	32.7	.1	227	<23	<1.6	90.9	27.3	<1.9	<4.3	<50	1060
Quapaw 2	09-22-92	1330	28.1	<.4	217	—	<1	81.7	—	<4.5	<2.7	<3.5	943
Quapaw 2	09-22-92	1333	31.8	<.9	217	<45	<2.3	83.8	27.4	<2.4	<3.5	<51	861
Quapaw 2	09-22-92	1334	32.7	<.9	217	<45	<2.3	84.1	27.3	<2.4	<3.5	<51	868
Quapaw 2	10-20-92	1440	32.6	1	215	—	<4	84.5	—	<3	<5	<4	883
Quapaw 2	10-20-92	1443	36.2	<.2	215	48.7	<1.7	88.5	28	<.8	2.3	<4.8	960
Ouapaw 2	10-20-92	1444	37.1	<.2	215	57.1	<1.7	87.7	27.5	<.8	<1.8	<4.8	958
Quapaw 2	11-16-92	1320	33.6	<1	214	—	<3	84.5	—	<8	<7	10	947
Quapaw 2	11-16-92	1323	32.1	<5	214	48.3	<2.1	85.2	29.6	<1.6	<2.7	<20	903
Quapaw 2	11-16-92	1324	31.9	<5	214	40	<2.1	84.1	30.1	<1.6	<2.7	<20	880
Quapaw 2	12-14-92	1610	33	<1	224	—	<4	82.2	28.9	<3	<5	<4	910
Quapaw 2	12-14-92	1613	31.9	<.2	224	81	<2.6	86.4	30.3	<1.4	<1.7	<15	918
Quapaw 2	12-14-92	1614	31.8	<.2	224	112	<2.6	84.2	31.2	<1.4	<1.7	<15	906
Quapaw 2	01-25-93	1440	32.4	<1.7	219	—	<2.3	86.2	28	<5.7	<10.6	<2.6	893
Quapaw 2	01-25-93	1443	33.3	.2	219	20	<1.6	89.8	28	<2.3	<8.2	<38	970
Quapaw 2	01-25-93	1444	33.8	<.1	219	27	<1.6	89.7	34.7	<2.3	<8.2	<38	990
Quapaw 4	08-18-92	1620	9.6	<1.6	146	—	<3.6	27.3	—	<4.1	<14	<2.7	29.9

OWNER	DATES	TIMES	BA	BE	HCO3	B	CD	CA	CL	CR	CO	CU	FE
Quapaw 4	08-18-92	1623	9.1	<5	146	<9.4	<1.6	29.5	7.47	<1.9	<4.3	<50	<6.1
Quapaw 4	08-18-92	1624	8.8	<5	146	<9.4	<1.6	30.2	7.27	<1.9	<4.3	<50	<6.1
Quapaw 4	09-22-92	1500	8.2	<.4	145	—	<1	28.8	—	<4.5	<2.7	<3.5	24.7
Quapaw 4	09-22-92	1503	10.7	<.9	145	<19	<2.3	29.8	9.15	<2.4	4.3	<51	1120
Quapaw 4	09-22-92	1504	12	<1	145	<20	<2.4	31.6	9.78	<2.5	<3.7	<53	<99
Quapaw 4	10-20-92	1540	9.1	<1	142	—	<4	28.4	—	<3	<5	<4	6.7
Quapaw 4	10-20-92	1543	11	<.2	142	22.1	<1.7	29.2	5.48	<.8	<1.8	<4.8	34
Quapaw 4	10-20-92	1544	10	<.2	142	15.5	<1.7	29.3	5.21	1	<1.8	<4.8	15
Quapaw 4	11-16-92	1450	9.6	<1	162	—	<3	26.8	—	<8	<7	7.3	33.7
Quapaw 4	11-16-92	1453	8.3	<5	162	19.9	<2.1	27.5	6.5	<1.6	<2.7	<20	20.9
Quapaw 4	11-16-92	1454	9.4	<5	162	17	<2.1	27.7	7.24	<1.6	4.8	<20	<8.5
Quapaw 4	12-14-92	1730	10.6	<1	146	—	<4	28.1	10.9	<3	<5	<4	19.3
Quapaw 4	12-14-92	1733	11.6	<.2	146	188	2.9	29.7	10.2	<1.4	<1.7	<15	65
Quapaw 4	12-14-92	1734	11.4	.3	146	<50	<2.6	30	10.6	<1.4	<1.7	<15	33
Quapaw 4	01-25-93	1550	13.7	<1.7	149	—	<2.3	33.5	10.8	<5.7	<10.6	<2.6	43.7
Quapaw 4	01-25-93	1553	14	<5	149	<15	2.2	34.6	10.7	<2.3	<8.2	<38	<11
Quapaw 4	01-25-93	1554	14	.1	149	<15	<1.6	34.7	10.6	<2.3	<8.2	<38	12
RWD 4 Well 2	01-28-93	0830	17	<1.7	151	—	<2.3	36.6	29	<5.7	<10.6	<2.6	236
RWD 4 Well 2	01-28-93	0833	14.5	<.1	151	39	<1.6	33.3	29.6	<2.3	<8.2	<38	204
RWD 4 Well 2	01-28-93	0834	14.9	.1	151	32	<1.6	32.9	29.7	<2.3	<8.2	<38	202
RWD 4 Well 3	01-28-93	0930	5.6	<1.7	141	—	<2.3	29.6	10.6	<5.7	<10.6	<2.6	75.5
RWD 4 Well 3	01-28-93	0933	5.6	<.1	141	<15	<1.6	29.9	9.76	<2.3	<8.2	<38	24
RWD 4 Well 3	01-28-93	0934	5.2	<.1	141	<15	<1.6	30.7	9.88	<2.3	<8.2	<38	39
RWD 4 Well 4	08-18-92	0930	5.2	<1.6	144	—	<3.6	27.1	—	<4.1	<14	<2.7	44
RWD 4 Well 4	08-18-92	0933	43.8	.3	144	<14	<1.6	29.6	5.93	2	<4.3	<50	39.2
RWD 4 Well 4	08-18-92	0934	9.9	<5	144	<9.9	<1.6	29.5	5.98	<1.9	<4.3	<50	34.3
RWD 4 Well 4	09-22-92	1110	4.7	<.4	144	—	<1	26.6	—	<4.5	<2.7	<3.5	53.6
RWD 4 Well 4	09-22-92	1113	5.6	<.9	144	<20	<2.3	28.7	6.81	<2.4	<3.5	<51	<94
RWD 4 Well 4	09-22-92	1114	6.2	<.9	144	<20	<2.3	28.6	7.04	3.1	<3.5	<51	<94
RWD 4 Well 4	10-20-92	1640	6.4	<1	146	—	<4	28.3	—	<3	<5	<4	36.6
RWD 4 Well 4	10-20-92	1643	6.9	<.2	146	5.9	<1.7	28.3	7.34	<.8	<1.8	<4.8	56
RWD 4 Well 4	10-20-92	1644	6.8	<.2	146	9.9	<1.7	28.6	7.33	1.8	<1.8	4.8	37
RWD 4 Well 4	11-16-92	1050	6.8	<1	167	—	<3	27.7	—	<8	<7	7.3	56
RWD 4 Well 4	11-16-92	1051	7.1	<1	167	—	<3	27.2	—	<8	<7	<6	49.2
RWD 4 Well 4	11-16-92	1053	5.9	<5	167	<6.3	<2.1	27.7	7.92	<1.6	<2.7	<20	31.3
RWD 4 Well 4	11-16-92	1054	5.5	<5	167	<6.3	<2.1	27.9	19.2	<1.6	<2.7	<20	42
RWD 4 Well 4	12-15-92	1130	7.1	<1	146	—	<4	26.4	8.93	<3	<5	25.4	138
RWD 4 Well 4	12-15-92	1133	7.1	<.2	146	<50	<2.6	27.1	7.8	<1.4	2	<15	31
RWD 4 Well 4	12-15-92	1134	6.5	<.2	146	<50	<2.6	28.2	7.84	<1.4	1.9	<15	38
RWD 4 Well 4	01-25-93	1640	6.8	<1.7	144	—	<2.3	26.9	8.71	<5.7	<10.6	<2.6	62.9
RWD 4 Well 4	01-25-93	1643	6.4	.1	144	<15	<1.6	29.4	7.68	<2.3	<8.2	<38	64
RWD 4 Well 4	01-25-93	1644	7.2	<.1	144	<15	<1.6	29.4	7.62	<2.3	<8.2	<38	48
RWD 6 Well 1	01-26-93	1700	30.9	<1.7	151	—	<2.3	28.2	60.4	<5.7	<10.6	6	56.6
RWD 6 Well 1	01-26-93	1703	32.8	.1	151	124	<1.6	28.6	62.7	<2.3	<8.2	<38	47
RWD 6 Well 1	01-26-93	1704	32.7	<5	151	121	<1.6	28.9	62.7	<2.3	<8.2	<38	30

OWNER	DATES	TIMES	PB	LI	MG	MN	HG	MO	NI	PH	K	SE
Cardin	08-18-92	1050	<12	—	21.6	<.8	<.2	—	<14.5	7.26	2.23	<1.6
Cardin	08-18-92	1053	<18	18.7	23.4	9.3	—	3.8	<5.6	7.26	2	11.1
Cardin	08-18-92	1054	<18	17.9	23	9.3	—	<2.3	<5.6	7.26	1.9	<7.5
Cardin	09-22-92	0900	2.1	—	21.7	8	<.1	—	<5.4	7.56	2.12	<2.9
Cardin	09-22-92	0901	1.6	—	20.6	7.3	.16	—	<5.4	7.56	2.05	<2.9
Cardin	09-22-92	0903	<26	23.6	22.6	<7.9	—	<2.2	<4.1	7.56	1.9	<10
Cardin	09-22-92	0904	237	23.7	22.4	<7.9	—	<2.2	<4.1	7.56	2.1	<10
Cardin	10-21-92	0900	1.9	—	20.1	8	<.2	—	<5	7.62	1.4	<1
Cardin	10-21-92	0903	<22	33.4	23	8.4	—	<2.7	<4.6	7.62	3.41	<26
Cardin	10-21-92	0904	<22	34.3	22.2	8.4	—	<2.7	<4.6	7.62	3.47	<26
Cardin	11-17-92	1050	2.3	—	20.8	8.7	<.2	—	<7	7.5	2.19	<1
Cardin	11-17-92	1053	<17	21.4	22.4	5.7	—	<2.8	<8.1	7.5	2.13	<24
Cardin	11-17-92	1054	<17	21.9	22.1	6.9	—	<2.8	<8.1	7.5	2.28	<24
Cardin	12-14-92	0920	2	—	21.7	7.5	<.2	—	<5	7.45	2.45	1.6
Cardin	12-14-92	0921	<1	—	21.3	6.6	<.2	—	<5	7.45	2.57	<1
Cardin	12-14-92	0923	<20	29.1	21.9	9.4	—	3	9.2	7.45	3.27	23.2
Cardin	12-14-92	0924	<20	28.6	22.2	8.5	—	<1.3	<8.9	7.45	2.82	<9.9
Cardin	01-25-93	0920	<14	—	22.1	7.6	<.2	—	<8.8	7.5	2.62	<.9
Cardin	01-25-93	0921	<14	—	21.6	7.2	<.2	—	<8.8	7.5	2.42	<.9
Cardin	01-25-93	0923	<8.1	27.3	22.5	4.2	—	<3.6	5.1	7.5	1.25	<21
Cardin	01-25-93	0924	<8.1	30.4	21.4	4.3	—	<3.6	21.9	7.5	1.69	<21
Commerce 1	08-17-92	0930	<1.2	—	19.8	<.8	<.2	—	<14.5	7.4	2.5	<1.6
Commerce 1	08-17-92	0931	<12	—	19.7	<.8	<.2	—	<14.5	7.4	2.46	<1.6
Commerce 1	08-17-92	0933	<18	26.8	21.1	3.8	—	<2.3	<5.6	7.4	2.7	<7.5
Commerce 1	08-17-92	0934	<18	22.4	20.5	6.6	—	2.8	<5.6	7.4	1	<7.5
Commerce 1	09-23-92	1050	3.7	—	19	4.7	.31	—	<5.4	7.39	2.52	<2.9
Commerce 1	09-23-92	1053	<26	30.5	20.2	<7.9	—	<2.2	<4.1	7.39	2.4	<10
Commerce 1	09-23-92	1054	<26	30.6	20	7.9	—	<2.2	<4.1	7.39	2.4	<10
Commerce 1	10-21-92	1140	2.4	—	19.3	5	<.2	—	<5	7.47	1.92	<1
Commerce 1	10-21-92	1143	<22	43.3	21.6	2.7	—	<2.7	<4.6	7.47	4.07	<26
Commerce 1	10-21-92	1144	<22	40.4	21.3	3.6	—	<2.7	<4.6	7.47	3.85	<26
Commerc4 1	11-17-92	1200	2.4	—	19.4	5.2	<.2	—	<7	7.41	2.62	<1
Commerce 1	11-17-92	1203	<17	30.8	20.7	3	—	3.5	<8.1	7.41	2.76	<24
Commerce 1	11-17-92	1204	<7.8	36.1	20.2	4.6	—	<4.2	<8.1	7.41	3	<13
Commerce 1	12-14-92	1120	<1	—	19.1	5.1	<.2	—	15	7.44	3.72	<1
Commerce 1	12-14-92	1123	<20	34.9	20.4	3.7	—	1.5	<8.9	7.44	2.73	<9.9
Commerce 1	12-14-92	1124	<20	32.9	20.1	4.7	—	1.4	<8.9	7.44	2.61	10.9
Commerce 1	01-26-93	1050	<1.4	—	19.5	5.2	<.2	—	<8.8	7.5	3.28	<.9
Commerce 1	01-26-93	1053	<8.1	32.9	20	<2.3	—	<3.6	4.5	7.5	1.69	<21
Commerce 1	01-26-93	1054	<8.1	37.8	19.9	<2.3	—	<3.6	15.6	7.5	1.87	<21
Commerce 2	08-17-92	1100	<1.2	—	15.5	<.8	<.2	—	<14.5	7.61	1.98	<1.6
Commerce 2	08-17-92	1103	<18	19.4	16.3	<3.7	—	2.3	<5.6	7.61	1.7	<7.5
Commerce 2	08-17-92	1104	<18	17.3	15.6	<3.7	—	2.4	<5.6	7.61	1.4	<7.5
Commerce 2	09-23-92	1150	4	—	14.9	<4.7	.16	—	<5.4	7.67	1.95	<2.9
Commerce 2	09-23-92	1153	<26	25.2	15.9	<7.8	—	<2.2	<4.1	7.67	1.4	<10
Commerce 2	09-23-92	1154	<26	27.3	15.6	<7.8	—	<2.2	<4.1	7.67	1.5	<10
Commerce 2	10-21-92	1030	1	—	14.7	3.9	<.2	—	5.5	7.71	1.83	<1
Commerce 2	10-21-92	1031	1.8	—	14.5	3.9	<.2	—	5.9	7.71	1.71	<1
Commerce 2	10-21-92	1033	<22	35	16.3	2.7	—	<2.7	<4.6	7.71	3.28	<26
Commerce 2	10-21-92	1034	<22	33.7	15.9	4.6	—	<2.7	<4.6	7.71	3.07	<26
Commerce 2	11-17-92	1250	2.8	—	14.2	3.2	<.2	—	<7	7.85	2.03	<1

OWNER	DATES	TIMES	PB	LI	MG	MN	HG	MO	NI	PH	K	SE
Commerce 2	11-17-92	1253	<7.8	22.1	15	.8	—	<4.2	<8.1	7.85	<2.1	<13
Commerce 2	11-17-92	1254	<17	24.9	15.5	<2.5	—	<2.8	<8.1	7.85	1.9	<24
Commerce 2	12-14-92	1310	1.5	—	13.5	3.7	<.2	—	<5	7.81	2.58	<1
Commerce 2	12-14-92	1313	<20	30.5	14.8	4	—	<1.3	<8.9	7.81	2.5	<9.9
Commerce 2	12-14-92	1314	<20	33.7	14.6	5	—	3	<8.9	7.81	.02	20.6
Commerce 2	01-26-93	1130	<1.4	—	12.7	4.2	<.2	—	<8.8	7.77	3.6	<.9
Commerce 2	01-26-93	1133	<8.1	44	12.9	<2.3	—	<3.6	<2.6	7.77	1.99	<21
Commerce 2	01-26-93	1134	<8.1	41	13.2	<2.3	—	<3.6	3	7.77	1.91	<21
Commerce 3	08-17-92	1340	<1.2	—	26	<.8	<.2	—	<14.5	6.96	3.21	<1.6
Commerce 3	08-17-92	1343	<18	37.1	27.1	19	—	<2.3	<5.6	6.96	2.8	<7.5
Commerce 3	08-17-92	1344	<18	45	28.5	9.8	—	<2.3	6.9	6.96	3.7	<7.5
Commerce 3	09-23-92	1350	2.2	—	26.1	11.3	.23	—	<5.4	7.24	3.18	<2.9
Commerce 3	09-23-92	1353	<26	45.9	27.2	<8	—	<2.2	<4.1	7.24	2.8	<10
Commerce 3	09-23-92	1354	<26	45.9	27.3	<8	—	<2.2	9.9	7.24	2.9	<10
Commerce 3	10-21-92	1520	2.2	—	25.9	12.6	<.2	—	<5	7.32	3.25	1.4
Commerce 3	10-21-92	1523	<22	60.2	28.5	13.1	—	<2.7	<4.6	7.32	4.67	<26
Commerce 3	10-21-92	1524	<22	56.2	27.9	15.1	—	2.8	<4.6	7.32	4.65	<26
Commerce 3	11-17-92	1440	10.9	—	26	11.9	<.2	—	<7	7.3	3.37	<1
Commerce 3	11-17-92	1443	<17	44.1	26.7	7.3	—	3.2	<8.1	7.3	3.56	<24
Commerce 3	11-17-92	1444	<17	46.7	27	7.3	—	<2.8	<8.1	7.3	3.59	<24
Commerce 3	12-14-92	1410	1.6	—	25.6	11.4	<.2	—	<5	7.26	3.48	<1
Commerce 3	12-14-92	1413	<20	58.5	27.2	10	—	<1.3	<8.9	7.26	4.2	<9.9
Commerce 3	12-14-92	1414	<20	55.7	27.2	12.9	—	<1.3	<8.9	7.26	4.13	<9.9
Commerce 3	01-26-93	1400	<1.4	—	25.8	10.9	<.2	—	<8.8	7.01	4.34	<.9
Commerce 3	01-26-93	1401	<14	—	25.9	12.2	<.2	—	<8.8	7.01	4.53	<.9
Commerce 3	01-26-93	1403	<8.2	54.1	27.5	9.9	—	<3.6	<2.6	7.01	2.71	<21
Commerce 3	01-26-93	1404	<8.2	52.6	27.7	8.9	—	<3.6	<2.6	7.01	2.26	<21
Commerce 4	08-17-92	1430	<1.2	—	14	<.8	<.2	—	<14.5	7.85	1.84	<1.6
Commerce 4	08-17-92	1433	<18	16	15	<3.7	—	2.6	<5.6	7.85	1.4	<7.5
Commerce 4	08-17-92	1434	<18	15.3	14.7	4.1	—	<2.3	<5.6	7.85	1.1	<7.5
Commerce 4	09-23-92	1510	1.1	—	13.8	<4.7	.16	—	<5.4	7.87	1.83	<2.9
Commerce 4	09-23-92	1513	<26	19.1	14.5	<7.8	—	<2.2	<4.1	7.87	1.3	<10
Commerce 4	09-23-92	1514	<26	18.1	14.7	<7.8	—	<2.2	<4.1	7.87	<1.1	<10
Commerce 4	10-21-92	1340	1.6	—	13.4	3.9	<.2	—	<5	7.99	1.67	1
Commerce 4	10-21-92	1343	<22	27.8	15.2	3.6	—	<2.7	<4.6	7.99	2.77	<26
Commerce 4	10-21-92	1344	<22	28.9	14.6	3.6	—	<2.7	<4.6	7.99	2.86	<26
Commerce 4	11-17-92	1550	2.1	—	13.7	2.8	<.2	—	<7	7.8	1.99	<1
Commerce 4	11-17-92	1551	2.4	—	13.6	3.2	<.2	—	<7	7.8	1.9	<1
Commerce 4	11-17-92	1553	<17	20.1	14.5	<2.5	—	<2.8	<8.1	7.8	1.8	<24
Commerce 4	11-17-92	1554	<17	20.3	14.3	<2.5	—	<2.8	<8.1	7.8	1.88	<24
Commerce 4	12-14-92	1500	1.3	—	13	2.3	<.2	—	<5	7.8	2.32	<1
Commerce 4	12-14-92	1503	<20	31	14.4	4.1	—	2.3	<8.9	7.8	2.5	<9.9
Commerce 4	12-14-92	1504	<20	28.6	15	3.1	—	<1.3	<8.9	7.8	2.56	20.7
Commerce 4	01-26-93	1440	<1.4	—	13.9	2.9	<.2	—	<8.8	7.64	2.73	<.9
Commerce 4	01-26-93	1443	<8.1	22.2	14.6	<2.3	—	<3.6	8	7.64	1.38	<21
Commerce 4	01-26-93	1444	<8.1	22.8	14.5	<2.3	—	<3.6	<2.6	7.64	1.02	<21
Cook, Joe	01-27-93	1750	<1.4	—	4.27	<1.7	<.2	—	<8.8	7.09	.955	<.9
Cook, Joe	01-27-93	1753	<8.2	16	3.76	<2.3	—	<3.6	<2.6	7.09	<.44	<21
Cook, Joe	01-27-93	1754	<8.2	20.6	3.72	<2.3	—	<3.6	10.1	7.09	<.44	28

OWNER	DATES	TIMES	PB	LI	MG	MN	HG	MO	NI	PH	K	SE
Fairland 2	01-26-93	0910	<1.4	—	13.4	2.5	<.2	—	9.4	7.85	4.05	<.9
Fairland 2	01-26-93	0913	<8.1	65.7	14.1	<2.3	—	<3.6	<2.6	7.85	2.23	<21
Fairland 2	01-26-93	0914	<8.1	70.5	14.2	<2.3	—	<3.6	3	7.85	2.31	<21
Grand Lake Shores	01-27-93	1430	<1.4	—	14.6	<1.7	<.2	—	<8.8	7.68	1.94	<.9
Grand Lake Shores	01-27-93	1431	<1.4	—	14.6	<1.7	<.2	—	<8.8	7.68	1.9	<.9
Grand Lake Shores	01-27-93	1433	<8.1	40.3	13.3	<2.3	—	<3.6	<2.6	7.68	.55	<21
Grand Lake Shores	01-27-93	1434	<8.1	36.7	13.4	<2.3	—	<3.6	<2.6	7.68	<.44	<21
Miami 6	01-27-93	0910	<1.4	—	14.4	3.3	<.2	—	<8.8	7.88	3.62	<.9
Miami 6	01-27-93	0913	<8.1	50	14.9	<2.3	—	<3.6	3	7.88	1.54	<21
Miami 6	01-27-93	0914	<8.1	52.6	15	<2.3	—	<3.6	<2.6	7.88	1.6	<21
Miami 1	01-27-93	1040	<1.4	—	16.6	<1.7	<.2	—	<8.8	7.94	3.92	<.9
Miami 1	01-27-93	1043	<8.1	38.4	15.3	<2.3	—	<3.6	<2.6	7.94	1.12	<21
Miami 1	01-27-93	1044	<8.1	39.5	15.2	<2.3	—	<3.6	<2.6	7.94	.85	<21
Miami 3	01-27-93	1230	<1.4	—	74.2	36.5	<.2	—	15.8	7.89	13.8	<.9
Miami 3	01-27-93	1233	12.8	57.4	13.3	10.8	—	<3.6	12.5	7.89	1.98	<21
Miami 3	01-27-93	1234	<8.1	53.7	13.5	6.1	—	<3.6	.9	7.89	1.19	<21
Ogeechee Farms	01-27-93	1620	1.8	—	15.3	2.1	<.2	—	<8.8	7.8	3.33	<.9
Ogeechee Farms	01-27-93	1623	<8.1	54	13.5	<2.3	—	<3.6	<2.6	7.8	1.52	<21
Ogeechee Farms	01-27-93	1624	<8.1	51.7	13.6	<2.3	—	<3.6	<2.6	7.8	1.01	<21
Picher 2	08-17-92	1540	<12	—	23.4	<.8	<.2	—	<14.5	7.15	2.2	<1.6
Picher 2	08-17-92	1543	<18	17.3	25.3	7.5	—	7.4	6.6	7.15	2.2	<7.5
Picher 2	08-17-92	1544	<18	16.8	24.7	7.5	—	4.6	<5.6	7.15	2	<7.5
Picher 2	09-22-92	1600	2.3	—	24.4	7.3	.31	—	<5.4	7.47	2.24	3.7
Picher 2	09-22-92	1603	<26	22.9	25.6	<8	—	4.4	<4.1	7.47	2	<10
Picher 2	09-22-92	1604	<26	22.8	25.7	<8	—	3.5	<4.1	7.47	1.9	<10
Picher 2	10-20-92	0940	2.3	—	23.9	7.9	<.2	—	6.2	7.52	1.83	1.4
Picher 2	10-20-92	0941	1.7	—	24	7.3	<.2	—	12.6	7.52	2.1	1.3
Picher 2	10-20-92	0943	<22	31.1	25.9	9.4	—	6.8	6.7	7.52	3.01	<26
Picher 2	10-20-92	0944	<22	31.3	27	7.5	—	3.7	<4.6	7.52	3	<26
Picher 2	11-16-92	1610	2.2	—	23	9.1	<.2	—	9.2	7.5	2.23	<1
Picher 2	11-16-92	1613	<17	22.6	24.4	5.3	—	5.5	<8.1	7.5	2.41	<24
Picher 2	11-16-92	1614	<17	22.7	25.6	4.4	—	5.6	<8.1	7.5	2.17	<24
Picher 2	12-15-92	0850	1.4	—	23	7.5	<.2	—	<5	7.25	3.06	<1
Picher 2	12-15-92	0853	<20	28	25.2	7.4	—	3.7	<8.9	7.25	2.77	15.6
Picher 2	12-15-92	0854	<20	31.2	2[illegible].4	6.4	—	8.7	<8.9	7.25	3.29	18.2
Picher 2	01-25-93	1120	<14	—	25.7	7	<.2	—	<8.8	7.55	2.54	<.9
Picher 2	01-25-93	1123	<8.2	23.6	26.1	4	—	<3.6	4	7.55	<.45	<21
Picher 2	01-25-93	1124	<8.2	21.6	26	4	—	4.5	6.6	7.55	<.45	<21
Picher 3	08-17-92	1610	<12	—	28.4	<.8	<.2	—	<14.5	7.54	2.56	<1.6
Picher 3	08-17-92	1611	<12	—	28.7	<.8	<.2	—	<14.5	7.54	2.6	<1.6
Picher 3	08-17-92	1613	<18	17.7	29.2	10	—	6.2	<5.6	7.54	2.2	<7.5
Picher 3	08-17-92	1614	<18	16.6	29.5	<3.7	—	7.9	<5.6	7.54	2	8
Picher 3	09-22-92	1700	1.2	—	31.6	9.4	2.9	—	<5.4	7.32	2.6	<2.9
Picher 3	09-22-92	1703	<26	24.5	33.7	<8.2	—	3.7	<4.1	7.32	2.5	<10
Picher 3	09-22-92	1704	<26	23.4	33.1	<8.2	—	5.5	<4.1	7.32	2.5	<10
Picher 3	10-20-92	1050	1.6	—	33.2	9	<.2	—	<5	7.28	2.39	1.1

OWNER	DATES	TIMES	PB	LI	MG	MN	HG	MO	NI	PH	K	SE
Picher 3	10-20-92	1053	<22	34.9	35.7	10.4	—	7.5	<4.6	7.28	3.38	<26
Picher 3	10-20-92	1054	<22	32.4	36.3	10.4	—	7.8	<4.6	7.28	3.55	<26
Picher 3	11-16-92	1710	1.9	—	30.3	9.9	<.2	—	<7	7:26	2.66	1
Picher 3	11-16-92	1713	<17	23.8	32.4	7.1	—	6.1	<8.1	7.26	2.71	<24
Picher 3	11-16-92	1714	<17	23.9	32.8	7	—	5.9	<8.1	7.26	2.71	<24
Picher 3	12-15-92	0920	1.6	—	31.9	9.3	<.2	—	7.9	7.16	3.13	<1
Picher 3	12-15-92	0923	<20	33.3	24.9	7.4	—	7.4	13.6	7.16	3.07	<9.9
Picher 3	12-15-92	0924	<20	33.1	33.6	6.8	—	1.7	<8.9	7.16	3.3	18.4
Picher 3	01-25-93	1200	<14	—	40.4	13.1	<.2	—	<8.8	7.28	3.93	<.9
Picher 3	01-25-93	1203	<8.3	26.9	43.2	9.1	—	<3.6	<2.6	7.28	.59	<21
Picher 3	01-25-93	1204	<8.3	34	43.3	10.1	—	6.1	<2.6	7.28	1.3	26
Picher 4	08-18-92	1210	<12	—	40.6	<.8	<.2	—	<14.5	7.57	2.95	<1.6
Picher 4	08-18-92	1213	<18	33.4	42.9	18.7	—	5.2	7.2	7.57	3.2	<7.5
Picher 4	08-18-92	1214	<18	33.5	45.1	19.3	—	<2.3	9.5	7.57	3.4	10.1
Picher 4	09-23-92	0910	2.8	—	42.5	16.7	.23	—	9.6	7.02	3.2	<2.9
Picher 4	09-23-92	0911	4.8	—	41.1	16.7	.16	—	9.2	7.02	3.12	<2.9
Picher 4	09-23-92	0913	<26	41.4	42.5	<8.6	—	<2.2	8.9	7.02	2.8	<10
Picher 4	09-23-92	0914	<26	39.7	42.2	<8.6	—	<2.2	15.3	7.02	2.8	<10
Picher 4	10-20-92	1250	1.9	—	41.5	18.3	<.2	—	14.7	7.08	2.89	1.4
Picher 4	10-20-92	1253	<22	50.2	45.4	16.2	—	<2.8	12.2	7.08	4	<26
Picher 4	10-20-92	1254	<22	50.2	45.4	17	—	<2.7	11	7.08	3.86	<26
Picher 4	11-17-92	0930	2.6	—	40.9	17.9	<.2	—	12.9	7.13	3.14	<5
Picher 4	11-17-92	0933	<17	41.2	43.2	15.9	—	3	15.8	7.13	3.34	<24
Picher 4	11-17-92	0934	<17	41.6	43.7	15.8	—	<2.8	11.5	7.13	3.35	<24
Picher 4	12-15-92	1010	<1	—	41.1	17.1	<.2	—	31.1	6.95	3.4	<1
Picher 4	12-15-92	1011	2.5	—	41.7	17.1	<.2	—	<5	6.95	3.57	<1
Picher 4	12-15-92	1013	<20	33.1	33.3	7.8	—	5.9	<8.9	6.95	3.1	<9.9
Picher 4	12-15-92	1014	<20	47.5	43.2	16.8	—	<1.3	11.9	6.95	3.23	<9.9
Picher 4	01-25-93	1330	<14	—	43.6	17.4	<.2	—	14.2	7.07	3.99	<.9
Picher 4	01-25-93	1333	<8.3	51.7	46.7	18	—	<3.6	11.4	7.07	1.41	<21
Picher 4	01-25-93	1334	<5.7	48.1	40.4	15.8	—	<1.9	6.6	7.07	1.28	<12
Quapaw 2	08-18-92	1520	<12	—	34.9	<.8	<.2	—	<14.5	7.1	2.41	<1.6
Quapaw 2	08-18-92	1523	<18	25	37.2	16.2	—	2.8	<5.6	7.1	2.3	<7.5
Quapaw 2	08-18-92	1524	<18	30.5	39	15.3	—	4.4	11.7	7.1	2.7	<7.5
Quapaw 2	09-22-92	1330	2.3	—	35.5	14.8	.61	—	<5.4	7.24	2.5	<2.9
Quapaw 2	09-22-92	1333	<26	37.3	36.8	<8.4	—	<2.2	<4.1	7.24	2.6	<10
Quapaw 2	09-22-92	1334	<26	35.4	36.9	<8.4	—	4.2	<4.1	7.24	2.6	<10
Quapaw 2	10-20-92	1440	2.7	—	34.8	15.4	<.2	—	<5	7.2	2.28	<1
Quapaw 2	10-20-92	1443	<22	41.	39.1	14.1	—	4.5	<4.6	7.2	2.87	<26
Quapaw 2	10-20-92	1444	<22	41.3	38.8	16	—	<2.7	<4.6	7.2	3.15	<26
Quapaw 2	11-16-92	1320	2	—	35.4	15.5	<.2	—	<7	7.24	2.56	<1
Quapaw 2	11-16-92	1323	<17	33.2	36.8	11.7	—	4.1	<8.1	7.24	2.54	<24
Quapaw 2	11-16-92	1324	<17	33.4	36.4	11.7	—	4.2	<8.1	7.24	2.65	<24
Quapaw 2	12-14-92	1610	1.2	—	35	13.7	<.2	—	<5	7.24	3.81	<1
Quapaw 2	12-14-92	1613	<20	41.7	37	12.5	—	2.1	<8.9	7.24	3.12	25.9
Quapaw 2	12-14-92	1614	<20	42.6	36.1	12.6	—	4.9	<8.9	7.24	3.33	24.2
Quapaw 2	01-25-93	1440	<14	—	37.1	14.6	<.2	—	<8.8	7.22	3.51	<.9
Quapaw 2	01-25-93	1443	<8.2	34.8	38.7	14.5	—	<3.6	<2.6	7.22	.61	<21
Quapaw 2	01-25-93	1444	<8.2	39.3	38.6	13.6	—	<3.6	<2.6	7.22	.76	<21
Quapaw 4	08-18-92	1620	<1.2	—	13.5	<.8	<.2	—	<14.5	7.61	1.56	<1.6

OWNER	DATES	TIMES	PB	LI	MG	MN	HG	MO	NI	PH	K	SE
Quapaw 4	08-18-92	1623	<18	7.2	14.5	<3.7	—	6.5	<5.6	7.61	1.3	8.3
Quapaw 4	08-18-92	1624	<18	7.2	14.9	<3.7	—	8.4	<5.6	7.61	1.5	<7.5
Quapaw 4	09-22-92	1500	4.6	—	13.8	<4.7	.23	—	<5.4	7.87	1.44	<2.9
Quapaw 4	09-22-92	1503	<26	13.3	14.5	<7.8	—	6.1	<4.1	7.87	1.5	<10
Quapaw 4	09-22-92	1504	<27	13.9	15.3	<8.1	—	5.3	<4.3	7.87	1.5	<11
Quapaw 4	10-20-92	1540	1.7	—	13.3	<2	<.2	—	<5	7.85	.064	<1
Quapaw 4	10-20-92	1543	<22	12.2	14.8	<2.5	—	6.7	<4.6	7.85	1.71	<26
Quapaw 4	10-20-92	1544	<22	12.2	14.8	<2.5	—	4.6	<4.6	7.85	1.62	<26
Quapaw 4	11-16-92	1450	2.1	—	12.8	<2	<.2	—	<7	8.03	1.3	<1
Quapaw 4	11-16-92	1453	<17	8.6	13.7	<2.5	—	8.5	<8.1	8.03	1.32	<24
Quapaw 4	11-16-92	1454	<17	8.4	13.8	<2.5	—	8.7	<8.1	8.03	1.23	<24
Quapaw 4	12-14-92	1730	<1	—	12.9	<2	<.2	—	<5	7.42	1.41	<1
Quapaw 4	12-14-92	1733	<20	22	14.1	3.2	—	4	<8.9	7.42	2.65	<9.9
Quapaw 4	12-14-92	1734	<20	21.6	14.3	4.1	—	5.7	<8.9	7.42	2.26	23.8
Quapaw 4	01-25-93	1550	<1.4	—	15	4.1	<.2	—	24.1	7.91	2.8	<.9
Quapaw 4	01-25-93	1553	<8.1	17.8	15.8	<2.3	—	<3.6	<2.6	7.91	.48	28
Quapaw 4	01-25-93	1554	<8.1	19.4	15.8	<2.3	—	<3.6	<2.6	7.91	.62	<21
RWD 4 Well 2	01-28-93	0830	<1.4	—	16.9	2.2	<.2	—	<8.8	7.83	2.57	<.9
RWD 4 Well 2	01-28-93	0833	<8.1	18.6	15.7	<2.3	—	<3.6	<2.6	7.83	<.44	<21
RWD 4 Well 2	01-28-93	0834	<8.1	20.9	15.5	<2.3	—	<3.6	<2.6	7.83	.81	<21
RWD 4 Well 3	01-28-93	0930	<1.4	—	14.5	3.3	<.2	—	9.2	7.78	2.26	<.9
RWD 4 Well 3	01-28-93	0933	<8.1	6.8	14.9	<2.3	—	<3.6	<2.6	7.78	<.44	<21
RWD 4 Well 3	01-28-93	0934	<8.1	<4.6	15.3	<2.3	—	<3.6	<2.6	7.78	<.44	<21
RWD 4 Well 4	08-18-92	0930	<1.2	—	14.9	<.8	<.2	—	<14.5	7.49	.996	<1.6
RWD 4 Well 4	08-18-92	0933	<18	<7.2	16.2	6.8	—	7.1	<5.6	7.49	<1	<7.5
RWD 4 Well 4	08-18-92	0934	<18	<7.2	16	<3.7	—	5.2	<5.6	7.49	<1	7.5
RWD 4 Well 4	09-22-92	1110	1.8	—	14.4	<4.7	.53	—	<5.4	7.95	.801	<2.9
RWD 4 Well 4	09-22-92	1113	<26	<6.9	15.8	<7.8	—	<2.2	<4.1	7.95	<1.1	<10
RWD 4 Well 4	09-22-92	1114	<26	<6.9	15.8	<7.8	—	4	<4.1	7.95	<1.1	<10
RWD 4 Well 4	10-20-92	1640	1.6	—	14.6	2.1	<.2	—	<5	8.08	<.494	<1
RWD 4 Well 4	10-20-92	1643	<22	10	15.9	<2.5	—	5.6	<4.6	8.08	1.55	<26
RWD 4 Well 4	10-20-92	1644	<22	7.8	16.1	<2.5	—	6.2	<4.6	8.08	1.44	<26
RWD 4 Well 4	11-16-92	1050	8.8	—	14.6	<2	<.2	—	<7	7.85	.893	<1
RWD 4 Well 4	11-16-92	1051	1.3	—	14.3	<2	<.2	—	<7	7.85	.866	<1
RWD 4 Well 4	11-16-92	1053	<17	3.2	15.3	<2.5	—	4.3	<8.1	7.85	.83	<24
RWD 4 Well 4	11-16-92	1054	<17	3.6	15.4	<2.5	—	5.1	<8.1	7.85	.78	<24
RWD 4 Well 4	12-15-92	1130	1.7	—	14.2	2.2	<.2	—	6.3	7.77	1.23	<1
RWD 4 Well 4	12-15-92	1133	25	15	14.7	.3	—	3.9	<8.9	7.77	2.03	15.9
RWD 4 Well 4	12-15-92	1134	<20	13.3	15.4	2.2	—	4.9	<8.9	7.77	1.39	<9.9
RWD 4 Well 4	01-25-93	1640	<1.4	—	14.5	2	<.2	—	<8.8	7.8	1.76	<.9
RWD 4 Well 4	01-25-93	1643	<8.1	<4.6	16.1	<2.3	—	3.7	<2.6	7.8	<.44	<21
RWD 4 Well 4	01-25-93	1644	<8.1	<4.6	16	<2.3	—	<3.6	<2.6	7.8	<.44	<21
RWD 6 Well 1	01-26-93	1700	<1.4	—	12.8	2.1	<.2	—	<8.8	7.59	3.58	<.9
RWD 6 Well 1	01-26-93	1703	<8.1	71.4	13.1	<2.3	—	<3.6	<2.6	7.59	1.85	<21
RWD 6 Well 1	01-26-93	1704	<8.1	70.9	13.2	<2.3	—	<3.6	<2.6	7.59	1.75	<21

RESULT OF MODIFY PAGE

OWNER	DATES	TIMES	AG	NA	COND	SR	SO4	TEMP	TL	TI	V	ZN
Cardin	08-18-92	1050	<2	12.7	460	—	67.2	19.2	<1.2	—	<5	9.6
Cardin	08-18-92	1053	<3.8	14.6	460	493	70.6	19.2	<24	<17	<14	<6.1
Cardin	08-18-92	1054	<3.8	13.7	460	484	70.3	19.2	<24	<17	<14	6.2
Cardin	09-22-92	0900	2.6	13.1	456	—	69.2	19.2	<3.8	—	<2.8	11.9
Cardin	09-22-92	0901	<2.5	12.4	456	—	77.5	19.2	<3.8	—	<2.8	8.8
Cardin	09-22-92	0903	<3.4	14.7	456	46	70.8	19.2	<19	<2.4	<8.6	<7.6
Cardin	09-22-92	0904	<3.4	13.7	456	45.7	70.6	19.2	<19	6.4	<8.6	<7.6
Cardin	10-21-92	0900	<4	12	437	—	37.51	19.1	<1	—	<3	6.7
Cardin	10-21-92	0903	<6.1	15.2	437	49.2	67.4	19.1	11	7.8	<13	<40
Cardin	10-21-92	0904	<6.1	13.5	437	48	69,2	19.1	16	8.9	<13	<40
Cardin	11-17-92	1050	<5	12.4	455	—	70	19.1	<2	—	<6	11
Cardin	11-17-92	1053	<6.4	14.1	455	45	73.1	19.1	<18	<1.9	<13	4.6
Cardin	11-17-92	1054	<6.4	13	455	44.5	72.1	19.1	<18	4.4	<13	<3.6
Cardin	12-14-92	0920	<4	13	469	—	73	19.1	<1	—	<3	6.1
Cardin	12-14-92	0921	<4	12.8	469	—	72.6	19.1	<1	—	<3	6.8
Cardin	12-14-92	0923	10.8	12.6	469	41.9	73	19.1	<15	6.9	<24	<1.5
Cardin	12-14-92	0924	<7.4	12.8	469	42.5	82	19.1	<15	<5.6	<24	<1.5
Cardin	01-25-93	0920	<4	12.7	461	—	65.3	19.1	<2.5	—	3.8	9.1
Cardin	01-25-93	0921	<4	13.3	461	—	65.5	19.1	<2.5	—	<3.7	9.4
Cardin	01-25-93	0923	<7.8	13.6	461	490	67	19.1	<8.1	.6	<13	<3.2
Cardin	01-25-93	0924	<7.8	12.5	461	470	66.3	19.1	<8.1	4.7	<13	<3.2
Commerce 1	08-17-92	0930	<2	20.4	480	—	55	19.7	<1.2	—	<5	9.7
Commerce 1	08-17-92	0931	<2	20.2	480	—	59.7	19.7	<1.2	—	<5	6.4
Commerce 1	08-17-92	0933	<3.8	23	480	484	59.7	19.7	<24	<17	<14	<6.1
Commerce 1	08-17-92	0934	<3.8	20.7	480	486	59.9	19.7	<24	<17	<14	<6.1
Commerce 1	09-23-92	1050	<2.5	20.2	483	—	66.7	19.6	<3.8	—	<2.8	6.6
Commerce 1	09-23-92	1053	<3.4	22.3	483	46.1	59	19.6	<19	3.8	<8.6	<7.6
Commerce 1	09-23-92	1054	<3.4	21.4	483	45.2	58.6	19.6	<19	9.3	<8.6	<7.6
Commerce 1	10-21-92	1140	<4	19.9	480	—	48.05	19.7	<1	—	<3	4.7
Commerce 1	10-21-92	1143	<6.1	25.4	480	47.7	58.4	19.7	12	6.7	<13	<40
Commerce 1	10-21-92	1144	<6.1	24.3	480	47.3	56.1	19.7	23	6.7	<13	<40
Commerce 1	11-17-92	1200	<5	19.9	485	—	26	19.6	<2	—	<6	33.9
Commerce 1	11-17-92	1203	<6.4	21.7	485	47.3	61.4	19.6	<18	2.1	<13	<3.6
Commerce 1	11-17-92	1204	<1.8	22.2	485	47.3	61	19.6	5	<9	<4.7	<1.3
Commerce 1	12-14-92	1120	<4	20.2	477	—	58.1	19.5	<1	—	<3	3.5
Commerce 1	12-14-92	1123	<7.4	20.9	477	45.7	57.3	19.5	<15	<5.6	<24	5.9
Commerce 1	12-14-92	1124	<7.4	20.9	477	44.9	56.9	19.5	<15	<5.6	<24	<1.5
Commerce 1	01-26-93	1050	<4	19.4	459	—	50.7	19.5	<2.5	—	5.7	3.9
Commerce 1	01-26-93	1053	<7.8	21.1	459	470	53.1	19.5	<8.1	<1.3	<13	<3.2
Commerce 1	01-26-93	1054	<7.8	21	459	467	52.8	19.5	8.5	<1.3	<13	<3.2
Commerce 2	08-17-92	1100	<2	11.9	342	—	35.8	19.9	<1.2	—	<5	5
Commerce 2	08-17-92	1103	<3.8	13.6	342	428	33.4	19.9	<24	<17	<14	<6.1
Commerce 2	08-17-92	1104	<3.8	12.4	342	414	34	19.9	<24	<17	<14	<6.1
Commerce 2	09-23-92	1150	<2.5	12.3	337	—	31.9	19.5	<3.8	—	<2.8	5.8
Commerce 2	09-23-92	1153	<3.4	14.1	337	44.2	31.8	19.5	<19	<2.4	<8.6	<7.6
Commerce 2	09-23-92	1154	<3.4	13.5	337	44.4	31	19.5	<19	3.1	<8.6	<7.6
Commerce 2	10-21-92	1030	<4	11.5	329	—	28.2	19.7	<1	—	<3	10.4
Commerce 2	10-21-92	1031	<4	11.4	329	—	20.83	19.7	<1	—	<3	10.4
Commerce 2	10-21-92	1033	<6.1	14.3	329	42.3	35.6	19.7	19	4.4	<13	<40
Commerce 2	10-21-92	1034	6.3	11.6	329	41.3	35.4	19.7	11	5.6	<13	<40
Commerce 2	11-17-92	1250	<5	11.5	284	—	30	18.8	<2	—	<6	8.5

OWNER	DATES	TIMES	AG	NA	COND	SR	SO4	TEMP	TL	TI	V	ZN
Commerce 2	11-17-92	1253	<1.8	13.7	284	43.1	29.4	18.8	<4.7	<9	<4.7	<1.3
Commerce 2	11-17-92	1254	<6.4	12.9	284	43.4	29	18.8	<18	<1.9	<13	<3.6
Commerce 2	12-14-92	1310	<4	12.2	321	—	27.5	19.6	<1	—	<3	6.7
Commerce 2	12-14-92	1313	<7.4	12.5	321	42.8	26	19.6	<15	<5.6	<24	1.7
Commerce 2	12-14-92	1314	<7.4	12.3	321	42.7	27.3	19.6	<15	<5.6	<24	8
Commerce 2	01-26-93	1130	<4	13.3	296	—	17.1	19.2	<2.5	—	9.4	4.9
Commerce 2	01-26-93	1133	<7.8	14	296	536	17	19.2	<8	<1.3	<13	<3.2
Commerce 2	01-26-93	1134	<7.8	14.7	296	550	16.8	19.2	<8	<1.3	<13	<3.2
Commerce 3	08-17-92	1340	<2	51.3	796	—	104	20.9	<1.2	—	<5	88.1
Commerce 3	08-17-92	1343	<3.8	49.9	796	759	128	20.9	<24	<17	<14	72.1
Commerce 3	08-17-92	1344	<3.8	57.2	796	784	125	20.9	<24	<17	<14	<6.1
Commerce 3	09-23-92	1350	<2.5	47.4	763	—	126	20.8	<3.8	—	<2.8	62.8
Commerce 3	09-23-92	1353	<3.4	52.4	763	72.4	123	20.8	<19	5	<8.6	45.4
Commerce 3	09-23-92	1354	<3.4	52.1	763	72.7	101	20.8	<19	6.1	<8.6	<7.6
Commerce 3	10-21-92	1520	<4	53.1	841	—	100.3	20.9	<1	—	<3	75.1
Commerce 3	10-21-92	1523	<6.1	61.1	841	74.5	123	20.9	<10	4.4	<13	49
Commerce 3	10-21-92	1524	<6.1	58	841	72.8	123	20.9	<10	5.6	<13	<40
Commerce 3	11-17-92	1440	<5	46.8	765	—	121	20.7	<2	—	<6	79
Commerce 3	11-17-92	1443	<6.4	47.4	765	70	124	20.7	<18	3.7	<13	62.5
Commerce 3	11-17-92	1444	<6.4	49.7	765	71.1	124	20.7	22	2.9	<13	<3.6
Commerce 3	12-14-92	1410	<4	51.1	760	—	139	20.7	<1	—	<3	90.9
Commerce 3	12-14-92	1413	<7.4	51.6	760	71.6	123	20.7	<15	<5.6	<24	74.3
Commerce 3	12-14-92	1414	<7.4	51.4	760	71.7	125	20.7	25	6.3	<24	<1.5
Commerce 3	0l-26-93	1400	<4	44.7	790	—	135	20.7	<2.5	—	8	67.6
Commerce 3	01-26-93	1401	<4	45	790	—	134	20.7	<2.5	—	11	68.4
Commerce 3	01-26-93	1403	<7.8	51.9	790	738	123	20.7	10	4.7	<13	62.3
Commerce 3	01-26-93	1404	<7.8	53.5	790	743	121	20.7	<8.1	<1.3	<13	<3.2
Commerce 4	08-17-92	1430	<2	14.1	328	—	22.6	20	<1.2	—	<5	<2.6
Commerce 4	08-17-92	1433	<3.8	16.2	328	392	18.9	20	<24	<17	<14	<6.1
Commerce 4	08-17-92	1434	<3.8	15	328	393	19.1	20	<24	<17	<14	<6.1
Commerce 4	09-23-92	1510	<2.5	14.2	326	—	20.9	20.1	<3.8	—	<2.8	11.1
Commerce 4	09-23-92	1513	<3.4	15.4	326	37	18.4	20.1	<19	5.1	<8.6	24.2
Commerce 4	09-23-92	1514	<3.4	15.9	326	37.2	18.4	20.1	<19	<2.4	<8.6	<7.6
Commerce 4	10-21-92	1340	<4	13.5	329	—	17.16	20.1	<1	—	<3	11.4
Commerce 4	10-21-92	1343	<6.1	16.1	329	37.1	18.1	20.1	<10	<2.6	<13	<40
Commerce 4	10-21-92	1344	<6.1	15.2	329	35.4	18.1	20.1	15	4.4	<13	<40
Commerce 4	11-17-92	1550	<5	14.1	334	—	21	20	<2	—	<6	4.9
Commerce 4	11-17-92	1551	<5	13.7	334	—	18	20	<2	—	<6	10.6
Commerce 4	11-17-92	1553	<6.4	14.8	334	36.9	18.2	20	<18	<1.9	<13	<3.5
Commerce 4	11-17-92	1554	<6.4	14.2	334	36	17.8	20	<18	2.1	<13	<3.5
Commerce 4	12-14-92	1500	<4	13.5	326	—	19.1	20	<1	—	<3	3.8
Commerce 4	12-14-92	1503	<7.4	14.1	326	35.2	18.1	20	<15	<5.6	<24	1.7
Commerce 4	12-14-92	1504	<7.4	15	326	36.7	17.9	20	25	<5.6	<24	<1.4
Commerce 4	01-26-93	1440	<4	13.5	329	—	18.5	20	<2.5	—	9.1	5.6
Commerce 4	01-26-93	1443	<7.8	14.5	329	368	18	20	<8	2.7	<13	<3.2
Commerce 4	01-26-93	1444	<7.8	14.8	329	368	18.2	20	<8	<1.3	<13	27.8
Cook, Joe	01-27-93	1750	<4	7.39	463	—	12.9	16.3	<2.5	—	<3.7	46.2
Cook, Joe	01-27-93	1753	<7.8	7.07	463	436	72.9	16.3	<8.2	5.9	<13	27.3
Cook, Joe	01-27-93	1754	<7.8	6.79	463	428	74.6	16.3	18.4	5.9	13	27.2

OWNER	DATES	TIMES	AG	NA	COND	SR	SO4	TEMP	TL	TI	V	ZN
Fairland 2	01-26-93	0910	<4	56.1	559	—	13.2	20.5	<2.5	—	4.8	7.4
Fairland 2	01-26-93	0913	<7.8	62.5	559	630	12	20.5	<8	<1.3	<13	<3.2
Fairland 2	01-26-93	0914	<7.8	63.9	559	634	11.9	20.5	<8	<1.3	13	<3.2
Grand Lake Shores	01-27-93	1430	<4	24.1	364	—	14.7	18.4	<2.5	—	<3.7	18.6
Grand Lake Shores	01-27-93	1431	<4	24.2	364	—	14.7	18.4	<2.5	—	<3.7	15.4
Grand Lake Shores	01-27-93	1433	<7.8	23.8	364	489	2.7	18.4	<8.1	<1.7	<13	18.6
Grand Lake Shores	01-27-93	1434	<7.8	24.7	364	498	12.1	18.4	<8.1	<1.7	<13	<3.2
Miami 6	01-27-93	0910	<4	59.5	589	—	147	19.5	<2.5	—	9	<3.6
Miami 6	01-27-93	0913	<7.8	66.7	589	490	11.9	19.5	<8	<1.3	<13	<3.2
Miami 6	01-27-93	0914	<7.8	66.7	589	491	11.5	19.5	<8.1	<1.7	<13	<3.2
Miami 1	01-27-93	1040	<4	51.8	523	—	15.5	19.6	<2.5	—	4.1	3.6
Miami 1	01-27-93	1043	<7.8	54.2	523	503	12.8	19.6	<8.1	<1.7	<13	<3.2
Miami 1	01-27-93	1044	<7.8	54.7	523	502	13.2	19.6	<8.1	<1.9	<13	<3.2
Miami 3	01-27-93	1230	<4	155	373	—	13.4	19.2	<2.5	—	<3.7	<3.6
Miami 3	01-27-93	1233	<7.8	29.9	373	638	12.2	19.2	<8	<1.4	18	<3.2
Miami 3	01-27-93	1234	<7.8	30	373	657	11	19.2	<8.1	<1.8	<13	<3.2
Ogeechee Farms	01-27-93	1620	<4	59.6	516	—	15.4	20.2	<2.5	—	<3.7	<3.6
Ogeechee Farms	01-27-93	1623	<7.8	58.7	516	403	13.6	20.2	<8.1	<1.9	<13	<3.2
Ogeechee Farms	01-27-93	1624	<7.8	59.2	516	407	12.5	20.2	<8.1	<2	13	<3.2
Picher 2	08-17-92	1540	<2	12.8	529	—	114	19.9	<1.2	—	<5	145
Picher 2	08-17-92	1543	<3.8	14.1	529	723	122	19.9	<24	<17	<14	164
Picher 2	08-17-92	1544	<3.8	14	529	705	122	19.9	<24	<17	<14	135
Picher 2	09-22-92	1600	<2.5	13.6	511	—	154	19.9	<3.8	—	<2.8	166
Picher 2	09-22-92	1603	<3.4	15.3	511	70.9	119	19.9	<19	2.5	<8.6	147
Picher 2	09-22-92	1604	<3.4	15.1	511	71.1	119	19.9	<19	4.7	<8.6	138
Picher 2	10-20-92	0940	<4	12.9	521	—	121.5	19.8	<1	—	<3	171
Picher 2	10-20-92	0941	<4	12.7	521	—	108	19.8	<1	—	<3	177
Picher 2	10-20-92	0943	<6.1	15	521	71.9	129	19.8	<10	<2.6	<13	139
Picher 2	10-20-92	0944	<6.1	18.2	521	76.4	127	19.8	<10	<2.9	<13	122
Picher 2	11-16-92	1610	<5	12.3	511	—	121	19.6	<2	—	<6	242
Picher 2	11-16-92	1613	<6.4	12.5	511	68.1	119	19.6	<18	2.7	<13	175
Picher 2	11-16-92	1614	<6.4	15.4	511	72.4	120	19.6	<18	<1.9	<13	135
Picher 2	12-15-92	0850	<4	12.4	518	—	136	19.7	<1	—	<3	166
Picher 2	12-15-92	0853	<7.4	13.2	518	71.3	118	19.7	<15	<5.6	<24	157
Picher 2	12-15-92	0854	8.2	12.7	518	68.9	122	19.7	22	6.2	<24	117
Picher 2	01-25-93	1120	<4	13.[illegible]	516	—	125	19.9	<2.5	—	<3.7	132
Picher 2	01-25-93	1123	<7.8	14.8	516	746	111	19.9	<8.1	<1.3	<13	127
Picher 2	01-25-93	1124	<7.8	15	516	742	111	19.9	<8.1	<1.7	<13	101
Picher 3	08-17-92	1610	<2	15.1	603	—	157	20.1	<1.2	—	<5	126
Picher 3	08-17-92	1611	<2	15.2	603	—	146	20.1	<1.2	—	<5	114
Picher 3	08-17-92	1613	<3.8	14.9	603	661	154	20.1	<24	<17	<14	122
Picher 3	08-17-92	1614	<3.8	16.6	603	680	158	20.1	<24	<17	<14	114
Picher 3	09-22-92	1700	<2.5	16.7	674	—	220	20	<3.8	—	<2.8	52.9
Picher 3	09-22-92	1703	<3.4	19.1	674	71.9	200	20	<19	<7	<8.6	43.6
Picher 3	09-22-92	1704	<3.4	18.2	674	69	199	20	<19	11.4	<8.6	21.4
Picher 3	10-20-92	1050	<4	17.3	711	—	216.9	19.9	<1	—	<3	42.8

OWNER	DATES	TIMES	AG	NA	COND	SR	SO4	TEMP	TL	TI	V	ZN
Picher 3	10-20-92	1053	<6.1	20.8	711	81	213	19.9	<10	<2.6	<13	<40
Picher 3	10-20-92	1054	<6.1	22.8	711	82.7	215	19.9	<10	<2.6	<13	<40
Picher 3	11-16-92	1710	<5	16	659	—	173	19.7	<2	—	<6	88.8
Picher 3	11-16-92	1713	<6.4	17	659	72.4	192	19.7	<18	<1.9	<13	70
Picher 3	11-16-92	1714	<6.4	18.2	659	72.9	192	19.7	20	3.1	<13	29.8
Picher 3	12-15-92	0920	<4	18.5	697	—	206	19.5	<1	—	<3	42
Picher 3	12-15-92	0923	<7.4	13.2	697	70.5	204	19.5	30	<5.6	<24	125
Picher 3	12-15-92	0924	<7.4	17.6	697	76.2	203	19.5	<15	<5.6	<24	38.4
Picher 3	01-25-93	1200	<4	19.2	841	—	256	19.8	<2.5	—	10.9	50.7
Picher 3	01-25-93	1203	<7.8	22.6	841	922	263	19.8	<8.3	2.2	<13	42.1
Picher 3	01-25-93	1204	<7.8	22.2	841	919	264	19.8	11.1	<1.3	<13	22.1
Picher 4	08-18-92	1210	<2	18.1	870	—	306	20.3	<1.2	—	<5	156
Plcher 4	08-18-92	1213	<3.8	21.4	870	1160	283	20.3	24	<17	<14	169
Picher 4	08-18-92	1214	<3.8	20.7	870	1160	279	20.3	<24	<17	<14	79
Picher 4	09-23-92	0910	<2.5	19	880	—	277	20.3	<3.8	—	<2.8	166
Picher 4	09-23-92	0911	<2.5	18.4	880	—	292	20.3	<3.8	—	<2.8	157
Picher 4	09-23-92	0913	<3.4	20.5	880	111	288	20.3	<19	8.5	<8.6	135
Picher 4	09-23-92	0914	<3.4	19.6	880	110	287	20.3	<19	9.6	<8.6	69
Picher 4	10-20-92	1250	<4	17.9	881	—	271.9	20.3	<1	—	<3	161
Picher 4	10-20-92	1253	<6.2	24.4	881	118	300	20.3	<10	<2.6	<14	135
Picher 4	10-20-92	1254	<6.1	24.7	881	119	301	20.3	<10	<2.6	<13	58
Picher 4	11-17-92	0930	<5	18.1	885	—	268	20.3	<2	—	<6	169
Picher 4	11-17-92	0933	<6.4	19.9	885	113	297	20.3	20	6.1	<13	154
Picher 4	11-17-92	0934	<6.4	21.1	885	115	292	20.3	21	4.2	<13	48.5
Picher 4	12-15-92	1010	<4	18.8	886	—	294	20.5	<1	—	<3	173
Picher 4	12-15-92	1011	<4	19.5	886	—	295 -	20.5	<1	—	<3	177
Picher 4	12-15-92	1013	<7.4	17.6	886	76	294	20.5	27	<5.6	<24	24.2
Picher 4	12-15-92	1014	<7.4	19.8	886	110	291	20.5	21	12.3	<24	195
Picher 4	01-25-93	1330	<4	18.8	893	—	284	20.4	<2.5	—	7.2	158
Picher 4	01-25-93	1333	<7.8	21.8	893	1250	291	20.4	14	<1.3	<13	156
Picher 4	01-25-93	1334	<1.7	20.3	893	1290	293	20.4	<8.3	<14	<2.3	44
Quapaw 2	08-18-92	1520	<2	18.7	743	—	195	19.5	<1.2	—	<5	46.7
Quapaw 2	08-18-92	1523	<3.8	18.8	743	298	182	19.5	<24	<17	<14	42.1
Quapaw 2	08-18-92	1524	<3.8	23	743	313	185	19.5	<24	<17	<14	83
Quapaw 2	09-22-92	1330	<2.5	19.5	745	—	176	20	<3.8	—	<2.8	50.9
Quapaw 2	09-22-92	1333	<3.4	22	745	28.1	190	20	<19	6.4	<8.6	39.2
Quapaw 2	09-22-92	1334	<3.4	20.7	745	28	189	20	<19	7.6	<8.6	32.8
Quapaw 2	10-20-92	1440	<4	19.1	754	—	168.6	19.1	<1	—	<3	53.2
Quapaw 2	10-20-92	1443	<6.1	25.6	754	30.6	193	19.1	<10	<2.8	<13	<40
Quapaw 2	10-20-92	1444	<6.1	26.7	754	30.4	190	19.1	<10	<2.8	<13	49
Quapaw 2	11-16-92	1320	<5	19.4	749	—	173	19.1	<2	—	<6	70.7
Quapaw 2	11-16-92	1323	<6.4	20.3	749	28.2	187	19.1	21	4.8	<13	32.8
Quapaw 2	11-16-92	1324	<6.4	21	749	27.9	184	19.1	<18	3.3	<13	26.7
Quapaw 2	12-14-92	1610	<4	19	752	—	194	19.2	<1	—	<3	48.9
Quapaw 2	12-14-92	1613	<7.4	21	752	27.4	188	19.2	21	<5.6	<24	38.1
Quapaw 2	12-14-92	1614	<7.4	19.7	752	26.6	193	19.2	38	5.6	<24	36.9
Quapaw 2	01-25-93	1440	<4	19.9	760	—	187	19.1	<25	—	8.7	47.2
Quapaw 2	01-25-93	1443	<7.8	22.4	760	310	183	19.1	<8.2	<1.3	<13	38.1
Quapaw 2	01-25-93	1444	<7.8	22.3	760	307	202	19.1	<8.2	<1.3	<13	30.2
Quapaw 4	08-18-92	1620	<2	6.67	274	—	15.3	19.1	<1.2	—	<5	9.6

OWNER	DATES	TIMES	AG	NA	COND	SR	SO4	TEMP	TL	TI	V	ZN
Quapaw 4	08-18-92	1623	<3.8	6.91	274	229	13.8	19.1	<24	<17	<14	<6.1
Quapaw 4	08-18-92	1624	<3.8	6.64	274	229	14.3	19.1	<24	<17	<14	9.5
Quapaw 4	09-22-92	1500	<2.5	7.77	300	—	18.6	19	<3.8	—	<2.8	5.2
Quapaw 4	09-22-92	1503	<3.4	8.45	300	28.8	16.7	19	<19	<2.4	<8.6	11.8
Quapaw 4	09-22-92	1504	<3.6	9.43	300	32.3	17.1	19	<19	<2.5	<9	<7.9
Quapaw 4	10-20-92	1540	<4	5.31	269	—	13.5	19.1	<1	—	<3	<3
Ouapaw 4	10-20-92	1543	<6.1	7.29	269	22.1	19.3	19.1	<10	<2.6	<13	<40
Quapaw 4	10-20-92	1544	<6.1	7.56	269	22.4	19.1	19.1	<10	<2.7	<13	<40
Quapaw 4	11-16-92	1450	<5	5.63	275	—	13	19.1	<2	—	<6	9.8
Quapaw 4	11-16-92	1453	<6.4	5.88	275	20.4	11.2	19.1	<18	3	<13	<3.5
Quapaw 4	11-16-92	1454	<6.4	5.96	275	20.8	10.8	19.1	<18	<1.9	<13	<3.5
Quapaw 4	12-14-92	1730	<4	7.51	300	—	19.1	19	<1	—	<3	<3
Quapaw 4	12-14-92	1733	<7.4	7.87	300	29.6	18.6	19	26	<5.6	<24	<1.4
Quapaw 4	12-14-92	1734	<7.4	7.73	300	29.2	19.2	19	22	6.8	<24	<1.4
Quapaw 4	01-25-93	1550	<4	8.49	319	—	23.8	18.8	<2.5	—	8.9	3.6
Quapaw 4	01-25-93	1553	<7.8	9.41	319	431	25.8	18.8	<8	<1.3	<13	<3.2
Quapaw 4	01-25-93	1554	<7.8	9.29	319	436	26.6	18.8	<8	<1.3	<13	<3.2
RWD 4 Well 2	01-28-93	0830	<4	19.8	362	—	14.1	19.9	<2.5	—	<3.7	<3.6
RWD 4 Well 2	01-28-93	0833	<7.8	20.6	362	189	13	19.9	<8.1	<2	<13	<3.2
RWD 4 Well 2	01-28-93	0834	<7.8	20.3	362	186	13	19.9	<8.1	<2	<13	<3.2
RWD 4 Well 3	01-28-93	0930	<4	4.34	271	—	13.4	19.1	<2.5	—	9.1	5
RWD 4 Well 3	01-28-93	0933	<7.8	4.38.	271	88.3	12.7	19.1	<8.1	<1.7	<13	<3.2
RWD 4 Well 3	01-28-93	0934	<7.8	4.51	271	90.6	12.6	19.1	<8.1	<1.9	<13	<3.2
RWD 4 Well 4	08-18-92	0930	<2	2.66	259	—	9.3	19.2	<1.2	—	<5	<2.6
RWD 4 Well 4	08-18-92	0933	<3.8	3.15	259	42.6	8.58	19.2	<24	72	<14	<6.1
RWD 4 Well 4	08-18-92	0934	<3.8	2.67	259	42.2	9.17	19.2	<24	<17	<14	<6.1
RWD 4 Well 4	09-22-92	1110	<2.5	2.75	256	—	7.45	19.4	<3.8	—	<2.8	4.7
RWD 4 Well 4	09-22-92	1113	<3.4	3.28	256	4.2	8.99	19.4	<19	<2.4	<8.6	<7.6
RWD 4 Well 4	09-22-92	1114	<3.4	3.17	256	3.9	8.87	19.4	<19	<2.4	<8.6	<7.6
RWD 4 Well 4	10-20-92	1640	<4	2.8	262	—	7.42	19.3	<1	—	<3	<3
RWD 4 Well 4	10-20-92	1643	<6.1	3.44	262	4.2	8.89	19.3	<10	3.3	<13	<40
RWD 4 Well 4	10-20-92	1644	<6.1	3.54	262	4.2	9.11	19.3	<10	<2.6	<13	<40
RWD 4 Well 4	11-16-92	1050	<5	3.11	261	—	4	19.3	<2	—	<6	6.1
RWD 4 Well 4	11-16-92	1051	<5	3.06	261	—	7	19.3	<2	—	<6	4.9
RWD 4 Well 4	11-16-92	1053	<6.4	3.15	261	3.8	8.64	19.3	<18	<1.9	<13	<3.5
RWD 4 Well 4	11-16-92	1054	<6.4	3.18	261	3.7	11.1	19.3	<18	<1.9	<13	<3.5
RWD 4 Well 4	12-15-92	1130	<4	2.71	254	—	11.2	19.3	<1	—	<3	17.2
RWD 4 Well 4	12-15-92	1133	11.4	2.69	254	3.6	8.95	19.3	16	<5.6	<24	<1.4
RWD 4 Well 4	12-15-92	1134	<7.4	2.8	254	3.7	9.04	19.3	<15	<5.6	<24	<1.4
RWD 4 Well 4	01-25-93	1640	<4	2.92	260	—	10.2	19.2	<2.5	—	6.1	<3.6
RWD 4 Well 4	01-25-93	1643	<7.8	3.37	260	44	9.03	19.2	<8.1	<2	<13	<3.2
RWD 4 Well 4	01-25-93	1644	<7.8	3.08	260	44.1	8.82	19.2	<8.1	<2.2	<13	12.5
RWD 6 Well 1	01-26-93	1700	<4	45.4	444	—	135	19.8	<2.5	—	6.4	<3.6
RWD 6 Well 1	01-26-93	1703	<7.8	50.1	444	584	10.9	19.8	<8	2.7	<13	<3.2
RWD 6 Well 1	01-26-93	1704	<7.8	51.8	444	591	10.6	19.8	<8	<1.3	<13	<3.2

Appendix B

Statistical Tables

TABLE 5. TOLERANCE FACTORS (K) FOR ONE-SIDED NORMAL TOLERANCE INTERVALS WITH PROBABILITY LEVEL (CONFIDENCE FACTOR) Y = 0.95 AND COVERAGE P = 95%

n	K	n	K
3	7.655	75	1.972
4	5.145	100	1.924
5	4.202	125	1.891
6	3.707	150	1.868
7	3.399	175	1.850
8	3.188	200	1.836
9	3.031	225	1.824
10	2.911	250	1.814
11	2.815	275	1.806
12	2.736	300	1.799
13	2.670	325	1.792
14	2.614	350	1.787
15	2.568	375	1.782
16	2.523	400	1.777
17	2.486	425	1.773
18	2.543	450	1.769
19	2.423	475	1.766
20	2.396	500	1.763
21	2.371	525	1.760
22	2.350	550	1.757
23	2.329	575	1.754
24	2.309	600	1.752
25	2.292	625	1.750
30	2.220	650	1.748
35	2.166	675	1.746
40	2.126	700	1.744
45	2.092	725	1.742
50	2.065	750	1.740
		775	1.739
		800	1.737
		825	0.736
		850	1.734
		875	1.733
		900	1.732
		925	1.731
		950	1.729
		975	1.728
		1000	1.727

SOURCE: (a) for sample sizes ≤ 50: Lieberman, Gerald F. 1958. “Tables for One-sided Statistical Tolerance Limits.” *Industrial Quality Control*. Vol. XIV, No. 10. (b) for sample sizes ≥ 50: K values were calculated from large sample approximation.

Background Roubidoux sampling results/statistical analysis

	Zn	ln Zn	Fe	SO4	ln SO4
	46.2	3.83	34	12.9	2.56
	27.3	3.31	42	72.9	4.29
	7.4	2.00	63	74.6	4.31
	3.2	1.16	28	13.2	2.58
	18.6	2.92	23.1	12	2.48
	15.4	2.73	11	11.9	2.48
	18.6	2.92	66.5	14.7	2.69
	3.6	1.28	11	14.7	2.69
	3.2	1.16	71.8	12.7	2.54
	3.6	1.28	50	12.1	2.49
	3.2	1.16	73.6	147	4.99
	3.6	1.28	32	11.9	2.48
	3.2	1.16	236	11.5	2.44
	3.6	1.28	204	15.5	2.74
	3.2	1.16	75.5	12.8	2.55
	3.6	1.28	24	13.2	2.58
	3.2	1.16	56.6	13.4	2.60
	5	1.61	47	13.2	2.58
	3.2	1.16	20	11	2.40
	3.6	1.28		15.4	2.73
	3.2	1.16		13.6	2.61
				12.5	2.52
				14.1	2.65
				13	2.56
				13	2.56
				13.4	2.59
				12.7	2.54
				12.6	2.53
				135	4.91
				10.9	2.39
				10.6	2.36
N	21	21	19	31	31
Mean	8.84	1.73	61.53	25.10	2.82
Std	10.97	0.86	59.83	33.33	0.72

APPENDIX F

LETTER ON BLOOD LEAD DATA

AUTHOR: DONALD S. ACKERMAN
U.S. PUBLIC HEALTH SERVICE - INDIAN HEALTH SERVICE

DATE: JANUARY 21, 1994

DEPARTMENT OF HEALTH & HUMAN SERVICES **Public Health Service**

Oklahoma City Area Indian Health Service
Five Corporate Plaza
3625 N.W. 56th Street
Oklahoma City, OK 73112

January 21, 1994

Michael D. Overbay
Remedial Project Manager
OK/TX Remedial Section (6H-SR)

Dear Mr. Overbay:

Approximately 34% (66 of the total 192) of the people tested for blood lead have had a 10 ug/dl or higher blood lead level. Of these 66 children 4% are above 20 ug/dl. Most of the individuals tested are participants of the WIC program here at the clinic. Some of these children come from outside the Oklahoma area.

Location does not seem to be a factor when comparing the levels among these children. I would say that a small majority of these people live within one-half to five miles from chat piles and there is a possibility that some of the older homes and public water systems contain lead in some form as part of the plumbing. Occupational exposures, debris around the home(items suspected of containing lead), and hobbies may all be contributing factors to these blood lead levels.

Two methods are used here at the clinic for collecting blood samples for lead, venal puncture and finger prick. We have experienced some high readings with the finger prick method when compared to the venal puncture sample of blood. I am notified of some of the blood lead levels as they come in, but most of the time I will go back and pull the charts on these people to gather data.

The mean blood lead level for the entire group is 8.34 ug/dl and for those children that are above 10 ug/dl the mean is 13.56 ug/dl.

Sincerely,

Donald S. Ackerman

Donald S. Ackerman
Field Sanitarian
Office of Environmental Health
USPHS Indian Health Center
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