Tri-State Transition Zone Assessment Study

Kansas, Missouri and Oklahoma

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List of Acronyms and Abbreviations

ALAD	δ-aminolevulinic acid dehydratase
COPC	Contaminant of Primary Concern
EPA	United States Environmental Protection Agency
GIS	Geographic Information System
ICP-AES	Inductively Coupled Plasma-Mass Spectrometry
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
KS	State of Kansas
MO	State of Missouri
NAIP	National Agriculture Imagery Program
OK	State of Oklahoma
OU	Operable Unit
RAO	Remedial Action Objective
RI	Remedial Investigation
ROD	Record of Decision
SAP	Sampling and Analysis Plan
TERL	Trace Element Research Laboratory
TSMD	Tri-State Mining District
TZ	Transition Zone
XRF	X-Ray Fluorescence Analyzer
Cd	Cadmium
Pb	Lead
Zn	Zinc

Executive Summary

The Tri-State Mining District (TSMD) spans portions Cherokee County, Kansas; Barry, Christian, Greene, Lawrence, Jasper, and Newton Counties, Missouri; and Ottawa County, Oklahoma. Mining operations began in the TSMD in the mid-1800's to extract deposits of lead and zinc ore. Mining operations have ended. However, vast amounts of waste in the form of mine wastes and fine tailings still exist throughout the TSMD. This waste contains elevated levels of cadmium, lead, and zinc and is a continuing source of heavy metal contamination to the surrounding area. The U.S. Environmental Protection Agency (EPA) has taken different approaches in identifying Transition Zone (TZs) across the TSMD. In Cherokee County Superfund Site the EPA specified that the TZ is 300 feet, Jasper and Newton counties Superfund sites the EPA specified that the TZ is 200 feet and at the Tar Creek Superfund Site the EPA specified that the TZ is 50feet. In Oklahoma, this distance was defined by EPA Region 6 to estimate clean-up costs and it does not reflect the actual size of the TZ for any given chat pile/base.

Sampling was conducted along 45 transects in all three states near the cities of Picher, OK, Waco, Crestline, Springs, KS, and Joplin, MO. Sample sites were selected from a combination of aerial photography and field investigation. Data were analyzed as an entire set representing the entire TSMD and in subsets representing differing land uses designated as wooded, pasture, and tilled. Mean metal concentrations were calculated from datasets representing each state. All analysis was done using a portable X-Ray Fluorescence analyzer (XRF) with confirmation samples sent to a certified lab.

The Trustees define TZs as "Those soils or mixed soils and transported incidental mine wastes that are adjacent to and surround a chat pile/base and that extends in a horizontal direction away from the pile. Typically, the TZ represents the area where hazardous substance concentrations transition from a maximum to background concentrations". The Trustees were interested in identifying a mean TZ width compared to EPA action level and compared to background levels. Results of this study indicate that mean TZ, as defined by the Trustees, width is at least 167 feet throughout the TSMD based on EPA clean up levels. Also, data collected in this study indicate that various agricultural practices reduce levels of Cd, Pb, and Zn in TZs. Analysis indicated that the average TZ width for wooded areas was 175 feet. Pasture and tilled areas had average TZ widths of 164 feet and 25 feet respectively. Tilling resulted in narrower TZ widths than wooded or pastured areas. Mixing of heavily contaminated uppers soil layers with relatively clean deeper soil results in lower overall metal concentrations and indicates that tilling may be the only agricultural practice that significantly reduces TZ width. Mean metal concentrations were calculated for all distances sampled throughout the TSMD and for each state. This was done to allow the estimation of soil metal levels throughout the TZ of an associated chat pile. In the TSMD, mean metal concentrations were above background and EPA Action Levels at all distances sampled with the exception of those used to determine where each transect ended. When two consecutive samples measured in situ were below background, no further sampling was done on the associated transect and these samples were not used in data analysis.

Natural and anthropogenic processes that have occurred since chat piles and bases were surveyed in the TSMD have resulted in unmapped mine waste and soil contamination that extends far

away from chat piles. Some samples were taken along transects that intersected unmapped mine waste. These samples consisted primarily of chat and were considered part of the TZ. Site specific data is the most accurate means of estimating metal concentrations throughout the TZ. However, in the absence of this data, the results of this study may be applied to estimate TZ widths or metals concentrations at specific distances away from chat pile boundary. Average TZ widths and mean metal concentrations presented here demonstrate that heavy metal contamination and related injury to natural resources extends well beyond 50 feet from EPA delineated chat pile boundaries at the Tar Creek Superfund Site. TZ concentrations of Cd, Pb, and Zn that exceed EPA Action Levels have been shown to occur at distances of 600 feet in this study and likely extend to greater distances in some cases.

1.0 Introduction

1.1 Background

The Tri-State Mining District (TSMD) spans portions Cherokee County, Kansas; Barry, Christian, Greene, Lawrence, Jasper, and Newton Counties, Missouri; and Ottawa County, Oklahoma (figure 1). Mining operations began in the TSMD in the mid-1800's to extract deposits of lead and zinc ore. Mining operations have ended. However, vast amounts of waste in the form of mine wastes and fine tailings still exist throughout the TSMD. This waste contains elevated levels of cadmium, lead, and zinc and is a continuing source of heavy metal contamination to the surrounding area.

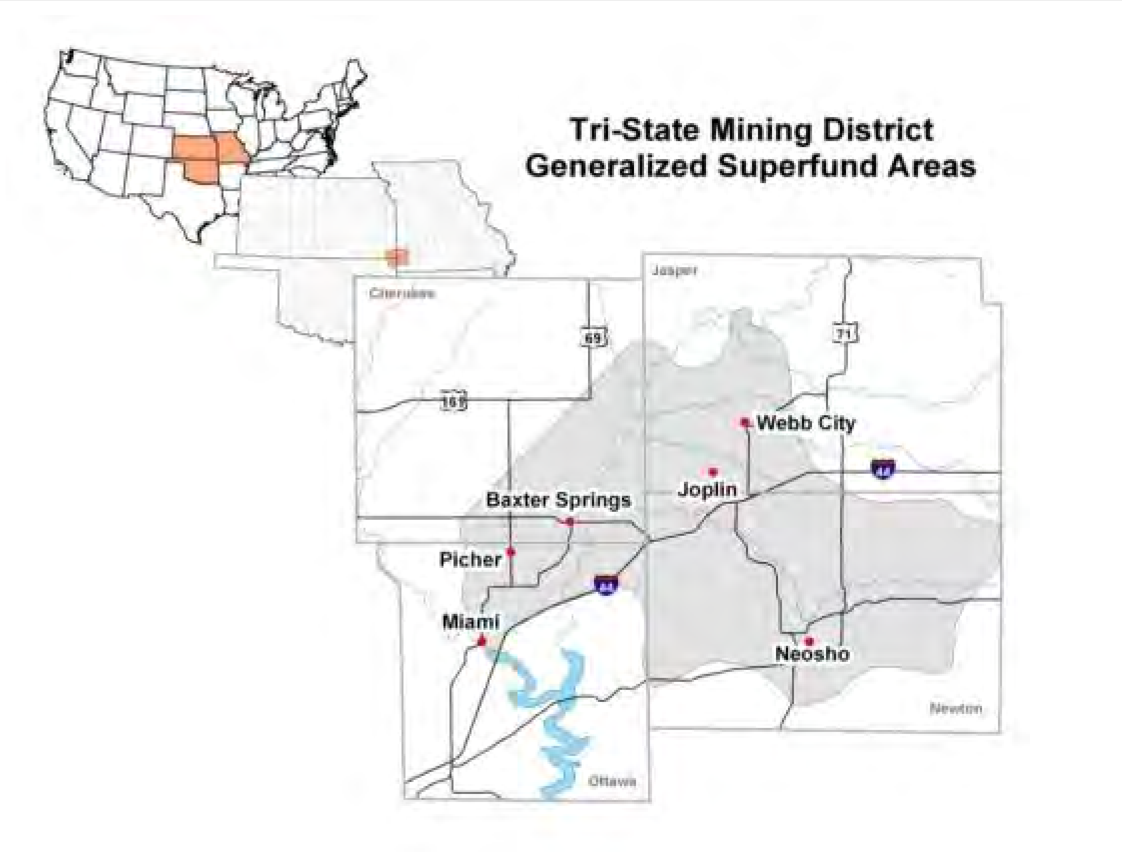

Figure 1. Tri-State Mining District.

The U.S. Environmental Protection Agency (EPA) has taken different approaches in identifying Transition Zone (TZs) across the TSMD. In Cherokee County Superfund Site the TZ is 300 feet, Jasper and Newton counties Superfund sites the TZ is 200 feet and at the Tar Creek Superfund Site the TZ is 50feet. In Oklahoma, this distance was defined by EPA Region 6 to estimate clean-up costs and it does not reflect the actual size of the TZ for any given chat pile/base.

The EPA Records of Decision (ROD) for the TSMD use the term "transition zone" without the inclusion of "soil" to describe a contaminated medium with no definite spatial component or distance related to metal concentration. In Oklahoma, this distance was defined by EPA Region 6 to estimate clean-up costs and it does not reflect the actual size of the TZ for any given chat pile/base. However, the Trustees have determined that metals concentrations in TZ are sufficiently elevated above background concentrations to a point to cause injury, and have used this distance to conservatively estimate natural resource damage claims.

The Trustees define Transition zones as:

> Those soils or mixed soils and transported incidental mine wastes that are adjacent to and surround a chat pile/base and that extend in a horizontal direction away from the pile. Typically, the TZ represents the area where hazardous substance concentrations transition from a maximum to background concentrations.

Re-distribution of metal contamination from erosion processes from both wind and water and mechanical removal of chat for construction purposes can result in variation in TZ size. Land use surrounding areas of chat deposition can also affect TZ size. Agricultural tilling can reduce the TZ size by diluting contaminated soil with cleaner soils from a greater depth. Field sampling has shown metal content in TZs can drop to background levels where tillage occurs adjacent to chat piles (see figure 4). The extent of TZ areas have not been fully mapped or identified across TSMD. The current study was conducted by the Trustees to gather more site-specific data to accurately describe TZ widths in settlement discussions.

1.2 Contaminants of Primary Concern

Cadmium, lead, and zinc, are the Contaminants of Primary Concern (COPC) identified for this study. These metals are hazardous substances as listed in Federal regulations found at 40 C.F.R. § 116.4 and as toxic pollutants pursuant to 40 C.F.R. Part 401.15, as amended. Exposure to these metals has been shown to cause adverse biological effects in both aquatic and terrestrial ecosystems (Newman & Unger 2003). Several studies found that exposure to lead resulted in δ-aminolevulinic acid dehydratase (ALAD) inhibition and exposure to zinc resulted in internal organ lesions of waterfowl from the TSMD and other areas (Carpenter et al. 2004; Levengood and Skowron 2007; van der Mewe 2010). Van der Merwe (2010) found greater than 50% decrease in ALAD activity in Canada Geese (*Branta canadensis*) collected from the TSMD as compared to individuals collected from control sites well outside of the mining area. This level of ALAD inhibition constitutes an injury to birds per 43CFR11.62(f)(2)(i-iv). Other studies have shown cadmium biomagnification by willow trees (*Salix* spp.) and accumulation in avian species at sufficient levels to cause adverse health effects (Larison et al. 2000). Table 1 lists background concentrations of COPCs in the TSMD. Historical mining activities have resulted in elevated metal concentrations in soils of the TSMD near mine waste accumulations (Dames & Moore 1995).

Table 1. Mean Background Concentrations of COPCs in the TSMD.

	Cd	Pb	Zn
KS*	0.4	17	44
MO**	4.1	91	433
OK***	0.73	31.25	83.25

Units=mg/kg
*Dames & Moore. Final Remedial Investigation for Cherokee Co. ,KS CERCLA Site, Baxter Springs/Treece Subsites. (1993).
**Oronogo-Duenweg Mining Belt Record of Decision OU1, USEPA (2004).
***Remedial Investigation OU4, Tar Creek, USEPA.

1.3 EPA Remedial Actions to Address Remediation of Transition Zones

Remedial actions conducted in Kansas to address terrestrial contamination are described in the ROD documents for Operable Unit (OU) 3 and 4 (Baxter Springs and Treece Subsites) and OU6 (Badger, Lawton, Waco, and Crestline Subsites). Terrestrial contamination is also addressed in the ROD for OU1 (Oronogo-Duenweg Mining Belt) and OU1 and 2 (Newton County Mine Tailings Superfund Site) in Missouri and the ROD for OU4 (Tar Creek Superfund Site) in Oklahoma.

All applicable ROD documents acknowledge the widespread presence of contaminated TZs and the likelihood of risk to exposed biota. Each ROD establishes Remedial Action Objectives (RAOs) that the selected remedies must meet. In addition, the RODs list specific concentrations that designate when contaminated soils must be removed (Table 2). Among sites, a significant disparity exists in the ability of the remedial actions to meet described RAOs and this limits the effectiveness of the remedy and potentially increases further injury caused by contaminated TZs. More specifically:

Kansas

The OU-5 Remedial Action (Galena Groundwater/Surface Water) included the remediation of approximately 900 acres of surface mining wastes around the community of Galena, Kansas (U.S. EPA 1989). The remedy consisted of the consolidation and placement of mining wastes into dry subsidence features, collapses, and mine shafts. Mining waste was also contoured and surface drainage was re-channeled and diverted to minimize erosion. The mining wastes were then treated with 2 tons of hay mulch, 2 tons of lime, and 40 tons of compost (all on a per acre basis) which was shallow-tilled into the top of the mine waste. All areas were then re-vegetated with a warm-season grass mixture (U.S. EPA 1995).

Remedial Investigation (RI) for the Baxter Springs and Treece Subsites (OU3/4): The 1993 RI describes heavy metal contamination in soils in the immediate vicinity of surfaces mine wastes (Dames & Moore 1993). The 1997 ROD set action levels for residential soils and mine waste within 500 feet of residential areas. In a 2006 ROD amendment, action levels for the remaining mine waste accumulations were set at 10ppm Cd, 400ppm Pb, and 1,100ppm Zn. The remedies for the OU 3 and 4 terrestrial environments were determined in several Remedial Design/Remedial Action documents; and include a combination of waste volume minimization through on-going chat sales and subaqueous disposal, relocation, consolidation, capping and revegetation.

ROD OU6 (Badger, Lawton, Waco, and Crestline Subsites): Soils and source materials RAOs address the prevention of ecological and human risk due to exposure to materials contaminated with visible mine wastes (EPA 2004). The remedial action performance criteria for terrestrial mining wastes were established through several Remedial Design/Remedial Action documents, and were set at 400ppm Pb and 1,100ppm Zn. The remedial actions included subaqueous disposal, excavation and relocation, consolidation, capping and revegetation.

Table 2. EPA Soil Action Levels for Applicable Operable Units.

	Cd	Pb	Zn
Kansas[a]			
OU3	10	400	1,100
OU4	10	400	1,100
OU6	No Numerical Values		
Missouri[b]			
OU1*	40	400	6,400
OU1**	40	400	6,400
OU2**	40	400	6,400
Oklahoma[c]			
OU4	10	500	1,100

Units=ppm
*Oronogo-Duenweg Mining Belt
**Newton County Mine Tailings Superfund Site
[a]Cherokee County KS Record of Decision Amendment OU3&4, USEPA (2006).
Cherokee County KS Record of Decision Amendment OU6, USEPA (2004).
[b]Orenogo-Duenweg Mining Belt Record of Decision OU1, USEPA (2004).
Newton County Mine Tailings Superfund Site Record of Decision OU1&2, USEPA (2010).
[c]Tar Creek Superfund Site Record of Decision OU4, USEPA (2008).

ROD OU6 (Badger, Lawton, Waco, and Crestline Subsites): RAOs of this subsite are media specific. Soils and source materials RAOs address the prevention of ecological and human risk due to exposure to materials contaminated with heavy metals. The document indicates that this RAO is met by relocating, consolidating, disposing, and capping of all surface accumulations of soils and mining waste. For the selected remedy, action levels for residential mining waste are 75ppm Cd and 800ppm Pb.

Missouri

ROD OU1 (Oronongo-Duenweg Mining Belt): A source material RAO was developed to address potential ecological risks associated with direct exposure to heavy metals in mine and mill wastes, and in the transition zone soils. Action levels were set at 40ppm Cd, 400ppm Pb, and 6,400ppm Zn. The selected remedy consists of source material excavation and deposition into subsidence pits followed by capping. All floodplain transition zone soils that exceeded action levels are to be incorporated into waste caps, as well as those upland transition zone soils required to complete caps after floodplain materials are exhausted. The remainder of upland transition zone soils that exceed action levels are to be deep tilled with soil amendments to reduce metal content and excavated areas are to be re-vegetated.

ROD OU1&2 (Newton County Mine Tailings Superfund Site): This document defines a source material RAO that controls ecological and human health risks from exposure to metal contamination from mining and milling wastes and affected soils within the site. Action levels were set at 40ppm Cd, 400ppm Pb, and 6,400ppm Zn. The selected remedy specifically addresses remediation of transition zone soils with all soils and mine waste that exceed action levels excavated and placed in a central repository in an upland area. These repositories will be capped with clay and clean topsoil with a vegetative cover.

Oklahoma

ROD OU4 (Chat Piles, Other Mine and Mill Waste, and Smelter Waste Tar Creek Superfund Site): This document lists a RAO to prevent terrestrial fauna from coming in direct or indirect contact, through the ingestion exposure pathway, with Cd, Pb, Zn contaminated source materials and soils where the concentration of these metals exceed established action levels of 10ppm Cd, 500ppm Pb, and 1,100ppm Zn. The selected remedy includes excavation of all transition zone soils and soils underlying mine waste that exceed action levels. However, budgeting for the excavation of transition zone soils only allow for the removal of soils in a 50 feet transitional area surrounding chat piles. EPA has since determined that metals contamination extends much further from chat piles and the use of a 50 foot TZ assumption significantly underestimates the volume of contaminated TZ soils and the associated cost of remediation (CH2M Hill 2011). This document outlines methods to reduce costs of remediating TZ soils by reducing the volume that will require cleanup. This reduction of TZ soil volume for excavated will be accomplished by reducing sampling efforts to identify areas of contamination above EPA Action Levels and leaving the contamination in place causing further injury.

1.4 Study Area and Sampling Description

Sampling was conducted in all three states near the cities of Picher, OK, Waco, Crestline, Springs, KS, and Joplin, MO (figure 2). Sample sites were selected from a combination of aerial photography and field investigation. It was necessary to select sites over a sufficient area to ensure sampling efforts accounted for variation in land uses that are likely to occur throughout the entire TSMD.

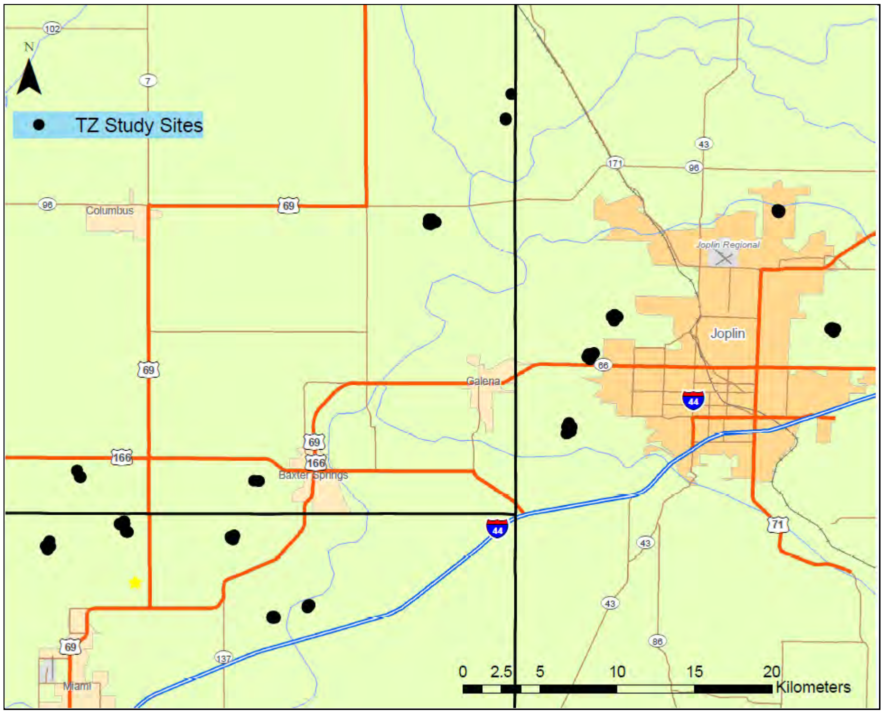

Figure 2. 2009 Transition Zone Study Area.

1.5 Study Area and Sampling Description

The 2009 Tri-State Transition Zone Study was intended to provide the information needed to determine the extent of soil contamination from historic mining operations in the TSMD. The study objectives listed in the initial Sampling and Analysis Plan (SAP) were:

1) Obtain data on the concentrations of target metals in 250 soil samples collected from Cherokee, KS; Jasper/Newton, MO and Ottawa, OK counties in areas of potential deposition of heavy metals from historic mining operations (i.e. analysis of dried samples using a portable X-ray fluorescence (XRF) for metals as described in EPA Method 6200).
2) Confirm the results of XRF-based metal analyses of samples through analysis of a subset of the collected samples for target metals. The samples will be sieved to <250 microns, digested following EPA Method 3052, and analyzed by Inductively Coupled Plasma/Atomic Emission Spectrometry (ICP-AES, EPA Method 6010B).

The SAP was written and released prior to site selection and the development of a final study design. It was assumed that the selection of sample sites, study design development, and sample analysis results would determine how the final dataset would be analyzed and presented. For these reasons, the objectives listed in the SAP were developed as broad guidelines to accommodate a variety of study designs and methods of data analysis. Upon completion of field work and sample analysis, the resulting dataset was analyzed and presented based upon the following objectives:

1) Measure the distance of transition zone from maximum concentrations of Cadmium, Lead, and Zinc at the boundary of chat piles/bases to background concentrations.
2) Characterize the variability of the transition zone due to surrounding land use.

2.0 Materials and Methods

2.1 Land Use Selection

Chat piles were selected based on three broad categories of land use consisting of pasture, wooded, and mechanically tilled cropland. 2008 National Agriculture Imagery Program (NAIP) aerial photography was downloaded to Geographical Information System (GIS) (ESRI Redlands, CA) along with shapefiles depicting chat pile boundaries as determined by EPA. Individual chat piles were then selected for field investigation. Ground-truthing revealed that most chat piles were subject to a wide array of land uses and other anthropogenic activities that could influence TZ metal content. However, there were enough chat piles subject to adjacent land management practices or heavy vegetation to select a sufficient sample size for each of the target land uses identified for the study.

Sample sites consisted of dense woody vegetation, converted and native pasture, and row-crop field subject to frequent tilling. On aerial photographs, sites that were surrounded by dense vegetation made it difficult to detect visible chat outside the EPA digitized boundaries. However, field investigations revealed that mine waste was often concealed by the vegetation. Several sites were adjacent to pastures that consisted of native plant communities or had been converted to cool season grasses. Typically, pasture vegetation was not dense enough to conceal mine waste but areas of sparse vegetation interspersed with mine waste were occasionally encountered. Sampling near row-crop agriculture usually ended abruptly at the boundary of tilled areas or had narrow bands of vegetation between the edge of the chat pile/base and the tilled area.

2.2 Sample Collection and Analysis

2.2.1 Field Collection

Samples for lab analysis were taken in transects from the EPA designated chat pile/base boundary toward areas of hazardous material concentration/background levels. EPA Chat pile/base boundaries were delineated on EPA shapefiles and, in most cases, did not accurately represent actual boundaries of chat piles/bases as observed in the field. This is due to chat migration outside of delineated boundaries over time from natural and anthropogenic means. Some samples were taken along transects that intersected unmapped mine waste. These samples consisted primarily of chat and were considered part of the TZ. To ensure spatial accuracy of each sample, the real-time position of the sampling team was displayed on a laptop computer or Garman GPS device displaying digitized chat pile/base boundaries via GPS (Garmin, Olathe, KS) interfaced with GIS software. An initial surface reading was taken with a portable X-Ray Fluorescence analyzer (XRF) at digitized boundary and recorded. Samples for lab analysis were collected in bags. To estimate field contamination, XRF readings were taken at 50 foot intervals along each transect beginning 50 feet from chat pile/base boundary and continued until two consecutive XRF readings were at or below background concentrations listed for the State of Missouri (Table 2). Missouri background concentrations were the highest for all three metals and were used for comparison to sampled concentrations to ensure consistency throughout the TSMD. An attempt was made to sample in four opposing directions (i.e. north, south, east, west, or northeast, southwest, northwest, southeast) for a total of four sampling transects per pile/base.

However, if it was not possible to sample in all four directions a minimum of two transect directions was acceptable. Landowner permission was acquired for all sampled properties. Some transects were prematurely truncated when the sampling team encountered a property boundary where permission had not been acquired or other if another obvious chat pile/base was intersected before reaching background metal concentration. Results of XRF analysis and location maps of transects are presented in Appendices A&B.

At each sampling location all plant material and any organic detritus was removed from the surface, and a soil sample was taken at a depth of no greater than 6 inches using a shovel or trowel. A description of the sample (i.e. sandy, clay, etc.) was made on a sample sheet and sample was placed in a 1L zip lock bag and homogenized. Approximately 10% of samples were split for quality assurance and confirmatory laboratory analysis.

2.2.2 Sample Analysis

Samples were placed in 1L jars and homogenized with a stainless steel spoon. The sample was then dried at 100C to consistent moisture content determined by weight comparison before and after drying. Samples were then analyzed using EPA Method 6200 (EPA 1998). A 2007 Thermo Niton XL3t 600 XRF Analyzer (Thermo Scientific, Billerica, MA) was used for sample analysis. Samples were homogenized after drying and prior to analysis using hand manipulation. Each sample was analyzed for 90 seconds by placing sample bag directly on a Shielded Portable Test Stand (Thermo Niton, Billerica, MA). This device allows for hands-free sample analysis. The XRF analyzer is attached to the stand and operated via laptop computer. An arithmetic mean was calculated from three readings of each sample, with the sample re-homogenized between readings.

2.3 Quality Control

2.3.1 Instrument Calibration

All calibration checks were performed as required by EPA Method 6200 (EPA 2008). These calibration checks ensure adequate stability and consistency of all analyses. The calibration check samples were analyzed daily; prior to analysis, during analysis, and upon completion of analysis. Results of these analyses were required to be within ±20% difference (%D) of the listed value. Results that were not within the required range were reanalyzed (EPA 2008).

2.3.2 Laboratory Confirmatory Samples

EPA Method 6200 requires a minimum confirmatory sample rate of 5%. These samples are submitted for lab analysis by an appropriate method for comparison to XRF results. Nineteen confirmatory samples (11.8% of sample data set) were sent to the Trace Element Research Laboratory (TERL) (Texas Tech University Lubbock, TX) for Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) analysis (Appendix A). These samples consisted of splits from field samples that represented metal concentrations from low, mid, and high ranges of concentrations observed from XRF analysis, as well as, samples containing metals at concentrations near EPA action levels. Sample metal content, total organic carbon and grain size were measured using TERL Method Codes 016, 012, and 011 respectively (TERL 2011). Sample digestion was conducted using TERL Method Code 002 (TERL 2011).

Data quality was determined by comparing results obtained from XRF analysis to those obtained from ICP-MS analysis. Compared metals concentrations that varied by less than 30% were considered acceptable. Nineteen comparisons were made for both Pb and Zn resulting in a total of 38 individual comparisons of metal concentrations obtained from the two analysis methods. Seven samples had Pb concentration comparisons and 7 samples had Zn concentrations comparisons varied by greater than 30%. Overall, 14 of 38 samples analyzed by ICP-MS were not within 30% of XRF analysis results. Due to the relatively high detection limit for Cd in the XRF, only 12 of 19 samples submitted to the TERL had Cd XRF readings.

The results of confirmatory analysis by ICP-MS and XRF methods were compared by least squares linear regression analysis using SYSTAT 12 (Systat Software Inc., Chicago, IL). Variance testing was conducted on the confirmatory dataset and results indicated that all data required a LOG transformation to equalize variances. Regression results indicated that confirmatory samples and XRF samples were highly correlated for Pb (R^2=0.93) and Zn (R^2=0.91). Initial regression analysis of Zn indicated a statistical outlier (OK25N3) and reduced correlation (R^2=0.85). Removal of this sample did not violate the 5% confirmatory sample requirement; therefore, the sample was removed and this improved the correlation coefficient. Statistical analysis was not performed on Cd due to insufficient data. XRF detection limits for Cd were too high to provide enough data points for a reliable analysis to be performed.

2.4 Data Analysis

Sampling data initially consisted of Cd, Pb, and Zn concentration from 240 samples taken throughout the TSMD. Field confirmatory samples served as markers to determine the end of sampling transects and were removed from further analysis along with any samples collected outside of the established sampling plan procedures. This data subset (n=165) was used for comparison of sample metals concentrations to MO background metals concentrations and EPA Action Levels. EPA Action Levels (Cd=10ppm, Pb=400ppm, Zn=1,100ppm) were used for comparisons to field data that will allow for the most conservative estimate of TZ width.

Samples that consisted of large amounts of chat were a very small portion (17.5%) (n=29) of the total dataset. Sampling efforts were to begin at the digitized chat pile boundaries. However, large amounts of chat occurred further out than this boundary likely due to anthropogenic and erosional processes and error from the digitization of chat pile/base boundaries. The greatest distance where a sample (n=1) was taken that consisted primarily of chat was taken at 450 feet and the greatest number of samples that were primarily chat were taken at 50 feet (n=12).

3.0 Results and Discussion

3.1 Transect Data

Samples were taken along 45 TZ transects throughout the TSMD. Per the sampling plan, transects were to be discontinued upon detection of two consecutive surface metal concentrations below background. However, nine transects were discontinued due to encountering property boundaries, impenetrable vegetation, large streams, or adjacent chat piles/bases or associated TZs. The longest transect was 600feet (OK25N). This transect was discontinued upon reaching the property boundary for which the sampling team was granted access.

Figure 3 illustrates the number of transects from which samples were taken that had sufficient metal content to exceed background concentrations and EPA Action Levels by distance. All transects contained samples that exceeded both of these criteria. The number of samples exceeding background metal concentrations and EPA Action Levels decreased with increasing distance from chat pile boundary as sample metal concentrations decreased to background levels. However, samples exceeded background and EPA Action Levels at distances along most transects.

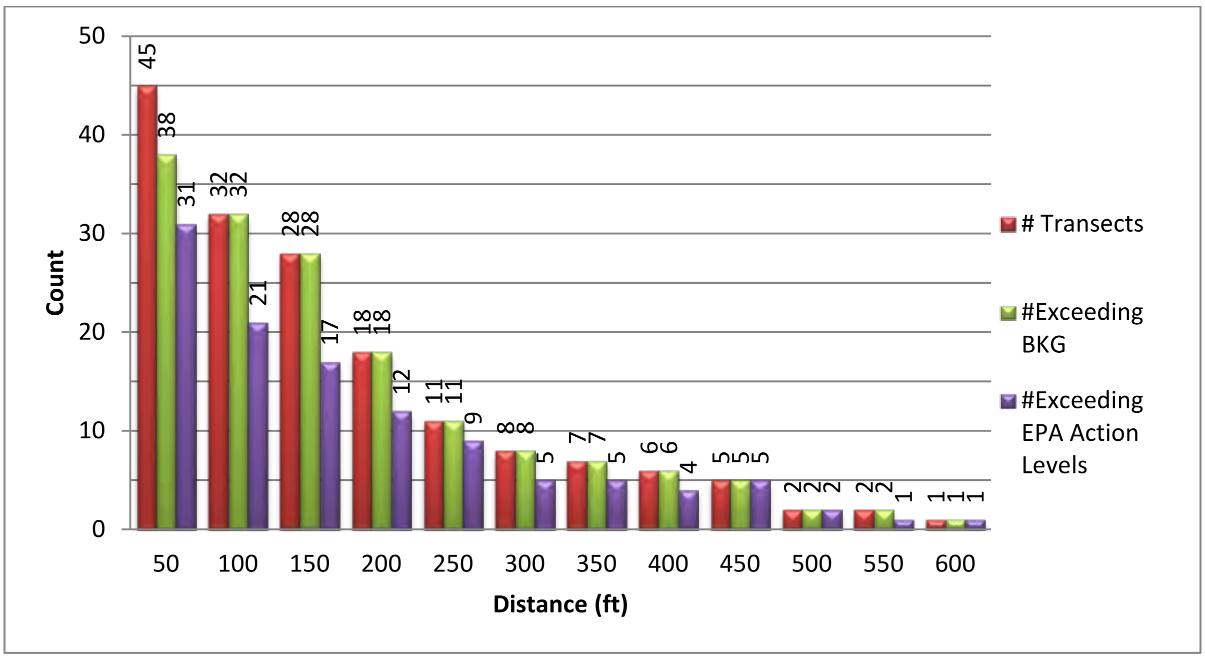

Figure 3. Transects Containing Samples Exceeding Comparison Criteria by Distance.

At 50 feet, 31 of 45 transects contained samples that exceeded EPA Action Levels. Thirteen transects did not continue past 50 feet. However, most transects in this study were 100 feet or more and more than half exceeded EPA Action Levels at this distance (Figure 3). Data collected for this study indicate that TZs can be as wide as 600 feet and generally reach background metals levels at distances much greater than 50 feet.

Mean TZ widths were calculated for the entire TSMD and for each land use category.
In order to calculate a mean TZ width, metals concentrations from samples in each transect were compared to MO background values and EPA Action Levels. The furthest distance sampled

which exceeded either background values or EPA Action Level was used as the TZ width for each transect. Therefore, each of the 45 transects had an observed distance for exceedance of background values and for exceedance of EPA Action Levels. Each distance was weighted in the average distance calculation according to the number of instances in which the corresponding sample exceeded the applicable comparison criteria. In instances where samples taken at 50 feet did not contain metals concentrations above background or EPA Action Levels, a distance of 25 feet was assigned to the sample.

Because no sampling occurred closer than 50 feet, it was assumed that sample metals concentrations would likely exceed comparison criteria somewhere between the chat pile boundary and 50 feet resulting in the 25 feet assignment. In instances where a sample contained metals exceeding comparison criteria and the following sample did not, it was assumed that metals concentrations decreased to concentration below comparison criteria at some distance in between. To account for this, and addition of 25 feet was added to the first sample. For example, if a sample exceeded comparison criteria at 100 feet but not 150 feet the resulting TZ width was assigned 125 feet. These distances were used to produce a weighted mean of TZ width.

3.2 Average Transition Zone Width

Figure 4 illustrates the mean TZ widths for the entire TSMD and by land use. Land use was grouped into three general categories: Wooded; pasture; and tilled. Wooded areas were subject to little or no agricultural activity. In addition, wooded areas where covered by large amounts of chat that had migrated outward via anthropogenic and erosional processes. Pasture sites included areas of native plant assemblages and areas of converted to cool season grasses. Pasture sites were generally subjected to a moderate level of cattle grazing and/or haying operations. Tilled sites consisted of high levels of agricultural disturbance. These sites were mechanically tilled on a regular basis for row crop production

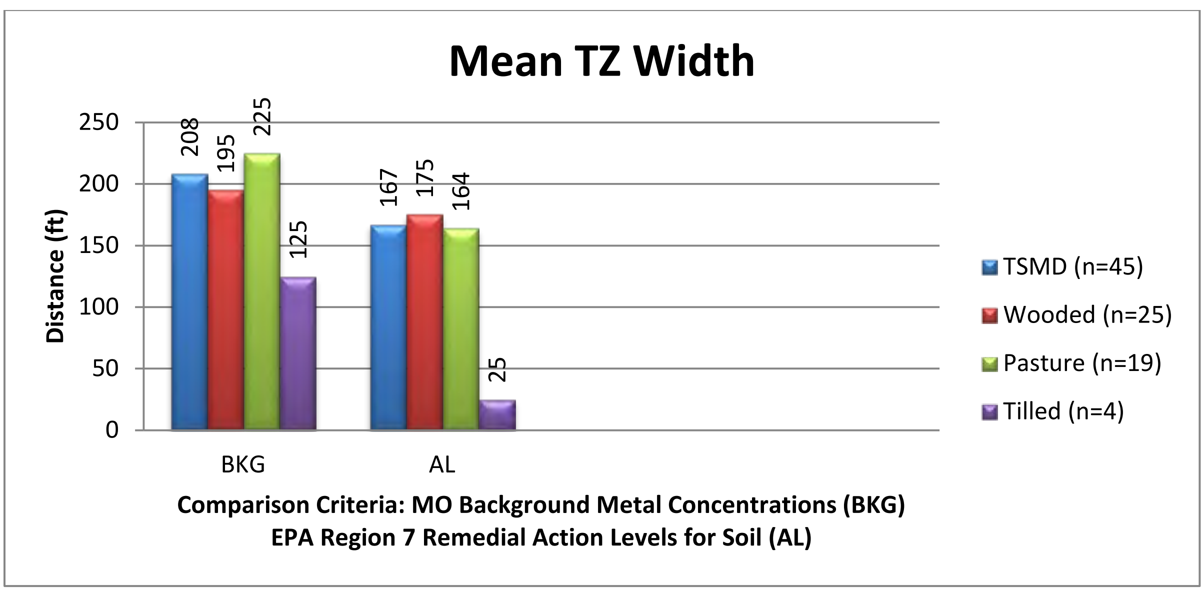

Figure 4. Mean TZ Width Throughout TSMD and by Land Use.

Over the entire TSMD, mean TZ width was 208 feet when compared to background metals values. When compared to EPA Action Levels, the mean TZ width observed throughout the TSMD was167 feet. However, twelve transects contained samples that exceeded EPA Action Levels at distances of 200 feet and greater with one transect (OK25N) exceeding this criteria at 600 feet.

The mean TZ width for wooded areas was 195 feet in comparison to background values and the mean TZ width with respect to EPA Action Levels was 175 feet. Samples taken in wooded areas tended to exceed both background metals concentrations and EPA Action Levels. These areas also tended to be subject to fewer disturbances than observed with other land uses. This likely explains the relatively minor difference in mean TZ width among comparison criteria.

In areas designated as a pasture land use, comparisons to background concentrations resulted in a mean TZ width of 225 feet and comparison to EPA Action Levels resulted in a mean TZ width of 164 feet. It was hypothesized that the agricultural practices associated with the pasture land use (haying and grazing) would somewhat reduce metal concentrations through the removal of vegetation and result in a reduced mean TZ width for this land use when compared to the mean TZ widths of wooded areas. This relationship was observed when comparing the average distance required for sample metals to fall below EPA Action Levels for areas of wooded and pasture land use. However, the difference was only eleven feet. The average distance for sample metals concentrations to fall below background levels were greater for transects sampled in pasture areas than those in wooded areas. It was expected that agricultural practices applied in pasture areas would result in a larger reduction in metals concentration; thereby, significantly reducing TZ widths when comparing to wooded areas. This result was likely due to a large proportion of the dataset designated as a pasture land use and contained samples that were gathered in the Picher, Oklahoma area which contained a large number of chat piles and bases in close proximity to one another. During sampling, transects in this area often continued for long distances and sometimes ran into the TZs of other chat piles/bases or sampling was terminated without reaching background because a property line or impenetrable barrier was reached. All transects in the Picher area were designated as a pasture land use and consisted of four of the longest transects observed in the study. Chat piles OK21 and OK5 contained one transect each that exceeded background values and EPA Action Levels to 450 feet. Chat pile OK25 contained two transects that exceeded background values and EPA Action Levels to 550 feet and 600 feet.

Mean TZ width calculated from comparison to background values for tilled areas was 125 feet. When compared to EPA Action Levels, mean TZ width for tilled areas was reduced to 25 feet. However, mean TZ widths were calculated from relatively few samples (n=4). In addition, no sample taken at 50 feet in this land use contained metals that exceeded EPA Action Levels. Therefore, they were assigned a sample distance of 25 feet to account for higher metal concentrations that likely exist closer to the associated chat pile. Despite the small sample size, it is likely that that tilling dilutes the upper layers of mine wastes material with cleaner soil below, thereby reducing measured metals concentrations overall.

3.3 Sample Metal Concentrations

3.3.1 Mean Sample Metals Concentrations in the TSMD.

It was determined that calculation of mean sample metal concentrations for each distance sampled in the TSMD may allow for an identification of a particular distance, or range of distances beyond which, metals concentrations are generally below EPA Action Levels. Figure 5 illustrates the number of samples used in mean calculations for these distances. All transects were at least 50 feet and had the dataset contained the largest number of samples at this distance. As distance increased, the number of transects decreased resulting smaller samples sizes for the greater distances. Sample sizes at distances of 500 and 550 feet were extremely small with the value reported as a mean at 600 feet resulting from a single observance. This is noted on Figures 6-8 as a double asterisk on the 600 feet label to remind the reader of this fact. Small sample sizes and a study design that targeted areas of potentially higher metals contamination resulted in mean metals concentrations that were very high at greater distances. However, all transects that reached distances of 500 feet and greater occurred in the Picher, OK area where chat piles are in close proximity of one another and very high metals concentrations far from chat pile boundaries can often occur.

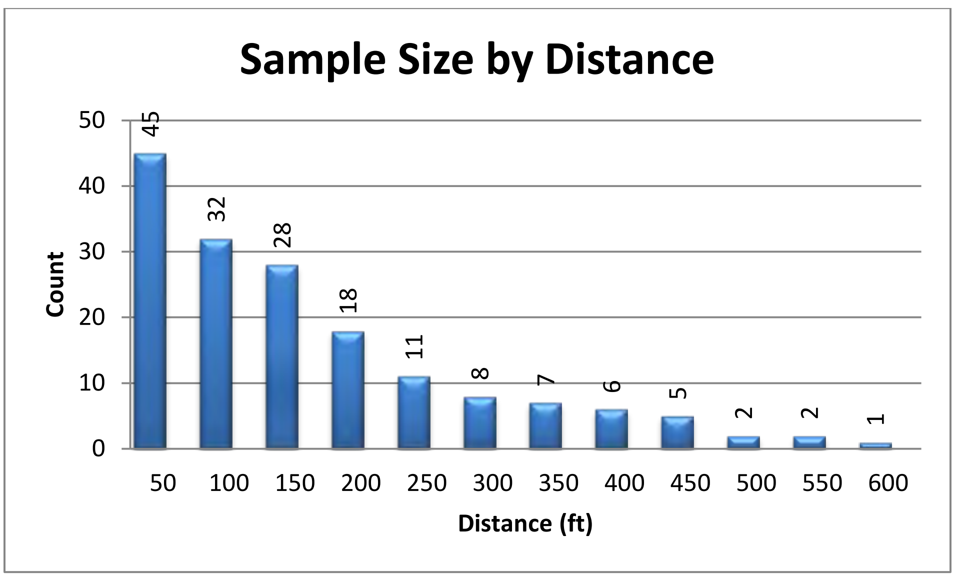

Figure 5. Number of Samples Used in Average Metals Concentrations Calculations for TSMD.

Mean Cd concentrations were greater (2x on average) than EPA Action Levels at all distances where results for Cd were obtained from field samples. The XRF detection limit for Cd was greater than background concentrations (Table 1) and approximately matched the EPA Action Level. This resulted in a lack of Cd detection in the majority of samples. However, for those samples, background values for each state were substituted for the non-detect values of zero and used to calculate mean concentrations. Despite the additions, the high mean Cd concentrations were driven by a small number of samples that contained very high Cd concentrations.

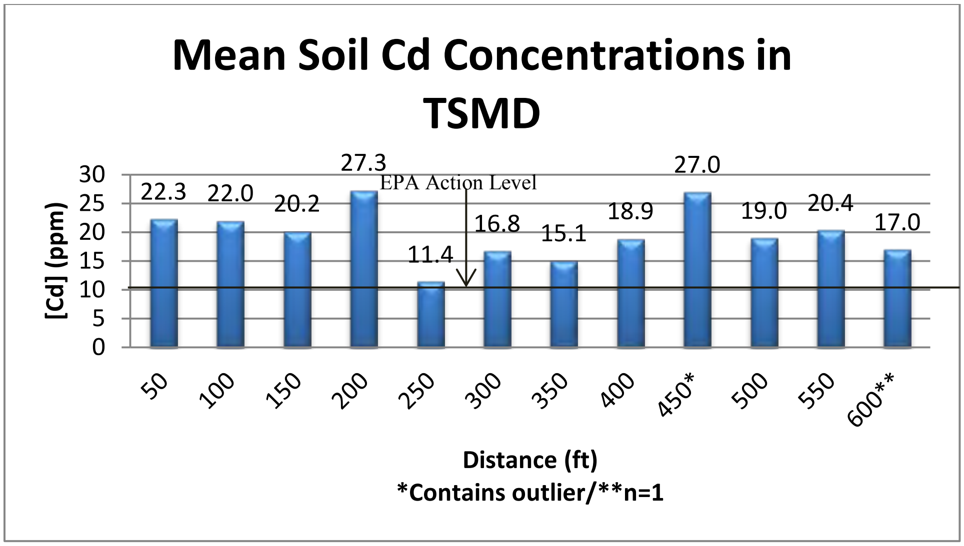

Figure 6. Mean Cd Concentration by Distance. (Refer to Figure 5 for n at each distance.)

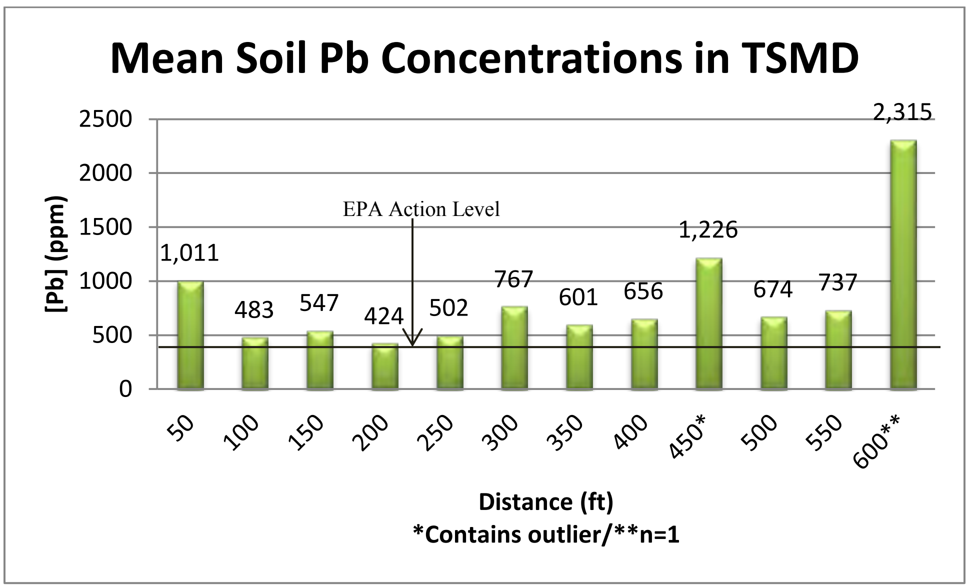

Figure 7. Mean Soil Pb Concentration by Distance. (Refer to Figure 5 for n at each distance.)

Mean Pb and Zn concentrations (Figures 7&8) were greater than EPA Action Levels at all distances. On average, Pb and Zn concentration exceeded these levels by 2.7x and 5x respectively. One sample (MOBCNE9) was taken at 450feet from the chat pile boundary and contained high metal content (Cd=123mg/kg; Pb=31,889mg/kg; Zn=41,250mg/kg) and can be considered an outlier. The mean metals concentration at 600 feet is reported as a mean value; however, this was calculated with only one observation.

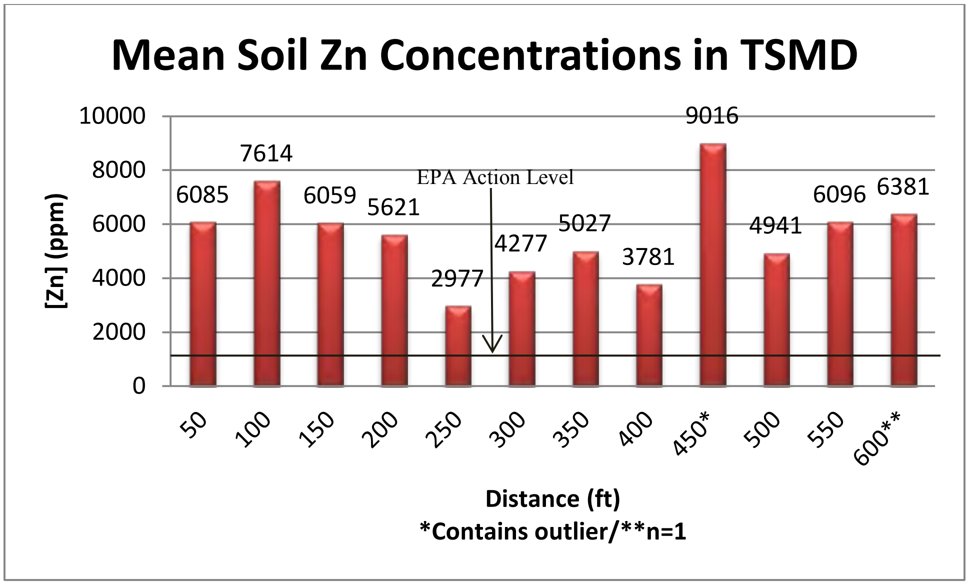

Figure 8. Mean Zn Concentration by Distance. (Refer to Figure 5 for n at each distance.)

Overall, the greatest mean Cd and Zn concentration was observed at 450 feet (Cd=27ppm; Zn=9,016ppm) and the greatest mean concentration of Pb was observed at 600 feet (Pb=2,315). At 50 feet, mean Cd, Pb, and Zn were 22.3 ppm, 2,011 ppm, and 6,085 ppm respectively. At 200 feet, Cd, Pb, and Zn mean concentrations were 27.3 ppm, 424 ppm, and 5,621 ppm respectively. All of which exceed EPA Action Levels.

Average metals concentrations by distance were calculated and reported for use as a general estimation of metals concentrations in the absence of site-specific data. Analyzing the entire TSMD dataset revealed that mean metal concentration for Cd, Pb, and Zn were above EPA Action Levels at all distances analyzed. However, the sampling teams encountered unmapped mine waste that occurred throughout the TZ. Analysis of samples that contained unmapped mine waste resulted in metals concentrations that were higher than those that consisted primarily of soil; thus, introducing increased variation in sampling data. However, due to erosional and anthropogenic processes that have occurred since the mine waste was mapped, the likelihood of encountering mine waste throughout the TZ is high in the TSMD.

3.4.3 Average Metal Concentrations by State.

The dataset was divided into three subsets corresponding to each state of the TSMD in order to calculate more specific mean metal concentrations. Despite the state by state evaluation, care should be given to the data interpretation, since the data set is more robust when interpreted across the entire district. The study design was not intended to provide definitive state by state distances and concentrations. Mean metal concentrations were reported by distance for each state and the sample sizes for each state and distance are reported in Figure 9.

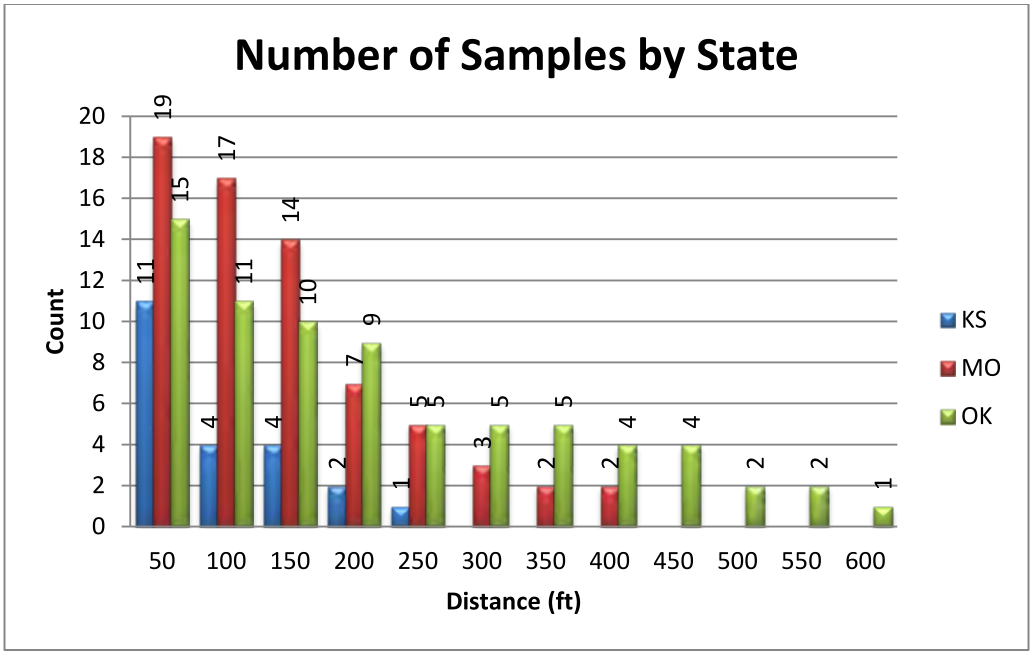

Figure 9. Number of Samples Used for Average Metal Concentrations Calculations.

The longest transect in KS extended to 250 feet. A larger portion of transects sampled in KS were selected to represent agricultural tilling in TZs. The longest transect sampled in MO reached 400 feet and in OK the longest transect sampled was 600 feet. All transects in OK that reached distances greater than 400 feet, with the exception of transect OK5S, were in the Picher, OK area where chat piles/bases were in close proximity and transects possibly included TZs of other chat piles. Without these factors, transect distances in MO and OK may have been similar. Also, for the same reasons described above in the mean metal analysis for the entire TSMD, as distance increased the sample size decreased. This resulted in smaller sample sizes at greater distances.

The greatest distance where mean metal concentrations were above EPA Action Levels in KS were 150 feet for Cd and 150 feet for Zn (Figures 10-12). Mean Pb concentrations were not observed at concentrations above EPA Action Levels at any distance. The greatest distance mean metal concentrations were above EPA Action Levels in MO was 400 feet for all metals analyzed. It should be noted that each transect in MO that went out to 400 feet had at least one instance where mean metal concentrations for Cd, Pb, and Zn were below EPA Action Levels but then increased above action levels at 400 feet. In contrast, sample MOCCE8 (Cd=25ppm; Pb=749ppm; Zn=6377ppm) was included in the mean metals concentration calculation at 400 feet. The relatively high metals concentrations were likely due to the inclusion of unmapped mine waste in the sample. Sample MOBCNE9 at 450 feet contained extremely high metal concentrations (Cd=123ppm; Pb=31,889ppm; Zn=41,250ppm) and did not display well graphically and was excluded from graph.

OK had greater mean metal concentrations for all metals analyzed than KS or MO at all distances sampled. Also, these mean concentrations were observed to be well above EPA Action Levels at all distances for all metals. Each transect in OK contained at least one sample that contained extremely high metal concentrations. Seven of 15 transects in OK were located in areas with chat piles/bases in close proximity to one another. Some of the TZs sampled in these areas overlapped and transects potentially continued into the TZ of another chat pile/base resulting in very high metal concentrations at great distances. These high metal concentrations are reflected in the mean concentrations reported in Figures 10-12.

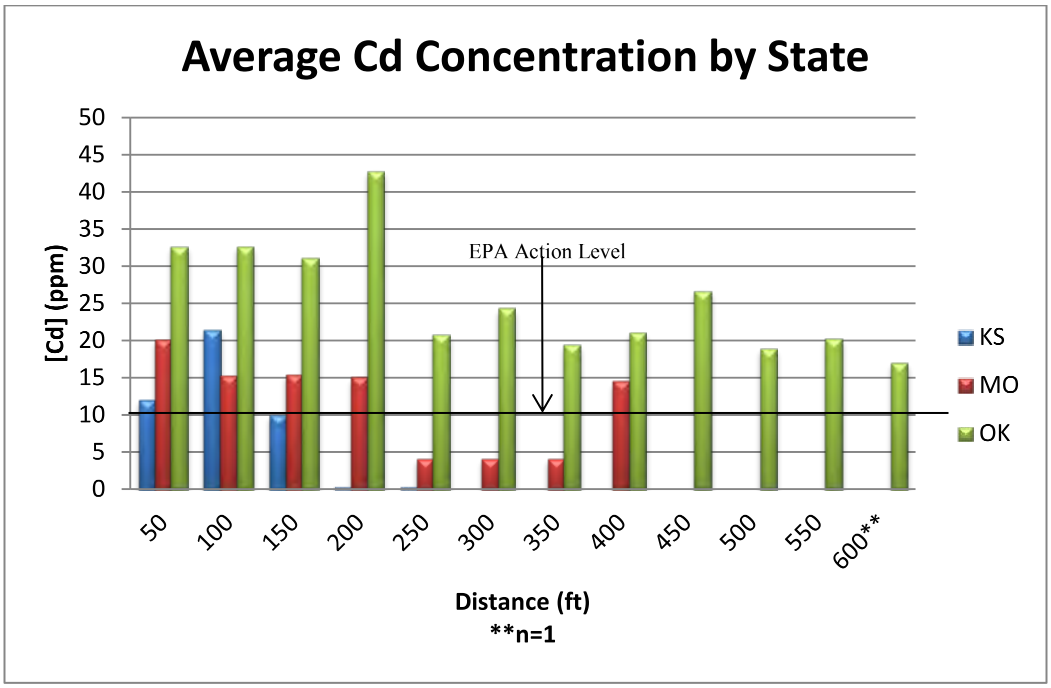

Figure 10. Mean Cd Concentrations by Distance.

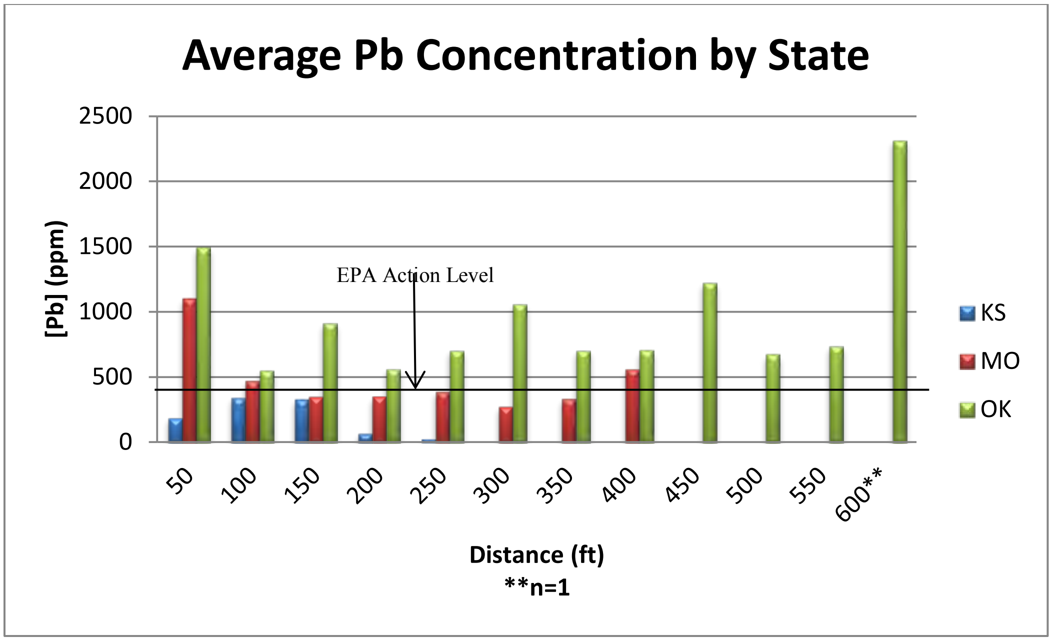

Figure 11. Mean Pb Concentration by Distance.

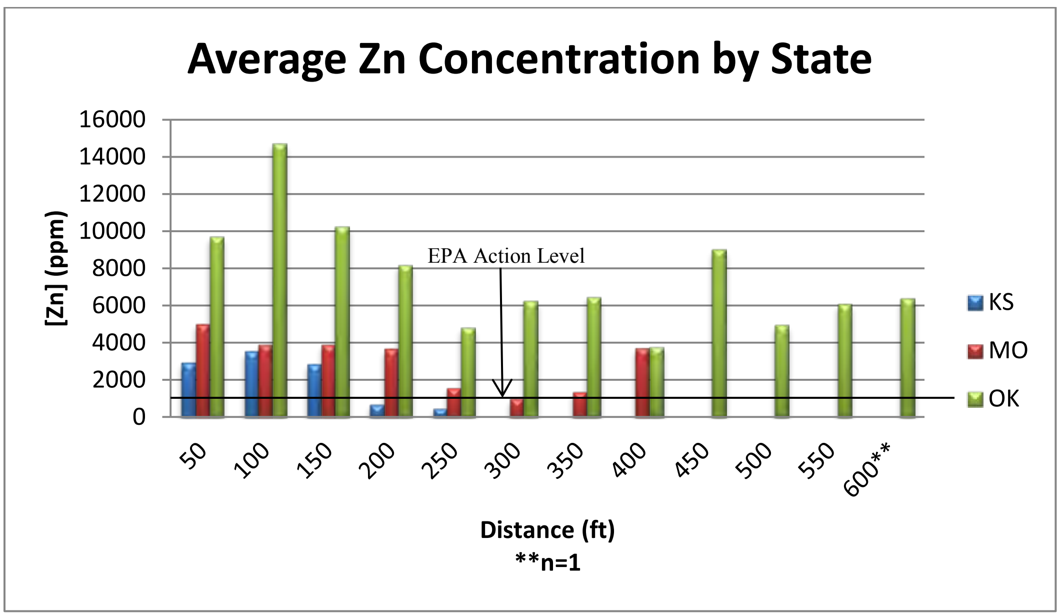

Figure 12. Mean Soil Zn Concentration by Distance.

4.0 Conclusions

Analysis of mean TZ width indicates that mining waste contamination extends further than 50 feet from chat pile boundaries unless the chat base/pile is surrounded by tilled areas. Natural and anthropogenic processes have resulted in the migration of mining waste outside of digitized boundaries delineated in EPA mapping in MO and OK. It is likely that terrestrial injury from heavy metals commonly occurs throughout the TSMD at distances much greater than 50 feet from chat pile boundaries. Results of this study indicate that mean TZ width based on EPA action levels is 167 feet throughout the TSMD. This describes the distance from the delineated chat pile boundary required for metal concentrations to fall below EPA Action Levels. Data collected in this study indicate that various agricultural practices reduce levels of Cd, Pb, and Zn in TZs.

It was hypothesized that metals levels would be reduced due to increasingly intensive agricultural practices surrounding chat piles. Analysis indicated that the average TZ width for wooded areas was 175 feet. Pasture and tilled areas had average TZ widths of 164 feet and 25 feet respectively. These results suggest that average TZ widths are reduced in areas of increased agricultural disturbance with tilled areas having a smaller TZ that wooded or pasture areas. Mixing of heavily contaminated uppers layers with relatively clean deeper soil results in lower overall metal concentrations and indicates that tilling may be the only agricultural practice that significantly reduces TZ width. A greater difference in TZ width between wooded and pasture areas may be established with the selection of transects that do not change between differing land uses and ensuring more equal sample sizes to aid in statistical analysis.

Mean metal concentrations were calculated for all distances sampled throughout the TSMD and for each state. This was done to allow the estimation of metal levels throughout the TZ of an associated chat pile. In the TSMD, mean metal concentrations were above background at all distances sampled. This was expected due to the study design. However, mean metal concentrations were also above EPA Action Levels at all distances sampled. Data subsets that were designated by distance often contained highly variable metal concentrations with a portion of samples results well below comparison criteria along with those reporting extremely high metals results. This caused the reported mean metal concentration for the associated distance to be very high. Also, mean metal concentrations reported for each state were not uniformly high at all distances. This was likely due to sampling teams encountering unmapped mine waste throughout the TZ.

The EPA used varying TZ widths throughout the TSMD to estimate contaminated acres. This study was conducted to gather more site-specific data to more accurately describe TZ widths. Data have indicated that TZs frequently extend to distances of over 50feet in the TSMD and may continue out to 600 feet or greater. When analyzing data from the entire TSMD, mean concentrations for Cd, Pb, and Zn were above background levels and EPA Action Levels at all distances sampled. This indicates that trust resource exposure to heavy metals in the TZs occurs at greater distances that previously acknowledged.

When the dataset was segregated by state, this was not observed for the following reasons. Transects sampled in Oklahoma were longer than transects sampled in KS and MO with these states having several distances where mean metal concentrations were below EPA Action Levels (Figures 10-12). Tilled areas were only sampled in KS transects and samples from tilled areas had lower concentrations of all metals analyzed. However, samples from tilled areas in MO and OK would likely show similar metal concentrations. The majority of samples that exceeded EPA Action Levels did so for Zn (98.8% of dataset). Only two samples (OK25N5 and MOWWE1) contained metal concentrations that were greater than EPA Action Levels that did not include Zn. This indicates that remedial efforts that focus on removal of Zn contamination would reduce levels of Cd and Pb to concentrations below EPA Action Levels.

Natural and anthropogenic processes that have occurred since chat piles/bases were surveyed in the TSMD have resulted in unmapped mine waste and soil contamination that extends far away from chat piles/bases. Site specific data is the most accurate means of estimating metal concentrations throughout the TZ. However, in the absence of this data, the results of this study may be applied to estimate TZ widths or metals concentrations at specific distances away from chat pile boundary. Results of these data suggest that surrounding land use and proximity of other chat piles affects TZ width and should be considered when planning remedial actions to address TZ contamination. Also, average TZ widths and mean metal concentrations presented here demonstrate that heavy metal contamination and related injury to natural resources extends well beyond 50 feet from delineated chat pile boundaries. Concentrations of Cd, Pb, and Zn that exceed EPA Action Levels have been shown to occur at distances of 600 feet in this study and likely extend to greater distances in some cases.

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Appendix A: TSMD Transition Zone Study Sample XRF Analysis and Laboratory Confirmatory Sample Results

Units- Mg/kg Dry Weight

site	distance	land use	substrate	cd	pb	zn
KS125NW2	50.00	pasture	soil	0.00	72.00	582.00
KS125SE2	50.00	pasture	chat	70.00	1049.00	15796.00
KS125SE3	100.00	pasture	chat	67.00	1210.00	11039.00
KS125SE4	150.00	pasture	chat	39.00	981.00	8860.00
KS125SE5	200.00	pasture	soil	0.00	104.00	628.00
KS17N1	50.00	wooded	chat	25.00	387.00	6993.00
KS17N2	150.00	tilled	soil	0.00	216.00	869.00
KS17S2	50.00	pasture	soil	0.00	40.00	551.00
KS198S1	50.00	wooded	chat	34.00	126.00	4575.00
KS198S2	100.00	wooded	soil	18.00	41.00	2094.00
KS198S3	150.00	tilled	soil	0.00	31.00	1021.00
KS198S4	200.00	tilled	soil	0.00	29.00	738.00
KS198S5	250.00	tilled	soil	0.00	25.00	488.00
KS19E3	50.00	pasture	soil	0.00	177.00	2109.00
KS19E4	100.00	pasture	soil	0.00	71.00	530.00
KS19N2	50.00	pasture	soil	0.00	27.00	268.00
KS19N3	100.00	pasture	soil	0.00	55.00	518.00
KS19N4	150.00	pasture	soil	0.00	98.00	726.00
KS19S1	50.00	tilled	soil	0.00	42.00	339.00
KS3N3	50.00	tilled	soil	0.00	19.00	221.00
KS78E2	50.00	pasture	soil	0.00	83.00	788.00
KS78W2	50.00	pasture	soil	0.00	43.00	194.00
MO249E1	50.00	pasture	soil	17.00	208.00	2884.00
MO249E2	100.00	pasture	soil	0.00	86.00	642.00
MO249NW2	50.00	pasture	soil	0.00	63.00	422.00
MO249S2	50.00	pasture	soil	0.00	20.00	1114.00

MO249S3	100.00	pasture	soil	0.00	37.00	890.00
MO249S4	150.00	pasture	soil	0.00	55.00	471.00
MO249W2	50.00	pasture	soil	0.00	50.00	778.00
MO249W3	100.00	pasture	soil	0.00	40.00	972.00
MO249W4	150.00	pasture	soil	0.00	32.00	985.00
MO249W5	200.00	pasture	soil	0.00	50.00	802.00
MO249W6	250.00	pasture	soil	0.00	33.00	543.00
MOBCN1	50.00	wooded	chat	13.00	1029.00	4166.00
MOBCN2	100.00	wooded	chat	13.00	1250.00	3344.00
MOBCN3	150.00	wooded	soil	0.00	623.00	1973.00
MOBCN4	200.00	wooded	soil	0.00	309.00	672.00
MOBCNE1	50.00	wooded	soil	52.00	1189.00	12127.00
MOBCNE2	100.00	wooded	soil	53.00	1689.00	14763.00
MOBCNE3	150.00	wooded	chat	29.00	1474.00	9642.00
MOBCNE4	200.00	wooded	chat	24.00	1435.00	4504.00
MOBCNE5	250.00	wooded	soil	0.00	801.00	2461.00
MOBCNE6	300.00	wooded	soil	0.00	468.00	1603.00
MOBCNE7	350.00	wooded	soil	0.00	436.00	1837.00
MOBCNE8	400.00	wooded	soil	0.00	372.00	1101.00
MOBCNE9	450.00	wooded	chat	123.00	31889.00	41250.00
MOBCS1	50.00	wooded	chat	22.00	665.00	4266.00
MOBCS2	100.00	pasture	soil	0.00	142.00	722.00
MOBCS3	150.00	pasture	soil	0.00	117.00	465.00
MOBCW1	50.00	wooded	chat	73.00	2908.00	15652.00
MOBCW2	100.00	wooded	soil	27.00	566.00	4196.00
MOBCW3	150.00	wooded	soil	0.00	181.00	741.00
MOBCW4	200.00	wooded	soil	0.00	153.00	484.00
MOCCE1	50.00	wooded	chat	94.00	2965.00	18832.00
MOCCE2	100.00	wooded	soil	35.00	1586.00	7335.00
MOCCE3	150.00	wooded	soil	12.00	922.00	3577.00
MOCCE4	250.00	wooded	soil	0.00	380.00	1314.00
MOCCE5	300.00	wooded	soil	0.00	178.00	761.00
MOCCE6	300.00	wooded	soil	0.00	172.00	636.00
MOCCE7	350.00	wooded	soil	0.00	233.00	898.00
MOCCE8	400.00	wooded	chat	25.00	749.00	6377.00
MOCCN1	50.00	wooded	soil	0.00	339.00	1726.00

MOCCN2	100.00	wooded	soil	0.00	534.00	2438.00
MOCCN3	150.00	wooded	soil	0.00	441.00	2001.00
MOCCN4	200.00	wooded	soil	0.00	265.00	1105.00
MOCCSE1	50.00	wooded	soil	0.00	485.00	1632.00
MOCCSE2	100.00	wooded	soil	0.00	423.00	1608.00
MOCCSE3	250.00	wooded	soil	0.00	670.00	2238.00
MODWE2	50.00	pasture	soil	0.00	163.00	1021.00
MODWE4	150.00	pasture	soil	0.00	102.00	277.00
MODWN2	50.00	wooded	chat	22.00	270.00	6027.00
MODWN3	100.00	wooded	chat	35.00	180.00	9655.00
MODWN4	150.00	wooded	soil	49.00	202.00	13315.00
MODWS2	50.00	wooded	chat	0.00	360.00	5052.00
MODWS3	100.00	wooded	chat	52.00	86.00	13058.00
MODWS4	150.00	wooded	chat	85.00	200.00	20183.00
MODWS5	200.00	wooded	chat	61.00	112.00	17736.00
MODWS6	250.00	wooded	soil	0.00	79.00	1496.00
MOWWE1	50.00	wooded	soil	0.00	1591.00	767.00
MOWWE2	100.00	wooded	soil	0.00	561.00	2537.00
MOWWE3	150.00	wooded	soil	0.00	257.00	874.00
MOWWE4	200.00	wooded	soil	0.00	130.00	533.00
MOWWN2	50.00	wooded	soil	0.00	585.00	2196.00
MOWWN3	100.00	wooded	soil	0.00	302.00	1130.00
MOWWN4	150.00	wooded	soil	0.00	112.00	305.00
MOWWSE1	50.00	wooded	soil	44.00	7234.00	11715.00
MOWWSE2	100.00	wooded	soil	0.00	115.00	229.00
MOWWSE3	150.00	wooded	soil	0.00	139.00	430.00
MOWWSW1	50.00	wooded	soil	0.00	470.00	4696.00
MOWWSW2	100.00	wooded	soil	0.00	234.00	2862.00
MOWWW2	50.00	wooded	soil	0.00	398.00	329.00
MOWWW3	100.00	wooded	soil	0.00	217.00	583.00
OK104NE2	50.00	pasture	soil	0.00	67.00	236.00
OK104SW2	50.00	pasture	chat	74.00	7209.00	22560.00

OK104SW3	100.00	pasture	chat	188.00	295.00	43921.00
OK104SW4	150.00	pasture	soil	19.00	922.00	4636.00
OK104SW5	300.00	pasture	soil	16.00	551.00	2072.00
OK104SW6	350.00	pasture	soil	0.00	109.00	388.00
OK11SE1	50.00	wooded	chat	75.00	8375.00	20664.00
OK11SE2	100.00	wooded	chat	35.00	215.00	5819.00
OK11SE3	150.00	wooded	chat	30.00	159.00	7515.00
OK11SE4	200.00	wooded	chat	26.00	45.00	5014.00
OK11SW1	50.00	wooded	soil	19.00	473.00	4985.00
OK11SW2	100.00	wooded	soil	0.00	334.00	3531.00
OK11SW3	150.00	wooded	soil	18.00	344.00	3401.00
OK11SW4	200.00	wooded	soil	31.00	422.00	4687.00
OK11SW5	250.00	wooded	chat	29.00	301.00	6426.00
OK21SE1	50.00	pasture	soil	0.00	247.00	1282.00
OK21SE2	100.00	pasture	soil	0.00	690.00	2359.00
OK21SE3	150.00	pasture	soil	0.00	304.00	1229.00
OK21SE4	200.00	pasture	soil	0.00	513.00	2360.00
OK21SE5	250.00	pasture	soil	18.00	1574.00	4473.00
OK21SE6	300.00	pasture	soil	28.00	2196.00	5056.00
OK21SE7	350.00	pasture	soil	15.00	1708.00	2788.00
OK21SE8	400.00	pasture	soil	61.00	1880.00	7502.00
OK21SE9	450.00	pasture	soil	26.00	1118.00	9541.00
OK25N1	50.00	pasture	soil	41.00	325.00	10363.00
OK25N2	100.00	pasture	soil	37.00	3188.00	10142.00
OK25N3	150.00	pasture	soil	139.00	4977.00	40945.00
OK25N4	200.00	pasture	soil	0.00	339.00	1147.00
OK25N5	250.00	pasture	soil	0.00	460.00	983.00
OK25N6	300.00	pasture	chat	50.00	1734.00	12346.00
OK25N7	350.00	pasture	soil	19.00	651.00	5489.00
OK25N8	400.00	pasture	soil	0.00	288.00	808.00
OK25N9	450.00	pasture	soil	23.00	1304.00	12473.00
OK25N10	500.00	pasture	soil	12.00	815.00	5045.00
OK25N11	550.00	pasture	soil	0.00	281.00	860.00
OK25N12	600.00	pasture	soil	17.00	2315.00	6381.00
OK25NW1	50.00	pasture	soil	0.00	103.00	514.00
OK25NW2	100.00	pasture	soil	0.00	221.00	916.00
OK25NW3	150.00	pasture	soil	0.00	772.00	3254.00
OK25NW4	200.00	pasture	soil	248.00	1197.00	40212.00

OK25NW5	250.00	pasture	soil	56.00	862.00	10457.00
OK25NW6	300.00	pasture	soil	27.00	734.00	10847.00
OK25NW7	350.00	pasture	soil	62.00	679.00	17761.00
OK25NW8	400.00	pasture	soil	22.00	583.00	6185.00
OK25NW9	450.00	pasture	soil	26.00	970.00	8517.00
OK25NW10	500.00	pasture	soil	26.00	532.00	4837.00
OK25NW11	550.00	pasture	soil	40.00	1193.00	11332.00
OK54N1	50.00	wooded	soil	121.00	664.00	26217.00
OK54N2	100.00	wooded	soil	0.00	49.00	1356.00
OK54NW1	50.00	wooded	soil	63.00	822.00	21247.00
OK54NW2	100.00	wooded	soil	69.00	479.00	83048.00
OK54NW3	150.00	wooded	soil	0.00	247.00	5546.00
OK54NW4	200.00	wooded	soil	0.00	78.00	3029.00
OK54S1	50.00	wooded	soil	19.00	939.00	5839.00
OK54S2	100.00	wooded	soil	0.00	141.00	657.00
OK54S3	150.00	wooded	soil	0.00	133.00	2354.00
OK54S4	200.00	wooded	soil	39.00	1484.00	11015.00
OK54SW1	50.00	wooded	soil	34.00	380.00	7352.00
OK5E1	50.00	wooded	soil	0.00	62.00	277.00
OK5N1	50.00	pasture	chat	40.00	2626.00	17364.00
OK5N2	100.00	pasture	soil	26.00	349.00	10131.00
OK5N3	150.00	pasture	soil	0.00	628.00	4213.00
OK5N4	200.00	pasture	soil	0.00	511.00	1168.00
OK5N5	250.00	pasture	soil	0.00	334.00	1873.00
OK5N6	300.00	pasture	soil	0.00	102.00	893.00
OK5N7	350.00	pasture	soil	0.00	388.00	6027.00
OK5N8	400.00	pasture	soil	0.00	65.00	714.00
OK5N9	450.00	pasture	soil	32.00	1513.00	5534.00
OK5S1	50.00	wooded	soil	0.00	97.00	5621.00
OK5W1	50.00	wooded	soil	0.00	67.00	1486.00
OK5W2	100.00	wooded	soil	0.00	63.00	634.00
OK5W3	150.00	wooded	soil	101.00	658.00	29836.00
OK5W4	200.00	wooded	soil	39.00	463.00	5347.00

Laboratory Confirmatory Samples

Site	Cd		Pb		Zn	
	TERL	FWS	TERL	FWS	TERL	FWS
OK11SE4	66.5	26	24.6	45	11200	5014
OK5N5	9.04	< LOD	133	334	1620	1873
OK54N1	133	121	701	664	23700	26217
OK54NW2	115	69	665	479	72700	83048
OK104SW2	80.1	74	3450	7209	14400	22560
OK54NW4	5.81	< LOD	94.8	78	2640	3029
OK25N3	62.5	139	1980	4977	9090	40945
OK5W3	165	101	631	658	31100	29836
OK25NW5	78.4	56	804	862	8370	10457
MOWWW3	5.1	< LOD	171	217	631	583
MODWS4	82.7	85	98.4	200	15400	20183
MODWS2	66.4	< LOD	317	360	13100	5052
MOBCNE2	127	53	1980	1689	18000	14763
MOBCN3	8.45	< LOD	369	623	1330	1973
MOWWSW2	8.08	< LOD	167	234	1970	2862
KS198S3	8.88	< LOD	30.2	31	1400	1021
KS198S2	16.6	18	41.2	41	2550	2094
KS125SE3	85.1	67	1320	1210	12900	11039
KS125SE4	55.8	39	911	981	9470	8860

mg/kg dry weight

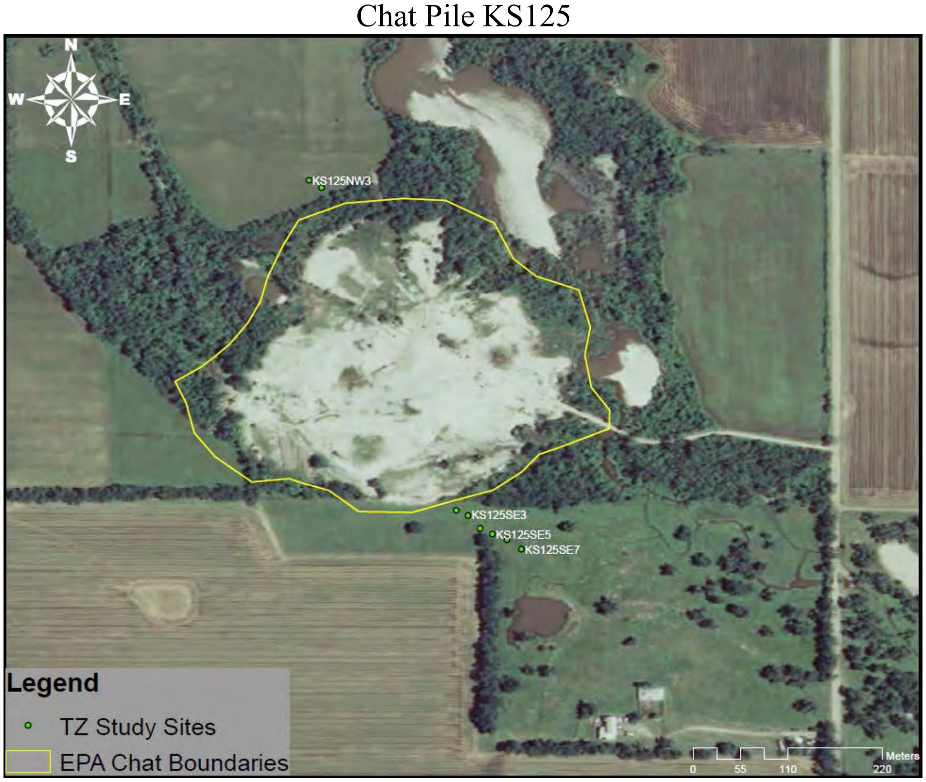
Appendix B: TSMD Transition Zone Study Sample Sites

Chat Pile KS0003

Chat Pile KS017 & 019

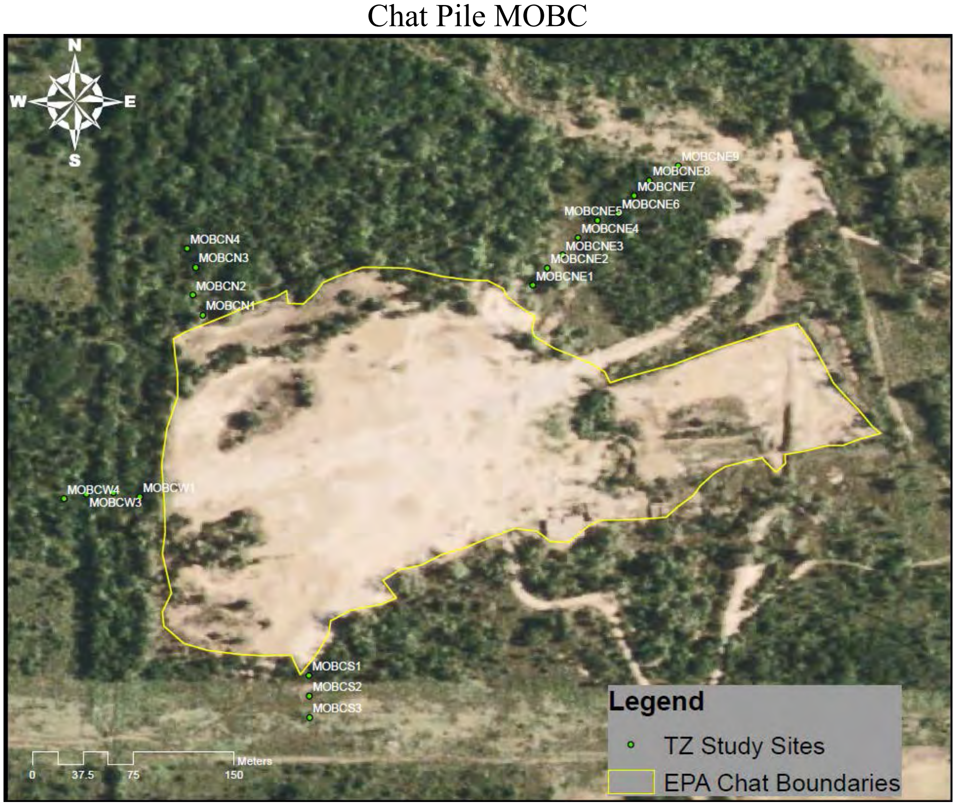
Chat Pile KS078

Chat Pile KS125



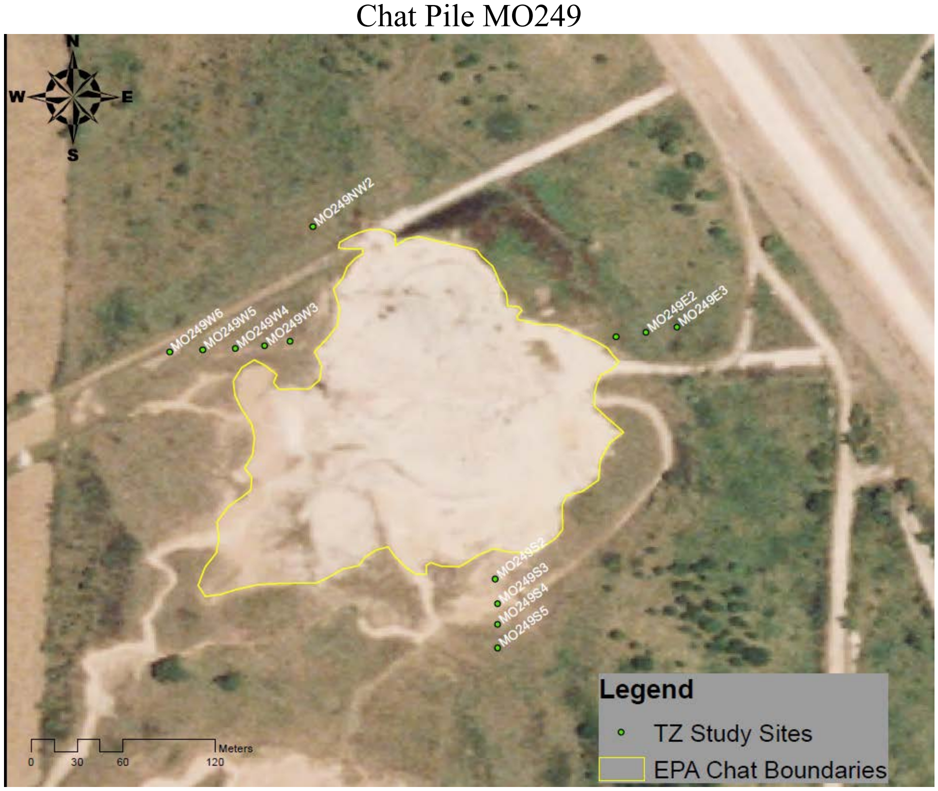
Chat Pile KS198

Chat Pile MOBC



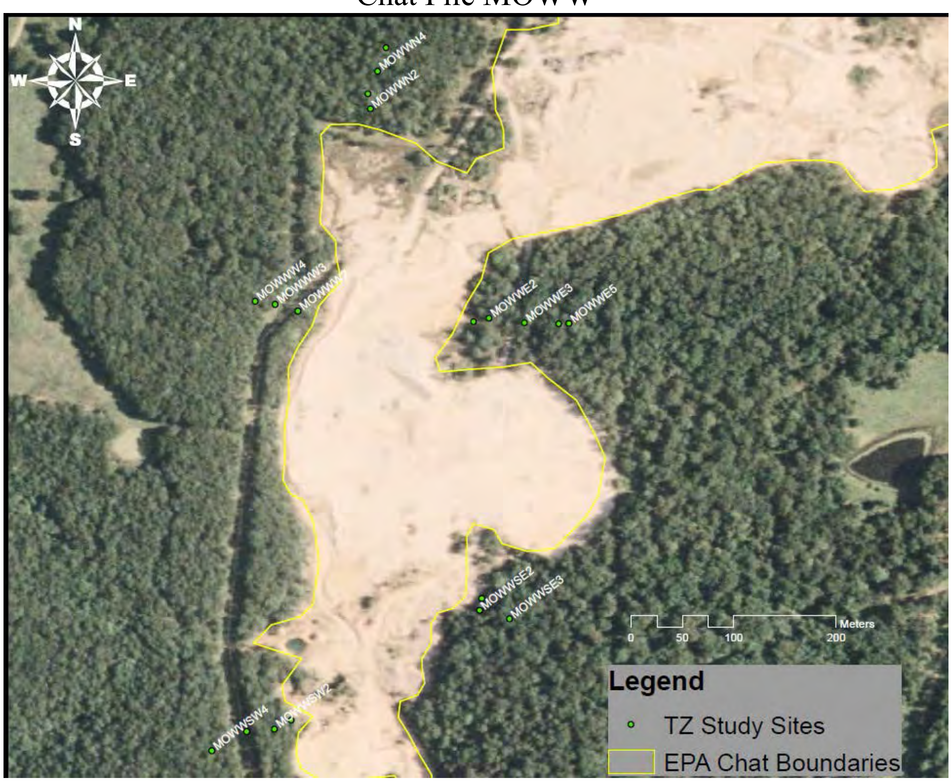
Chat Pile MOCC

Chat Pile MO249

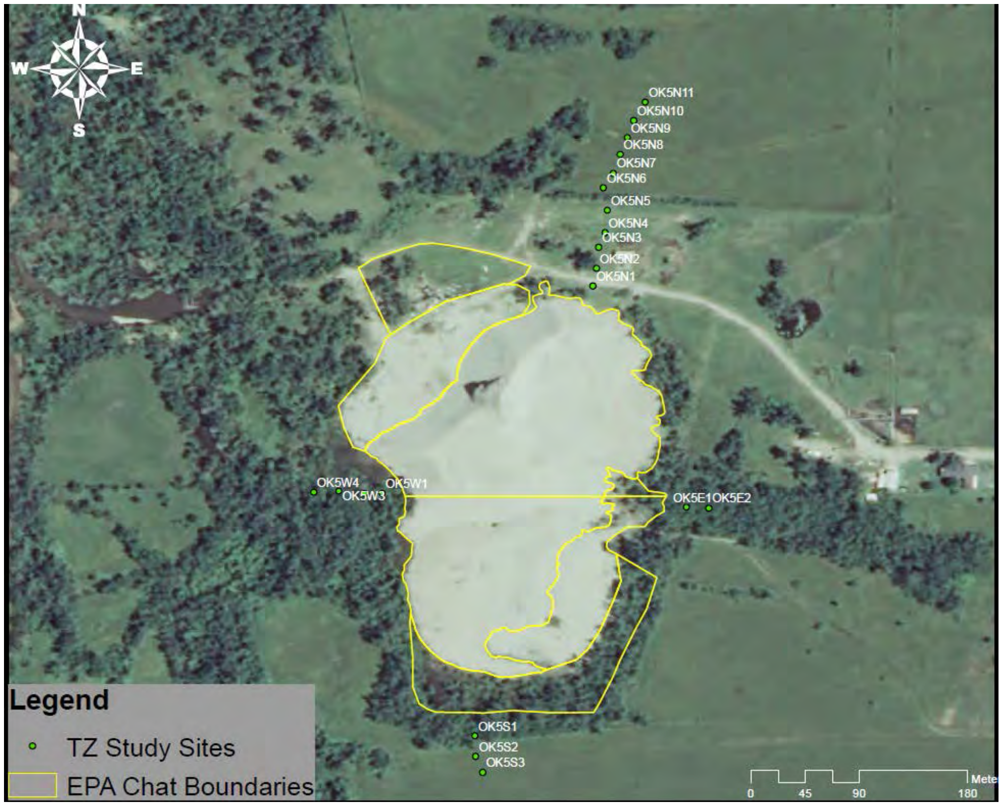


Chat Pile MODW

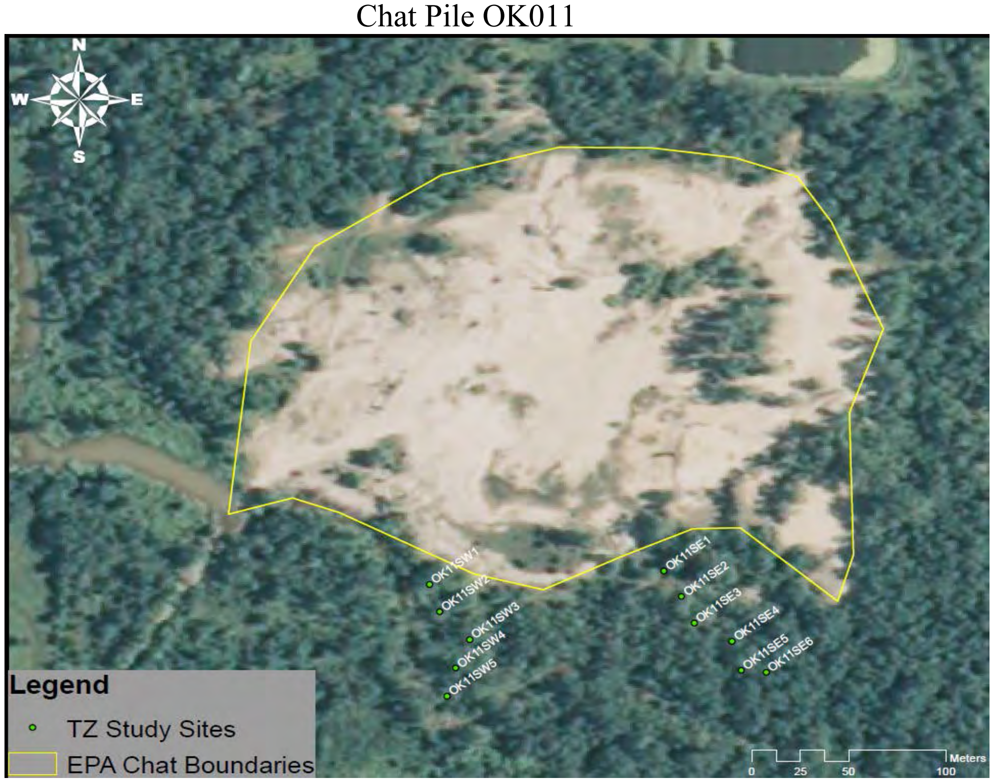
Chat Pile MOWW



Chat Pile OK005

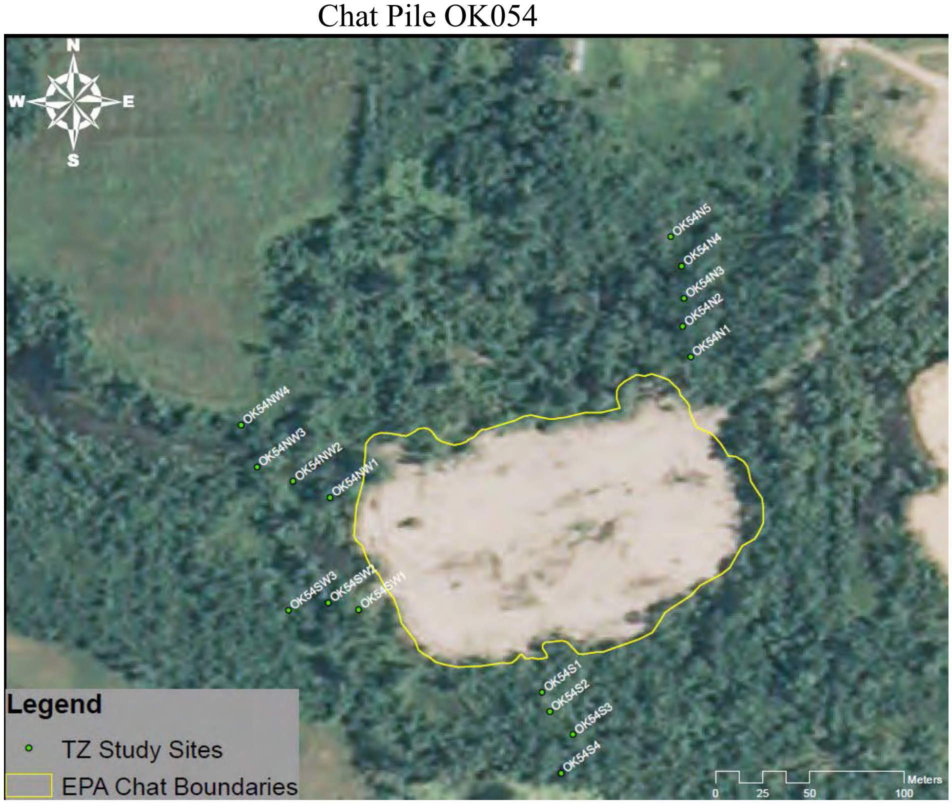


Chat Pile OK011



Chat Pile OK021 & OK025

Chat Pile OK054



Chat Pile OK104

Appendix C: Quality Control Data

Quality Assurance Data for XRF Analysis.

Reading No	Time	Duration	Units	SAMPLE	Pb	%D(Pb)	Zn	%D(Zn)	Cd	%D(Cd)
1	2/16/2010 10:33	56.09	cps							
2	2/16/2010 10:35	90	ppm	NCS DC7308	31.61	17.07407	22.46	-51.1739	12.39	1026.364
3	2/16/2010 10:37	90	ppm	NCS DC7308	30.11	11.51852	23.02	-49.9565	12.19	1008.182
4	2/16/2010 10:40	90	ppm	NISTM	1141.52	-1.76248	324.78	-7.20571	50.48	21.05516
5	2/16/2010 10:51	90	ppm	NIST h	5531.87	-0.00235	6995.8	0.630035	23.41	7.385321
6	2/16/2010 10:54	90	ppm	SI O2 BLANK	< LOD	0	< LOD	0	< LOD	0
7	2/16/2010 10:56	90	ppm	RCRA	440.65		70.6		461.03	
142	2/17/2010 9:00	58	cps							
143	2/17/2010 9:02	90	ppm	NCS 73308 low	29.56	9.481481	41.37	-10.0652	< LOD	0
144	2/17/2010 9:04	90	ppm	NIST M	1090.33	-6.16781	277.05	-20.8429	41.19	-1.22302
145	2/17/2010 9:06	90	ppm	NIST M	1116.13	-3.9475	308.31	-11.9114	47.66	14.29257
146	2/17/2010 9:12	90	ppm	NIST M	1099.91	-5.34337	319.54	-8.70286	47.69	14.36451
147	2/17/2010 9:14	90	ppm	NIST H	5265.55	-4.81652	7071.96	1.725547	32.06	47.06422
148	2/17/2010 9:16	90	ppm	si o2 blank	< LOD	0	< LOD	0	< LOD	
149	2/17/2010 9:19	90	ppm	RCRA	460.33		61.53		471.3	
337	2/17/2010 17:53	65.17	ppm	ncs 73308 lo	25.66	-4.96296	28.33	-38.413	< LOD	0
338	2/17/2010 17:55	66.85	ppm	ncs 73308 lo	19.33	-28.4074	40.19	-12.6304	< LOD	0
339	2/17/2010 17:55	38.85	ppm	ncs 73308 lo	29.07	7.666667	37.48	-18.5217	< LOD	0
340	2/17/2010 17:57	58.88	ppm	nist med	1121.83	-3.45697	281.1	-19.6857		-100
341	2/17/2010 17:58	45.85	ppm	nist med	1124.12	-3.2599	328.65	-6.1		-100
342	2/17/2010 18:00	60.88	ppm	nist hi	5270.37	-4.72939	7115.47	2.35141		-100
343	2/17/2010 18:01	55.43	ppm	sio2	< LOD	0	< LOD	0		
344	2/17/2010 18:03	90	ppm	rcra	535.57		80.31		473.78	
345	2/18/2010 9:02	57.84	cps							
346	2/18/2010 9:11	56.15	cps							
347	2/18/2010 9:21	90	ppm	NCS 73308 lo	29.69	9.962963	39.99	-13.0652	12.32	1020
348	2/18/2010 9:23	90	ppm	nist med	1114.63	-4.07659	333.89	-4.60286	44.96	7.817746
349	2/18/2010 9:26	58.82	ppm	nist hi	5509.13	-0.41341	7246.61	4.237773		-100
350	2/18/2010 9:29	90	ppm	sio2	< LOD	0	< LOD	0	< LOD	0
351	2/18/2010 9:31	90	ppm	RCRA	480.44		65.15		481.34	
537	2/19/2010 8:57	90	ppm	ncs 73308 lo	27.91	3.37037	30.6	-33.4783	< LOD	0
538	2/19/2010 8:59	43.07	ppm	nist med	1113.93	-4.13683	332.85	-4.9		-100
539	2/19/2010 9:00	49.24	ppm	nist hi	5396.64	-2.44685	7100.29	2.133055		-100
540	2/19/2010 9:01	46.73	ppm	nist hi	5557.66	0.463847	6998.19	0.664413		-100
541	2/19/2010 9:03	90	ppm	sio2	< LOD	0	< LOD	0	10.3	
542	2/19/2010 9:05	90	ppm	sio2	< LOD	0	< LOD	0	11.28	
543	2/19/2010 9:08	90	ppm	sio2	< LOD	0	< LOD	0	< LOD	0
544	2/19/2010 9:10	90	ppm	rcra	513.31		55.5		486.74	
603	3/3/2010 14:11	90	ppm	nist low	27.14	0.518519	38.71	-15.8478	16.84	1430.909
604	3/3/2010 14:14	90	ppm	nist med	1157.22	-0.41136	341.08	-2.54857	36.72	-11.9424
605	3/3/2010 14:17	90	ppm	nist high	5641.44	1.978308	7276.3	4.664845	36.23	66.19266
606	3/3/2010 14:19	90	ppm	sio2	< LOD	0	< LOD	0	< LOD	0
607	3/3/2010 14:25	90	ppm	rcra	508.81		85.26		55.26	
669	3/8/2010 11:37	90	ppm	NCS 73308	32.11	18.92593	55.39	20.41304	10.83	884.5455
670	3/8/2010 11:40	90	ppm	NIST medium	1049.89	-9.64802	311.63	-10.9629	49.39	18.44125
671	3/8/2010 11:47	90	ppm	NIST high	5324	-3.75994	7059.86	1.551496	36.27	66.37615
672	3/8/2010 11:50	90	ppm	SIO2 BLANK	< LOD	0	< LOD	0	< LOD	0
766	3/8/2010 17:03	90	ppm	NCS 73308	31.42	16.37037	41.66	-9.43478	12.95	1077.273
767	3/8/2010 17:05	90	ppm	Nist M	1098.88	-5.43201	323.62	-7.53714	46.87	12.39808
768	3/8/2010 17:08	90	ppm	Nist H	5657.03	2.260123	7281.19	4.735184	27.74	27.24771
769	3/8/2010 17:10	90	ppm	si o2	< LOD	0	< LOD	0	< LOD	0
777	3/11/2010 10:08	90	ppm	NCS 73308	17.51	-35.1481	37.67	-18.1087	< LOD	0
778	3/11/2010 10:09	90	ppm	NCS 73308	25.4	-5.92593	46.82	1.782609	< LOD	0
779	3/11/2010 10:12	90	ppm	Nist M	1106.84	-4.74699	337.9	-3.45714	40.92	-1.8705
780	3/11/2010 10:14	90	ppm	Nist H	5342.47	-3.42607	7118.45	2.394275	36.67	68.21101
781	3/11/2010 10:16	90	ppm	Nist H	5499.93	-0.57972	7184.38	3.342635	30.85	41.51376
782	3/11/2010 10:18	90	ppm	si o2	< LOD	0	< LOD	0	< LOD	
783	3/11/2010 10:20	56.04	cps						13.76	
784	3/11/2010 10:22	90	ppm	SIO2 BLANK	< LOD	0	< LOD	0	< LOD	0

Appendix D: Sample Locations

Sample Site Coordinates:

Site	Latitude	Longitude
MOWWW2	37.049222	-94.587622
MOWWW3	37.049281	-94.587821
MOWWW4	37.049310	-94.587997
MOWWE1	37.049129	-94.586077
MOWWE2	37.049160	-94.585942
MOWWE3	37.049118	-94.585630
MOWWE4	37.049110	-94.585332
MOWWE5	37.049113	-94.585241
MOWWN2	37.050997	-94.586986
MOWWN3	37.051128	-94.587007
MOWWN4	37.051326	-94.586921
MOWWN5	37.051533	-94.586848
MOWWSE1	37.046699	-94.586009
MOWWSE2	37.046593	-94.586027
MOWWSE3	37.046520	-94.585763
MOWWSW1	37.045630	-94.587680
MOWWSW2	37.045554	-94.587828
MOWWSW3	37.045533	-94.588073
MOWWSW4	37.045362	-94.588379
MOBCNE1	37.091560	-94.572986
MOBCNE2	37.091675	-94.572888
MOBCNE3	37.091763	-94.572786
MOBCNE4	37.091879	-94.572683
MOBCNE5	37.091997	-94.572551
MOBCNE6	37.092043	-94.572410
MOBCNE7	37.092162	-94.572305
MOBCNE8	37.092263	-94.572206
MOBCNE9	37.092364	-94.572011
MOBCN1	37.091358	-94.575197
MOBCN2	37.091494	-94.575264
MOBCN3	37.091680	-94.575247
MOBCN4	37.091807	-94.575303
MOBCS1	37.088941	-94.574485
MOBCS2	37.088806	-94.574483
MOBCS3	37.088661	-94.574482
MOBCW1	37.090141	-94.575619
MOBCW2	37.090170	-94.575796
MOBCW3	37.090160	-94.575977
MOBCW4	37.090129	-94.576127
MODWW2	37.113586	-94.562068

Site	Latitude	Longitude
MODWS3	37.111763	-94.560601
MODWS4	37.111620	-94.560457
MODWS5	37.111561	-94.560516
MODWS6	37.111405	-94.560499
MODWS7	37.111263	-94.560457
MODWE2	37.113525	-94.558955
MODWE3	37.113521	-94.558769
MODWE4	37.113475	-94.558555
MODWN2	37.114488	-94.560377
MODWN3	37.114540	-94.560273
MODWN4	37.114643	-94.560230
MODWNA2	37.114417	-94.560600
MOCCN1	37.175497	-94.465455
MOCCN2	37.175597	-94.465366
MOCCN3	37.175715	-94.465272
MOCCN4	37.175848	-94.465274
MOCCE1	37.175274	-94.465221
MOCCE2	37.175226	-94.464994
MOCCE3	37.175235	-94.464826
MOCCE5	37.175289	-94.464279
MOCCE4	37.175371	-94.464407
MOCCE6	37.175291	-94.464265
MOCCE7	37.175308	-94.464060
MOCCE8	37.175276	-94.463891
MOCCSE1	37.174628	-94.465029
MOCCSE2	37.174468	-94.464768
MOCCSE3	37.174415	-94.464317
MO249W2	37.106318	-94.433926
MO249W3	37.106291	-94.434076
MO249W4	37.106276	-94.434249
MO249W5	37.106268	-94.434441
MO249W6	37.106256	-94.434635
MO249NW2	37.106993	-94.433793
MO249E1	37.106344	-94.432011
MO249E2	37.106372	-94.431834
MO249E3	37.106402	-94.431651
MO249S2	37.104923	-94.432721
MO249S3	37.104777	-94.432706
MO249S4	37.104654	-94.432706
MO249S5	37.104518	-94.432706

Site	Latitude	Longitude
OK104SW1	36.945046	-94.738854
OK104SW2	36.944893	-94.738865
OK104SW3	36.944805	-94.738905
OK104SW4	36.944645	-94.738966
OK104SW5	36.944273	-94.739105
OK104SW6	36.944144	-94.739167
OK104SW7	36.944031	-94.739112
OK54S1	36.983875	-94.782429
OK54S2	36.983783	-94.782394
OK54S3	36.983673	-94.782283
OK54S4	36.983488	-94.782338
OK54SW1	36.984270	-94.783307
OK54SW2	36.984303	-94.783453
OK54SW3	36.984267	-94.783643
OK54NW1	36.984807	-94.783443
OK54NW2	36.984885	-94.783620
OK54NW3	36.984951	-94.783793
OK54NW4	36.985154	-94.783869
OK54N1	36.985479	-94.781720
OK54N2	36.985625	-94.781759
OK54N3	36.985759	-94.781751
OK54N5	36.986054	-94.781815
OK5S1	36.977919	-94.890433
OK5S2	36.977765	-94.890428
OK5S3	36.977646	-94.890376
OK5W1	36.979731	-94.891128
OK5W2	36.979729	-94.891257
OK5W3	36.979748	-94.891452
OK5W4	36.979739	-94.891642
OK5E1	36.979628	-94.888851
OK5E2	36.979621	-94.888684
OK5N1	36.981283	-94.889553
OK5N2	36.981412	-94.889526
OK5N3	36.981572	-94.889510
OK5N4	36.981679	-94.889459
OK5N5	36.981847	-94.889444
OK5N6	36.982015	-94.889474
OK5N7	36.982124	-94.889399
OK5N8	36.982266	-94.889348
OK5N9	36.982390	-94.889293
OK5N10	36.982519	-94.889246
OK5N11	36.982655	-94.889161

Site	Latitude	Longitude
OK25N1	36.992788	-94.845728
OK25N2	36.992925	-94.845728
OK25N3	36.993031	-94.845795
OK25N4	36.993189	-94.845835
OK25N5	36.993309	-94.845883
OK25N6	36.993430	-94.845882
OK25N7	36.993592	-94.845937
OK25N8	36.993719	-94.845899
OK25N9	36.993864	-94.845917
OK25N10	36.994016	-94.845900
OK25N11	36.994160	-94.845923
OK25N12	36.994290	-94.845920
OK25NW1	36.992164	-94.846950
OK25NW2	36.992210	-94.847108
OK25NW3	36.992255	-94.847256
OK25NW4	36.992315	-94.847438
OK25NW5	36.992358	-94.847591
OK25NW6	36.992388	-94.847763
OK25NW7	36.992473	-94.847917
OK25NW8	36.992523	-94.848077
OK25NW9	36.992634	-94.848139
OK25NW10	36.992612	-94.848441
OK25NW11	36.992703	-94.848556
OK21SE1	36.988318	-94.844961
OK21SE2	36.988234	-94.844828
OK21SE3	36.988159	-94.844680
OK21SE4	36.988094	-94.844492
OK21SE5	36.988030	-94.844347
OK21SE6	36.988002	-94.844146
OK21SE7	36.987967	-94.843996
OK21SE8	36.987921	-94.843826
OK21SE9	36.987858	-94.843657
OK11SW1	36.938539	-94.759646
OK11SW2	36.938402	-94.759597
OK11SW3	36.938264	-94.759459
OK11SW4	36.938120	-94.759523
OK11SW5	36.937980	-94.759563
OK11SE1	36.938607	-94.758556
OK11SE2	36.938478	-94.758474
OK11SE3	36.938346	-94.758416
OK11SE4	36.938255	-94.758240
OK11SE5	36.938109	-94.758197

Site	Latitude	Longitude
OK54N4	36.985920	-94.781750
KS3N2	37.243113	-94.620404
KS3N3	37.243272	-94.620382
KS3N4	37.243428	-94.620402
KS198S2	37.229154	-94.623606
KS198S3	37.229006	-94.623611
KS198S4	37.228864	-94.623627
KS198S5	37.228736	-94.623649
KS198S6	37.228593	-94.623640
KS198S7	37.228454	-94.623642
KS17S2	37.167861	-94.668527
KS17S3	37.167736	-94.668552
KS17S4	37.167597	-94.668564
KS17N2	37.170078	-94.668323
KS17N3	37.170225	-94.668322
KS17N4	37.170356	-94.668327
KS19S2	37.167308	-94.667480
KS19S3	37.167150	-94.667495
KS19E2	37.168791	-94.665064
KS19E3	37.168779	-94.664929
KS19E4	37.168775	-94.664783
KS19E5	37.168761	-94.664617
KS19E6	37.168751	-94.664419
KS19N2	37.169794	-94.666505
KS19N3	37.169944	-94.666492
KS19N4	37.170103	-94.666468
KS19N5	37.170223	-94.666443
KS19N6	37.170386	-94.666407
KS78E2	37.017688	-94.767657
KS78E3	37.017658	-94.767511
KS78E4	37.017613	-94.767336
KS78W2	37.017779	-94.770124
KS78W3	37.017837	-94.770264
KS125SE2	37.020369	-94.871834
KS125SE3	37.020316	-94.871709
KS125SE4	37.020181	-94.871585
KS125SE5	37.020119	-94.871453
KS125SE6	37.020061	-94.871302
KS125SE7	37.019961	-94.871149
KS125NW2	37.023751	-94.873245
KS125NW3	37.023829	-94.873378