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Cyprus Amax Minerals Company

Streamlined Ecological Risk Evaluation

Former Altoona Smelter Property

Altoona, Kansas

May 27, 2014, Revised September 26, 2014

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Streamlined Ecological Risk Evaluation

Former Altoona Smelter Property
Altoona, Kansas

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List of Acronyms and Abbreviations

ARCADIS	ARCADIS U.S., Inc.
amsl	above mean sea level
ASTM	ASTM International
AUF	area use factor
AVS	acid volatile sulfide
bss	below sediment surface
$CaCO_3$	calcium carbonate
COPEC	constituent of potential ecological concern
CSM	conceptual site model
EPC	exposure point concentration
FFSA	Focused Former Smelter Assessment
f_{oc}	fraction of organic carbon
ft	feet
g_{oc}	grams of organic carbon
HCl	hydrochloric acid
KDHE	Kansas Department of Health and Environment
kg	kilogram
kg/L	kilogram per liter
LDEQ	Louisiana Department of Environmental Quality

M	molar
m	meter
MADEP	Massachusetts Department of Environmental Protection
MDEQ	Mississippi Department of Environmental Quality
mg/kg	milligram per kilogram
mg/L	milligram per liter
mL/g	milliliter per gram
mm	millimeters
MPCA	Minnesota Pollution Control Agency
OC	organic carbon
PADEP	Pennsylvania Department of Environmental Protection
PRP	potentially responsible party
RA	Removal Action
RAD	Removal Action Design
RSE	Removal Site Evaluation
SEM	simultaneously extracted metal
SERE	Streamlined Ecological Risk Evaluation
TCEQ	Texas Commission on Environmental Quality
TEC	threshold effect concentration
TNRCC	Texas Natural Resources Conservation Commission

UCL	upper confidence limit
USEPA	United States Environmental Protection Agency
UTL	Upper Tolerance Limit
UTL ER	UTL Exceedance Ratio
WQC	Water Quality Criteria

Executive Summary

ARCADIS U.S., Inc. has prepared this Streamlined Ecological Risk Evaluation (SERE) Report on behalf of Cyprus Amax Minerals Company (Cyprus) to evaluate potential impacts from metals in sediment in man-made ponds and drainage areas associated with the Former Altoona Zinc Smelter Property (Property) located in Altoona, Kansas. The Kansas Department of Health and the Environment (KDHE) requested this SERE Report in comments to the Removal Site Evaluation (RSE) Data Report, submitted on October 9, 2013 in accordance with the Consent Agreement and Order No. 09-E-0156BER (Order) which Cyprus and KDHE entered into on December 14, 2009. Subsequent meetings (March 13, 2014) and conference calls (April 4, 18, and 30, 2014) between the KDHE, their external consultant, Cyprus, and their consultant outlined the work plan for this SERE Report.

ARCADIS prepared this report to summarize the methodology and results of the SERE conducted to evaluate whether ecological receptors may be adversely impacted by exposure to metal constituents (arsenic, cadmium, lead, zinc) detected in sediment that were previously identified as constituents of interest in the following areas sampled: the Lower Drainage Area Transects 24 through 27 and off-Property Man-Made Ponds (Pond 1, Pond 3, Pond 4, and Northeast Pond).

Constituents of potential ecological concern (COPECs) were identified based on UTL exceedance ratios (UTL ERs; calculated for direct contact using ratio of exposure point concentrations to background UTL concentrations) and risks were characterized based on the bioavailability of the metals, limited size of the Lower Drainage Area and off-Property Man-Made Ponds, and quality of the available habitat. Toxicity-based sediment screening benchmarks were not used to screen the data because those benchmarks fell below the background UTLs for the four metal constituents of interest.

Based on the exposure evaluation and risk characterization for the receptors of concern (benthic invertebrates, aquatic life [including fish and other water column organisms], and aquatic mammalian and avian wildlife), the SERE resulted in the following conclusions:

Lower Drainage Area Transects 24 through 27

- Metal concentrations in pore water samples from Transects 24 through 27 are below KDHE chronic aquatic life Water Quality Criteria (WQC) values. Therefore,

the metal concentrations in sediments from the Lower Drainage Area are considered to be protective of aquatic life.

- For simultaneously extracted metals/acid volatile sulfides (SEM/AVS), the analysis indicates that toxicity to benthic invertebrates from cadmium, lead and zinc is predicted to be not likely or uncertain because all (or a significant portion) of the metals are bound as insoluble sulfides and are not biologically available to benthic receptors from sediment.
- The "allowable" cadmium, lead, and zinc concentrations calculated using empirical, site-specific carbon-partition coefficients are greater than the measured SEM concentrations; therefore, the bulk sediment concentrations in the Lower Drainage Area are protective of aquatic organisms.
- Based on the limited size of the Lower Drainage Area (relative to the home or foraging range of common wildlife receptors), it is extremely unlikely that an upper trophic level wildlife receptor could obtain its entire dietary intake from this area. Therefore, the metal concentrations in sediments of the Lower Drainage Area are not expected to pose a risk to the sustainability of herbivorous, invertivorous, and piscivorous mammal and bird populations.

Man-Made Pond 1

- The metal concentrations in pore water samples collected from Pond 1 are below KDHE chronic aquatic life WQC values. Therefore, the metal concentrations in sediments from Pond 1 are considered protective of aquatic life.
- For all samples collected from Pond 1, the SEM/AVS analysis indicates that toxicity due to lead and zinc will not be observed because all of the metals are bound as insoluble sulfides and are not biologically available to benthic receptors from sediment.
- The "allowable" lead and zinc concentrations calculated using empirical, site-specific carbon-partition coefficients are greater than the measured SEM concentrations; therefore, the bulk sediment concentrations in Pond 1 are protective of biological organisms.
- Based on the limited size of Pond 1 (relative to the home or foraging range of common wildlife receptors), it is extremely unlikely that an upper trophic level wildlife receptor could obtain its entire dietary intake from this pond. Therefore, the metal concentrations in sediments of Pond 1 are not expected to pose a risk to the

sustainability of herbivorous, invertivorous, and piscivorous mammal and bird populations.

Man-Made Pond 3, Pond 4, and Northeast Pond

- Based on a comparison of the pond-specific sediment metal concentrations to background metal concentrations, none of the metals in sediment from Pond 3, Pond 4, and Northeast Pond were identified as COPECs. Therefore, these ponds are not expected to represent an exposure concern for ecological receptors.

Based on these conclusions, and in accordance with U.S. Environmental Protection Agency (USEPA) ecological risk assessment guidance (1997), there is adequate information to conclude that any ecological risks are negligible and no further ecological assessment of the Lower Drainage Area and the off-Property Man-Made Ponds is warranted.

1. Introduction

ARCADIS U.S., Inc. has prepared this Streamlined Ecological Risk Evaluation (SERE) Report on behalf of Cyprus Amax Minerals Company (Cyprus) to evaluate potential impacts from metals in sediment in man-made ponds and drainage areas associated with the Former Altoona Zinc Smelter Property (Property) located in Altoona, Kansas. Kansas Department of Health and Environment (KDHE) requested this SERE Report in comments to the Removal Site Evaluation (RSE) Data Report, submitted on October 9, 2013 in accordance with the Consent Agreement and Order No. 09-E-0156BER (Order) which Cyprus and KDHE entered into on December 14, 2009. Subsequent meetings (March 13, 2014) and conference calls (April 4, 18, and 30, 2014) between the KDHE, their external consultant, Cyprus, and their consultant outlined the work plan for this SERE Report.

1.1 Site Definitions

Property: The 53 acres of land where a majority of the historical day-to-day operations of the Former Altoona Smelter occurred.

Site: The Property, associated drainages, and other areas adjacent to the Property where arsenic, cadmium, lead and zinc impacts have been identified.

Media: Dry or saturated solid material at the base of the Drainage Areas associated with the Site that are further identified as sediment based on KDHE Sediment Policy.

Man-Made Pond: Includes only the six man-made ponds associated with the Site. The man-made features were constructed for industrial and agricultural purposes. The two man-made ponds on the Property (North Pond and South Pond) have been observed to be dry and are screened in the RSE Report (ARCADIS 2014) as soil in accordance with KDHE Sediment Policy (KDHE 2004a). Only the four off-Property Man-Made Ponds are evaluated in this SERE.

Drainage Area: The lineal surface water drainage feature that connects the Property to the Verdigris River. Media present in the base of the Drainage Area can be screened as soil or sediment in accordance with KDHE Sediment Policy.

Upper Drainage Area: The portion of the Drainage Area that includes Transect 00 to the point of Transect 24. Media in the Upper Drainage Area are screened as soil based on KDHE Sediment Policy.

Lower Drainage Area: The portion of the Drainage Area from Transect 24 through Transect 27. Media in the Lower Drainage Area are screened as sediment based on KDHE Sediment Policy.

1.2 Project Overview

This section describes the previous investigations conducted at the Site and presents a discussion of the classification of the media present in the Man-Made Ponds and Drainage Area. This section sets the stage for the remainder of the report, which discusses the SERE approach, exposure estimation, and risk characterization.

1.2.1 Summary of Previous Investigations

The Property was identified and initially investigated by KDHE through its State Water Plan program. Specifically, KDHE performed two investigations at the Site in 2002 and 2003. KDHE completed both investigations as part of an overall identification and assessment of former smelter sites in Kansas.

KDHE contracted with Maxim Technologies to perform a Focused Former Smelter Assessment (FFSA) in 2002 and 2003. Maxim presented the results of the FFSA investigation in the Focused Former Smelter Assessment Report dated January 31, 2003.

KDHE performed a Supplemental FFSA at the Site in 2003 to further assess the extent of arsenic, lead, cadmium, and zinc at residential and non-residential areas adjacent to the Property including off-Property and background sample collection. A September 15, 2003 report presents the results of the Supplemental FFSA.

As part of its investigations, KDHE performed a Potentially Responsible Party (PRP) search. Thereafter, KDHE notified Cyprus (in August 2005) and Mueller Industries (in October 2006) that they were PRPs at the Site, and requested that they enter into an agreement with KDHE to investigate and clean up the Site. Cyprus entered into discussions with KDHE regarding an agreement to perform the investigation and cleanup. Cyprus and the KDHE entered into Consent Agreement and Order No. 09-E-0156BER (Order) dated December 14, 2009.

The Bridgewater Group, Inc. (Bridgewater) prepared the RSE Work Plan (the Plan) in accordance with the Order and consistent with the November 2009 KDHE policy and scope of work for RSE/Removal Action Design (RAD)/Removal Action (RA), and submitted it to the KDHE on March 5, 2010. After subsequent revisions, the KDHE approved the RSE Work Plan in a letter dated October 4, 2011.

ARCADIS proposed additional sampling and reporting activities in an RSE Work Plan revision dated May 2, 2012. The KDHE approved the additional RSE activities in a letter dated May 11, 2012. ARCADIS proposed a revised Soil Sampling Letter Plan on August 27, 2012 that was approved by KDHE in an email dated August 23, 2012.

ARCADIS conducted the RSE activities in accordance with the approved RSE Work Plan and subsequent addenda. On behalf of Cyprus, ARCADIS has completed all sediment investigation work contemplated by the RSE Work Plan and supporting addenda. Additional discussion the previous investigations for the Property are included in the RSE Report (ARCADIS 2014), which is being submitted concurrently with this report.

1.2.2 Classification of Soil and Sediment in Man-Made Ponds and Drainage Area

KDHE and Cyprus agreed upon the classification of material within the six Man-Made Ponds and the Drainage Area as soil or sediment in accordance with KDHE Sediment Policy during the March 13, 2014 meeting, as formally documented in the meeting notes submittal dated April 2, 2014 and the response to comment letter dated April 15, 2014. The primary factor used to differentiate between soil and sediment is whether a Man-Made Pond and the Drainage Area segment have been observed to be dry. Cyprus presented the data to support this evaluation to the KDHE during the site visit on March 12, 2014 and during the meeting presentation on March 13, 2014. KDHE agreed that the material within the two Man-Made Ponds on the Property (North Pond and South Pond) and the Upper Drainage Area, defined as the area from Transect 00 to the point of Transect 24, are considered soil in accordance with KDHE Sediment Policy. The primary lines of evidence to support this determination include:

- The North and South Ponds have been observed to be dry in the past and are expected to be dry at times in the future.

- The Upper Drainage Area is a storm water conveyance feature that transects pasture and agricultural fields, and has been observed to be dry following precipitation events.

In addition, the North and South Ponds are located on the operational area of the former smelter and are within the proposed repository design area.

KDHE and Cyprus agreed that the material in the four off-Property Man-Made Ponds (Pond 1, Pond 3, Pond 4, and Northeast Pond) and the Lower Drainage Area, defined as the area inclusive of Transect 24 through Transect 27, are considered sediment in accordance with KDHE Sediment Policy and will be evaluated herein as sediment.

Figure 1-1 presents the areas classified and evaluated as sediment in the SERE Report.

1.3 Streamlined Ecological Risk Evaluation Approach

The purpose of the SERE is to identify metals and areas that may pose an unacceptable risk to appropriate receptors using site-specific information. The overall approach used to assess risks for the Lower Drainage Area Transects 24 through 27 and Man-Made Ponds is generally based on U.S. Environmental Protection Agency (USEPA) ecological risk assessment guidance (USEPA 1997, 1998, 2000a, 2001a, 2001b) and includes components of a typical screening-level ecological risk assessment (e.g., problem formulation, effects assessment, risk characterization); however, it is a streamlined evaluation and does not include certain components such as a screening against maximum detected concentrations. This SERE adheres to the following protocols:

- Those outlined in the KDHE Sediment Policy
- Those included in the approach presented to KDHE during the March 13, 2014 meeting (verbally approved on the subsequent April 4, 18 and 30, 2014 conference calls) and an email dated April 15, 2014 from KDHE (Maura O'Halloran) to Cyprus (Alicia Voss)
- Those in an April 11, 2014 phone conversation between Mr. Chris Carey of KDHE and Mr. John Shonfelt of ARCADIS, in which Mr. Carey agreed that food chain modeling would not be required for the SERE.

  Cyprus and the KDHE jointly inspected the Site on March 13, 2014 and then jointly determined that quantitative food chain modeling for wildlife was not going to change the outcome of the SERE and thus, was not warranted at the Altoona site. This determination was based on the generally low sediment concentrations relative to the background UTL concentrations, and on the small spatial extent of the Man-Made Ponds and Lower Drainage Area relative to the home ranges of typical wildlife receptors. Therefore, food chain modeling was not included in this SERE Report.

The SERE includes a screening assessment and a bioavailability evaluation and focuses only on sediment within the Lower Drainage Area Transects 24 through 27 and the off-Property Man-Made Ponds (Pond 1, Pond 3, Pond 4, Northeast Pond).

The SERE presents three assessment and measurement endpoints (in Section 2.1.5) and culminates in a clearly defined scientific management decision point. The following types of decisions are considered at the conclusion of the SERE:

- Whether the available information is adequate to conclude that ecological risks (if any) are negligible and, therefore, there is no need for further action on the basis of ecological risk

- Whether the available information is not adequate to make a decision at this point, and the ecological risk evaluation process should continue

- Whether the available information indicates a potential for adverse ecological effects, and a more thorough assessment or remediation is warranted.

1.4 Organization

This SERE Report is organized as follows:

- **Section 1** – Introduction. This section provides background information related to the SERE.

- **Section 2** – SERE Problem Formulation, Exposure Estimate and Risk Calculation, and Risk Characterization. This section provides the rationale for the methods and procedures used during the evaluation of the data, and the results of that evaluation.

- **Section 3** – Uncertainty Analysis. This section identifies and discusses uncertainties associated with the results of the SERE.

- **Section 4** – Summary and Conclusions. This section presents a summary of the conclusions drawn from the SERE.

- **Section 5** – References.

2. Components of the Streamlined Ecological Risk Evaluation

As discussed previously, the purpose of the SERE Report is to evaluate whether ecological receptors may be adversely impacted by exposure to constituents detected in sediment within the Lower Drainage Area Transects 24 through 27 and the off-Property Man-Made Ponds. The SERE results are intended to provide input for risk management decision-making, while maintaining a conservative approach protective of ecological receptor populations and communities. During the SERE process, risks to individual ecological receptors are assessed only if they are protected under the Endangered Species Act or other species-specific legislation, if they are a candidate for listing, or if they are considered rare.

A SERE involves a conservative estimate of the risks that may exist for ecological receptors and incorporates uncertainty in a precautionary manner. The SERE is composed of the following major components:

- Problem Formulation
- Exposure Estimate and Risk Calculation Methodology
- Risk Characterization

These components are discussed in the following sections.

2.1 Problem Formulation

The problem formulation section of the SERE presents information on environmental settings, receptors, and ecosystem characteristics, as well as information on the sources and effects of the stressors (USEPA 1998). This information is used to develop a Conceptual Site Model (CSM) that illustrates the potential relationships among stressors, pathways, and receptors such as:

- Environmental Setting
- Description of Constituent Fate and Transport Pathways
- Description of Potentially Exposed Receptors
- Identification of Potentially Complete Exposure Pathways

- Identification of Constituents Detected
- Description of Constituent Mechanisms of Ecotoxicity
- Selection of Assessment and Measurement Endpoints

2.1.1 Environmental Setting

The Former Altoona Smelter Property is located in northern Altoona, Wilson County, Kansas (**Figure 1-1**). The Property occupies approximately 30 acres that is bounded on the north, west, and south by agricultural properties and on the east by the northwest-to-southeast trending railroad tracks.

The surface elevation across the Property varies from approximately 830 feet (ft) above mean sea level (amsl) to 820 ft amsl. The Property is situated on the west side of a low divide located between the Verdigris River to the west and the Little Cedar Creek to the east. The Property is located at the transition area between the Verdigris River flood plain to the west and southwest and the uplands area. The Property drains to the south via a poorly defined ditch extending through agricultural fields to an unnamed intermittent ditch that contributes to the Verdigris River west of Altoona. The confluence of the Verdigris River and the unnamed intermittent ditch is located approximately 0.5 mile west-southwest of the Property. The Verdigris River has been designated a "Special Aquatic Life Use Waters" during its route through Wilson County. The term "Special Aquatic Life Use Waters" means surface waters that contain combinations of habitat types and indigenous biota not found commonly in the state, or surface waters that contain representative populations of threatened or endangered species (Maxim 2003).

The Upper Drainage Area (Transects 00 to 23) traverses disturbed agricultural fields and drains into the Lower Drainage Area (Transect 24 through 27), an approximately 400-foot segment which ultimately joins the Verdigris River. This segment is characterized by backwash from the Verdigris River. Trend graphs presented during the March 13, 2014 meeting and submitted with meeting notes dated April 2, 2014 show that sediment transport is negligible downgradient of the property purchased in May 2013 by Midwest Property Acquisition Company (affiliated to Cyprus) due to a 90-degree west turn in the drainage itself and a berm (**Figure 1-1**).

Four ponds are located off-Property (**Figure 1-1**); the largest is a man-made pond (Pond 1) in the central portion of the adjacent property to the south; a second man-made pond is on an adjacent property southeast of the Property (Pond 3); a third small

man-made pond is on the adjacent property north of the Property (Pond 4); and a forth man-made pond is on adjacent property northeast of the Property (Northeast Pond). The Man-Made Ponds were constructed for industrial and agricultural purposes, and are currently used to control runoff from agricultural areas. Surface-water elevations in the Man-Made Ponds vary significantly depending on the frequency, duration, and intensity of rainfall events.

2.1.1.1 Kansas EcoRegion

The Site is located within the Central Irregular Plains ecoregion of Kansas. The Central Irregular Plains ecoregion has a variety of land use types, and the potential natural vegetation of the region is a mosaic of tallgrass prairie and oak-hickory forest. The climate is humid, with rainfall averaging 28 to 40 inches per year, most of it falling during the growing season (Chapman et al. 2001).

The Osage Cuestas region within the Central Irregular Plains ecoregion is a gently undulating cuesta plain composed of several alternating layers of sandstone, limestone, and shale. Topography is distinct from the more dramatic rolling hills of the Flint Hills to the west. Potential natural vegetation ranges from a mosaic of mostly tallgrass prairie in the west to a mixture of tallgrass prairie and oak-hickory forest in the east, with floodplain forests along streams. The moist, silty clay loams are formed in material weathered from limestone and shale, and support a land use composite of cropland, woodland, and grassland/rangeland (Chapman et al. 2001).

2.1.2 Conceptual Site Model

Knowledge about the CSM is vital to understanding which constituents and receptors are associated with complete exposure pathways because a constituent may reach an ecological receptor in a variety of ways. In addition, the pathway and route of exposure may have a strong influence on the ecological effect of a constituent. CSMs are illustrated on **Figure 2-1** for the Lower Drainage Area and **Figure 2-2** for the off-Property Man-Made Ponds.

2.1.2.1 Fate and Transport Pathways

Fate and transport of COPECs are relevant issues because they affect whether constituents are likely to persist, be degraded or transformed, or move beyond the extent of impact that was identified during the investigation, which in turn can influence the form, toxicity, and bioavailability of the COPECs. Metals, unlike organics, cannot be degraded, although some metals (e.g., arsenic) can be transformed to other

oxidation states (See Section 2.1.4). Metals can become part of the sediment mass through precipitation or adsorption.

Sediment transport in fluvial systems generally occurs as suspended and bed loads, which are affected by current velocity. Intermittent flows and poorly defined channels in the upper portions of the Drainage Area provide a depositional setting, and extensive empirical data show that metal concentrations decrease with distance from the Property, indicating that the drainage is not acting as a conduit for higher levels of metals to enter into the Verdigris River. A detailed discussion of this information is presented in the April 15, 2014 response to comment letter for the RSE Data Report that was submitted to KDHE, and in Section 9.4 and Figure 9.1 of the RSE Report (ARCADIS 2014). Sediment transport out of the Man-Made Ponds is highly unlikely due to their physical settings (e.g., constructed ponds with no outlets).

2.1.2.2 Description of Potentially Exposed Receptors

Identifying the categories of receptors most likely to be exposed helps to focus the SERE. Potentially exposed receptors are designated based on the available habitat associated with the Lower Drainage Area and the off-Property Man-Made Ponds. Potentially exposed receptors include aquatic wildlife (e.g., mammals, birds, fish, invertebrates, amphibians, and aquatic plants [including algae, by convention]).

2.1.2.3 Threatened and Endangered Species

This section provides an evaluation of the potential for exposures to individual organisms of threatened and endangered species in Wilson County. There are eight state-listed threatened or endangered species for Wilson County, Kansas (KDWPT 2014) including two federally listed threatened or endangered species. The listed species are further discussed below.

The American burying beetle (*Nicrophorus americanus*) has been frequently found in upland grasslands or near the edge of grassland/forest. Sandy/clay loam soils and food (carrion) availability are important habitat requirements.

The eastern spotted skunk (*Spilogale putorius*) prefers forest edges and upland prairie grasslands, especially where rock outcrops and shrub clumps are present.

The Ouachita kidneyshell mussel (*Ptychobranchus occidentalis*), The Neosho mucket (*Lampsilis rafinesqueana*), rabbitsfoot mussel (*Quadrula cylindrical*), and the Western fanshell mussel (*Cyprogenia aberti*) are obligate riverine species preferring shallow

clean flowing water in fine to medium gravel substrates. Historically, they have been found in area river systems including the Verdigris River system. Like all freshwater mussels, they are filter feeders and must have a permanent source of flowing water surrounding them (KDWPT 2014).

Common map turtle (*Graptemys geographica*) habitat includes creeks, rivers, oxbows, and lakes with abundant basking sites, slow to moderate current, and soft substrate with aquatic vegetation and tree-lined banks (KDWPT 2014).

Piping plover (*Charadrius melodus*) are rare migrants through Kansas. They require sparsely vegetated shallow wetlands and open beaches and sandbars adjacent to or within streams and impoundments. Nesting has been recorded on sand bars along the Kansas River. Piping plovers may occur occasionally anywhere in the state where suitable habitat is found (KDWPT 2014).

Based on the preferred habitat requirements for the listed species in Wilson County, the American burying beetle, eastern spotted skunk, and piping plover are not likely to access the soft bottom substrate in the Man-Made Ponds or the Lower Drainage Area from which the sediment samples were collected. The common map turtle is also not expected to frequent the Man-Made Ponds or Lower Drainage Area due to the lack of aquatic vegetation; and similarly, the mussel species are not likely to occur in the Man-Made Ponds or Lower Drainage Area due to the lack of flowing water and lack of gravel substrate.

2.1.2.4 Identification of Potentially Complete Exposure Pathways

A complete exposure pathway must have four connected elements: source and mechanism for release, a retention or transport medium, a receptor at a point of exposure to an impacted medium, and a constituent-specific mechanism(s) of toxicity (USEPA 2001d).

Based on past investigations, off-Property surface water was not identified as a medium of interest for the RSE. The KDHE Supplemental FFSA report dated September 15, 2003 stated that the “Initial phase sampling did not identify any off-site surface water impacts”, nor was it a medium of interest in the March 13, 2014 site visit and meeting between KDHE and Cyprus. Therefore, surface water was not evaluated as a medium of interest in this SERE Report.

The table below summarizes the potential exposure routes for the Lower Drainage Area and the off-Property Man-Made Ponds.

Organism	Possible Exposure Routes
Fish (and other water column organisms) and benthic invertebrates	Ingestion of sediment, surface contact, and food chain
Aquatic avian and mammalian wildlife	Ingestion of sediment and surface water, dermal uptake, and food chain
Aquatic plants	Uptake from and surface contact with sediment

As discussed previously, Cyprus and the KDHE jointly inspected the Site on March 13, 2014 and then jointly determined that quantitative food chain modeling for wildlife was not going to change the outcome of the SERE and thus, was not warranted at the Altoona Site. Therefore, food chain modeling was not included in this SERE Report.

2.1.3 Constituents of Potential Ecological Concern

The four metals evaluated in this SERE (arsenic, cadmium, lead, and zinc) are based on data collected from previous investigations conducted by the KDHE (Maxim 2003). After reviewing the assessment data, the KDHE concluded the constituents of potential concern were arsenic, cadmium, lead, and zinc. These established constituents of potential concern were also discussed in the KDHE approved Removal Site Evaluation Work Plan (Bridgewater 2011). Sediments potentially impacted with arsenic, cadmium, lead, and zinc are present in the Man-Made Ponds as well as the Lower Drainage Area. The Man-Made Ponds and Lower Drainage Area (Transects 24 through 27) transect locations are identified on **Figure 1-1**. The analytical data are provided in **Appendix A**.

The process for selecting COPECs is appropriate for the type of average exposures likely to occur for biota exposed to constituents in the sediment. This process consisted of the comparison of exposure point concentrations (EPCs) to background upper tolerance limits (UTLs) established for reference sediments. In a March 13, 2014 meeting, KDHE agreed that conservative screening levels (i.e., Threshold Effect Concentrations [TECs; MacDonald et al. 2000]), are not suitable for use at the Altoona site because they are below background concentrations. The background UTLs are presented in the table below:

Background UTLs in Sediment			
Arsenic (mg/kg)	**Cadmium (mg/kg)**	**Lead (mg/kg)**	**Zinc (mg/kg)**
19.9	3.45	96.7	402

mg/kg – Milligrams per kilogram

The data collection and calculation of UTLs are further discussed in the RSE Report (ARCADIS 2014) and in the Response to KDHE Comments dated April 21, 2014, which are provided in **Appendix B** of this SERE Report.

As agreed to by KDHE in the March 13, 2014 meeting, the representative EPC used for the selection of sediment COPECs is the 95% Upper Confidence Level (95% UCL) on the mean concentration. The USEPA (1992, 1989) recommends that the arithmetic average concentration of the data be used for evaluating long-term exposure and that, because of the uncertainty associated with estimating the true average concentration at a site, the 95% UCL on the arithmetic average be used as the EPC. The 95% UCL concentration provides reasonable confidence that the true average will not be under-estimated.

The ProUCL® 4.1.00 (ProUCL) program developed by the USEPA's Technology Support Center for Monitoring and Site Characterization was used to plot the data, test the distributional assumptions, and calculate 95% UCL concentrations. When entering data into ProUCL, if a COPEC was not detected in a sample, the sample reporting limit was entered as a proxy concentration, and the sample result was coded as non-detect. ProUCL contains rigorous parametric and non-parametric statistical methods that can be used on full or uncensored data sets and on data sets with below detection limit observations (also called left-censored data sets). Depending on the distribution and 95% UCL estimation method, ProUCL will use only detected data or will incorporate detection limits (USEPA 2010).

Sediment data collected from the Lower Drainage Area and Man-Made Ponds for the RSE report were used to calculate 95% UCLs for use as EPCs, as described further below. 95% UCLs were calculated for datasets with a minimum of eight samples. Samples were collected from 0.1 and 1.0 foot below sediment surface (ft bss) at five boring locations across each transect. Each Man-Made Pond location was split into four quadrants, and sediment samples from 0.1 and 1.0 ft bss were collected from

each quadrant. Bulk sediment samples were submitted for analysis of total arsenic, cadmium, lead, and zinc using USEPA Method 6020. A full description of the Lower Drainage Area and Man-Made Pond sampling methodology is presented in the RSE Report (ARCADIS 2014).

2.1.3.1 Lower Drainage Area Channel Sediments

The 95% UCLs for Lower Drainage Area channel sediments were first calculated for each individual transect (Transect 24 through Transect 26) using the data collected at the RSE sampling depths (i.e., 0-0.1 foot and 0.1-1.0 foot) from multiple locations along each transect. A full description of the sediment sampling methodology for the Lower Drainage Area is presented in the RSE Report (ARCADIS 2014). A total of ten samples were available for Transects 24 and 25. Fourteen samples were available for Transect 26. Only one sample was available from Transect 27; therefore, a 95% UCL was not calculated. In addition to the samples discussed above, the Combined Transect UCL (Transects 24 through 27) also included four confirmation samples that were collected in November of 2012 (i.e., E-C-25+25-M-00.0-00.1, E-C-25+50-M-00.0-00.1, E-C-25+75-M-00.0-00.1, and E-C-25+100-M-00.0-00.1) in an effort to replicate concentrations at Transect 26 (see Section 3.2 for discussion).

In instances when ProUCL recommended the 95% H-UCL (based on Land's H-statistic), which is recognized as unreliable[1], USEPA (2010) recommends use of non-parametric statistics as the preferred UCL for skewed datasets which do not follow a gamma distribution. Because the 99% Chebyshev (Mean, Sd) UCL may be overly conservative given the skewed dataset, the 95% Chebyshev (Mean, Sd) UCL was selected as the UCL in instances when ProUCL recommended either the 95% H-UCL or the 99% Chebyshev (Mean, Sd) UCL. The EPCs (i.e., 95% UCLs) for the COPECs in Lower Drainage Area sediments are presented in **Table 2-1**. The ProUCL output sheets for individual COPECs are provided in **Appendix C**.

[1] In instances when ProUCL includes the H-UCL as a potential UCL to use, the ProUCL output summary page states that "ProUCL computes and outputs H-statistic based UCLs for historical reasons only. H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide. It is therefore recommended to avoid the use of H-statistic based 95% UCLs." (USEPA 2010).

2.1.3.2 Off-Property Man-Made Pond Sediments

The 95% UCLs for Man-Made Pond sediments were calculated using the data collected at the RSE sampling depths (i.e., 0-0.1 foot and 0.1-1.0 foot) from each pond. A full description of the sediment sampling methodology for the Man-Made Ponds is presented in the RSE Report (ARCADIS 2014). Eight samples were available from Pond 1 and Pond 3, ten samples from Pond 4, and 14 samples from the Northeast Pond. The EPCs (i.e., 95% UCLs) for the pond sediments are presented in **Table 2-1**. The ProUCL output sheets for individual COPECs are provided in **Appendix C**.

Each constituent identified as a COPEC based on the comparison to the UTL is considered a COPEC for direct contact exposures. The results of the COPEC selection process are discussed in the Risk Characterization Section (Section 2.3).

2.1.4 Description of Constituent Mechanisms of Ecotoxicity

The mechanisms of ecotoxicity for constituents vary depending on a wide range of factors, such as constituent concentration, the exposed ecological receptor species, the exposure route (e.g., ingestion or direct-contact), and physical factors (e.g., pH, temperature, dissolved oxygen concentrations). Some of the effects that might be observed in ecological receptors are mortality, decreased reproduction, decreased fertility, decreased offspring survival, alteration of immune and behavioral function, decreased hatching success of eggs/larvae, and retarded growth (Sample et al. 1996; USEPA 2001c). The mechanisms of ecotoxicity for the metals are discussed in the toxicity profiles provided in **Appendix D**. These constituent mechanisms of toxicity are described without consideration of constituent concentrations because the descriptions seek to convey an understanding of possible effects rather than describe the concentrations at which these effects might occur. However, it should be remembered that adverse effects will not occur below a threshold concentration specific to the toxicity endpoint for the biological species of concern.

2.1.5 Selection of Assessment and Measurement Endpoints

Assessment endpoints are the explicit expression of the ecological values to be protected (USEPA 1997). The selection of assessment endpoints depends on knowledge of the receiving environment, knowledge about the constituents released (including their toxicological properties and the relevant concentrations), and an understanding of the values that will drive risk management decision-making (Suter et al. 1995). Consistent with USEPA (1998) guidance, two elements are required to

define an assessment endpoint: the specific valued ecological entity and the characteristic about the entity that is important to protect.

USEPA guidance states that assessment endpoints are any adverse effects on ecological receptors, where receptors are plant and animal populations and communities, habitats, and sensitive environments. Many of the ecotoxicity screening values are based on generic assessment endpoints and are assumed to be widely applicable to sites around the United States (USEPA 1997). As discussed in a March 13, 2014 meeting with KDHE, the TECs (MacDonald et al. 2000) typically used to evaluate sediment in Kansas are not suitable for use as screening values at the Lower Drainage Area and the off-Property Man-Made Ponds because they are below background concentrations. Therefore, background UTLs are used in the place of screening values for the SERE.

Because direct measurement of assessment endpoints is often difficult (or impossible), surrogate endpoints (called measurement endpoints) are used to provide the information necessary to evaluate whether the values associated with the assessment endpoint are being protected. A measurement endpoint is a measurable ecological characteristic and/or response to a stressor (USEPA 1998). Measurement endpoints are also referred to as measures of potential effect (USEPA 1998). Measurement endpoints are indirectly evaluated in the SERE through the use of bioavailability data (i.e., pore water measurements, acid volatile sulfide [AVS], simultaneously extracted metals [SEM], and partitioning coefficients) and spatial extent of the evaluated areas.

Based on the potentially complete exposure pathways and potential receptor categories identified for the Lower Drainage Area and the off-Property Man-Made Ponds, the following assessment endpoints, measurement endpoints, and wildlife receptor species were identified:

<u>Assessment Endpoint 1:</u>

Question: Are COPECs in sediment bioavailable at concentrations that pose a potential risk to benthic invertebrate communities?

Measurement Endpoint 1a: Evaluate pore water to determine if metal COPECs in sediment are bioavailable.

Measurement Endpoint 1b: Evaluate SEM/AVS data in accordance with USEPA (2005b) guidance to determine if metals in sediment are bioavailable.

Measurement Endpoint 1c: Calculate allowable metal concentrations using empirical, site-specific carbon-partition coefficients to determine if metals in sediment pose a hazard to benthic invertebrates.

Assessment Endpoint 2:

Question: Do COPEC concentrations in sediment pose a potential risk to fish and other water column organisms at each location?

Measurement Endpoint 2: Compare measured pore water concentrations to KDHE chronic aquatic life water quality criteria (WQC) for the COPECs, conservatively assuming pore water concentrations are representative of the water column.

Assessment Endpoint 3:

Question: Do COPEC concentrations in sediment pose a potential risk to the sustainability of herbivorous, invertivorous, and piscivorous mammal and bird populations?

Measurement Endpoint 3: Evaluate the limited exposure potential for wildlife receptors.

2.2 Exposure Estimate and Risk Calculation Methodology

The outcome of the exposure estimate and risk calculation is a list of direct contact COPECs to be retained for further evaluation. This section presents the methods used in that evaluation. Predictions of the likelihood of adverse effects, if any, for the direct-contact COPECs are based on UTL exceedance ratios (UTL ERs). The results of the risk calculations are presented in tabular form, and metals with UTL ERs greater than 1 (rounded to one significant figure) are further considered as COPECs to assess whether unacceptable ecological risks may exist.

2.2.1 Bioavailability of Metals to Benthic Invertebrates

If bulk sediment COPEC concentrations indicate a potential for impact to benthos in the Lower Drainage Area and Man-Made Ponds, sediment was further evaluated using an approach that estimates the bioavailability of the COPECs.

The USEPA (2005b) has developed guidelines for assessing the risk of sediment toxicity due to mixtures of divalent metals cadmium, copper, lead, nickel, silver (monovalent), and zinc, based on an understanding of the primary factors controlling

the concentrations of these metals in sediment pore water. Partitioning of divalent metals between sediments and interstitial water is dependent on a number of site-specific conditions, including the presence of AVS, organic carbon (OC), and other parameters. AVS and OC partitioning are typically the two primary mechanisms used in evaluating bioavailability of these divalent metals in sediments.

The partitioning of divalent metals with AVS is a key mechanism for evaluating the bioavailability and toxicity of metals in the bulk sediment/interstitial water system. AVS is the amount of sulfide liberated from a sediment during extraction in 1 molar (M) hydrochloric acid (HCl) at room temperature. In sediments, AVS binds to the cationic metals including five divalent metals of environmental concern (cadmium, copper, nickel, lead, and zinc) on a 1:1 mole-to-mole basis (and to monovalent silver on a 2:1 ratio of moles silver:moles AVS basis). Metals bound by AVS form an insoluble metal sulfide, thereby maintaining metal concentrations in the interstitial water below toxic levels as long as the molar concentration of AVS exceeds the molar concentration of metals (Di Toro et al 1991, Ankley et al. 1996). In that insoluble form, the metals are thus considered to not be bioavailable. It should be noted that arsenic does not bind to AVS, and thus the bioavailability of arsenic does not include the AVS partitioning mechanism.

Based on these guidelines and concepts, the bioavailability of the COPECs in sediments was evaluated using three lines of evidence:

1. The evaluation of pore water data collected from the Lower Drainage Area and the off-Property Man-Made Ponds by comparison to KDHE WQC protective of aquatic life;
2. The SEM/AVS equilibrium partitioning (EqP) approach described in USEPA guidance (2005a); and
3. The calculation of total “allowable” metal concentrations in bulk sediment using empirical, site-specific carbon-partition coefficients.

The first approach is a direct measurement of the concentrations to which sediment organisms are exposed in a given pore water, but pore water data are not always available. The second approach uses SEM/AVS extraction results to estimate bioavailability of metals by comparison of normalized concentrations of the extracted metals to empirically determined categories of non-toxic, potentially toxic, and likely toxic concentrations. The third approach uses SEM, AVS, and published coefficients for partitioning of metals to particulate organic matter to predict the pore water concentrations of metals in a given sediment. Each line of evidence is further discussed in the following sections.

2.2.1.1 Pore Water Evaluation

Bioavailability is a key consideration in relating metal concentrations to the potential for adverse biological effects. Numerous studies have demonstrated that bulk metal concentrations in sediment samples are not a reliable indicator of toxicity; instead, biological effects are more closely correlated with metal concentrations in interstitial water or pore water (Adams et al. 1983, Swartz et al. 1985, Kemp and Swartz 1986). The biological effects of metal concentrations in interstitial water are essentially equivalent to their effects concentrations in the water column (Ankley et al. 1996), allowing established WQC to be used to assess protection of benthic organisms. In fact, bulk sediment concentrations of metals, whether normalized (e.g., to organic-carbon content of the sediment) or not normalized, are only indirect indicators of potential risk to organisms; however, concentrations of metals in interstitial pore water (the medium in which the organisms are directly exposed to the metals) are a more direct indicator of potential risk and, when available, should be given the most weight in a risk assessment.

Large-volume bulk sediment samples were collected from the four off-Property Man-Made Ponds during 2011 and from Lower Drainage Area locations during June 2012. For Man-Made Ponds and Lower Drainage Area locations where pore water data are available, dissolved pore water concentrations were compared to KDHE chronic aquatic life WQC values (KDHE 2004b) as modified using USEPA (USEPA 2013) conversion factors to convert from criteria expressed on the basis of total-metal concentrations to criteria based on dissolved-metal concentrations. Total-metal concentrations are not meaningful to interpret for interstitial waters because sediment particles usually are entrained during pore water sampling and thus bias the total-metal concentration upward above the total-metal concentration that exists *in situ*. Sediment locations with pore water concentrations below the KDHE WQC were considered to be not impacted.

The USEPA bases its criteria for cationic metals (including arsenic, cadmium, lead, and zinc) on dissolved-metal concentrations instead of total-metal concentrations. The USEPA Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria (Prothro 1993) concluded, “dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal.” Therefore, the KDHE total-metal criteria for cadmium, lead, and zinc were calculated using a site-specific hardness of 361 milligrams per liter (mg/L) as calcium carbonate($CaCO_3$), and were then converted to dissolved-metal concentrations using the USEPA (2013) total-to-dissolved criteria conversion factors. Because dissolved-metal concentrations were analyzed in the pore

water samples, and because dissolved-metal concentrations are a better indicator of metal bioavailability (Prothro 1993), the dissolved-metal criteria that would be predicted from the KDHE total-metal chronic aquatic life WQC screening values were chosen for the bioavailability evaluation. The pore water evaluation is presented in **Table 2-2**. The results of the pore water evaluation are discussed in Section 2.3.

2.2.1.2 SEM-AVS Equilibrium Partitioning Approach

As mentioned above, metal (cadmium, copper, lead, nickel, silver and zinc) bioavailability can be assessed by comparing the molar AVS concentration to the SEM concentrations, which is the concentration of metal released from the sediment during AVS extraction. If the sum of SEM concentrations for all five divalent metals (SSEM) is less than or equal to the concentration of AVS (SSEM/AVS ≤ 1), the metal toxicity for benthic organisms is low. If the SSEM is greater than the concentration of AVS (SSEM/AVS > 1), the excess fraction is potentially available as free metal and thus might cause toxicity. In this case, additional analyses might be needed to evaluate whether the excess free metal can bind to other constituents in the interstitial water such as OC or ferric oxides. For this SERE, the SEM concentration of silver was not analyzed; therefore, the SSEM includes only the concentration of cadmium, copper, lead, nickel, and zinc (in units of micromoles per gram [µmol/g]). The monovalent metal silver has the smallest solubility product and the greatest affinity for sulfides of all the SEM metals and, therefore, would be the first metal to bind with AVS and the last metal to be released from the AVS. The concentration of silver in Wilson County sediment, however, was assumed to be minimal for this assessment and is not expected to influence the final SSEM concentration.

If the concentration of AVS is greater than the concentration of SEM in sediment on a molar basis, the metals are at very low concentrations in the pore water and do not cause toxicity (Ankley et al. 1996; USEPA 2005b). This premise has been shown to be valid in toxicity tests of sediments collected from sites contaminated primarily with metals (Casas and Crecelius 1994; Hansen et al. 1996; Ogendi et al. 2007; Besser et al. 2009).

The SEM/AVS approach also addresses the role of OC as a secondary factor controlling the bioavailability of these metals in sediments where SEM concentrations exceed the concentrations of AVS. Di Toro et al. (1999) predicted with 90 percent confidence that sediment toxicity will not occur if the organic-carbon normalized concentration of “excess” metals ([SSEM-AVS]/fraction organic carbon [f_{oc}]) is lower than 130 micromole per gram organic carbon (µmol/g_{OC}). Similarly, sediment toxicity is expected with 90 percent confidence if (SSEM-AVS)/f_{oc} exceeds 3,000 µmol/g_{OC}. The

likelihood of toxicity associated with intermediate values is uncertain (i.e., [SSEM-AVS]/f_{oc} values between 130 and 3,000 µmol/g_{OC}). This same guidance is included in USEPA (2005b). The results from this second line of evidence are presented in **Table 2-3** and discussed in Section 2.3.

2.2.1.3 Total Allowable Metal Concentrations

Although the guidance for evaluating the potential toxicity of OC-normalized SSEM-AVS concentrations is useful, it does not differentiate among the different affinities of the metals for OC particles and does not account for additional solid phases (e.g., metal oxides) that might also render the metals less bioavailable. Therefore, the metal-specific calculations described in this section can be used to refine the OC-normalized SSEM-AVS calculations.

The relative affinity of a metal to bind to AVS can be used to assess the potential bioavailability of individual metals. Berry et al. (1996) reported that the relative AVS affinity for the five divalent cationic metals should be copper > lead > cadmium > zinc > nickel. Therefore, the AVS should preferentially bind to the metal with the greatest affinity (copper) before substantially binding with subsequent, lower-affinity metals. Applying this concept, the potential bioavailability of a given metal can be assessed by comparing the molar AVS concentration to the sum of the SEM concentrations for the divalent metals with greater affinity for AVS. For example, the bioavailability of SEM zinc can be evaluated by comparing its molar concentration in the sediment to the molar concentration of residual AVS available for binding to zinc after accounting for AVS binding to copper, lead, and cadmium (i.e., total AVS concentration minus the sum of the SEM concentrations for copper, lead, and cadmium).

In addition to the high affinity of AVS for cationic metals, OC has binding capacity that can decrease the activity of free metal not bound by AVS (i.e., if SSEM exceeds the AVS concentration), thereby decreasing sediment toxicity beyond what would be predicted by only calculating the difference between SSEM and AVS (i.e., SSEM/AVS). To evaluate the effect of OC binding, excess-metal concentrations are normalized to the f_{oc} in the sediment by calculating the ratio (SSEM-AVS)/f_{OC}. That ratio is then compared to the applicable chronic criteria concentration for the interstitial water in that sediment, after multiplying the criteria concentration by the OC partition coefficient ($K_{d,OC}$) for that metal (to account for amplification of the metal concentration bound to the OC, relative to the maximum metal concentration that would be allowed in the interstitial water; McGrath 2002). Metal-specific OC partition coefficients were reported by Mahony et al. (1996) and supplemented by Carbonaro et al. (2005).

Empirical, site-specific carbon-partition coefficients can be calculated when both the SEM concentration for a metal and its corresponding interstitial-water dissolved metal concentration are known as follows:

$$K_{d,OC} = \frac{C_{dry} - C_{dis} \cdot \frac{w}{1-w}}{f_{OC} \cdot C_{dis}}$$

where:

$K_{d,OC}$ = empirical OC partition coefficient of the metal (L/kg OC)
f_{OC} = measured fraction of OC in sediment (kg OC/kg dry sed)
w = moisture fraction in sediment (g moisture/g wet sed)
C_{dry} = excess metal concentration in dry sediment (SEM concentration of metal not bound by AVS; moles metal/kg dry sed)
C_{dis} = dissolved metal concentration in interstitial water (moles metal/L)

This third line of evidence for the bioavailability evaluation involved the calculation of total "allowable" COPEC concentrations in bulk sediment. The "allowable" concentration is the bulk sediment concentration that is protective to biological organisms. This concentration is calculated by applying the applicable KDHE chronic aquatic life WQC to the interstitial-water concentrations and assuming that metal concentrations bound by AVS and other binding phases (e.g., OC and ferric oxides) do not contribute to the sediment toxicity. Because arsenic does not bind to AVS, the calculations for the bioavailability of arsenic do not include the AVS partitioning mechanism (i.e., it does not include calculation C below). The total "allowable" metal concentration in dry sediment is assumed to be the sum of:

(1) the "allowable" concentration of a given metal bound to OC in the sediment:

$$\mathrm{A} = K_d \cdot f_{OC} \cdot WQC$$

(2) the "allowable" concentration of that metal in the interstitial water:

$$\mathrm{B} = WQC \cdot \frac{w}{1-w}$$

and

(3) the concentration of that metal bound to AVS in the sediment (C).

This concentration of the given metal is calculated by performing a series of comparisons to determine the appropriate value of C.

If: $\left(AVS - \sum SEM\right) < 0$

$C = 0$

If: $\left(AVS - \sum SEM\right) > \mathrm{SEM_M}$

$C = SEM_M$

If: $\left(AVS - \sum SEM\right) < \mathrm{SEM_M}$

$C = AVS - \sum SEM$

where:

K_d = empirical partitioning coefficient (L/kg OC)

WQC = Kansas chronic aquatic life water quality criterion (moles metal/L)

AVS = measured AVS (µmol/g)

ΣSEM = sum of SEM concentrations for metals with greater affinity to AVS than the given metal

SEM_M = SEM concentration of the metal of interest

The Kansas chronic aquatic life WQC values were taken from the KDHE, Bureau of Water, Kansas Surface Water Quality Standards, Tables of Numeric Criteria, December 6, 2004. Values shown are for the chronic aquatic life category and have been calculated using a Site hardness of 361 mg/L as $CaCO_3$ and converted to dissolved concentrations using the USEPA total-to-dissolved criteria calculator.

The initial evaluation was performed using an empirical OC partitioning coefficient for K_d to calculate A in Equation 1 above; however, it was observed that the OC mechanism provided limited additional binding capacity, in contrast to an apparent large amount of non-AVS-associated zinc, as indicated by measured concentrations of SEM zinc and interstitial-water zinc in Lower Drainage Area sediments. Therefore, a dry-sediment-basis empirical partition coefficient ($K_{d,dry\ sed}$) was developed based on partitioning to all non-AVS sediment particles instead of only to OC. This coefficient was calculated similarly to the OC partition coefficient equation presented above, but did not include the OC-fraction term:

$$K_{d,dry\ sed} = \frac{C_{dry} - C_{dis} \cdot \frac{w}{1-w}}{C_{dis}}$$

where:

$K_{d,dry\ sed}$ = empirical dry sediment partitioning coefficient (L/kg dry sed).

The empirical dry-sediment partition coefficient accounts for all binding phases other than AVS and therefore is more appropriate to use when calculating the true site-specific bioavailability of the metal. The empirical dry-sediment partition coefficient was calculated for sediments collected from the drainage area and for which interstitial-water metal concentrations and SEM concentrations were measured. A unique partition coefficient was calculated for each of the metals evaluated. Then the geometric mean of the calculated partition coefficients for each metal was applied to each sediment sample from the drainage area and the off-Property ponds (i.e., by substituting the empirical partition coefficient onto all solid phases in the sediment into Equation 1 above to calculate A), after which the total concentration of each metal that would be "allowable" in each sample was determined by summing the values of A, B, and C calculated in Equations 1, 2, and 3 above. Lacking data to calculate empirical K_d values for the pond sediments, it was assumed that the metal-partition coefficients would be similar in sediments in the drainage area and the ponds.

The "allowable" metal concentration calculated for each sediment sample was then compared to the laboratory reported dry-sediment concentration. Sediment with concentrations exceeding the "allowable" bulk sediment concentration for a given metal have the potential to contain interstitial-water concentrations that would exceed the KDHE chronic WQC at a Site surface water hardness of 361 mg/L as $CaCO_3$. "Allowable" metal concentrations are presented in **Table 2-4**. The calculations for all four metals (arsenic, cadmium, lead, and zinc) are included in **Appendix E**. The results of the "allowable" metal calculations are discussed in Section 2.3.

It should be noted that AVS/SEM data were collected at the Site for the purpose of completing an EqP analysis as described above; however, each location with AVS/SEM data also had pore water sample results, which were used as the primary line of evidence for the bioavailability evaluation.

2.2.2 Toxicity of Metals to Fish

Just as the dissolved pore water concentrations were compared to KDHE chronic aquatic life WQC values (KDHE 2004b) for the protection of benthic invertebrates, the WQC values can also be used to evaluate the potential risk to fish and other water

column organisms. Pore water data were conservatively used to evaluate the water column conditions using the calculated WQC described above. Pore water concentrations below the WQC were considered to be not impacted and protective of fish and other water column organisms. Values shown in **Table 2-2** are for the chronic aquatic life category and have been calculated using a Site surface water hardness of 361 mg/L as $CaCO_3$ and converted to dissolved concentrations using the USEPA total-to-dissolved criteria calculator.

It is important to note that, at this time, the presence of fish populations within the Man-Made Ponds has not been determined, and fish populations are not expected to occur in any of the Man-Made Ponds because of their known intermittency during the summer (ponds are dry for portions of the summer). Any fish that occur in the Man-Made Ponds are expected to be the result of entering a pond during flood events or via fish eggs introduced to the pond on visiting birds. The intermittent presence of water in the Man-Made Ponds prevents the establishment of resident fish populations and long-term benthic invertebrate life.

2.2.3 Wildlife Exposure

As mentioned previously, after a joint Site inspection on March 12, 2014, subsequent conference calls, and electronic and verbal correspondence, Cyprus and the KDHE jointly determined that quantitative food chain modeling was not going to change the outcome of the streamlined ecological risk evaluation and thus, was not warranted at the Altoona site. However, the issue was not ignored, and the exposure potential of common upper trophic level receptors (e.g., avian and mammalian herbivores, invertivores, and piscivores) was evaluated using the concept of spatial extent.

The potential for ecological exposure is directly related to the size or space of the affected area, if habitat is present. Spatial scale can be useful as a screening criterion if used in conjunction with other considerations, such as the valued ecological resources that may be present, current and future land use, and the proximity to a high value or sensitive ecological habitat (e.g., wildlife management area). Spatial-scale screening criteria are used widely in ecological risk assessment (Barnthouse et al. 2008). Although Kansas does not have any guidance on spatial-scale criteria, several states' guidance address the importance of spatial-scale in ecological assessments, as does the ASTM International (ASTM) Standard Guide for Risk-Based Corrective Action for Protection of Ecological Resources (ASTM 2002). For example, the following spatial-scale screening criteria are used by the following states: 1 to 2 acres for Minnesota (the smaller scale for bioaccumulative compounds); 1 acre for Texas and Mississippi; 2 acres for Pennsylvania; 5 acres for Louisiana; and 2 acres or

1,000 square feet of sediments for Massachusetts (Minnesota Pollution Control Agency [MPCA] 1998; Texas Commission on Environmental Quality [TCEQ], formerly Texas Natural Resource Conservation Commission [TNRCC] 2001; Mississippi Department of Environmental Quality [MDEQ] 1997; Louisiana Department of Environmental Quality [LDEQ] 2003; Pennsylvania Department of Environmental Protection [PADEP] 1998; and Massachusetts Department of Environmental Protection [MADEP] 1996). This spatial-scale criterion has often been referred to as "*de minimis*" because such small-scale impact is not expected to cause adverse effects to the population, community, or ecosystem, providing other conditions (e.g., absence of threatened or endangered species) are met (Suter et al. 1995; Henning and Shear 1998; Barnthouse et al. 2008). As discussed in Section 2.1.2, there have been no known occurrences of state or federal listed threatened or endangered species at the Man-Made Ponds or Lower Drainage Area. Therefore, the logic that such small-scale impact would not affect populations, communities, or ecosystems is reasonable for this SERE.

In addition, area use factors (AUF) were calculated based on literature values for the home/foraging range of typical wildlife receptors. For all receptors, those home/foraging ranges are larger than the evaluated area (i.e., the area encompassed by each of the Man-Made Ponds and the Lower Drainage Area). AUFs are a simple ratio wherein the area of the affected medium is divided by the area of the home or foraging range of the receptor. **Table 2-5** provides the home/foraging range acreages obtained from the literature for common receptors that may utilize the Lower Drainage Area and the off-Property Man-Made Ponds.

2.3 Risk Characterization

2.3.1 Benthic Invertebrates

As discussed in Section 2.1.3, metal concentrations in sediments that exceeded background UTLs were evaluated further in the SERE as COPECs. Based on the comparison to background UTLs (**Table 2-1**), the following metals were identified as sediment COPECs and were carried into the bioavailability evaluation:

Lower Drainage Area Transects 24 through 27: Cadmium, Lead, and Zinc
Man-Made Pond 1: Lead and Zinc
Man-Made Pond 3: No COPECs identified
Man-Made Pond 4: No COPECs identified
Northeast Pond: No COPECs identified

The results of the UTL ER analysis (based on the ratio of 95% UCL to background UTL) are presented in **Figure 2-3 and Figure 2-4**, for the Lower Drainage Area Transects 24 through 27 and Man-Made Ponds, respectively.

A bioavailability evaluation was completed for the Lower Drainage Area Transects and Man-Made Pond 1 with exceedances of the applicable UTLs. Bioavailability was evaluated through comparison of dissolved pore water metal concentrations to the KDHE chronic aquatic life WQC adjusted to dissolved-metal concentrations using the USEPA (2013) total-to-dissolved conversion factors, and through the use of the equilibrium partitioning approach, previously described in Section 2.2.1. The results for the bioavailability evaluation are presented in **Tables 2-2 through 2-4** and summarized in the following sections.

2.3.1.1 Lower Drainage Area Transects

Lower Drainage Area Transects with UTL exceedances were further examined as part of the bioavailability evaluation. Sediments were evaluated using three approaches that estimate the bioavailability of COPECs cadmium, lead, and zinc.

The first approach is the evaluation of pore water (**Table 2-2**). The metal concentrations in the 11 pore water samples collected from the Lower Drainage Area did not exceed the KDHE chronic aquatic life WQC values (**Figure 2-5**). As a result, cadmium, lead, and zinc concentrations reported in the bulk sediment samples that exceeded the UTL from Transects 24 through 27 are bioavailable at concentrations considered to be protective of aquatic life.

As a second approach, SEM metals data for all sediment samples collected from the Lower Drainage Area were evaluated using the EqP methodology. **Table 2-3** evaluates SEM metals data for these sediment samples. As discussed in Section 2.2, sediment toxicity is not expected to occur if the (SSEM-AVS)/f_{oc} is less than 130 µmol/g_{OC} but is expected if (SSEM-AVS)/f_{oc} exceeds 3,000 µmol/g_{OC}. The likelihood of toxicity associated with intermediate values is uncertain. For samples collected from the Lower Drainage Area Transects, the (SSEM-AVS)/foc values ranged from 106 µmol/gOC to 310 µmol/gOC. All results are less than 130 or slightly exceed 130 (between 130 and 3,000) µmol/gOC, which indicates that toxicity to benthic invertebrates is predicted to be not likely or uncertain.

The third approach, which is based on the results of the calculation of allowable metal concentrations using empirical, site-specific carbon-partition coefficients, further supports the conclusion that COPEC concentrations in the Lower Drainage Area

sediment do not pose a hazard to benthic invertebrates. As seen in **Table 2-4**, allowable cadmium, lead, and zinc concentrations in sediment are greater than the measured SEM concentrations; therefore, the bulk sediment concentrations in Transects 24 through 27 are protective of biological organisms.

2.3.1.2 Man-Made Pond Locations

Man-Made Pond 1 with UTL exceedances was further evaluated as part of the bioavailability evaluation. As in the Lower Drainage Area, Pond 1 sediments were evaluated using three approaches that estimate the bioavailability of COPECs lead and zinc.

The first approach is the evaluation of pore water. The metal concentrations in the Pond 1 pore water samples were below KDHE chronic aquatic life WQC values (**Figure 2-6**). Therefore, the metal concentrations in Pond 1 bulk sediments are considered bioavailable at concentrations protective of aquatic life.

As a second approach, SEM metals data for all sediment samples collected from Man-Made Pond 1 were evaluated using the EqP methodology. For all samples collected from Pond 1, the (SSEM-AVS)/f_{oc} is negative, indicating that toxicity due to lead and zinc will not be observed because all the metals are bound as insoluble sulfides and are not biologically available to benthic receptors from sediment. Excess capacities for metals were high, indicating that ample AVS is present to bind any cationic metals.

The third approach, which is based on the results of the calculation of allowable metal concentrations using empirical, site-specific carbon-partition coefficients further supports the conclusion that COPEC concentrations in Man-Made Pond 1 sediment do not pose a hazard to benthic invertebrates. As seen in **Table 2-4**, allowable lead and zinc concentrations in sediment are greater than the measured SEM concentrations; therefore, the bulk sediment concentrations in Pond 1 are protective of biological organisms.

2.3.2 Fish and Other Water Column Organisms

Pore water data collected from the Lower Drainage Area Transects and Man-Made Pond 1 was conservatively used to evaluate the water column conditions using the modified chronic WQC. This approach assumes that pore water concentrations are representative of water column concentrations, which is a very conservative assumption because the effect of dilution (from pore water to overlying water column) is not accounted for. As seen in **Table 2-2**, pore water concentrations are below the

WQC; therefore, they are considered to be not impacted and protective of fish and other water column organisms.

2.3.3 Wildlife

As discussed in Section 2.2.3, the potential for ecological exposure is directly related to the size or space of the affected area, if habitat is present. The acreage determined for the Lower Drainage Area (Transects 24 through 27) and for off-Property Pond 1 are 0.14 acre and 1 acre, respectively. In comparison, home ranges for common upper trophic level wildlife receptors presented in **Table 2-5** range from 220 acres (lesser scaup) to 7,413 acres (great blue heron).

AUFs were calculated based on literature values for the home/foraging range of common wildlife receptors. For all receptors, those home ranges are larger than the evaluated area (i.e., the area encompassed by the Man-Made Pond 1 and the Lower Drainage Area). AUFs are calculated for common upper tropic level mammalian and avian receptors on **Table 2-5** and range from 0.00002 to 0.00064 for the Lower Drainage Area and from 0.0001 to 0.0046 for Pond 1. Based on this evaluation, it is extremely unlikely that a receptor could obtain its entire dietary requirements from Pond 1 and the Lower Drainage Area, and the exposure risk for wildlife receptors is considered negligible.

3. Uncertainty Analysis

Uncertainties may result from the use of judgments or models in lieu of actual data, and from the error inherent in estimating exposure parameters. These uncertainties may result in a potential overestimation or underestimation of risks. However, because direct measurements are not available for many of the components upon which the risk estimates depend, conservative assumptions and methodologies are generally employed to eliminate the possibility of underestimating risk.

As described in the following sections, the SERE uses a conservative approach that is much more likely to overestimate risks than underestimate.

3.1 Complexity of Natural Systems

Natural systems are complex and involve the interaction of a number of physical, chemical, and biological systems. The SERE attempts to model these interactions to the extent possible and uses simplifying assumptions to do so. Direct measurements of chemical concentrations are used, along with information from current scientific literature, to model the interactions that may be occurring in natural systems. The assumptions made and models used, and how well or poorly these assumptions and models reproduce the interactions taking place in the natural system, introduce uncertainty in the SERE Report. An effort has been made to use conservative assumptions so that the potential risk to ecological receptors is not underestimated.

3.2 Sampling and Analysis, and Data Evaluation

Data used in the SERE were analyzed using approved USEPA methods and following appropriate quality assurance/quality control procedures in accordance with the SERE approach presented to KDHE representatives during conference calls on April 7, 18, and 30, 2014 (and verbally approved during those conference calls and through email correspondence on April 15, 2014 from Maura O'Halloran [KDHE] to Alicia Voss [Cyprus]). Data used in the SERE were validated, and the overall quality of the data was assessed.

The metal concentrations in the 11 pore water samples collected from the Lower Drainage Area did not exceed the KDHE chronic aquatic life WQC values with the exception of one sample (E-C-26-M-00.0-00.1). The results for sample E-C-26-M-00.0-00.1 were anomalously high when compared to surrounding samples. In an effort to replicate the June 2012 results, confirmation samples were collected in November 2012 from a total of eight locations:

- Four locations immediately upstream (Transects 25+25, 25+50, 25+75, and 25+100; where the number after the "+" sign indicates distance downstream from Transect 25, in feet)
- One location downstream (Transect 27)
- Two locations, one from each side of the original sample (Transects 26-M-East and 26-M-West)
- One location from the original sample location (Transect 26-M-Center).

The pore water concentrations of metals in the eight confirmation samples were similar across locations, were similar to the June 2012 concentrations from Transects 24 and 25, and were below the KDHE chronic WQC. The anomalous pore water concentrations of cadmium and zinc reported in the June 2012 analysis of E-C-26-M-00.0-00.1 could not be replicated in any of the eight confirmation samples.

As discussed during the April 30, 2014 conference call with KDHE, because the results from E-C-26-M-00.0-00.1 were not reproducible upon subsequent resampling at that location and surrounding locations, the pore water results from the eight confirmation samples are considered representative of sediment conditions in the area of Transects 24 through 27.

3.3 SEM-AVS Approach

As discussed previously, the SEM concentration of silver was not analyzed; therefore, the SSEM includes only the concentration of cadmium, copper, lead, nickel, and zinc. Silver has the smallest solubility product and the greatest affinity for sulfides of all the SEM metals and, therefore, would be the first metal to bind with AVS and the last metal to be released from the AVS. The concentration of silver in Wilson County sediment, however, was assumed to be minimal for this assessment and is not expected to influence the final SSEM concentration.

4. Summary and Conclusions

This SERE was conducted for the Lower Drainage Area Transects 24 through 27 and four off-Property Man-Made Ponds to evaluate whether aquatic ecological receptors may be adversely impacted by exposure to four metals (arsenic, cadmium, lead, and zinc) associated with the Former Altoona Zinc Smelter Property located in Altoona, Kansas. COPECs were identified based on UTL ERs (calculated for direct-contact using background UTLs) and risks were characterized based on the bioavailability of the metals, limited size of the Lower Drainage Area and off-Property Man-Made Ponds, and quality of the available habitat.

Sediment samples collected from Transects 24 through 27 and Man-Made Pond 1 contained concentrations of metals above background UTLs and, therefore, were carried forward in the evaluation as COPECs. The concentrations of metals in Man-Made Pond 3, Pond 4, and Northeast Pond were below background UTLs; therefore, no COPECs were identified for these three ponds.

Dissolved pore water concentrations and bulk sediment SEM/AVS data from the Lower Drainage Area Transects 24 through 27 and Man-Made Pond 1 were evaluated to determine if metals in sediment are present at concentrations considered protective of aquatic life. The conclusions from the SERE are presented below by area.

4.1 Lower Drainage Area Transects 24 through 27

- Metal concentrations in pore water samples from Transects 24 through 27 are below KDHE chronic aquatic life WQC values. Therefore, the metal concentrations in sediments from the Lower Drainage Area are considered to be protective of aquatic life.
- For SEM/AVS, the analysis indicates that toxicity to benthic invertebrates from cadmium, lead and zinc is predicted to be not likely or uncertain because all (or a significant portion) of the metals are bound as insoluble sulfides and are not biologically available to benthic receptors from sediment (specifically, all (SSEM-AVS)/f_{oc} results are less than 130 or slightly greater than 130 [between 130 and 3,000] µmol/g_{OC}).
- The “allowable” cadmium, lead, and zinc concentrations in sediment calculated using empirical, site-specific carbon-partition coefficients are greater than the measured SEM sediment concentrations; therefore, the bulk sediment concentrations in the Lower Drainage Area are protective of biological organisms.

- Based on the AUF evaluation, it is extremely unlikely that an upper trophic level wildlife receptor could obtain its entire dietary intake from the Lower Drainage Area. Therefore, the COPEC concentrations in sediments of the Lower Drainage Area are not expected to pose a risk to the sustainability of herbivorous, invertivorous, and piscivorous mammal and bird populations.

- Based on these conclusions and in accordance with USEPA guidance (1997), there is adequate information to conclude that any ecological risks are negligible and no further ecological assessment is warranted for the Lower Drainage Area Transects 24 through 27.

4.2 Man-Made Pond 1

- The metal concentrations in pore water samples collected from Pond 1 are below KDHE chronic aquatic life WQC values. Therefore, the metal concentrations in sediments from Pond 1 are considered protective of aquatic life.
- For all samples collected from Pond 1, the SEM/AVS analysis indicates that toxicity due to lead and zinc will not be observed because all of the metals are bound as insoluble sulfides and are not biologically available to benthic receptors from sediment (specifically, the (SSEM-AVS)/f_{oc} is less than 130 µmol/g_{OC}).

- The “allowable” lead and zinc concentrations calculated using empirical, site-specific carbon-partition coefficients are greater than the measured SEM concentrations; therefore, the bulk sediment concentrations in Pond 1 are protective of biological organisms.

- Based on the AUF evaluation, it is extremely unlikely that an upper trophic level wildlife receptor could obtain its entire dietary intake from Pond 1. Therefore, the COPEC concentrations in sediment of Pond 1 are not expected to pose a risk to the sustainability of herbivorous, invertivorous, and piscivorous mammal and bird populations.

- Based on these conclusions and in accordance with USEPA guidance (1997), there is adequate information to conclude that any ecological risks are negligible and no further ecological assessment is warranted for the Man-Made Pond 1.

5. References

Adams, W. J., Kimerle, R. A. and Mosher, R. G.1983. Aquatic safety assessment of chemicals sorbed to sediment. Proceedings of the Seventh Annual ASTM Aquatic Toxicology Symposium. R. D. Cardwell, R. Purdy and R. C. Bahner, editors. Special Technical Publication STP 854; pp. 429-453.

Ankley, G.T., D.M. Di Toro, D.J. Hansen, and W.J. Berry. 1996. Technical basis and proposal for deriving sediment criteria for metals. *Environ. Toxicol. Chem.* 15:2056-2066.

ARCADIS. 2014. Removal Site Evaluation, Former Altoona Smelter Property Altoona, Kansas. May 30, 2014.

ASTM International (ASTM). 2002. Risk-Based Standard Guide for the Protection of Ecological Resources (Eco-RBCA). ASTM International, E2205-02. Conshohocken, PA.

ATSDR. 2005. Toxicological Profile for Zinc. U.S. Department of Health and Human Services, Public Health Service. August.

ATSDR. 2007a. Toxicological Profile for Arsenic. U.S. Department of Health and Human Services.

ATSDR. 2007b. Toxicological Profile for Lead. U.S. Department of Health and Human Services, Public Health Service. August.

ATSDR. 2012. Draft Toxicological Profile for Cadmium. US Department of Health and Human Services, Public Health Service. September.

Barnthouse, L.W., W.R. Munns, and M.T. Sorensen (eds). 2008. Population-Level Ecological Risk Assessment. CRC/Taylor & Francis. Published by the Society of Environmental Toxicology and Chemistry (SETAC). 337 p.

Berry WJ, Hansen DJ, Mahony JD, Robson DL, Di Toro DM, Shipley BP, Rogers B, Corbin JM, Boothman WS. 1996. Predicting the toxicity of metal-spiked laboratory sediments using acid volatile sulfide and interstitial water normalizations. Environ Toxicol Chem 15:2067-2079.

Besser, J.M., W. G. Brumbaugh, D. K. Hardesty, J. P. Hughes, and C. G. Ingersoll. 2009. Assessment of metal-contaminated sediments from the Southeast Missouri (SEMO) mining district using sediment toxicity tests with amphipods and freshwater mussels. U.S. Geological Survey, Columbia Environmental Research Center, Columbia Missouri. Administrative Report 08-NRDAR-02.

Bridgewater Group, Inc. in Association with ARCADIS U.S., Inc. 2011. Removal Site Evaluation Plan, Former Zinc Smelter, Altoona, Kansas. September 2011.

Carbonaro RF, Mahony JD, Walter AD, Halper EB, Di Toro DM. 2005. Experimental and modeling investigation of metal release from metal-spiked sediments. Environ Toxicol Chem 24:3007-3019.

Casas, A.M. and E.A. Crecelius. 1994. Relationship between acid volatile sulfide and the toxicity of zinc, lead and copper in marine sediments. Environ. Tox. Chem. Volume 13, Issue 3, pp 529-536, March.

Chapman, Shannen S., Omernik, James M., Freeouf, Jerry A., Huggins, Donald G., McCauley, James R., Freeman, Craig C., Steinauer, Gerry, Angelo, Robert T., and Schlepp, Richard L. 2001. Ecoregions of Nebraska and Kansas (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,950,000).

Di Toro DM, Zarba CS, Hansen DJ, Berry WJ, Swartz RC, Cowan CE, Pavlou SP, Allen HE, Thomas NA, Paquin PR. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Environ Toxicol Chem 10:1541-1583.

Di Toro, D.M., D.J. Hansen, J. McGrath, and W.J. Berry. 1999. Predicting the toxicity of metals in sediments using SEM and AVS. Abstract, Society of Environmental Toxicology and Chemistry. 20th Annual Meeting, Philadelphia, PA. November.

Eisler, R. 1988. Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85(1.14)/Contaminant Hazard Review Report No. 14. US Fish and Wildlife Service. April.

Eisler, R. 1993. Zinc hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 10, Contaminant Hazard Reviews Report 26. 106 pp.

Fritioff, A. and M. Greger. 2006. Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant Potamogeton natans. Chemosphere. 63 (2): 220-227.

Genter, R.B., D.S. Cherry, E.P. Smith, and J. Cairns Jr. 1987. Algal-periphyton population and community changes from zinc stress in stream mesocosms. Hydrobiologia 153: 261-275.

Hansen, D.J., W.J. Berry, J.D. Mahony, W.S. Boothman, D.M. Di Toro, D.L. Robson, G.T. Ankley, D. Ma, Q. Yan, and C.E. Pesch. 1996. Predicting the Toxicology of Metal-Contaminated Field Sediment Using Interstitial Concentrations of Metals and Acid-Volatile Sulfide Normalizations. *Eviron. Toxicol. Chem.* (SETAC). Vol. 15 No. 12:2080-2094.

Henning, M. and N. Shear. 1998. Regulatory perspectives on the significance of ecological changes as reported in ecological risk assessments. Human and Ecological Risk Assessment, 4(4)807-814.

International Programme on Chemical Safety (IPCS). 1992. Environmental Health Criteria 135: Cadmium-Environmental Aspects. World Health Organization. Geneva.

Irwin, R.J. 1997. Environmental contaminants encyclopedia. Arsenic entry. National Park Service. WaterResources Division.

Kansas Department of Health and Environment (KDHE). 2004a. Sediment Policy. Bureau of Environmental Remediation (BER) Policy # BER-ARS-045. January 9.

KDHE. 2004b. Kansas Surface Water Quality Standards, Tables of Numeric Criteria. Bureau of Water. December 6.

Kansas Department of Wildlife, Parks and Tourism (KDWPT). 2014. Website accessed April 29, 2014. http://kdwpt.state.ks.us/Services/Threatened-and-Endangered-Wildlife/List-of-all-Kansas-Counties/Wilson

Kemp P.F. and Swartz RC. 1986. Acute toxicity of interstitial and particle-bound cadmium to a marine infaunal amphipod. Mar Environ Res 26:135-153.

Leland, H.V., and J.S. Kuwabara. 1985. Trace Metals. In: (Eds) G.M. Rand and S.R. Petrocelli. Fundamentals of Aquatic Toxicology. Hemisphere Publishing Corporation. New York, New York. pp. 374-415.

Louisiana Department of Environmental Quality (LDEQ). 2003. Risk Evaluation/Corrective Action Program. Louisiana Administrative Code 33:I. Chapter 13. October 20.

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

Mahony JD, Di Toro DM, Gonzalez AM, Curto M, Dilg M, De Rosa LD, Sparrow LA. 1996. Partitioning of metals to sediment organic carbon. Environ Toxicol Chem 15:2187-2197.

Mason, R.P., J.M. Laporte, and S. Andres. 2000. Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium, and cadmium, by freshwater invertebrates and fish. Archives of environmental contamination and toxicology. 38: 283-297.

Massachusetts Department of Environmental Protection (MADEP). 1996. Massachusetts Contingency Plan: Environmental Risk Characterization (Chapter 9). Bureau of Waste Site Cleanup, WCS/ORS-95-141. April.

Maxim Technologies Inc. (Maxim). 2003. Focused Former Smelter Assessment Report, Altoona, Kansas, January 31, 2003.

McGrath JA, Paquin RP, Di Toro DM. 2002. Use of SEM and AVS approach in predicting metal toxicity in sediments. ICMM. 10.

Minnesota Pollution Control Agency (MPCA). 1998. Appendix 2: The Risk-Based Site Evaluation Process, Checklist for RBSE Implementation and Documentation.

Mississippi Department of Environmental Quality (MDEQ). 1997. Risk Evaluation Procedures for Voluntary Cleanup and Redevelopment of Brownfield Sites. Subpart II.

Ogendi, G.M., W.G. Brumbaugh, R.E. Hannigan, and J.L. Farris. 2007. Effects of acid-volatile sulfide on metal bioavailability and toxicity to midge (Chironomus tentans) larvae in black shale sediments. *Environ Toxicol Chem.* 26(2):325-34.

Pennsylvania Department of Environmental Protection (PADEP). 1998. Ecological Screening Process. Attachment V.E.3 of Ecological Health Evaluation – Screening Procedure for Sites in Pennsylvania.

Prothro, M.G. 1993. Office of Water Policy and Technical Guidance On Interpretation and Implementation of Aquatic Metals Criteria. Memorandum from Acting Assistant Administrator for Water, Washington, DC. USEPA Office of Water, October 1, 1993.

Robertson, R.J., B.J. Stutchbury, and R.R. Cohen. 1992. Tree Swallow (Tachycineta bicolor). P. 1-26. In: A. Poole, P. Stettenheim, and F. Gill (eds). The Birds of North America, No. 11. The Birds of North America, Inc, Philadelphia, PA, USA.

Sample, B.E., D.M. Opresko, and G.W. Suter II. 1996. Toxicological Benchmarks for Wildlife, 1996 Revision. USDOE, Risk Assessment Program, Health Sciences Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Suter, G.W, B.W. Cornaby, C.T. Hadden, R. N. Hull, M. Stack, and F.A. Zafran. 1995. An approach for balancing health and ecological risks at hazardous waste Facilities. Risk Analysis 15(2)221-231.

Swartz R.C., Dittsworth G.R., Schults D.W., Lamberson J.O. 1985. Sediment toxicity to a marine infaunal amphipod:Cadmium and its interaction with sewage sludge. Mar Environ Res 18:133-153.

Texas Natural Resource Conservation Commission (TNRCC). 2001. Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas. RG-263 (revised). Office of Waste Management. December.

U.S. Environmental Protection Agency (USEPA). 1985. Ambient Aquatic Life Water Quality Criteria for Arsenic. EPA#: 440/5-84-033.

USEPA. 1989. Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Volume 1, Part A. Interim Final. Office of Emergency and Remedial Response, Washington, DC. EPA/540/1-89/002. December.

USEPA. 1992. Supplemental Guidance to RAGS: Calculating the Concentration Term. Publication 9285.7-08. Office of Solid Waste and Emergency Response, Washington, DC. (May 1992).

USEPA. 1993. Wildlife Exposure Factors Handbook. Office of Research and Development. EPA/600/R-93/187.

USEPA. 1997. "Ecological Risk Assessment Guidance for Superfund – Process for Designing and Conducting Ecological Risk Assessments." Environmental Response Team. June.

USEPA. 1998. "Guidelines for Ecological Assessment." Office of Research and Development, EPA/630/R-95/002FA. April 1998.

USEPA. 2000a. "Amended Guidance on Ecological Risk Assessment at Military Bases: Process Considerations, Timing of Activities, and Inclusion of Stakeholders." Memorandum from Ted W. Simon, Ph.D., Office of Technical Services. June 23.

USEPA. 2000b. Guidance for Data Quality Assessment, Practical Methods for Data Analysis, EPA QA/G-9, QA00 Update. Office of Environmental Information, Washington, DC. July. EPA/600/R-96/084.

USEPA. 2001a. Region 4 Ecological Risk Assessment Bulletins - Supplement to RAGS. [Webpage]. Located at: http://www.epa.gov/region4/waste/ots/ecolbul.htm. Accessed: 2001.

USEPA. 2001b. ECO-Update: Role of Screening-level Risk Assessments and Refining Contaminants of Concern in Baseline Ecological Risk Assessments. [Webpage]. Located at: http://www.epa.gov/superfund/programs/risk/ecoup/slera0601.pdf. Accessed: 2002.

USEPA. 2001c. Ecotox Database System. [Webpage]. Located at:. http://www.epa.gov/med/databases/databases.html. Accessed: 2001.

USEPA. 2001d. "Region 5 Superfund Ecology Technical Center Glossary". [Webpage] Located at: http://www.epa.gov/R5Super/eco/eco_glossary.html. Accessed April 2010.

USEPA. 2001e. Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments). Publication 9285.7-47. December 2001.

USEPA. 2005a. Guidance for Developing Ecological Soil Screening Levels. United States Environmental Protection Agency. OSWER Directive 9285.7-55. Office of Solid Waste and Emergency Response, Washington, DC.

USEPA. 2005b. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc). EPA-600-R-02-011. Office of Research and Development, Washington, DC.

USEPA. 2007. Ecological Soil Screening Levels for Zinc. Interim Final. OSWER Directive 9285.7-73. Office of Solid Waste and Emergency Response. Washington, D.C. June.

USEPA. 2010. ProUCL Version 4.00.05 Technical Guide (Draft). EPA/600/R-07/041. Office of Research and Development, Washington, DC. (May 2010).

USEPA. 2013. National Recommended Water Quality Criteria. 2013. U.S. Environmental Protection Agency Office of Water. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#appendxa.

World Health Organization (WHO). 2001. Zinc. Environmental Health Criteria 221. Geneva, Switzerland: World Health Organization. [Webpage] Located at: http://www.who.int/ipcs/publications/ehc/ehc_221/en/index.html. Accessed in: March 2013.

Tables

Table 2-1
Sediment Risk Characterization and Identification of COPECs

Streamlined Ecological Risk Evaluation Report
Former Zinc Smelter
Altoona, Kansas

Constituent	95% Upper Confidence Limit in Sediment (a) (mg/kg)	Background Sediment Upper Tolerance Limit (UTL) (mg/kg)	Sediment UTL ER (b)	COPEC? (c) (Yes/No)	Rationale (c)
Sediment Samples from Lower Drainage Area Transects (T24-T27)					
Metals					
Arsenic	11.61	19.9	0.6	No	ER ≤ 1
Cadmium	7.19	3.45	2	Yes	ER > 1
Lead	80	96.7	0.8	No	ER ≤ 1
Zinc	708	402	2	Yes	ER > 1
Sediment Samples from Transect 24					
Metals					
Arsenic	12.58	19.9	0.6	No	ER ≤ 1
Cadmium	5.98	3.45	2	Yes	ER > 1
Lead	161	96.7	2	Yes	ER > 1
Zinc	751	402	2	Yes	ER > 1
Sediment Samples from Transect 25					
Metals					
Arsenic	11.96	19.9	0.6	No	ER ≤ 1
Cadmium	15.41	3.45	4	Yes	ER > 1
Lead	82	96.7	0.8	No	ER ≤ 1
Zinc	1397	402	3	Yes	ER > 1
Sediment Samples from Transect 26					
Metals					
Arsenic	11.08	19.9	0.6	No	ER ≤ 1
Cadmium	6.04	3.45	2	Yes	ER > 1
Lead	58	96.7	0.6	No	ER ≤ 1
Zinc	541	402	1	No	ER ≤ 1
Sediment Sample from Transect 27 (d)					
Metals					
Arsenic	6.3	19.9	0.3	No	ER ≤ 1
Cadmium	1.5	3.45	0.4	No	ER ≤ 1
Lead	26	96.7	0.3	No	ER ≤ 1
Zinc	180	402	0.4	No	ER ≤ 1
Sediment Samples from Pond 1					
Metals					
Arsenic	12.6	19.9	0.6	No	ER ≤ 1
Cadmium	4.8	3.45	1	No	ER ≤ 1
Lead	247	96.7	3	Yes	ER > 1
Zinc	965	402	2	Yes	ER > 1
Sediment Samples from Pond 3					
Metals					
Arsenic	8.46	19.9	0.4	No	ER ≤ 1
Cadmium	2.48	3.45	0.7	No	ER ≤ 1
Lead	130	96.7	1	No	ER ≤ 1
Zinc	529	402	1	No	ER ≤ 1
Sediment Samples from Pond 4					
Metals					
Arsenic	20.12	19.9	1	No	ER ≤ 1
Cadmium	0.49	3.45	0.1	No	ER ≤ 1
Lead	46	96.7	0.5	No	ER ≤ 1
Zinc	113	402	0.3	No	ER ≤ 1
Sediment Samples from Northeast Pond					
Metals					
Arsenic	6.72	19.9	0.3	No	ER ≤ 1
Cadmium	1.06	3.45	0.3	No	ER ≤ 1
Lead	54	96.7	0.6	No	ER ≤ 1
Zinc	194	402	0.5	No	ER ≤ 1

Table 2-1
Sediment Risk Characterization and Identification of COPECs

Streamlined Ecological Risk Evaluation Report
Former Zinc Smelter
Altoona, Kansas

Notes:

COPEC	Constituent of Potential Ecological Concern.
UTL ER	Upper Tolerance Limit Exceedance Ratio.
mg/kg	Milligrams per kilogram.
(a)	95% Upper Confidence Limit (UCL) as recommended by the U.S. Environmental Protection Agency's (USEPA's) ProUCL software; using 0.1-1 foot depth interval.
(b)	The UTL ER is the ratio of the UCL to the background upper tolerance limit (UTL). ERs are expressed as one significant figure in accordance with USEPA guidance (USEPA 1989, 2001e).
(c)	Designated as a COPEC if the UTL ER is greater than 1.
(d)	UCLs could not be calculated for Transect 27; presented concentrations from one sample only.

Table 2-2
Man-Made Ponds and Lower Drainage Area (Transects 24 through 27) Pore Water Samples

Streamlined Ecological Risk Assessment
Former Zinc Smelter
Altoona, Kansas

Analyte		Cadmium	Lead	Zinc
KDHE WQC - Dissolved		0.599	9.85	351
Sample ID	Sample Date	µg/L	µg/L	µg/L
Dissolved Pore Water Samples from Lower Drainage Area Transects (T24-T27)				
E-C-24-M-00.0-00.1	6/13/2012	0.35 J	9.2	26
E-C-25+100-M-00.0-00.1	11/23/2012	< 0.11 U	0.077 JB	1.6 JB
E-C-25+25-M-00.0-00.1	11/23/2012	< 0.11 U	0.11 JB	4.0 JB
E-C-25+50-M-00.0-00.1	11/23/2012	< 0.11 U	0.66 JB	3.3 JB
E-C-25+75-M-00.0-00.1	11/23/2012	< 0.11 U	0.24 JB	2.3 JB
E-C-25-M-00.0-00.1	6/13/2012	< 0.11 U	0.15 J	5.3
E-C-26-M-00.0-00.1 [2]	6/13/2012	91	3.9	23000
E-C-26-M-CENTER-00.1	11/23/2012	< 0.11 U	0.038 JB	1.8 JB
E-C-26-M-EAST-00.1	11/23/2012	< 0.11 U	0.50 JB	2.3 JB
E-C-26-M-WEST-00.1	11/23/2012	< 0.11 U	0.39 JB	3.5 JB
E-C-27-00.0-00.1	11/14/2012	< 0.11 U	2.7 B	7.3 B
Dissolved Pore Water Samples from Pond 1				
E-P1-PW-00.1	12/12/2011	< 0.11 U	0.43 J	8.8

Notes:

µg/L = Micrograms per liter
J = Compound positively identified; however, associated numerical value is estimated concentration.
U = The compound was analyzed for but not detected. Value is the compound quantitation limit.
< = The compound was analyzed for but not detected. Value is the compound quantitation limit.
B = Compound was found in the blank and sample.
KDHE = Kansas Department of Health and the Environment
WQC = Water quality criteria
Shade Exceed KDHE WQC[1] value

1. KDHE WQC values taken from the KDHE, Bureau of Water, Kansas Surface Water Quality Standards, Tables of Numeric Criteria, December 6, 2004. Values shown are the for chronic aquatic life category and have been calculated using a site hardness of 361 mg/L as $CaCO_3$ and converted to dissolved concentrations using the U.S. Environmental Protection Agency (USEPA) total-to dissolved criteria calculator.

2. The results for sample E-C-26-M-00.0-00.1 were anomalously high when compared to surrounding samples, and the results were not reproducible upon subsequent resampling at that location and surrounding locations.

Table 2-3
Evaluation of AVS and SEM Concentrations

Streamlined Ecological Risk Assessment
Former Zinc Smelter
Altoona, Kansas

Location	SEM Metal Concentration								
	SEM Cadmium (µmol/g)	SEM Copper (µmol/g)	SEM Lead (µmol/g)	SEM Nickel (µmol/g)	SEM Zinc (µmol/g)	Sum SEM (µmol/g)	AVS (µmol/g)	Fraction Organic Carbon	Organic Carbon Normalized Excess SEM (µmol/g_{OC}) (a)
Sediment Samples from Lower Drainage Area Transects (T24-T27)									
Transect 24	0.04	0.21	0.8	0.28	8	9.33	4.99	0.014	310
Transect 25	0.022	0.18	0.32	0.18	5.6	6.30	4.37	0.010	204
Transect 25+25	0.024	0.11	0.14	0.13	5.1	5.50	2.93	0.019	135
Transect 25+50	0.024	0.15	0.26	0.14	6.3	6.87	3.12	0.015	250
Transect 25+75	0.012	0.11	0.11	0.12	2.6	2.95	1.68	0.012	106
Transect 25+100	0.018	0.13	0.17	0.13	4	4.45	1.75	0.015	180
Transect 26	0.013	0.11	0.099	0.12	2.5	2.84	1.15	0.013	130
Transect 27	0.02	0.093	0.18	0.14	3.5	3.93	0.75	0.011	290
Sediment Samples from Man-Made Ponds									
Off-Property Pond 1-1	0.041	0.039	0.97	0.085	11	12.14	21.52	0.019	-494
Off-Property Pond 1-2	0.012	0.046	0.31	0.08	3.2	3.65	18.71	0.015	-1004
Off-Property Pond 1-3	0.035	0.39	1.2	0.12	12	13.75	40.54	0.017	-1576
Off-Property Pond 1-4	0.029	0.004	0.6	0.068	8.1	8.80	12.47	0.013	-283

Notes:
[a]
- Toxicity to benthic invertebrates is likely when (∑SEM-AVS)/f_{oc} concentration is >3,000 µmol/g_{OC}.
- Toxicity is uncertain when the (∑SEM-AVS)/f_{oc} concentration is between 130 and 3,000 µmol/g_{OC}.
- Toxicity is not likely when the (∑SEM-AVS)/f_{oc} concentration is <130 µmol/g_{OC}.

AVS = Acid Volatile Sulfide.
SEM = Simultaneously Extracted Metals.
µmol/g = micromoles per gram.
µmol/g_{OC} = micromole per gram organic carbon.

Table 2-4
Total Allowable Metal Concentrations in Sediment

Streamlined Ecological Risk Evaluation Report
Former Zinc Smelter
Altoona, Kansas

Transect/Pond ID	Total Allowable Cadmium (empirical Kd for dry sed)	SEM Cadmium	Total SEM Cadmium > Allowable Cadmium?	Total Allowable Lead (empirical Kd for dry sed)	SEM Lead	Total SEM Lead > Allowable Lead?	Total Allowable Zinc (empirical Kd for dry sed)	SEM Zinc	Total SEM Zinc > Allowable Zinc?
Sediment Samples from Lower Drainage Area Transects (T24-T27)									
Transect 24	447.6	4.5	NO	1461.1	160	NO	1106.1	520	NO
Transect 25	434.9	2.4	NO	1338.1	67	NO	1099.8	360	NO
Transect 25+25	301.7	2.6	NO	1085.9	28	NO	1058.6	340	NO
Transect 25+50	304.7	2.7	NO	986.1	54	NO	899.7	410	NO
Transect 25+75	164.9	1.4	NO	761.2	22	NO	900.1	170	NO
Transect 25+100	162.9	2	NO	836.2	36	NO	978.1	260	NO
Transect 26	106.6	1.5	NO	945.3	20	NO	1196.2	160	NO
Transect 27	53.7	2.2	NO	445.0	36	NO	671.2	230	NO
Sediment Samples from Pond 1									
Off-Property Pond 1-1	2305.6	4.6	NO	4921.3	200	NO	2186.9	700	NO
Off-Property Pond 1-2	2063.5	1.4	NO	4338.3	65	NO	2047.8	210	NO
Off-Property Pond 1-3	4378.6	3.9	NO	8790.3	260	NO	3393.3	800	NO
Off-Property Pond 1-4	1334.6	3.3	NO	3054.6	120	NO	1622.7	530	NO

Units are in milligrams per kilogram (mg/kg).
SEM = Simultaneously Extracted Metals.
WQC = Kansas Aquatic Life Water Quality Criteria.

Total Allowable Metal (empirical Kd for dry sed) = (A) Allowable Metal Sorbed to dry sediment (empirical Kd) + (B) Allowable Metal in Water; where:
A= Geometric Mean Empirical Partition Coefficient Kd x WQC
B= WQC x (fraction Moisture)/(1-fraction Moisture)

Table 2-5
Area Use Factors for Potential Receptors

Streamlined Ecological Risk Evaluation Report
Former Zinc Smelter
Altoona, Kansas

Area of Concern	Acreage (acres) [a]
Transects 24-27	0.14
Pond 1	1.0

[a] Area of channel calculated using a length of 400 feet and a width of 15 feet. The area of the pond was determined using aerial imagery from February 18, 2012.

Common Receptor	Trophic Level	Home Range (acres)	Source	Area Use Factor Range (unitless)
Great Blue Heron	Avian Aquatic Piscivore	7413	Foraging territory size (USEPA 1993)	0.00002-0.0001
Tree Swallow	Avian Aquatic Invertivore (emergent adult)	1236	Home range during incubation and nesting (Robertson et al. 1992)	0.00011-0.0008
Lesser Scaup	Avian Aquatic Invertivore (benthic)	220	USEPA 1993	0.00064-0.0046
Mallard	Avian Aquatic Herbivore	1074	Average of both adult male and female home ranges (USEPA 1993)	0.00013-0.0009
Mink	Mammalian Aquatic Piscivore	1902	USEPA 1993	0.00007-0.0005
Raccoon	Mammalian Aquatic Invertivore	1556	Average of both adult male and female home ranges (USEPA 1993)	0.00009-0.0007

Figures

CITY: (HIGHLANDS RANCH) DIV/GROUP:(ENV) DB:GMCKINNEY LD: PIC: PM: TM:
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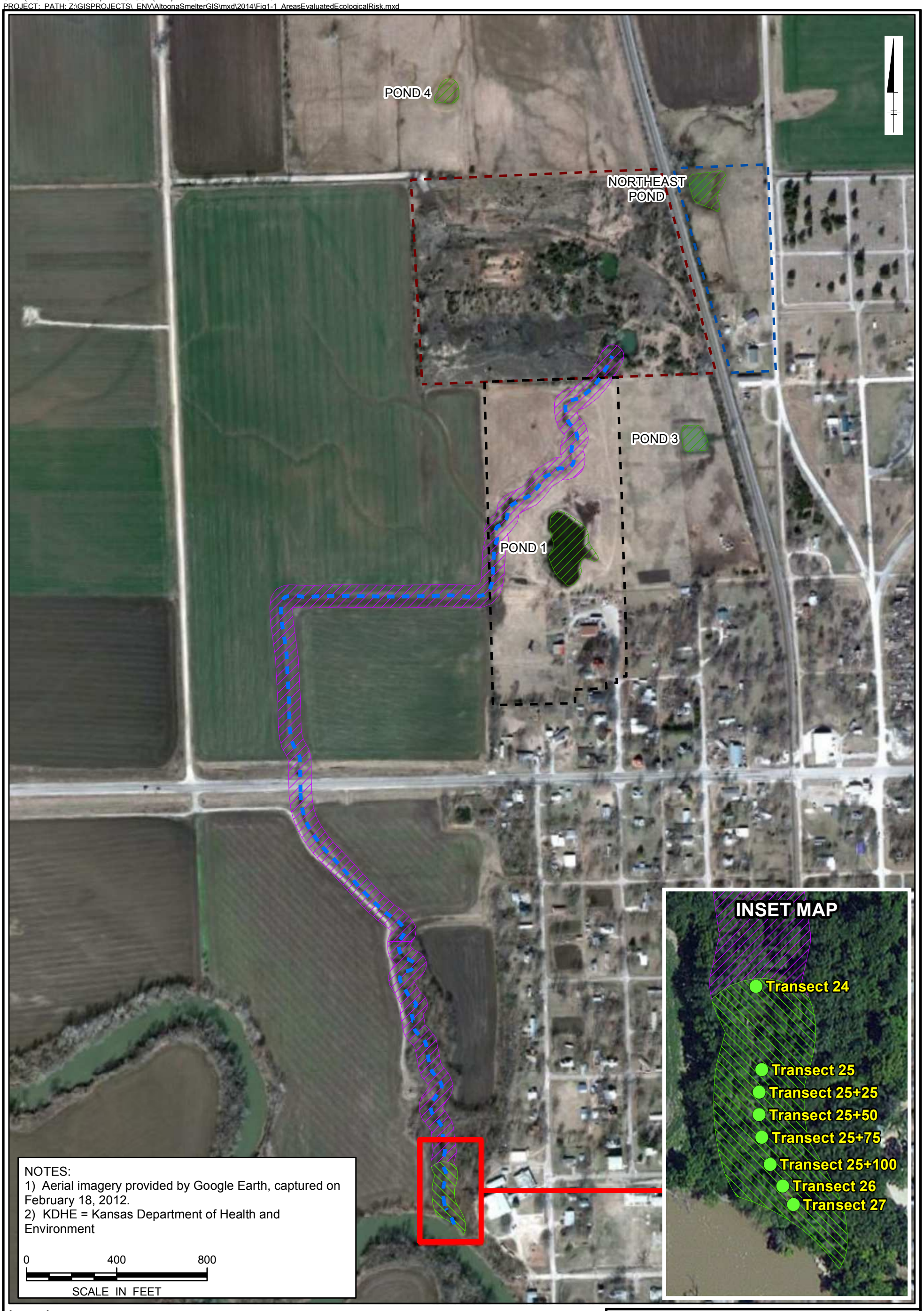


Legend

- Transect Location
- **LOW QUALITY AQUATIC HABITAT** -Highly variable water depths
- UPPER DRAINAGE AREA -Screened as Soil based on KDHE Sediment Policy
- LOWER DRAINAGE AREA -Screened as Sediment based on KDHE Sediment Policy
- Drainage Ditch
- Formerly Associated with Property. Now used for agricultural and residential purposes
- Former Altoona Smelter Property **(Property)**
- Property Purchased in May 2013 by Midwest Property Acquisition Co., (Affiliated to Cyprus)

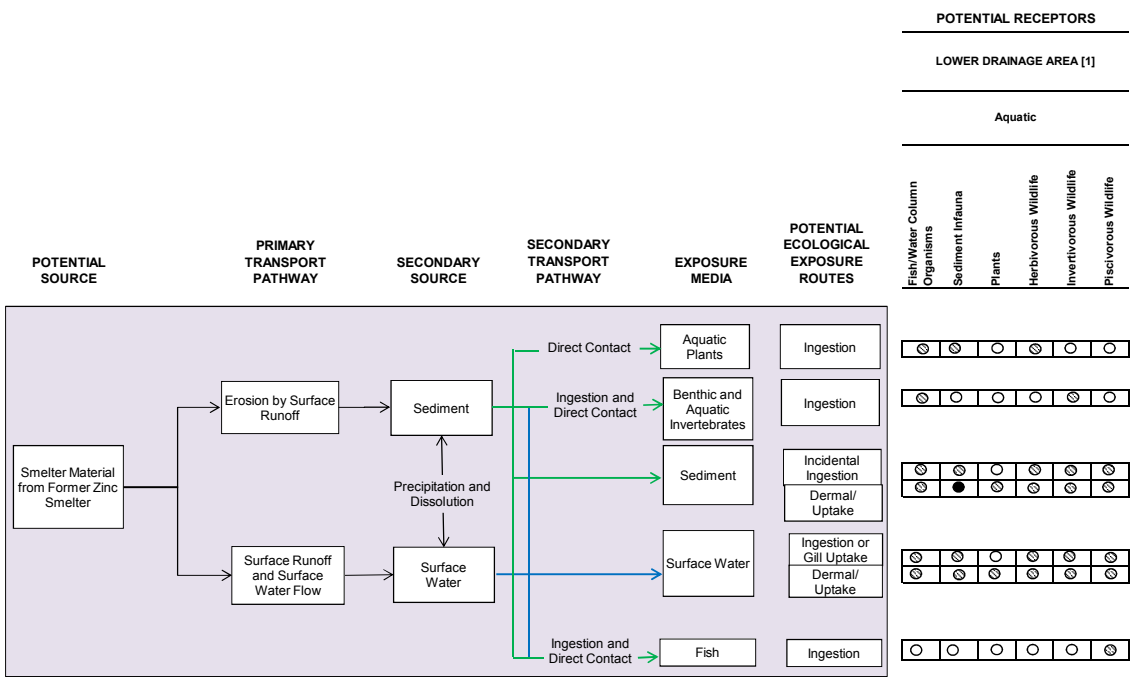
FORMER ZINC SMELTER
ALTOONA, KANSAS

AREAS EVALUATED IN THE STREAMLINED ECOLOGICAL RISK EVALUATION

ARCADIS

FIGURE
1-1

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



○	Pathway is considered incomplete.
●	Pathway is considered potentially complete (quantitatively evaluated).
⊘	Pathway is considered potentially complete (methodology not available or considered insignificant exposure).

Notes: Different line colors are only used to allow ease of reading.

[1] The aquatic pathways depicted in this CSM are applicable only for the furthest downstream portion of the Lower Drainage Area (i.e., Transects 24, 25, 26, and 27). because it is inundated most of the year and contains sediment. The portion of the ephemeral drainage ditch located upstream of Transect 24, including the Upper Drainage Area, is dry most of the year and therefore is not an aquatic environment due to the lack of water and sediment. This is consistent with KDHE Sediment Policy (2004).

CSM = Conceptual Site Model
KDHE = Kansas Department of Health and Environment

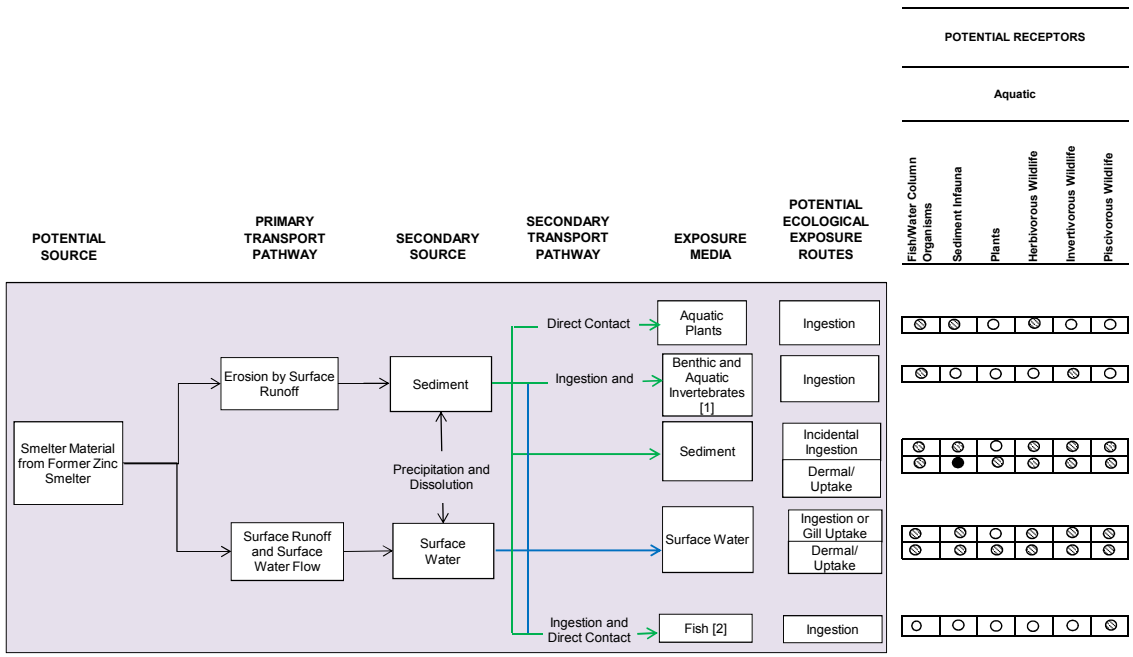
FORMER ZINC SMELTER
ALTOONA, KANSAS

Lower Drainage Area Conceptual Site Model

CONCEPTUAL SITE MODEL - ECOLOGICAL

ARCADIS

FIGURE
2-1



○	Pathway is considered incomplete.
●	Pathway is considered potentially complete (quantitatively evaluated).
⊘	Pathway is considered potentially complete (methodology not available or considered insignificant exposure).

Notes: Different line colors are only used to allow ease of reading.

[1] The aquatic pathways depicted in this CSM are applicable only for the man-made pond(s) that contain water most of the year, such that aquatic biota like benthic invertebrates may be present. Those man-made ponds that contain water intermittently are not considered to be representative of an aquatic environment due to the lack of water and sediment. This is consistent with KDHE Sediment Policy (2004).

[2] At this time, fish populations have not been determined to be present and are not expected to occur within the man-made ponds because they can dry up during the summer. Therefore, any fish that occur in the man-made ponds are expected to be the result of pond entry during flood events or via fish eggs introduced to the pond on the the legs of visiting birds. The intermittent presence of water in the man-made ponds prevents the establishment of resident fish populations and long-term benthic invertebrate life.

CSM = Conceptual Site Model
KDHE = Kansas Department of Health and the Environment

FORMER ZINC SMELTER
ALTOONA, KANSAS

Man-Made Ponds Conceptual Site Model

CONCEPTUAL SITE MODEL - ECOLOGICAL

ARCADIS

FIGURE
2-2

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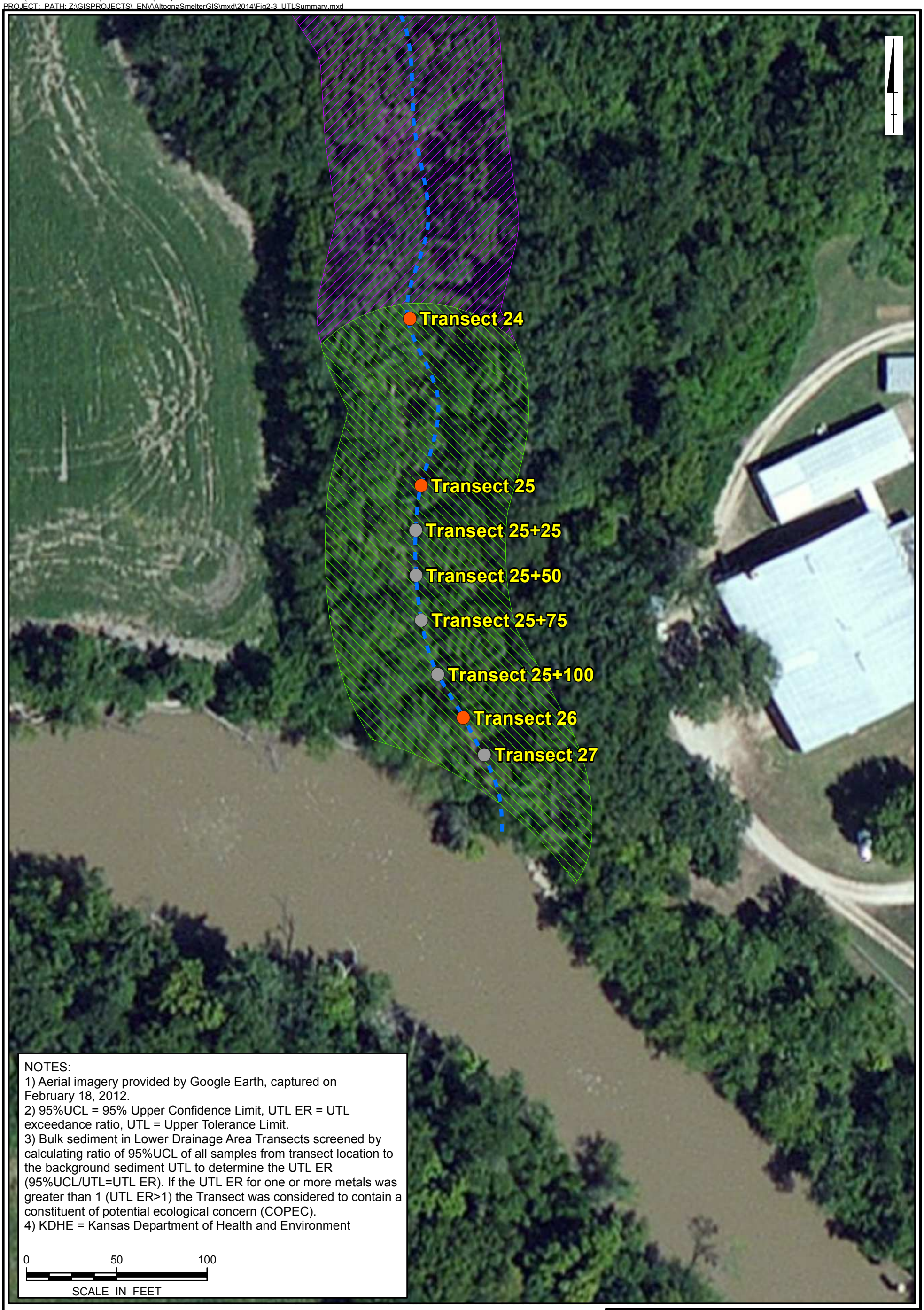

NOTES:
1) Aerial imagery provided by Google Earth, captured on February 18, 2012.
2) 95%UCL = 95% Upper Confidence Limit, UTL ER = UTL exceedance ratio, UTL = Upper Tolerance Limit.
3) Bulk sediment in Lower Drainage Area Transects screened by calculating ratio of 95%UCL of all samples from transect location to the background sediment UTL to determine the UTL ER (95%UCL/UTL=UTL ER). If the UTL ER for one or more metals was greater than 1 (UTL ER>1) the Transect was considered to contain a constituent of potential ecological concern (COPEC).
4) KDHE = Kansas Department of Health and Environment

UTL ER > 1 for one or moremetals in transect

UTL ER cannot be calculated due to low sample population

Drainage Ditch

UPPER DRAINAGE AREA
-Screened as Soil based on KDHE Sediment Policy

LOWER DRAINAGE AREA
-Screened as Sediment based on KDHE Sediment Policy

Property Purchased in May 2013 by Midwest Property Acquisition Co. (Affiliated to Cyprus)

Formerly Associated with Property.
Now used for agricultural and residential purposes

Former Altoona Smelter Property **(Property)**

FORMER ZINC SMELTER
ALTOONA, KANSAS

UTL EXCEEDANCE RATIO SUMMARY FOR SEDIMENT IN LOWER DRAINAGE AREA : TRANSECTS 24 THROUGH 27

ARCADIS

FIGURE
2-3

CITY: (HIGHLANDS RANCH) DIV/GROUP:(ENV) DB:GMCKINNEY LD: PIC: PM: TM:
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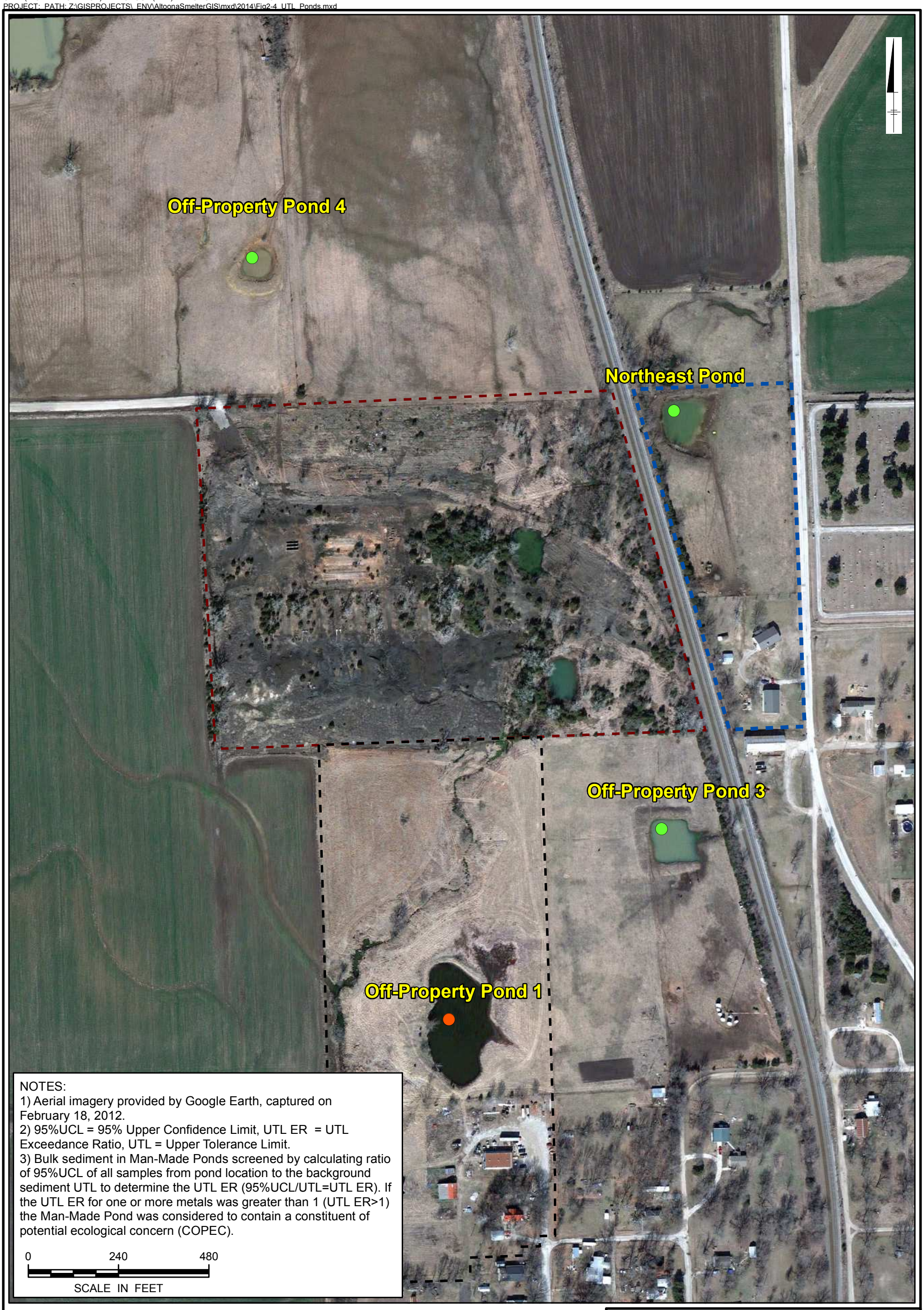

- UTL ER > 1 for one or more metals at man-made pond location
- UTL ER ≤ 1 for all metals at man-made pond location
- Former Altoona Smelter Property **(Property)**
- Formerly Associated with Property. Now used for agricultural and residential purposes
- Property Purchased in May 2013 by Midwest Property Acquisition Co. (Affiliated to Cyprus)

FORMER ZINC SMELTER
ALTOONA, KANSAS

UTL EXCEEDANCE RATIO SUMMARY FOR SEDIMENT IN MAN-MADE PONDS: OFF-PROPERTY

ARCADIS

FIGURE
2-4

CITY: (HIGHLANDS RANCH) DIV/GROUP:(ENV) DB:GMCKINNEY LD: PIC: PM: TM:
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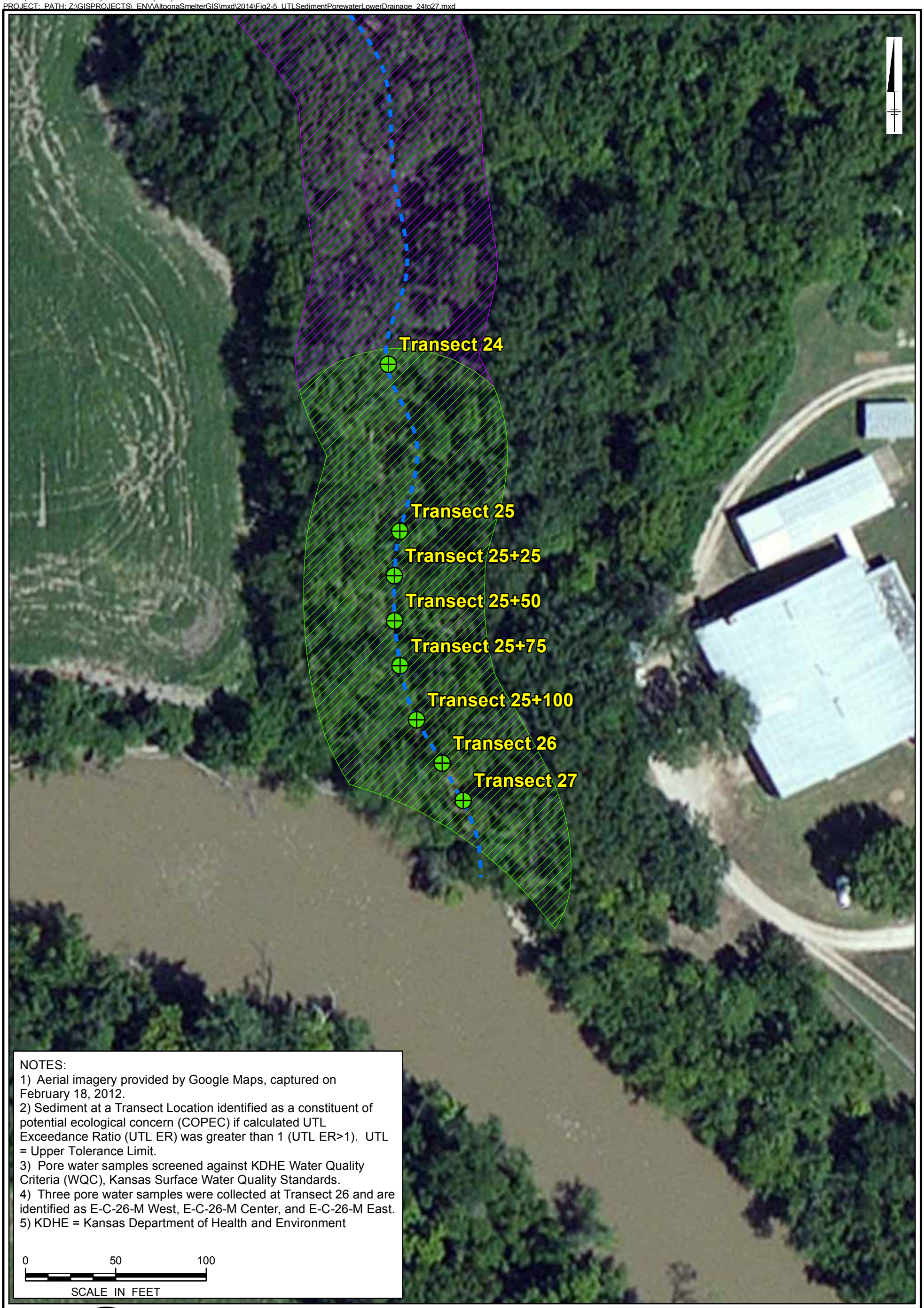

NOTES:
1) Aerial imagery provided by Google Maps, captured on February 18, 2012.
2) Sediment at a Transect Location identified as a constituent of potential ecological concern (COPEC) if calculated UTL Exceedance Ratio (UTL ER) was greater than 1 (UTL ER>1). UTL = Upper Tolerance Limit.
3) Pore water samples screened against KDHE Water Quality Criteria (WQC), Kansas Surface Water Quality Standards.
4) Three pore water samples were collected at Transect 26 and are identified as E-C-26-M West, E-C-26-M Center, and E-C-26-M East.
5) KDHE = Kansas Department of Health and Environment

ARSENIC CADMIUM
ZINC LEAD

Location does not exceed screening assessment and/or metal concentration in porewater sample is below KDHE WQC

Drainage Ditch
UPPER DRAINAGE AREA
- Screened as soil based on KDHE Sediment Policy
LOWER DRAINAGE AREA
- Screened as sediment based on KDHE sediment policy
Property Purchased in May 2013 by Midwest Property Acquisition Co. (Affiliated to Cyprus)
Formerly Associated with Property. Now used for agricultural and residential purposes
Former Altoona Smelter Property **(Property)**

FORMER ZINC SMELTER
ALTOONA, KANSAS

SEDIMENT PORE WATER RESULTS FOR LOWER DRAINAGE AREA: TRANSECTS 24 THROUGH 27

ARCADIS

FIGURE
2-5

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NOTES:
1) Aerial imagery provided by Google Maps, captured on February 18, 2012.
2) Sediment at a Man-Made Pond Location identified as a constituent of potential ecological concern (COPEC) if calculated UTL Exceedance Ratio (UTL ER) was greater than 1 (UTL ER>1). UTL = Upper Tolerance Limit.
3) Pore water samples screened against KDHE Water Quality Criteria (WQC), Kansas Surface Water Quality Standards.
4) KDHE = Kansas Department of Health and Environment

0 240 480
SCALE IN FEET

ARSENIC CADMIUM
ZINC LEAD

Location does not exceed screening assessment and/or metal concentration in porewater sample is below KDHE WQC

MAN-MADE POND: SEDIMENT
-Screened as Sediment based on KDHE Sediment Policy

Property Purchased in May 2013 by Midwest Property Acquisition Co. (Affiliated to Cyprus)

Formerly Associated with Property. Now used for agricultural and residential purposes

Former Altoona Smelter Property **(Property)**

FORMER ZINC SMELTER
ALTOONA, KANSAS

SEDIMENT PORE WATER RESULTS FOR MAN-MADE POND LOCATIONS

ARCADIS

FIGURE
2-6

Appendix A

Analytical Data Used in the SERE

Appendix A-1
Lower Drainage Area Sediment Samples, Transects 24 Through 27

Streamlined Ecological Risk Evaluation
Former Zinc Smelter
Altoona, Kansas

Analyte			Depth	Arsenic	Cadmium	Lead	Zinc
Sample ID	Lab Sample ID	Sample Date	(feet)	mg/kg	mg/kg	mg/kg	mg/kg
E-C-24-L-2.5-00.1	280-29891-3	6/6/2012	0.1	2.6	0.65 J	12 J	90 J
E-C-24-L-2.5-01.0	280-29891-4	6/6/2012	1	3.4	1.1 J	16 J	150 J
E-C-24-L-5.0-00.1	280-29891-1	6/6/2012	0.1	5.4	0.71 J	13 J	130 J
E-C-24-L-5.0-01.0	280-29891-2	6/6/2012	1	3.4	1.5 J	12 J	150 J
E-C-24-M-00.0-00.1	280-29891-5	6/6/2012	0.1	8.3	0.89 J	17 J	140 J
E-C-24-M-00.0-00.1-D	280-29891-11	6/6/2012	0.1	11	2.6 J	59 J	320 J
E-C-24-M-00.0-01.0	280-29891-6	6/6/2012	1	5.2	0.98 J	21 J	150 J
E-C-24-R-2.5-00.1	280-29891-9	6/6/2012	0.1	20	6.3 J	190 J	850 J
E-C-24-R-2.5-01.0	280-29891-10	6/6/2012	1	4.5	1.2 J	22 J	150 J
E-C-24-R-5.0-00.1	280-29891-7	6/6/2012	0.1	19	7.4 J	210 J	860 J
E-C-24-R-5.0-01.0	280-29891-8	6/6/2012	1	7.6	4.2 J	31 J	560 J
E-C-25+100-M-00.0-00.1	180-16487-4	11/15/2012	0.1	5.5	1.3	24	180
E-C-25+25-M-00.0-00.1	180-16487-1	11/15/2012	0.1	4.5	2.1	26	240
E-C-25+50-M-00.0-00.1	180-16487-2	11/15/2012	0.1	6.1	2.0	43	290
E-C-25+75-M-00.0-00.1	180-16487-3	11/15/2012	0.1	4.1	1.2	20	150
E-C-25-L-3.25-00.1	280-29891-14	6/6/2012	0.1	4.9	1.0 J	22 J	150 J
E-C-25-L-3.25-01.0	280-29891-15	6/6/2012	1	3.1	0.37 J	13 J	68 J
E-C-25-L-6.5-00.1	280-29891-12	6/6/2012	0.1	8.7	0.33 J	15 J	70 J
E-C-25-L-6.5-01.0	280-29891-13	6/6/2012	1	6.4	0.33 J	14 J	62 J
E-C-25-M-00.0-00.1	280-29891-16	6/6/2012	0.1	8.0	3.5 J	45 J	450 J
E-C-25-M-00.0-01.0	280-29891-17	6/6/2012	1	18	6.5 J	76 J	550 J
E-C-25-R-3.25-00.1	280-29891-20	6/6/2012	0.1	6.4	3.6 J	35 J	440 J
E-C-25-R-3.25-01.0	280-29891-21	6/6/2012	1	9.8	8.2 J	70 J	1200 J
E-C-25-R-6.5-00.1	280-29891-18	6/6/2012	0.1	16	24 J	150 J	2000 J
E-C-25-R-6.5-01.0	280-29891-19	6/6/2012	1	11	15 J	110 J	1500 J
E-C-26-L-3.25-00.1	280-29891-24	6/5/2012	0.1	5.0	1.2 J	20 J	170 J
E-C-26-L-3.25-01.0	280-29891-25	6/5/2012	1	4.7	0.64 J	14 J	79 J
E-C-26-L-6.5-00.1	280-29891-22	6/5/2012	0.1	5.0	0.64 J	15 J	120 J
E-C-26-L-6.5-01.0	280-29891-23	6/5/2012	1	3.9	0.40 J	13 J	70 J
E-C-26-M-0.0-00.1	280-29891-26	6/5/2012	0.1	10	2.5 J	36 J	290 J
E-C-26-M-0.0-01.0 ǂ	280-29891-27	6/5/2012	1	23	5.3 J	110 J	520 J
E-C-26-M-00.0-00.1-D	280-29891-32	6/5/2012	0.1	7.8	5.0 J	36 J	350 J
E-C-26-M-CENTER-00.1	180-16487-6	11/14/2012	0.1	3.2	0.94	13	110
E-C-26-M-EAST-00.1	180-16487-7	11/14/2012	0.1	3.3	0.44	11	60
E-C-26-M-WEST-00.1	180-16487-5	11/14/2012	0.1	6.1	1.5	36	180
E-C-26-R-3.25-00.1	280-29891-30	6/5/2012	0.1	10	2.5 J	52 J	340 J
E-C-26-R-3.25-01.0	280-29891-31	6/5/2012	1	13	4.1 J	68 J	800 J
E-C-26-R-6.5-00.1	280-29891-28	6/5/2012	0.1	6.0	6.6 J	38 J	440 J
E-C-26-R-6.5-01.0	280-29891-29	6/5/2012	1	11	16 J	73 J	1100 J
E-C-27-00.0-00.1	180-16487-8	11/14/2012	0.1	6.3	1.5	26	180

Notes:

mg/kg = Milligrams per kilogram

J = The compound was positively identified; however, the associated numerical value is an estimated concentration only.

Appendix A-2
Lower Drainage Area Pore Water Samples, Transects 24 through 27

Streamlined Ecological Risk Evaluation
Former Zinc Smelter
Altoona, Kansas

Analyte		Arsenic	Cadmium	Lead	Zinc
Sample ID	Sample Date	µg/L	µg/L	µg/L	µg/L
Dissolved Pore Water Samples from Drainage Ditch Transects					
E-C-24-M-00.0-00.1	6/13/2012	5.3	0.35 J	9.2	26
E-C-25+100-M-00.0-00.1	11/23/2012	7.5	< 0.11 U	0.077 JB	1.6 JB
E-C-25+25-M-00.0-00.1	11/23/2012	6.4	< 0.11 U	0.11 JB	4.0 JB
E-C-25+50-M-00.0-00.1	11/23/2012	4.3	< 0.11 U	0.66 JB	3.3 JB
E-C-25+75-M-00.0-00.1	11/23/2012	5.9	< 0.11 U	0.24 JB	2.3 JB
E-C-25-M-00.0-00.1	6/13/2012	4.5	< 0.11 U	0.15 J	5.3
E-C-26-M-00.0-00.1 [1]	6/13/2012	7.4	91	3.9	23000
E-C-26-M-CENTER-00.1	11/23/2012	6.5	< 0.11 U	0.038 JB	1.8 JB
E-C-26-M-EAST-00.1	11/23/2012	8.7	< 0.11 U	0.50 JB	2.3 JB
E-C-26-M-WEST-00.1	11/23/2012	7.1	< 0.11 U	0.39 JB	3.5 JB
E-C-27-00.0-00.1	11/14/2012	7.6	< 0.11 U	2.7 B	7.3 B

Notes:

µg/L = Micrograms per liter
J = Compound positively identified; however, associated numerical value is estimated concentration.
U = The compound was analyzed for but not detected. Value is the compound quantitation limit.
< = The compound was analyzed for but not detected. Value is the compound quantitation limit.
B = Compound was found in the blank and sample.

1. The results for sample E-C-26-M-00.0-00.1 were anomalously high when compared to surrounding samples and the results were not reproducible upon subsequent resampling at that location and surrounding locations.

Appendix A-3
Off-Property Man-Made Pond Sediment Samples

Streamlined Ecological Risk Evaluation
Former Zinc Smelter
Altoona, Kansas

Analyte			Depth	Arsenic	Cadmium	Lead	Zinc
Sample ID	Lab Sample ID	Sample Date	(feet)	mg/kg	mg/kg	mg/kg	mg/kg
Off-Property Pond 1							
E-P1-1-00.1	280-23647-1	12/5/2011	0.1	11 J	4.7	210 J	880
E-P1-1-01.0	280-23647-2	12/5/2011	1	6.0 J	1.5	64 J	230
E-P1-2-00.1	280-23647-3	12/5/2011	0.1	9.9 J	3.0	160 J	630
E-P1-2-01.0	280-23647-4	12/5/2011	1	11 J	3.9	240 J	850
E-P1-3-00.1	280-23647-6	12/5/2011	0.1	15 J	4.8	250 J	1100
E-P1-3-01.0	280-23647-5	12/5/2011	1	14 J	4.5	300 J	1100
E-P1-4-00.1	280-23647-7	12/5/2011	0.1	9.1 J	4.3	180 J	740
E-P1-4-01.0	280-23647-8	12/5/2011	1	9.5 J	5.1	190 J	680
Off-Property Pond 3							
E-P3-1-00.1	280-23647-9	12/6/2011	0.1	9.3 J	2.9	170 J	670
E-P3-1-01.0	280-23647-10	12/6/2011	1	6.1 J	0.25	28 J	72
E-P3-2-00.1	280-23647-11	12/6/2011	0.1	6.5 J	1.1	66 J	250
E-P3-2-01.0	280-23647-12	12/6/2011	1	6.4 J	1.4	85 J	320
E-P3-3-00.1	280-23647-13	12/6/2011	0.1	9.4 J	3.6	180 J	730
E-P3-3-01.0	280-23647-14	12/6/2011	1	5.9 J	1.9	83 J	410
E-P3-4-00.1	280-23647-15	12/6/2011	0.1	9.3 J	2.1	91 J	400
E-P3-4-01.0	280-23647-16	12/6/2011	1	5.8 J	0.15	21 J	55
Off-Property Pond 4							
E-P4-1-00.1	280-23647-17	12/6/2011	0.1	8.5 J	0.80	53 J	190
E-P4-1-01.0	280-23647-18	12/6/2011	1	9.1 J	0.36	28 J	82
E-P4-2-00.1	280-23647-19	12/6/2011	0.1	15 J	0.59	58 J	110
E-P4-2-01.0	280-23647-20	12/6/2011	1	15 J	0.25	24 J	75
E-P4-3-00.1	280-23647-21	12/6/2011	0.1	32 J	0.34	38 J	88
E-P4-3-01.0	280-23647-22	12/6/2011	1	19 J	0.16	17 J	56
E-P4-4-00.1	280-23647-23	12/6/2011	0.1	22 J	0.41	57 J	86
E-P4-4-00.1-D	280-23647-24	12/6/2011	0.1	11 J	0.33	31 J	77
E-P4-4-01.0	280-23647-25	12/6/2011	1	13	0.20	22 J	57
E-P4-4-01.0-D	280-23647-26	12/6/2011	1	16	0.37	45 J	83
Northeast Pond							
E-PE-1-00.1	280-23647-27	12/6/2011	0.1	5.8 J	0.77	41 J	150
E-PE-1-01.0	280-23647-28	12/6/2011	1	8.0 J	1.6	69 J	280
E-PE-2-00.1	280-23647-29	12/6/2011	0.1	5.0 J	0.52	37 J	120
E-PE-2-01.0	280-23647-30	12/6/2011	1	5.8 J	0.71	41 J	130
E-PE-3-00.1	280-23647-31	12/6/2011	0.1	5.5 J	0.82	41 J	130
E-PE-3-01.0	280-23647-32	12/6/2011	1	6.0 J	0.72	47 J	150
E-PE-4-00.1	280-23647-33	12/6/2011	0.1	6.1 J	0.83	47 J	150
E-PE-4-01.0	280-23647-34	12/6/2011	1	6.7 J	0.83	51 J	170

Notes:

mg/kg = Milligrams per kilogram

J = The compound was positively identified; however, the associated numerical value is an estimated concentration only.

Appendix A-4
Off-Property Man-Made Pond Porewater Samples

Streamlined Ecological Risk Evaluation
Former Zinc Smelter
Altoona, Kansas

Analyte		Arsenic	Cadmium	Lead	Zinc
Sample ID	Sample Date	µg/L	µg/L	µg/L	µg/L
Dissolved Porewater Samples from Off-Property Ponds					
E-P1-PW-00.1	12/12/2011	2.2	< 0.11 U	0.43 J	8.8
E-P3-PW-00.1	12/12/2011	2.0	< 0.23 U	6.8	16
E-P4-PW-00.1	12/12/2011	2.6	< 0.11 U	0.25 J	9.9
E-PE-PW-00.1	12/12/2011	3.2	< 0.11 U	0.22 J	12

Notes:

µg/L = Micrograms per liter
J = Compound positively identified; however, associated numerical value is estimated concentration.
U = The compound was analyzed for but not detected. Value is the compound quantitation limit.
< = The compound was analyzed for but not detected. Value is the compound quantitation limit.

Appendix B

Response to KDHE Comments on UTLs

Response to KDHE Comments – April 21, 2014

Please find responses to comments from the Kansas Department of Health and Environment (KDHE) regarding the technical memos summarizing the calculation of background soil and sediment upper tolerance limits (UTLs) for the former zinc smelter in Altoona, Kansas (site).

KDHE Comment 1: *Both the sediment and soil background memos state that the data used in the UTL calculations must be independent of each other, because bias in selecting the sampling locations can bias the UTLs. Figure 1 in the soil background memo shows that many of the sampling locations appear to be associated with interconnected ditches. If so, the degree of independence between sampling locations may be suspect since water (and the sediment loads it carries) would flow downgradient, thereby "connecting" the various sampling location with each other and violating the independence clause. This potential issue should be recognized and discussed in the two memos.*

Response: It may appear from the aerial photograph that some of the background soil samples came from drainage ditches; however, this appearance is an artifact of the scale of the associated air photograph used in the figure. To clarify, the soil samples were not collected in drainage ditches but rather from soil horizons outside the influence of drainage ditches.

Comment 2: *For future reference, include all of the analytical data used in the sediment UTL calculations, as was done for the background soil As data set.*

Response: Comment acknowledged. The analytical data will be provided in the RSE Report.

Comment 3: *The memos should clearly state why the selected metals were chosen for UTLs calculations.*

Response: Comment acknowledged. The four potential constituents of concern pCOCs (arsenic, cadmium, lead, and zinc) at the site were based on data collected from previous investigations conducted by the KDHE and were established in the KDHE approved Removal Site Evaluation Work Plan (Bridgewater 2011). The UTLs for each of the four pCOCs (arsenic, cadmium, lead, and zinc) were calculated from background sediment samples because the KDHE Sediment Policy requires sediment samples to be compared to the Threshold Effect Concentrations (TECs) or background levels. The TEC values are often lower than background levels and thus, UTLs were calculated for each of the pCOCs as a screening level. The Work Plan indicated soils at the site will be screened against the KDHE Tier 2 Risk Based levels (RSK). With the exception of arsenic, the background soil concentrations for cadmium, lead, and zinc typically occur at levels significantly below the KDHE Tier 2 RSK levels. Therefore, only the arsenic UTL was calculated for background soils samples.

Comment 4: *The sediment memo should describe the depth at which the sediment samples were collected.*

Response: Comment acknowledged. The depth at which the background sediment samples were collected was 0.1 feet below ground surface (bgs).

Comment 5: *The background sediment As dataset had two outliers, one removed and one retained (see Table 1 in the sediment memo). The argument given for retaining the one outlier states that "if a normal distribution could be established with the point [outlier] present, the data point was retained in the statistical analysis, even if a transformation was necessary" (see Outliers on p. 3/5 of the sediment memo). Including outliers will, by definition, increase a UTL and allow higher site concentrations to be identified as background. This approach should be justified by including references from the scientific literature to support it.*

Response: It is true that the inclusion of statistical outliers will allow higher site concentrations to be identified as background. ARCADIS used best statistical practices and guidance from USEPA's Unified Guidance (March 2009, EPA 530-R-09-007) on how to address statistical outliers. The USEPA's Unified Guidance cautions against removing outliers unless the cause of the outlier is known (transcription error, laboratory procedural error). On page 12-10, Unified Guidance says, "Before excluding this point from further analysis, however, a valid explanation for this unusually high value should be sought. Otherwise the outliers may need to be treated as an extreme but valid concentration measurement." With this guidance in view, a data point is left in the analysis if a distribution could be identified that included the data point in question. If a distribution cannot be identified with that point included, then it was removed. One of the two data points fell into the former category and one in the latter. Thus the data point at BG11 was retained. It is of note (but not explained in the memo) that the data point in question, 19 mg/kg, is identified as an outlier only when the Dixon test is run at 95% confidence. It is not an outlier at 99% confidence. The new version of the memo will clarify the above information.

Comment 6*: The third sentence of the Discussion section (p. 5/5) in the sediment memo notes that a UTL can exceed the maximum value in a dataset with less than 20 data points. This represents a potential uncertainty with real-life implications for risk characterization. No further background sampling is required, but this issue should be acknowledged and discussed in the uncertainty section of the risk characterization of the updated risk report.*

Response: The definition of the 95/95 UTL is that it is the upper limit of an interval that captures 95%percent of the data points in a population with 95% confidence. As such, the UTL is the correct interval estimator for characterizing background soil and sediment data. Such an interval brackets 95% of the data points in a population. Therefore it is clear why it is often the case that the UTL can exceeds the maximum value in a data set.

Comment 7*: Both background memos refer to the same 13 sampling locations (i.e., BG01 to BG13) from which sediment and soil samples were collected. The samples were collected on December 2, 2011 (sediment and soil), May 29, 2012 (sediment only) and August 27, 2012 (soil only). This information suggests that the samples collected on December 2, 2011 were analyzed both as sediment and soil. The memos need to be clarified in order to avoid misunderstanding. Also, the sediment background memo should include a map showing the sediment sampling locations.*

Response: The sediment background sample locations had names with the prefix BG, such as BG01 and BG02. The soil sample locations had the prefix S-O-BG, for example S-O-BG01 and S-O-BG02. In the soil memo, the table listed each sample by its full name, but the text used a shortened prefix, BG. The sediment and soil samples are distinct samples collected from separate locations.

Comment 8: *The 13 background sediment and soil samples were all systematically collected north of the site. The introduction in both memos should identify the prevailing wind direction so that all the variables potentially impinging on the background datasets, and hence the UTLs, are acknowledged and recognized.*

Response: Several technical lines of evidence were used to select background locations from the north of the site which will be discussed below. However, it is important to note that the background soil and sediment locations were presented in the various KDHE approved Work Plans prior to collecting the samples. These background locations were subject to discussion with the KDHE and the KDHE did not have any objections to the background locations. The following lines of evidence were used to select background locations:

- The predominant wind direction in southeast Kansas is to the northeast and southwest while the majority of background locations were collected north of the site.

- Empirical data from the RSE investigation indicates the majority of elevated metal concentrations are located south of the former smelter site and thus, background samples were not collected south of the former smelter.

- Background samples should be collected from the same geologic zone as the samples to which they will be compared. In this case, the former smelter is located along the geologic transition between the Verdigris River alluvial valley to the west and south and the uplands to the east of the site. Therefore, collecting representative samples of background can be best accomplished by going north from the zone within the same geologic transition area. Samples collected to the west and south of the site would be located on the Verdigris River alluvial valley and samples collected to the east would be collected on the uplands area.

Cyprus believes the above responses adequately address the KDHE's request to clarify the Background Calculation Memos developed for soil and sediment at the former Altoona smelter site. The above clarifications will be made to the Memos that will be included as appendices in the RSE Report.

Cyprus requests the KDHE to review and approve the above responses before the Streamlined Ecological Risk Evaluation is conducted.

Appendix C

ProUCL Results

Off-Site Ponds

General UCL Statistics for Full Data Sets

Confidence Coefficient	95%
Number of Bootstrap Operations	2000

E-P1-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	6	Minimum of Log Data	1.792
Maximum	15	Maximum of Log Data	2.708
Mean	10.69	Mean of log Data	2.336
Geometric Mean	10.34	SD of log Data	0.283
Median	10.45		
SD	2.836		
Std. Error of Mean	1.003		
Coefficient of Variation	0.265		
Skewness	0.0622		

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.952	Shapiro Wilk Test Statistic	0.932
Shapiro Wilk Critical Value	0.818	Shapiro Wilk Critical Value	0.818
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	12.59	95% H-UCL	13.38
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	15.39
95% Adjusted-CLT UCL (Chen-1995)	12.36	97.5% Chebyshev (MVUE) UCL	17.41
95% Modified-t UCL (Johnson-1978)	12.59	99% Chebyshev (MVUE) UCL	21.39

Gamma Distribution Test		Data Distribution
k star (bias corrected)	9.59	Data appear Normal at 5% Significance Level
Theta Star	1.114	
MLE of Mean	10.69	
MLE of Standard Deviation	3.451	
nu star	153.4	
Approximate Chi Square Value (.05)	125.8	**Nonparametric Statistics**
Adjusted Level of Significance	0.0195	95% CLT UCL 12.34
Adjusted Chi Square Value	119.5	95% Jackknife UCL 12.59
		95% Standard Bootstrap UCL 12.27
Anderson-Darling Test Statistic	0.302	95% Bootstrap-t UCL 12.89
Anderson-Darling 5% Critical Value	0.716	95% Hall's Bootstrap UCL 13.34
Kolmogorov-Smirnov Test Statistic	0.175	95% Percentile Bootstrap UCL 12.18
Kolmogorov-Smirnov 5% Critical Value	0.294	95% BCA Bootstrap UCL 12.15
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 15.06
		97.5% Chebyshev(Mean, Sd) UCL 16.95
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 20.66
95% Approximate Gamma UCL (Use when n >= 40)	13.03	
95% Adjusted Gamma UCL (Use when n < 40)	13.73	

Potential UCL to Use	Use 95% Student's-t UCL 12.59

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P1-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	8

Raw Statistics		Log-transformed Statistics	
Minimum	1.5	Minimum of Log Data	0.405
Maximum	5.1	Maximum of Log Data	1.629
Mean	3.975	Mean of log Data	1.322
Geometric Mean	3.75	SD of log Data	0.405
Median	4.4		
SD	1.191		
Std. Error of Mean	0.421		
Coefficient of Variation	0.3		
Skewness	-1.526		

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.846	Shapiro Wilk Test Statistic	0.743
Shapiro Wilk Critical Value	0.818	Shapiro Wilk Critical Value	0.818
Data appear Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	4.773	95% H-UCL	5.704
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	6.559
95% Adjusted-CLT UCL (Chen-1995)	4.425	97.5% Chebyshev (MVUE) UCL	7.654
95% Modified-t UCL (Johnson-1978)	4.735	99% Chebyshev (MVUE) UCL	9.807

Gamma Distribution Test		Data Distribution
k star (bias corrected)	5.538	Data appear Normal at 5% Significance Level
Theta Star	0.718	
MLE of Mean	3.975	
MLE of Standard Deviation	1.689	
nu star	88.61	
Approximate Chi Square Value (.05)	67.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0195	95% CLT UCL 4.668
Adjusted Chi Square Value	63.34	95% Jackknife UCL 4.773
		95% Standard Bootstrap UCL 4.638
Anderson-Darling Test Statistic	0.823	95% Bootstrap-t UCL 4.553
Anderson-Darling 5% Critical Value	0.716	95% Hall's Bootstrap UCL 4.451
Kolmogorov-Smirnov Test Statistic	0.273	95% Percentile Bootstrap UCL 4.588
Kolmogorov-Smirnov 5% Critical Value	0.295	95% BCA Bootstrap UCL 4.488
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 5.811
		97.5% Chebyshev(Mean, Sd) UCL 6.605
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 8.166
95% Approximate Gamma UCL (Use when n >= 40)	5.187	
95% Adjusted Gamma UCL (Use when n < 40)	5.561	

Potential UCL to Use	Use 95% Student's-t UCL 4.773

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Note: For highly negative-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

E-P1-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	8

Raw Statistics		Log-transformed Statistics	
Minimum	64	Minimum of Log Data	4.159
Maximum	300	Maximum of Log Data	5.704
Mean	199.3	Mean of log Data	5.216
Geometric Mean	184.2	SD of log Data	0.472
Median	200		
SD	70.5		
Std. Error of Mean	24.93		
Coefficient of Variation	0.354		
Skewness	-0.718		

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.961	Shapiro Wilk Test Statistic	0.823
Shapiro Wilk Critical Value	0.818	Shapiro Wilk Critical Value	0.818
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	246.5	95% H-UCL	310.5
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	351.5
95% Adjusted-CLT UCL (Chen-1995)	233.5	97.5% Chebyshev (MVUE) UCL	415.9
95% Modified-t UCL (Johnson-1978)	245.4	99% Chebyshev (MVUE) UCL	542.3

Gamma Distribution Test		Data Distribution
k star (bias corrected)	4.156	Data appear Normal at 5% Significance Level
Theta Star	47.94	
MLE of Mean	199.3	
MLE of Standard Deviation	97.73	
nu star	66.5	
Approximate Chi Square Value (.05)	48.74	**Nonparametric Statistics**
Adjusted Level of Significance	0.0195	95% CLT UCL 240.2
Adjusted Chi Square Value	44.91	95% Jackknife UCL 246.5
		95% Standard Bootstrap UCL 236.4
Anderson-Darling Test Statistic	0.478	95% Bootstrap-t UCL 242.4
Anderson-Darling 5% Critical Value	0.718	95% Hall's Bootstrap UCL 238.9
Kolmogorov-Smirnov Test Statistic	0.217	95% Percentile Bootstrap UCL 235
Kolmogorov-Smirnov 5% Critical Value	0.295	95% BCA Bootstrap UCL 232.5
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 307.9
		97.5% Chebyshev(Mean, Sd) UCL 354.9
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 447.3
95% Approximate Gamma UCL (Use when n >= 40)	271.9	
95% Adjusted Gamma UCL (Use when n < 40)	295	

Potential UCL to Use	Use 95% Student's-t UCL 246.5

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Note: For highly negative-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

E-P1-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	7

Raw Statistics		**Log-transformed Statistics**	
Minimum	230	Minimum of Log Data	5.438
Maximum	1100	Maximum of Log Data	7.003
Mean	776.3	Mean of log Data	6.568
Geometric Mean	711.9	SD of log Data	0.5
Median	795		
SD	281.9		
Std. Error of Mean	99.66		
Coefficient of Variation	0.363		
Skewness	-0.831		

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.922	Shapiro Wilk Test Statistic	0.79
Shapiro Wilk Critical Value	0.818	Shapiro Wilk Critical Value	0.818
Data appear Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	965.1	95% H-UCL	1259
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1411
95% Adjusted-CLT UCL (Chen-1995)	908.9	97.5% Chebyshev (MVUE) UCL	1678
95% Modified-t UCL (Johnson-1978)	960.2	99% Chebyshev (MVUE) UCL	2202

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	3.797	Data appear Normal at 5% Significance Level
Theta Star	204.4	
MLE of Mean	776.3	
MLE of Standard Deviation	398.4	
nu star	60.76	
Approximate Chi Square Value (.05)	43.83	**Nonparametric Statistics**
Adjusted Level of Significance	0.0195	95% CLT UCL 940.2
Adjusted Chi Square Value	40.22	95% Jackknife UCL 965.1
		95% Standard Bootstrap UCL 930.7
Anderson-Darling Test Statistic	0.553	95% Bootstrap-t UCL 942.2
Anderson-Darling 5% Critical Value	0.718	95% Hall's Bootstrap UCL 929.7
Kolmogorov-Smirnov Test Statistic	0.237	95% Percentile Bootstrap UCL 927.5
Kolmogorov-Smirnov 5% Critical Value	0.295	95% BCA Bootstrap UCL 912.5
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 1211
		97.5% Chebyshev(Mean, Sd) UCL 1399
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1768
95% Approximate Gamma UCL (Use when n >= 40)	1076	
95% Adjusted Gamma UCL (Use when n < 40)	1173	

Potential UCL to Use		Use 95% Student's-t UCL	965.1

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Note: For highly negative-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

E-P3-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	7

Raw Statistics

Minimum	5.8
Maximum	9.4
Mean	7.338
Geometric Mean	7.18
Median	6.45
SD	1.669
Std. Error of Mean	0.59
Coefficient of Variation	0.227
Skewness	0.573

Log-transformed Statistics

Minimum of Log Data	1.758
Maximum of Log Data	2.241
Mean of log Data	1.971
SD of log Data	0.22

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.748
Shapiro Wilk Critical Value	0.818

Data not Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	8.455

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	8.436
95% Modified-t UCL (Johnson-1978)	8.475

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.766
Shapiro Wilk Critical Value	0.818

Data not Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	8.665
95% Chebyshev (MVUE) UCL	9.831
97.5% Chebyshev (MVUE) UCL	10.91
99% Chebyshev (MVUE) UCL	13.03

Gamma Distribution Test

k star (bias corrected)	14.55
Theta Star	0.504
MLE of Mean	7.338
MLE of Standard Deviation	1.924
nu star	232.8
Approximate Chi Square Value (.05)	198.5
Adjusted Level of Significance	0.0195
Adjusted Chi Square Value	190.5
Anderson-Darling Test Statistic	1.004
Anderson-Darling 5% Critical Value	0.716
Kolmogorov-Smirnov Test Statistic	0.317
Kolmogorov-Smirnov 5% Critical Value	0.294

Data not Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	8.606
95% Adjusted Gamma UCL (Use when n < 40)	8.969

Data Distribution

Data do not follow a Discernable Distribution (0.05)

Nonparametric Statistics

95% CLT UCL	8.308
95% Jackknife UCL	8.455
95% Standard Bootstrap UCL	8.255
95% Bootstrap-t UCL	8.574
95% Hall's Bootstrap UCL	7.926
95% Percentile Bootstrap UCL	8.213
95% BCA Bootstrap UCL	8.25
95% Chebyshev(Mean, Sd) UCL	9.91
97.5% Chebyshev(Mean, Sd) UCL	11.02
99% Chebyshev(Mean, Sd) UCL	13.21

Potential UCL to Use

Use 95% Student's-t UCL	8.455
or 95% Modified-t UCL	8.475

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P3-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	8

Raw Statistics		Log-transformed Statistics	
Minimum	0.15	Minimum of Log Data	-1.897
Maximum	3.6	Maximum of Log Data	1.281
Mean	1.675	Mean of log Data	0.11
Geometric Mean	1.116	SD of log Data	1.152
Median	1.65		
SD	1.207		
Std. Error of Mean	0.427		
Coefficient of Variation	0.721		
Skewness	0.261		

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.96	Shapiro Wilk Test Statistic	0.862
Shapiro Wilk Critical Value	0.818	Shapiro Wilk Critical Value	0.818
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	2.484	95% H-UCL	11.37
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	5.422
95% Adjusted-CLT UCL (Chen-1995)	2.419	97.5% Chebyshev (MVUE) UCL	6.933
95% Modified-t UCL (Johnson-1978)	2.49	99% Chebyshev (MVUE) UCL	9.901

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.942	Data appear Normal at 5% Significance Level
Theta Star	1.778	
MLE of Mean	1.675	
MLE of Standard Deviation	1.726	
nu star	15.07	
Approximate Chi Square Value (.05)	7.313	**Nonparametric Statistics**
Adjusted Level of Significance	0.0195	95% CLT UCL 2.377
Adjusted Chi Square Value	5.999	95% Jackknife UCL 2.484
		95% Standard Bootstrap UCL 2.338
Anderson-Darling Test Statistic	0.381	95% Bootstrap-t UCL 2.541
Anderson-Darling 5% Critical Value	0.73	95% Hall's Bootstrap UCL 2.555
Kolmogorov-Smirnov Test Statistic	0.184	95% Percentile Bootstrap UCL 2.319
Kolmogorov-Smirnov 5% Critical Value	0.3	95% BCA Bootstrap UCL 2.356
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 3.535
		97.5% Chebyshev(Mean, Sd) UCL 4.34
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 5.921
95% Approximate Gamma UCL (Use when n >= 40)	3.453	
95% Adjusted Gamma UCL (Use when n < 40)	4.209	

Potential UCL to Use	Use 95% Student's-t UCL 2.484

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P3-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	8

Raw Statistics

Minimum	21
Maximum	180
Mean	90.5
Geometric Mean	72.49
Median	84
SD	58.25
Std. Error of Mean	20.6
Coefficient of Variation	0.644
Skewness	0.601

Log-transformed Statistics

Minimum of Log Data	3.045
Maximum of Log Data	5.193
Mean of log Data	4.283
SD of log Data	0.765

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.893
Shapiro Wilk Critical Value	0.818

Data appear Normal at 5% Significance Level

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.907
Shapiro Wilk Critical Value	0.818

Data appear Lognormal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	129.5

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	129.1
95% Modified-t UCL (Johnson-1978)	130.2

Assuming Lognormal Distribution

95% H-UCL	223
95% Chebyshev (MVUE) UCL	204.6
97.5% Chebyshev (MVUE) UCL	252.9
99% Chebyshev (MVUE) UCL	347.8

Gamma Distribution Test

k star (bias corrected)	1.587
Theta Star	57.01
MLE of Mean	90.5
MLE of Standard Deviation	71.83
nu star	25.4
Approximate Chi Square Value (.05)	14.92
Adjusted Level of Significance	0.0195
Adjusted Chi Square Value	12.93
Anderson-Darling Test Statistic	0.36
Anderson-Darling 5% Critical Value	0.723
Kolmogorov-Smirnov Test Statistic	0.161
Kolmogorov-Smirnov 5% Critical Value	0.297

Data appear Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	154.1
95% Adjusted Gamma UCL (Use when n < 40)	177.8

Data Distribution

Data appear Normal at 5% Significance Level

Nonparametric Statistics

95% CLT UCL	124.4
95% Jackknife UCL	129.5
95% Standard Bootstrap UCL	121.5
95% Bootstrap-t UCL	145.1
95% Hall's Bootstrap UCL	186.7
95% Percentile Bootstrap UCL	122.6
95% BCA Bootstrap UCL	125.5
95% Chebyshev(Mean, Sd) UCL	180.3
97.5% Chebyshev(Mean, Sd) UCL	219.1
99% Chebyshev(Mean, Sd) UCL	295.4

Potential UCL to Use

Use 95% Student's-t UCL 129.5

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P3-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	8

Raw Statistics

Minimum	55
Maximum	730
Mean	363.4
Geometric Mean	266.5
Median	360
SD	246.9
Std. Error of Mean	87.29
Coefficient of Variation	0.679
Skewness	0.287

Log-transformed Statistics

Minimum of Log Data	4.007
Maximum of Log Data	6.593
Mean of log Data	5.585
SD of log Data	0.96

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.93
Shapiro Wilk Critical Value	0.818

Data appear Normal at 5% Significance Level

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.87
Shapiro Wilk Critical Value	0.818

Data appear Lognormal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	528.7

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	516.4
95% Modified-t UCL (Johnson-1978)	530.2

Assuming Lognormal Distribution

95% H-UCL	1415
95% Chebyshev (MVUE) UCL	985.3
97.5% Chebyshev (MVUE) UCL	1242
99% Chebyshev (MVUE) UCL	1746

Gamma Distribution Test

k star (bias corrected)	1.183
Theta Star	307.1
MLE of Mean	363.4
MLE of Standard Deviation	334
nu star	18.93
Approximate Chi Square Value (.05)	10.07
Adjusted Level of Significance	0.0195
Adjusted Chi Square Value	8.484
Anderson-Darling Test Statistic	0.387
Anderson-Darling 5% Critical Value	0.726
Kolmogorov-Smirnov Test Statistic	0.172
Kolmogorov-Smirnov 5% Critical Value	0.298

Data appear Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	683.3
95% Adjusted Gamma UCL (Use when n < 40)	811

Data Distribution

Data appear Normal at 5% Significance Level

Nonparametric Statistics

95% CLT UCL	507
95% Jackknife UCL	528.7
95% Standard Bootstrap UCL	496.2
95% Bootstrap-t UCL	564.6
95% Hall's Bootstrap UCL	575.6
95% Percentile Bootstrap UCL	499
95% BCA Bootstrap UCL	506.5
95% Chebyshev(Mean, Sd) UCL	743.9
97.5% Chebyshev(Mean, Sd) UCL	908.5
99% Chebyshev(Mean, Sd) UCL	1232

Potential UCL to Use

Use 95% Student's-t UCL 528.7

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P4-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	9

Raw Statistics		**Log-transformed Statistics**	
Minimum	8.5	Minimum of Log Data	2.14
Maximum	32	Maximum of Log Data	3.466
Mean	16.06	Mean of log Data	2.7
Geometric Mean	14.88	SD of log Data	0.404
Median	15		
SD	6.999		
Std. Error of Mean	2.213		
Coefficient of Variation	0.436		
Skewness	1.359		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.89	Shapiro Wilk Test Statistic	0.97
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	20.12	95% H-UCL	21.41
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	25.03
95% Adjusted-CLT UCL (Chen-1995)	20.72	97.5% Chebyshev (MVUE) UCL	28.94
95% Modified-t UCL (Johnson-1978)	20.28	99% Chebyshev (MVUE) UCL	36.61

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	4.772	Data appear Normal at 5% Significance Level
Theta Star	3.365	
MLE of Mean	16.06	
MLE of Standard Deviation	7.352	
nu star	95.44	
Approximate Chi Square Value (.05)	73.91	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 19.7
Adjusted Chi Square Value	70.62	95% Jackknife UCL 20.12
		95% Standard Bootstrap UCL 19.68
Anderson-Darling Test Statistic	0.236	95% Bootstrap-t UCL 22.38
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL 39.38
Kolmogorov-Smirnov Test Statistic	0.153	95% Percentile Bootstrap UCL 19.7
Kolmogorov-Smirnov 5% Critical Value	0.267	95% BCA Bootstrap UCL 20.4
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 25.71
		97.5% Chebyshev(Mean, Sd) UCL 29.88
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 38.08
95% Approximate Gamma UCL (Use when n >= 40)	20.74	
95% Adjusted Gamma UCL (Use when n < 40)	21.7	

Potential UCL to Use		Use 95% Student's-t UCL	20.12

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P4-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics

Minimum	0.16
Maximum	0.8
Mean	0.381
Geometric Mean	0.344
Median	0.35
SD	0.19
Std. Error of Mean	0.06
Coefficient of Variation	0.498
Skewness	1.294

Log-transformed Statistics

Minimum of Log Data	-1.833
Maximum of Log Data	-0.223
Mean of log Data	-1.067
SD of log Data	0.474

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.886
Shapiro Wilk Critical Value	0.842

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	0.491

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	0.506
95% Modified-t UCL (Johnson-1978)	0.495

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.97
Shapiro Wilk Critical Value	0.842

Data appear Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	0.544
95% Chebyshev (MVUE) UCL	0.633
97.5% Chebyshev (MVUE) UCL	0.742
99% Chebyshev (MVUE) UCL	0.957

Gamma Distribution Test

k star (bias corrected)	3.595
Theta Star	0.106
MLE of Mean	0.381
MLE of Standard Deviation	0.201
nu star	71.91
Approximate Chi Square Value (.05)	53.38
Adjusted Level of Significance	0.0267
Adjusted Chi Square Value	50.62
Anderson-Darling Test Statistic	0.292
Anderson-Darling 5% Critical Value	0.729
Kolmogorov-Smirnov Test Statistic	0.176
Kolmogorov-Smirnov 5% Critical Value	0.267

Data appear Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	0.513
95% Adjusted Gamma UCL (Use when n < 40)	0.541

Data Distribution

Data appear Normal at 5% Significance Level

Nonparametric Statistics

95% CLT UCL	0.48
95% Jackknife UCL	0.491
95% Standard Bootstrap UCL	0.477
95% Bootstrap-t UCL	0.556
95% Hall's Bootstrap UCL	1.169
95% Percentile Bootstrap UCL	0.482
95% BCA Bootstrap UCL	0.495
95% Chebyshev(Mean, Sd) UCL	0.642
97.5% Chebyshev(Mean, Sd) UCL	0.756
99% Chebyshev(Mean, Sd) UCL	0.978

Potential UCL to Use

Use 95% Student's-t UCL 0.491

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P4-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		Log-transformed Statistics	
Minimum	17	Minimum of Log Data	2.833
Maximum	58	Maximum of Log Data	4.06
Mean	37.3	Mean of log Data	3.539
Geometric Mean	34.42	SD of log Data	0.432
Median	34.5		
SD	15.17		
Std. Error of Mean	4.798		
Coefficient of Variation	0.407		
Skewness	0.218		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.918	Shapiro Wilk Test Statistic	0.937
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	46.1	95% H-UCL	51.31
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	59.97
95% Adjusted-CLT UCL (Chen-1995)	45.55	97.5% Chebyshev (MVUE) UCL	69.73
95% Modified-t UCL (Johnson-1978)	46.15	99% Chebyshev (MVUE) UCL	88.9

Gamma Distribution Test		Data Distribution
k star (bias corrected)	4.537	Data appear Normal at 5% Significance Level
Theta Star	8.222	
MLE of Mean	37.3	
MLE of Standard Deviation	17.51	
nu star	90.73	
Approximate Chi Square Value (.05)	69.77	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 45.19
Adjusted Chi Square Value	66.58	95% Jackknife UCL 46.1
		95% Standard Bootstrap UCL 44.85
Anderson-Darling Test Statistic	0.31	95% Bootstrap-t UCL 46.13
Anderson-Darling 5% Critical Value	0.728	95% Hall's Bootstrap UCL 44.34
Kolmogorov-Smirnov Test Statistic	0.158	95% Percentile Bootstrap UCL 45
Kolmogorov-Smirnov 5% Critical Value	0.267	95% BCA Bootstrap UCL 44.8
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 58.22
		97.5% Chebyshev(Mean, Sd) UCL 67.27
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 85.04
95% Approximate Gamma UCL (Use when n >= 40)	48.51	
95% Adjusted Gamma UCL (Use when n < 40)	50.83	

Potential UCL to Use		Use 95% Student's-t UCL	46.1

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-P4-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		**Log-transformed Statistics**	
Minimum	56	Minimum of Log Data	4.025
Maximum	190	Maximum of Log Data	5.247
Mean	90.4	Mean of log Data	4.443
Geometric Mean	85.07	SD of log Data	0.346
Median	82.5		
SD	38.25		
Std. Error of Mean	12.1		
Coefficient of Variation	0.423		
Skewness	2.259		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.733	Shapiro Wilk Test Statistic	0.867
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	112.6	95% H-UCL	114.1
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	132.9
95% Adjusted-CLT UCL (Chen-1995)	119.5	97.5% Chebyshev (MVUE) UCL	151.6
95% Modified-t UCL (Johnson-1978)	114	99% Chebyshev (MVUE) UCL	188.3

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	5.938	Data appear Lognormal at 5% Significance Level
Theta Star	15.23	
MLE of Mean	90.4	
MLE of Standard Deviation	37.1	
nu star	118.8	
Approximate Chi Square Value (.05)	94.59	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 110.3
Adjusted Chi Square Value	90.85	95% Jackknife UCL 112.6
		95% Standard Bootstrap UCL 109
Anderson-Darling Test Statistic	0.749	95% Bootstrap-t UCL 140.5
Anderson-Darling 5% Critical Value	0.726	95% Hall's Bootstrap UCL 216.4
Kolmogorov-Smirnov Test Statistic	0.285	95% Percentile Bootstrap UCL 110.1
Kolmogorov-Smirnov 5% Critical Value	0.267	95% BCA Bootstrap UCL 119.4
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 143.1
		97.5% Chebyshev(Mean, Sd) UCL 165.9
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 210.8
95% Approximate Gamma UCL (Use when n >= 40)	113.5	
95% Adjusted Gamma UCL (Use when n < 40)	118.2	

Potential UCL to Use	Use 95% Student's-t UCL 112.6
	or 95% Modified-t UCL 114
	or 95% H-UCL 114.1

ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-PE-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	7

Raw Statistics

Minimum	5
Maximum	8
Mean	6.113
Geometric Mean	6.058
Median	5.9
SD	0.905
Std. Error of Mean	0.32
Coefficient of Variation	0.148
Skewness	1.353

Log-transformed Statistics

Minimum of Log Data	1.609
Maximum of Log Data	2.079
Mean of log Data	1.801
SD of log Data	0.14

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.891
Shapiro Wilk Critical Value	0.818

Data appear Normal at 5% Significance Level

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.929
Shapiro Wilk Critical Value	0.818

Data appear Lognormal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	6.718

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	6.802
95% Modified-t UCL (Johnson-1978)	6.744

Assuming Lognormal Distribution

95% H-UCL	6.761
95% Chebyshev (MVUE) UCL	7.432
97.5% Chebyshev (MVUE) UCL	8.004
99% Chebyshev (MVUE) UCL	9.127

Gamma Distribution Test

k star (bias corrected)	35.31
Theta Star	0.173
MLE of Mean	6.113
MLE of Standard Deviation	1.029
nu star	564.9
Approximate Chi Square Value (.05)	510.8
Adjusted Level of Significance	0.0195
Adjusted Chi Square Value	497.7
Anderson-Darling Test Statistic	0.401
Anderson-Darling 5% Critical Value	0.715
Kolmogorov-Smirnov Test Statistic	0.238
Kolmogorov-Smirnov 5% Critical Value	0.293

Data appear Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	6.76
95% Adjusted Gamma UCL (Use when n < 40)	6.938

Data Distribution

Data appear Normal at 5% Significance Level

Nonparametric Statistics

95% CLT UCL	6.639
95% Jackknife UCL	6.718
95% Standard Bootstrap UCL	6.611
95% Bootstrap-t UCL	7.1
95% Hall's Bootstrap UCL	10.12
95% Percentile Bootstrap UCL	6.6
95% BCA Bootstrap UCL	6.775
95% Chebyshev(Mean, Sd) UCL	7.507
97.5% Chebyshev(Mean, Sd) UCL	8.11
99% Chebyshev(Mean, Sd) UCL	9.295

Potential UCL to Use

Use 95% Student's-t UCL 6.718

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-PE-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	7

Raw Statistics

Minimum	0.52
Maximum	1.6
Mean	0.85
Geometric Mean	0.81
Median	0.795
SD	0.32
Std. Error of Mean	0.113
Coefficient of Variation	0.376
Skewness	2.215

Log-transformed Statistics

Minimum of Log Data	-0.654
Maximum of Log Data	0.47
Mean of log Data	-0.211
SD of log Data	0.315

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set,
the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.711
Shapiro Wilk Critical Value	0.818

Data not Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	1.064

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	1.131
95% Modified-t UCL (Johnson-1978)	1.079

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.827
Shapiro Wilk Critical Value	0.818

Data appear Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	1.09
95% Chebyshev (MVUE) UCL	1.258
97.5% Chebyshev (MVUE) UCL	1.437
99% Chebyshev (MVUE) UCL	1.787

Gamma Distribution Test

k star (bias corrected)	6.642
Theta Star	0.128
MLE of Mean	0.85
MLE of Standard Deviation	0.33
nu star	106.3
Approximate Chi Square Value (.05)	83.48
Adjusted Level of Significance	0.0195
Adjusted Chi Square Value	78.38
Anderson-Darling Test Statistic	0.882
Anderson-Darling 5% Critical Value	0.715
Kolmogorov-Smirnov Test Statistic	0.364
Kolmogorov-Smirnov 5% Critical Value	0.294

Data not Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	1.082
95% Adjusted Gamma UCL (Use when n < 40)	1.152

Data Distribution

Data appear Lognormal at 5% Significance Level

Nonparametric Statistics

95% CLT UCL	1.036
95% Jackknife UCL	1.064
95% Standard Bootstrap UCL	1.025
95% Bootstrap-t UCL	1.318
95% Hall's Bootstrap UCL	1.943
95% Percentile Bootstrap UCL	1.058
95% BCA Bootstrap UCL	1.096
95% Chebyshev(Mean, Sd) UCL	1.343
97.5% Chebyshev(Mean, Sd) UCL	1.556
99% Chebyshev(Mean, Sd) UCL	1.975

Potential UCL to Use

Use 95% Student's-t UCL	1.064
or 95% Modified-t UCL	1.079
or 95% H-UCL	1.09

ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-PE-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	5

Raw Statistics		**Log-transformed Statistics**	
Minimum	37	Minimum of Log Data	3.611
Maximum	69	Maximum of Log Data	4.234
Mean	46.75	Mean of log Data	3.827
Geometric Mean	45.94	SD of log Data	0.194
Median	44		
SD	10.05		
Std. Error of Mean	3.554		
Coefficient of Variation	0.215		
Skewness	1.799		

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.808	Shapiro Wilk Test Statistic	0.867
Shapiro Wilk Critical Value	0.818	Shapiro Wilk Critical Value	0.818
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	53.48	95% H-UCL	53.94
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	60.67
95% Adjusted-CLT UCL (Chen-1995)	55.01	97.5% Chebyshev (MVUE) UCL	66.72
95% Modified-t UCL (Johnson-1978)	53.86	99% Chebyshev (MVUE) UCL	78.6

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	17.96	Data appear Gamma Distributed at 5% Significance Level
Theta Star	2.603	
MLE of Mean	46.75	
MLE of Standard Deviation	11.03	
nu star	287.4	
Approximate Chi Square Value (.05)	249.1	**Nonparametric Statistics**
Adjusted Level of Significance	0.0195	95% CLT UCL 52.6
Adjusted Chi Square Value	240.1	95% Jackknife UCL 53.48
		95% Standard Bootstrap UCL 52.29
Anderson-Darling Test Statistic	0.592	95% Bootstrap-t UCL 60.44
Anderson-Darling 5% Critical Value	0.716	95% Hall's Bootstrap UCL 79.4
Kolmogorov-Smirnov Test Statistic	0.234	95% Percentile Bootstrap UCL 52.75
Kolmogorov-Smirnov 5% Critical Value	0.294	95% BCA Bootstrap UCL 54.25
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 62.24
		97.5% Chebyshev(Mean, Sd) UCL 68.95
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 82.12
95% Approximate Gamma UCL (Use when n >= 40)	53.93	
95% Adjusted Gamma UCL (Use when n < 40)	55.96	

Potential UCL to Use	Use 95% Approximate Gamma UCL 53.93

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-PE-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	8	Number of Distinct Observations	5

Raw Statistics

Minimum	120
Maximum	280
Mean	160
Geometric Mean	154.6
Median	150
SD	50.99
Std. Error of Mean	18.03
Coefficient of Variation	0.319
Skewness	2.31

Log-transformed Statistics

Minimum of Log Data	4.787
Maximum of Log Data	5.635
Mean of log Data	5.041
SD of log Data	0.264

Warning: There are only 8 Values in this data
Note: It should be noted that even though bootstrap methods may be performed on this data set, the resulting calculations may not be reliable enough to draw conclusions

The literature suggests to use bootstrap methods on data sets having more than 10-15 observations.

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.701
Shapiro Wilk Critical Value	0.818

Data not Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	194.2

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	205.4
95% Modified-t UCL (Johnson-1978)	196.6

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.793
Shapiro Wilk Critical Value	0.818

Data not Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	195.7
95% Chebyshev (MVUE) UCL	224.4
97.5% Chebyshev (MVUE) UCL	252.6
99% Chebyshev (MVUE) UCL	307.9

Gamma Distribution Test

k star (bias corrected)	9.233
Theta Star	17.33
MLE of Mean	160
MLE of Standard Deviation	52.66
nu star	147.7
Approximate Chi Square Value (.05)	120.6
Adjusted Level of Significance	0.0195
Adjusted Chi Square Value	114.4
Anderson-Darling Test Statistic	0.876
Anderson-Darling 5% Critical Value	0.716
Kolmogorov-Smirnov Test Statistic	0.312
Kolmogorov-Smirnov 5% Critical Value	0.294

Data not Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	195.9
95% Adjusted Gamma UCL (Use when n < 40)	206.5

Data Distribution

Data do not follow a Discernable Distribution (0.05)

Nonparametric Statistics

95% CLT UCL	189.7
95% Jackknife UCL	194.2
95% Standard Bootstrap UCL	188.2
95% Bootstrap-t UCL	246.9
95% Hall's Bootstrap UCL	326.1
95% Percentile Bootstrap UCL	191.3
95% BCA Bootstrap UCL	200
95% Chebyshev(Mean, Sd) UCL	238.6
97.5% Chebyshev(Mean, Sd) UCL	272.6
99% Chebyshev(Mean, Sd) UCL	339.4

Potential UCL to Use

Use 95% Student's-t UCL	194.2
or 95% Modified-t UCL	196.6

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Lower Drainage Area Channel
Sediments – Individual Transects

General UCL Statistics for Full Data Sets

Confidence Coefficient 95%
Number of Bootstrap Operations 2000

E-C-24-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations 10
Number of Distinct Observations 9

Raw Statistics

Minimum	2.6
Maximum	20
Mean	7.94
Geometric Mean	6.251
Median	5.3
SD	6.356
Std. Error of Mean	2.01
Coefficient of Variation	0.8
Skewness	1.455

Log-transformed Statistics

Minimum of Log Data	0.956
Maximum of Log Data	2.996
Mean of log Data	1.833
SD of log Data	0.698

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.754
Shapiro Wilk Critical Value	0.842

Data not Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	11.62

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	12.23
95% Modified-t UCL (Johnson-1978)	11.78

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.907
Shapiro Wilk Critical Value	0.842

Data appear Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	14.35
95% Chebyshev (MVUE) UCL	15.43
97.5% Chebyshev (MVUE) UCL	18.76
99% Chebyshev (MVUE) UCL	25.29

Gamma Distribution Test

k star (bias corrected)	1.636
Theta Star	4.852
MLE of Mean	7.94
MLE of Standard Deviation	6.207
nu star	32.73
Approximate Chi Square Value (.05)	20.65
Adjusted Level of Significance	0.0267
Adjusted Chi Square Value	19
Anderson-Darling Test Statistic	0.643
Anderson-Darling 5% Critical Value	0.735
Kolmogorov-Smirnov Test Statistic	0.222
Kolmogorov-Smirnov 5% Critical Value	0.269

Data appear Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	12.58
95% Adjusted Gamma UCL (Use when n < 40)	13.68

Data Distribution

Data appear Gamma Distributed at 5% Significance Level

Nonparametric Statistics

95% CLT UCL	11.25
95% Jackknife UCL	11.62
95% Standard Bootstrap UCL	11.09
95% Bootstrap-t UCL	17.53
95% Hall's Bootstrap UCL	32.02
95% Percentile Bootstrap UCL	11.08
95% BCA Bootstrap UCL	12.1
95% Chebyshev(Mean, Sd) UCL	16.7
97.5% Chebyshev(Mean, Sd) UCL	20.49
99% Chebyshev(Mean, Sd) UCL	27.94

Potential UCL to Use

Use 95% Approximate Gamma UCL 12.58

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-24-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		Log-transformed Statistics	
Minimum	0.65	Minimum of Log Data	-0.431
Maximum	7.4	Maximum of Log Data	2.001
Mean	2.493	Mean of log Data	0.505
Geometric Mean	1.657	SD of log Data	0.908
Median	1.15		
SD	2.528		
Std. Error of Mean	0.799		
Coefficient of Variation	1.014		
Skewness	1.315		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.732	Shapiro Wilk Test Statistic	0.843
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	3.958	95% H-UCL	6.057
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	5.477
95% Adjusted-CLT UCL (Chen-1995)	4.163	97.5% Chebyshev (MVUE) UCL	6.82
95% Modified-t UCL (Johnson-1978)	4.014	99% Chebyshev (MVUE) UCL	9.458

Gamma Distribution Test		Data Distribution
k star (bias corrected)	1.023	Data appear Lognormal at 5% Significance Level
Theta Star	2.436	
MLE of Mean	2.493	
MLE of Standard Deviation	2.464	
nu star	20.47	
Approximate Chi Square Value (.05)	11.2	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 3.808
Adjusted Chi Square Value	10.03	95% Jackknife UCL 3.958
		95% Standard Bootstrap UCL 3.733
Anderson-Darling Test Statistic	0.969	95% Bootstrap-t UCL 5.313
Anderson-Darling 5% Critical Value	0.742	95% Hall's Bootstrap UCL 3.861
Kolmogorov-Smirnov Test Statistic	0.299	95% Percentile Bootstrap UCL 3.781
Kolmogorov-Smirnov 5% Critical Value	0.272	95% BCA Bootstrap UCL 4.126
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 5.978
		97.5% Chebyshev(Mean, Sd) UCL 7.485
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 10.45
95% Approximate Gamma UCL (Use when n >= 40)	4.557	
95% Adjusted Gamma UCL (Use when n < 40)	5.09	

Potential UCL to Use	Use 95% H-UCL 6.057

ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-24-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	9

Raw Statistics

Minimum	12
Maximum	210
Mean	54.4
Geometric Mean	27.95
Median	19
SD	77.1
Std. Error of Mean	24.38
Coefficient of Variation	1.417
Skewness	1.771

Log-transformed Statistics

Minimum of Log Data	2.485
Maximum of Log Data	5.347
Mean of log Data	3.33
SD of log Data	1.078

Relevant UCL Statistics

Normal Distribution Test

Shapiro Wilk Test Statistic	0.585
Shapiro Wilk Critical Value	0.842

Data not Normal at 5% Significance Level

Assuming Normal Distribution

95% Student's-t UCL	99.09

95% UCLs (Adjusted for Skewness)

95% Adjusted-CLT UCL (Chen-1995)	109.1
95% Modified-t UCL (Johnson-1978)	101.4

Gamma Distribution Test

k star (bias corrected)	0.683
Theta Star	79.66
MLE of Mean	54.4
MLE of Standard Deviation	65.83
nu star	13.66
Approximate Chi Square Value (.05)	6.338
Adjusted Level of Significance	0.0267
Adjusted Chi Square Value	5.495
Anderson-Darling Test Statistic	1.588
Anderson-Darling 5% Critical Value	0.752
Kolmogorov-Smirnov Test Statistic	0.344
Kolmogorov-Smirnov 5% Critical Value	0.275

Data not Gamma Distributed at 5% Significance Level

Assuming Gamma Distribution

95% Approximate Gamma UCL (Use when n >= 40)	117.2
95% Adjusted Gamma UCL (Use when n < 40)	135.2

Lognormal Distribution Test

Shapiro Wilk Test Statistic	0.741
Shapiro Wilk Critical Value	0.842

Data not Lognormal at 5% Significance Level

Assuming Lognormal Distribution

95% H-UCL	161.7
95% Chebyshev (MVUE) UCL	118.2
97.5% Chebyshev (MVUE) UCL	149.4
99% Chebyshev (MVUE) UCL	210.7

Data Distribution

Data do not follow a Discernable Distribution (0.05)

Nonparametric Statistics

95% CLT UCL	94.5
95% Jackknife UCL	99.09
95% Standard Bootstrap UCL	92.81
95% Bootstrap-t UCL	522.7
95% Hall's Bootstrap UCL	399.2
95% Percentile Bootstrap UCL	93.5
95% BCA Bootstrap UCL	109
95% Chebyshev(Mean, Sd) UCL	160.7
97.5% Chebyshev(Mean, Sd) UCL	206.7
99% Chebyshev(Mean, Sd) UCL	297

Potential UCL to Use

Use 95% Chebyshev (Mean, Sd) UCL 160.7

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-24-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	7

Raw Statistics		Log-transformed Statistics	
Minimum	90	Minimum of Log Data	4.5
Maximum	860	Maximum of Log Data	6.757
Mean	323	Mean of log Data	5.418
Geometric Mean	225.5	SD of log Data	0.845
Median	150		
SD	310.4		
Std. Error of Mean	98.15		
Coefficient of Variation	0.961		
Skewness	1.244		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.682	Shapiro Wilk Test Statistic	0.761
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	502.9	95% H-UCL	707.2
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	681.1
95% Adjusted-CLT UCL (Chen-1995)	525.7	97.5% Chebyshev (MVUE) UCL	842.5
95% Modified-t UCL (Johnson-1978)	509.4	99% Chebyshev (MVUE) UCL	1160

Gamma Distribution Test		Data Distribution
k star (bias corrected)	1.142	Data do not follow a Discernable Distribution (0.05)
Theta Star	282.8	
MLE of Mean	323	
MLE of Standard Deviation	302.2	
nu star	22.84	
Approximate Chi Square Value (.05)	12.97	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 484.4
Adjusted Chi Square Value	11.7	95% Jackknife UCL 502.9
		95% Standard Bootstrap UCL 478.8
Anderson-Darling Test Statistic	1.447	95% Bootstrap-t UCL 650.8
Anderson-Darling 5% Critical Value	0.739	95% Hall's Bootstrap UCL 463.2
Kolmogorov-Smirnov Test Statistic	0.412	95% Percentile Bootstrap UCL 482
Kolmogorov-Smirnov 5% Critical Value	0.271	95% BCA Bootstrap UCL 506
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 750.8
		97.5% Chebyshev(Mean, Sd) UCL 935.9
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1300
95% Approximate Gamma UCL (Use when n >= 40)	568.8	
95% Adjusted Gamma UCL (Use when n < 40)	630.7	

Potential UCL to Use		Use 95% Chebyshev (Mean, Sd) UCL	750.8

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-25-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	9

Raw Statistics		Log-transformed Statistics	
Minimum	3.1	Minimum of Log Data	1.131
Maximum	18	Maximum of Log Data	2.89
Mean	9.23	Mean of log Data	2.102
Geometric Mean	8.182	SD of log Data	0.529
Median	8.35		
SD	4.718		
Std. Error of Mean	1.492		
Coefficient of Variation	0.511		
Skewness	0.835		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.928	Shapiro Wilk Test Statistic	0.978
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	11.96	95% H-UCL	14.03
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	16.16
95% Adjusted-CLT UCL (Chen-1995)	12.11	97.5% Chebyshev (MVUE) UCL	19.15
95% Modified-t UCL (Johnson-1978)	12.03	99% Chebyshev (MVUE) UCL	25.01

Gamma Distribution Test		Data Distribution
k star (bias corrected)	3.082	Data appear Normal at 5% Significance Level
Theta Star	2.995	
MLE of Mean	9.23	
MLE of Standard Deviation	5.257	
nu star	61.64	
Approximate Chi Square Value (.05)	44.58	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 11.68
Adjusted Chi Square Value	42.07	95% Jackknife UCL 11.96
		95% Standard Bootstrap UCL 11.53
Anderson-Darling Test Statistic	0.181	95% Bootstrap-t UCL 13.07
Anderson-Darling 5% Critical Value	0.729	95% Hall's Bootstrap UCL 14.38
Kolmogorov-Smirnov Test Statistic	0.121	95% Percentile Bootstrap UCL 11.63
Kolmogorov-Smirnov 5% Critical Value	0.268	95% BCA Bootstrap UCL 12.05
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 15.73
		97.5% Chebyshev(Mean, Sd) UCL 18.55
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 24.08
95% Approximate Gamma UCL (Use when n >= 40)	12.76	
95% Adjusted Gamma UCL (Use when n < 40)	13.52	

Potential UCL to Use	Use 95% Student's-t UCL 11.96

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-25-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	9

Raw Statistics		Log-transformed Statistics	
Minimum	0.33	Minimum of Log Data	-1.109
Maximum	24	Maximum of Log Data	3.178
Mean	6.283	Mean of log Data	0.918
Geometric Mean	2.505	SD of log Data	1.619
Median	3.55		
SD	7.762		
Std. Error of Mean	2.455		
Coefficient of Variation	1.235		
Skewness	1.608		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.795	Shapiro Wilk Test Statistic	0.901
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	10.78	95% H-UCL	104.4
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	24.62
95% Adjusted-CLT UCL (Chen-1995)	11.65	97.5% Chebyshev (MVUE) UCL	32.09
95% Modified-t UCL (Johnson-1978)	10.99	99% Chebyshev (MVUE) UCL	46.76

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.53	Data appear Gamma Distributed at 5% Significance Level
Theta Star	11.85	
MLE of Mean	6.283	
MLE of Standard Deviation	8.627	
nu star	10.61	
Approximate Chi Square Value (.05)	4.325	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 10.32
Adjusted Chi Square Value	3.654	95% Jackknife UCL 10.78
		95% Standard Bootstrap UCL 10.11
Anderson-Darling Test Statistic	0.349	95% Bootstrap-t UCL 15.42
Anderson-Darling 5% Critical Value	0.764	95% Hall's Bootstrap UCL 30.59
Kolmogorov-Smirnov Test Statistic	0.173	95% Percentile Bootstrap UCL 10.07
Kolmogorov-Smirnov 5% Critical Value	0.278	95% BCA Bootstrap UCL 11.55
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 16.98
		97.5% Chebyshev(Mean, Sd) UCL 21.61
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 30.71
95% Approximate Gamma UCL (Use when n >= 40)	15.41	
95% Adjusted Gamma UCL (Use when n < 40)	18.24	

Potential UCL to Use	Use 95% Approximate Gamma UCL 15.41

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-25-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		Log-transformed Statistics	
Minimum	13	Minimum of Log Data	2.565
Maximum	150	Maximum of Log Data	5.011
Mean	55	Mean of log Data	3.666
Geometric Mean	39.08	SD of log Data	0.895
Median	40		
SD	46.37		
Std. Error of Mean	14.66		
Coefficient of Variation	0.843		
Skewness	1.093		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.867	Shapiro Wilk Test Statistic	0.924
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	81.88	95% H-UCL	138.2
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	126.7
95% Adjusted-CLT UCL (Chen-1995)	84.53	97.5% Chebyshev (MVUE) UCL	157.6
95% Modified-t UCL (Johnson-1978)	82.72	99% Chebyshev (MVUE) UCL	218.2

Gamma Distribution Test		Data Distribution
k star (bias corrected)	1.193	Data appear Normal at 5% Significance Level
Theta Star	46.09	
MLE of Mean	55	
MLE of Standard Deviation	50.35	
nu star	23.86	
Approximate Chi Square Value (.05)	13.75	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 79.12
Adjusted Chi Square Value	12.43	95% Jackknife UCL 81.88
		95% Standard Bootstrap UCL 77.77
Anderson-Darling Test Statistic	0.346	95% Bootstrap-t UCL 92.82
Anderson-Darling 5% Critical Value	0.738	95% Hall's Bootstrap UCL 93.3
Kolmogorov-Smirnov Test Statistic	0.167	95% Percentile Bootstrap UCL 79.1
Kolmogorov-Smirnov 5% Critical Value	0.271	95% BCA Bootstrap UCL 83.9
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 118.9
		97.5% Chebyshev(Mean, Sd) UCL 146.6
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 200.9
95% Approximate Gamma UCL (Use when n >= 40)	95.49	
95% Adjusted Gamma UCL (Use when n < 40)	105.6	

Potential UCL to Use	Use 95% Student's-t UCL 81.88

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-25-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	10	Number of Distinct Observations	10

Raw Statistics		Log-transformed Statistics	
Minimum	62	Minimum of Log Data	4.127
Maximum	2000	Maximum of Log Data	7.601
Mean	649	Mean of log Data	5.812
Geometric Mean	334.2	SD of log Data	1.332
Median	445		
SD	684.1		
Std. Error of Mean	216.3		
Coefficient of Variation	1.054		
Skewness	1.091		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.834	Shapiro Wilk Test Statistic	0.895
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	1046	95% H-UCL	4423
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	2076
95% Adjusted-CLT UCL (Chen-1995)	1085	97.5% Chebyshev (MVUE) UCL	2669
95% Modified-t UCL (Johnson-1978)	1058	99% Chebyshev (MVUE) UCL	3834

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.685	Data appear Gamma Distributed at 5% Significance Level
Theta Star	948	
MLE of Mean	649	
MLE of Standard Deviation	784.4	
nu star	13.69	
Approximate Chi Square Value (.05)	6.361	**Nonparametric Statistics**
Adjusted Level of Significance	0.0267	95% CLT UCL 1005
Adjusted Chi Square Value	5.516	95% Jackknife UCL 1046
		95% Standard Bootstrap UCL 982.1
Anderson-Darling Test Statistic	0.42	95% Bootstrap-t UCL 1225
Anderson-Darling 5% Critical Value	0.752	95% Hall's Bootstrap UCL 1082
Kolmogorov-Smirnov Test Statistic	0.174	95% Percentile Bootstrap UCL 985.4
Kolmogorov-Smirnov 5% Critical Value	0.275	95% BCA Bootstrap UCL 1073
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 1592
		97.5% Chebyshev(Mean, Sd) UCL 2000
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 2802
95% Approximate Gamma UCL (Use when n >= 40)	1397	
95% Adjusted Gamma UCL (Use when n < 40)	1611	

Potential UCL to Use		Use 95% Approximate Gamma UCL	1397

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-26-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	13	Number of Distinct Observations	11

Raw Statistics		Log-transformed Statistics	
Minimum	3.2	Minimum of Log Data	1.163
Maximum	23	Maximum of Log Data	3.135
Mean	8.015	Mean of log Data	1.907
Geometric Mean	6.731	SD of log Data	0.591
Median	6		
SD	5.518		
Std. Error of Mean	1.531		
Coefficient of Variation	0.688		
Skewness	1.839		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.797	Shapiro Wilk Test Statistic	0.936
Shapiro Wilk Critical Value	0.866	Shapiro Wilk Critical Value	0.866
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	10.74	95% H-UCL	11.71
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	13.72
95% Adjusted-CLT UCL (Chen-1995)	11.37	97.5% Chebyshev (MVUE) UCL	16.25
95% Modified-t UCL (Johnson-1978)	10.87	99% Chebyshev (MVUE) UCL	21.2

Gamma Distribution Test		Data Distribution
k star (bias corrected)	2.375	Data appear Gamma Distributed at 5% Significance Level
Theta Star	3.376	
MLE of Mean	8.015	
MLE of Standard Deviation	5.202	
nu star	61.74	
Approximate Chi Square Value (.05)	44.67	**Nonparametric Statistics**
Adjusted Level of Significance	0.0301	95% CLT UCL 10.53
Adjusted Chi Square Value	42.6	95% Jackknife UCL 10.74
		95% Standard Bootstrap UCL 10.39
Anderson-Darling Test Statistic	0.515	95% Bootstrap-t UCL 12.47
Anderson-Darling 5% Critical Value	0.739	95% Hall's Bootstrap UCL 20.47
Kolmogorov-Smirnov Test Statistic	0.217	95% Percentile Bootstrap UCL 10.4
Kolmogorov-Smirnov 5% Critical Value	0.238	95% BCA Bootstrap UCL 11.41
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 14.69
		97.5% Chebyshev(Mean, Sd) UCL 17.57
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 23.24
95% Approximate Gamma UCL (Use when n >= 40)	11.08	
95% Adjusted Gamma UCL (Use when n < 40)	11.62	

Potential UCL to Use	Use 95% Approximate Gamma UCL 11.08

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-26-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	13	Number of Distinct Observations	11

Raw Statistics		Log-transformed Statistics	
Minimum	0.4	Minimum of Log Data	-0.916
Maximum	16	Maximum of Log Data	2.773
Mean	3.289	Mean of log Data	0.574
Geometric Mean	1.776	SD of log Data	1.137
Median	1.5		
SD	4.302		
Std. Error of Mean	1.193		
Coefficient of Variation	1.308		
Skewness	2.456		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.688	Shapiro Wilk Test Statistic	0.955
Shapiro Wilk Critical Value	0.866	Shapiro Wilk Critical Value	0.866
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	5.416	95% H-UCL	9.358
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	7.88
95% Adjusted-CLT UCL (Chen-1995)	6.12	97.5% Chebyshev (MVUE) UCL	9.926
95% Modified-t UCL (Johnson-1978)	5.551	99% Chebyshev (MVUE) UCL	13.94

Gamma Distribution Test		Data Distribution
k star (bias corrected)	0.777	Data appear Gamma Distributed at 5% Significance Level
Theta Star	4.234	
MLE of Mean	3.289	
MLE of Standard Deviation	3.732	
nu star	20.2	
Approximate Chi Square Value (.05)	11	**Nonparametric Statistics**
Adjusted Level of Significance	0.0301	95% CLT UCL 5.252
Adjusted Chi Square Value	10.04	95% Jackknife UCL 5.416
		95% Standard Bootstrap UCL 5.156
Anderson-Darling Test Statistic	0.461	95% Bootstrap-t UCL 7.891
Anderson-Darling 5% Critical Value	0.76	95% Hall's Bootstrap UCL 12.71
Kolmogorov-Smirnov Test Statistic	0.161	95% Percentile Bootstrap UCL 5.315
Kolmogorov-Smirnov 5% Critical Value	0.244	95% BCA Bootstrap UCL 6.222
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 8.49
		97.5% Chebyshev(Mean, Sd) UCL 10.74
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 15.16
95% Approximate Gamma UCL (Use when n >= 40)	6.041	
95% Adjusted Gamma UCL (Use when n < 40)	6.616	

Potential UCL to Use	Use 95% Approximate Gamma UCL 6.041

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-26-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	13	Number of Distinct Observations	11

Raw Statistics		**Log-transformed Statistics**	
Minimum	11	Minimum of Log Data	2.398
Maximum	110	Maximum of Log Data	4.7
Mean	38.38	Mean of log Data	3.372
Geometric Mean	29.14	SD of log Data	0.774
Median	36		
SD	30.16		
Std. Error of Mean	8.366		
Coefficient of Variation	0.786		
Skewness	1.258		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.847	Shapiro Wilk Test Statistic	0.914
Shapiro Wilk Critical Value	0.866	Shapiro Wilk Critical Value	0.866
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	53.3	95% H-UCL	68.45
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	75.95
95% Adjusted-CLT UCL (Chen-1995)	55.26	97.5% Chebyshev (MVUE) UCL	92.28
95% Modified-t UCL (Johnson-1978)	53.78	99% Chebyshev (MVUE) UCL	124.3

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	1.563	Data appear Gamma Distributed at 5% Significance Level
Theta Star	24.57	
MLE of Mean	38.38	
MLE of Standard Deviation	30.71	
nu star	40.63	
Approximate Chi Square Value (.05)	27.02	**Nonparametric Statistics**
Adjusted Level of Significance	0.0301	95% CLT UCL 52.15
Adjusted Chi Square Value	25.45	95% Jackknife UCL 53.3
		95% Standard Bootstrap UCL 51.41
Anderson-Darling Test Statistic	0.527	95% Bootstrap-t UCL 60.47
Anderson-Darling 5% Critical Value	0.744	95% Hall's Bootstrap UCL 57.77
Kolmogorov-Smirnov Test Statistic	0.197	95% Percentile Bootstrap UCL 51.92
Kolmogorov-Smirnov 5% Critical Value	0.24	95% BCA Bootstrap UCL 53.92
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 74.85
		97.5% Chebyshev(Mean, Sd) UCL 90.63
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 121.6
95% Approximate Gamma UCL (Use when n >= 40)	57.71	
95% Adjusted Gamma UCL (Use when n < 40)	61.28	

Potential UCL to Use	Use 95% Approximate Gamma UCL 57.71

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

E-C-26-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	13	Number of Distinct Observations	13

Raw Statistics		Log-transformed Statistics	
Minimum	60	Minimum of Log Data	4.094
Maximum	1100	Maximum of Log Data	7.003
Mean	329.2	Mean of log Data	5.389
Geometric Mean	219	SD of log Data	0.946
Median	180		
SD	317.3		
Std. Error of Mean	87.99		
Coefficient of Variation	0.964		
Skewness	1.515		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.817	Shapiro Wilk Test Statistic	0.955
Shapiro Wilk Critical Value	0.866	Shapiro Wilk Critical Value	0.866
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	486	95% H-UCL	727.5
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	728.9
95% Adjusted-CLT UCL (Chen-1995)	513.4	97.5% Chebyshev (MVUE) UCL	902.7
95% Modified-t UCL (Johnson-1978)	492.1	99% Chebyshev (MVUE) UCL	1244

Gamma Distribution Test		Data Distribution
k star (bias corrected)	1.105	Data appear Gamma Distributed at 5% Significance Level
Theta Star	298	
MLE of Mean	329.2	
MLE of Standard Deviation	313.2	
nu star	28.72	
Approximate Chi Square Value (.05)	17.49	**Nonparametric Statistics**
Adjusted Level of Significance	0.0301	95% CLT UCL 473.9
Adjusted Chi Square Value	16.25	95% Jackknife UCL 486
		95% Standard Bootstrap UCL 468.6
Anderson-Darling Test Statistic	0.357	95% Bootstrap-t UCL 585
Anderson-Darling 5% Critical Value	0.752	95% Hall's Bootstrap UCL 644.8
Kolmogorov-Smirnov Test Statistic	0.173	95% Percentile Bootstrap UCL 469.2
Kolmogorov-Smirnov 5% Critical Value	0.241	95% BCA Bootstrap UCL 502.3
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 712.7
		97.5% Chebyshev(Mean, Sd) UCL 878.7
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1205
95% Approximate Gamma UCL (Use when n >= 40)	540.5	
95% Adjusted Gamma UCL (Use when n < 40)	581.7	

Potential UCL to Use	Use 95% Approximate Gamma UCL 540.5

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Lower Drainage Area Channel
Sediments – Combined Transects

General UCL Statistics for Full Data Sets

Confidence Coefficient	95%
ımber of Bootstrap Operations	2000

All LDA Channel Sediment-Arsenic (Units: mg/kg)

General Statistics

Number of Valid Observations	38	Number of Distinct Observations	31

Raw Statistics		Log-transformed Statistics	
Minimum	2.6	Minimum of Log Data	0.956
Maximum	23	Maximum of Log Data	3.135
Mean	7.958	Mean of log Data	1.905
Geometric Mean	6.722	SD of log Data	0.569
Median	6.1		
SD	5.159		
Std. Error of Mean	0.837		
Coefficient of Variation	0.648		
Skewness	1.489		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.819	Shapiro Wilk Test Statistic	0.951
Shapiro Wilk Critical Value	0.938	Shapiro Wilk Critical Value	0.938
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	9.37	95% H-UCL	9.503
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	11.22
95% Adjusted-CLT UCL (Chen-1995)	9.55	97.5% Chebyshev (MVUE) UCL	12.67
95% Modified-t UCL (Johnson-1978)	9.403	99% Chebyshev (MVUE) UCL	15.53

Gamma Distribution Test		Data Distribution
k star (bias corrected)	2.89	Data appear Lognormal at 5% Significance Level
Theta Star	2.754	
MLE of Mean	7.958	
MLE of Standard Deviation	4.681	
nu star	219.6	
Approximate Chi Square Value (.05)	186.3	
Adjusted Level of Significance	0.0434	
Adjusted Chi Square Value	185	
Anderson-Darling Test Statistic	0.995	
Anderson-Darling 5% Critical Value	0.754	
Kolmogorov-Smirnov Test Statistic	0.176	
Kolmogorov-Smirnov 5% Critical Value	0.144	
Data not Gamma Distributed at 5% Significance Level		

Nonparametric Statistics	
95% CLT UCL	9.334
95% Jackknife UCL	9.37
95% Standard Bootstrap UCL	9.323
95% Bootstrap-t UCL	9.776
95% Hall's Bootstrap UCL	9.554
95% Percentile Bootstrap UCL	9.329
95% BCA Bootstrap UCL	9.526
95% Chebyshev(Mean, Sd) UCL	11.61
97.5% Chebyshev(Mean, Sd) UCL	13.18
99% Chebyshev(Mean, Sd) UCL	16.28

Assuming Gamma Distribution	
95% Approximate Gamma UCL (Use when n >= 40)	9.38
95% Adjusted Gamma UCL (Use when n < 40)	9.444

Potential UCL to Use	Use 95% H-UCL 9.503

ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

All LDA Channel Sediment-Cadmium (Units: mg/kg)

General Statistics

Number of Valid Observations	38	Number of Distinct Observations	31

Raw Statistics		**Log-transformed Statistics**	
Minimum	0.33	Minimum of Log Data	-1.109
Maximum	24	Maximum of Log Data	3.178
Mean	3.648	Mean of log Data	0.631
Geometric Mean	1.88	SD of log Data	1.139
Median	1.5		
SD	5.007		
Std. Error of Mean	0.812		
Coefficient of Variation	1.373		
Skewness	2.619		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.661	Shapiro Wilk Test Statistic	0.955
Shapiro Wilk Critical Value	0.938	Shapiro Wilk Critical Value	0.938
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	5.018	95% H-UCL	5.804
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	6.88
95% Adjusted-CLT UCL (Chen-1995)	5.353	97.5% Chebyshev (MVUE) UCL	8.343
95% Modified-t UCL (Johnson-1978)	5.076	99% Chebyshev (MVUE) UCL	11.22

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	0.832	Data appear Lognormal at 5% Significance Level
Theta Star	4.386	
MLE of Mean	3.648	
MLE of Standard Deviation	4	
nu star	63.2	
Approximate Chi Square Value (.05)	45.92	**Nonparametric Statistics**
Adjusted Level of Significance	0.0434	95% CLT UCL 4.984
Adjusted Chi Square Value	45.3	95% Jackknife UCL 5.018
		95% Standard Bootstrap UCL 4.949
Anderson-Darling Test Statistic	1.284	95% Bootstrap-t UCL 5.765
Anderson-Darling 5% Critical Value	0.783	95% Hall's Bootstrap UCL 5.726
Kolmogorov-Smirnov Test Statistic	0.19	95% Percentile Bootstrap UCL 4.944
Kolmogorov-Smirnov 5% Critical Value	0.148	95% BCA Bootstrap UCL 5.337
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 7.188
		97.5% Chebyshev(Mean, Sd) UCL 8.72
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 11.73
95% Approximate Gamma UCL (Use when n >= 40)	5.021	
95% Adjusted Gamma UCL (Use when n < 40)	5.089	

Potential UCL to Use		Use 95% H-UCL	5.804

ProUCL computes and outputs H-statistic based UCLs for historical reasons only.
H-statistic often results in unstable (both high and low) values of UCL95 as shown in examples in the Technical Guide.
It is therefore recommended to avoid the use of H-statistic based 95% UCLs.
Use of nonparametric methods are preferred to compute UCL95 for skewed data sets which do not follow a gamma distribution.

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

All LDA Channel Sediment-Lead (Units: mg/kg)

General Statistics

Number of Valid Observations	38	Number of Distinct Observations	27

Raw Statistics		**Log-transformed Statistics**	
Minimum	11	Minimum of Log Data	2.398
Maximum	210	Maximum of Log Data	5.347
Mean	45.58	Mean of log Data	3.428
Geometric Mean	30.8	SD of log Data	0.838
Median	25		
SD	48.77		
Std. Error of Mean	7.911		
Coefficient of Variation	1.07		
Skewness	2.134		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.698	Shapiro Wilk Test Statistic	0.903
Shapiro Wilk Critical Value	0.938	Shapiro Wilk Critical Value	0.938
Data not Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	58.93	95% H-UCL	59.41
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	71.95
95% Adjusted-CLT UCL (Chen-1995)	61.52	97.5% Chebyshev (MVUE) UCL	84.37
95% Modified-t UCL (Johnson-1978)	59.38	99% Chebyshev (MVUE) UCL	108.8

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	1.325	Data do not follow a Discernable Distribution (0.05)
Theta Star	34.4	
MLE of Mean	45.58	
MLE of Standard Deviation	39.6	
nu star	100.7	
Approximate Chi Square Value (.05)	78.55	**Nonparametric Statistics**
Adjusted Level of Significance	0.0434	95% CLT UCL 58.59
Adjusted Chi Square Value	77.74	95% Jackknife UCL 58.93
		95% Standard Bootstrap UCL 58.49
Anderson-Darling Test Statistic	1.865	95% Bootstrap-t UCL 63.38
Anderson-Darling 5% Critical Value	0.768	95% Hall's Bootstrap UCL 61.36
Kolmogorov-Smirnov Test Statistic	0.178	95% Percentile Bootstrap UCL 59.24
Kolmogorov-Smirnov 5% Critical Value	0.146	95% BCA Bootstrap UCL 60.82
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 80.06
		97.5% Chebyshev(Mean, Sd) UCL 94.98
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 124.3
95% Approximate Gamma UCL (Use when n >= 40)	58.43	
95% Adjusted Gamma UCL (Use when n < 40)	59.04	

Potential UCL to Use		Use 95% Chebyshev (Mean, Sd) UCL	80.06

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

All LDA Channel Sediment-Zinc (Units: mg/kg)

General Statistics

Number of Valid Observations	38	Number of Distinct Observations	28

Raw Statistics		**Log-transformed Statistics**	
Minimum	60	Minimum of Log Data	4.094
Maximum	2000	Maximum of Log Data	7.601
Mean	395.8	Mean of log Data	5.497
Geometric Mean	244.1	SD of log Data	0.97
Median	180		
SD	442		
Std. Error of Mean	71.7		
Coefficient of Variation	1.117		
Skewness	2.035		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.736	Shapiro Wilk Test Statistic	0.937
Shapiro Wilk Critical Value	0.938	Shapiro Wilk Critical Value	0.938
Data not Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	516.7	95% H-UCL	568.9
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	687.4
95% Adjusted-CLT UCL (Chen-1995)	539	97.5% Chebyshev (MVUE) UCL	818.9
95% Modified-t UCL (Johnson-1978)	520.7	99% Chebyshev (MVUE) UCL	1077

Gamma Distribution Test		**Data Distribution**
k star (bias corrected)	1.098	Data do not follow a Discernable Distribution (0.05)
Theta Star	360.5	
MLE of Mean	395.8	
MLE of Standard Deviation	377.7	
nu star	83.43	
Approximate Chi Square Value (.05)	63.38	**Nonparametric Statistics**
Adjusted Level of Significance	0.0434	95% CLT UCL 513.7
Adjusted Chi Square Value	62.66	95% Jackknife UCL 516.7
		95% Standard Bootstrap UCL 511.8
Anderson-Darling Test Statistic	1.404	95% Bootstrap-t UCL 557.3
Anderson-Darling 5% Critical Value	0.774	95% Hall's Bootstrap UCL 551.3
Kolmogorov-Smirnov Test Statistic	0.218	95% Percentile Bootstrap UCL 514.4
Kolmogorov-Smirnov 5% Critical Value	0.147	95% BCA Bootstrap UCL 535.8
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL 708.3
		97.5% Chebyshev(Mean, Sd) UCL 843.5
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL 1109
95% Approximate Gamma UCL (Use when n >= 40)	521	
95% Adjusted Gamma UCL (Use when n < 40)	527	

Potential UCL to Use		Use 95% Chebyshev (Mean, Sd) UCL	708.3

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

Appendix D

Toxicity Profiles

Appendix D
Toxicity Profiles

Arsenic

Arsenic is a naturally occurring, non-essential trace element. In nature, arsenic is usually found combined with other elements such as oxygen, chlorine, and sulfur. Arsenic can exist in six oxidation states (-III, 0, +I, +II, +III, and +V) in various inorganic and organic forms. In the environment, arsenic is usually a mixture of the trivalent and pentavalent forms (ATSDR 2007a). In water, arsenic is subject to a number of complex transformations, including oxidation-reduction reactions, ligand exchange, precipitation, and biotransformation (ATSDR 2007a). The factors influencing these processes include redox potential (Eh), pH, metal sulfide and sulfide ion concentrations, iron concentrations, temperature, salinity, distribution and composition of biota, season, and the nature and composition of organic matter (ATSDR 2007a). Its bioavailability and toxic properties can be significantly modified by numerous abiotic and biotic factors that include the physical and chemical forms of arsenic tested, the route of administration, the dose, and the species of animal. Inorganic species of arsenic tend to be the most common forms in aquatic environments.

Bioconcentration factors for arsenic are relatively low for all organisms analyzed, with an exception being some algal species (USEPA 1985). Although some species (e.g., marine algae and shellfish) tend to bioconcentrate arsenic, it is not biomagnified through the food chain (ATSDR 2007a).

The toxic effects of arsenic are influenced by a number of factors, including the form of arsenic, species and/or species group, and organism life stage (Irwin 1997). In general, inorganic arsenic compounds are more toxic than organic compounds, and trivalent arsenic species are more toxic than pentavalent arsenic species. While the mechanisms of arsenic toxicity can vary among different forms, the overall symptoms of chronic arsenic intoxication in birds and mammals are generally similar and include muscular incoordination, debility, slowness, and seizures, all of which may also be commonly induced by other toxicants (Moore et al. 1990, as cited in Irwin 1997). Chronic exposures in fish may result in accumulation to toxic concentrations, affecting the liver and resulting in morphological alterations. In amphibians and reptiles, effects of arsenic may include mortality and/or malformations in developing embryos. In invertebrates, arsenic intoxication can result in decreased reproduction and/or survival. Adsorption of arsenic to the exoskeleton of invertebrates appears to be an important accumulation mechanism (Mason et al. 2000).

Cadmium

Cadmium is a non-essential trace metal that occurs naturally but at relatively low concentrations in the earth's crust. Although cadmium exists in three oxidation states (0, +I, and +II), it normally occurs only in the +II oxidation state in the aquatic environment. As with many inorganic substances, the solubility of cadmium compounds ranges from soluble (e.g., cadmium chloride) to insoluble (e.g., cadmium sulfide, cadmium carbonate, cadmium oxide, except through interaction with acids, light, and oxygen) in water. Higher pH and increased particulate organic matter concentrations result in greater sorption of cadmium to sediments, with associated decreases in its concentrations in the water (ATSDR 2012). Cadmium in water is not strongly influenced by oxidizing or reducing conditions, although cadmium can precipitate as cadmium sulfide under reducing conditions (ATSDR 2012). Cadmium remobilization from sediments depends on pH, salinity, Eh,

and mode of sorption. For example, cadmium adsorbed to clay or organic materials is more likely to dissolve, to be bioaccumulated, or otherwise remobilize after disturbance than cadmium associated with carbonate minerals (ATSDR 2012).

In aquatic plants, cadmium was taken up by all plant parts at similar concentrations including roots, stems, and leaves and translocated between leaves and stems (Fritioff and Greger 2006). Cadmium has been found to accumulate in the gills of crayfish (ATSDR 2012). The liver, kidneys, hepatopancreas, and exoskeleton are other sinks for cadmium in some invertebrates (IPCS 1992). In vertebrates, cadmium is not well absorbed through the intestine and accumulates mostly in the liver and kidneys (ATSDR 2012). Cadmium uptake from water can be reduced by hardness and the formation of inorganic chloride or organic complexes (IPCS 1992). The influence of hardness on cadmium uptake in organisms with gills may be related to shared uptake mechanisms between cadmium and calcium (IPCS 1992). Other factors, such as pH and the presence of food, sediment, zinc, manganese, or iron, may also affect uptake in aquatic organisms (IPCS 1992). Both aquatic and terrestrial organisms bioaccumulate cadmium at all levels in food chains (ATSDR 2012). However, data regarding biomagnification of cadmium through food chains are inconclusive (ATSDR 2012).

Aquatic invertebrates are sensitive to cadmium, with early life stages typically more sensitive than adults. Hardness, salinity, and the presence of inorganic or organic materials that can complex with cadmium tend to reduce toxicity, while increasing temperature can increase toxicity. Effects of toxic exposure in fish can include alterations to respiration, alterations to molting, potentially reversible gill damage, and changes to reproductive and developmental success and behavior. Effects of cadmium on early amphibian developmental stages may include alterations in gastrulation and neurulation, decreased or delayed limb regeneration, delayed development, mortality, and malformations. Organogenesis stages may be particularly sensitive. Effects observed in short-term studies in young birds have included increases in kidney, gizzard, and gastrointestinal tract weights; reduced food consumption; reduced weight gain; mortality; hematological changes; and kidney lesions. In mammals, ingested cadmium tends to target the kidney and bone, although developmental, reproductive, hepatic, hematological, and immunological effects are also possible.

Lead

Lead is a naturally occurring, non-essential trace metal that is widely present in the earth's crust in readily accessible ore deposits, although elevated concentrations are typically associated with human activities (ATSDR 2007b). Lead occurs in three oxidation states (0, +II, and +IV). Most lead in the environment is divalent. Metallic lead occurs naturally but is rare. In surface water, concentrations of soluble lead depend on pH and dissolved salt content. However, most lead in water is expected to be in insoluble forms: colloidal particles; particles of lead compounds such as carbonates, oxides, hydroxide, and sulfides; or lead compounds incorporated into particulate matter by sorption to substances such as organic matter, clay, and iron and manganese oxides (ATSDR 2007b). Generally, sorption of lead is greater at higher pH, although the amount of lead binding to organic matter decreases as water hardness increases (ATSDR 2007b). Due to lead's tendency to be bound to other materials, sediments are sinks for lead via precipitation and sedimentation (Eisler 1988).

Animals may take up lead in the diet, and older organisms or older parts of organisms tend to contain greater body burdens of lead (ATSDR 2007b; Eisler 1988). Skeletal materials tend to be sites of lead

accumulation in animals. In *Daphnia magna* (a freshwater invertebrate), most of the body burden of lead has been found adsorbed to the exoskeleton; and adsorption to the exoskeleton has also been noted in crayfish (Eisler 1988). In aquatic systems, algae and benthic organisms tend to contain higher concentrations of lead than top predators (ATSDR 2007b). Aquatic plants can also take up lead from sediment (Eisler 1988). Biomagnification of lead compounds in aquatic food chains is not known to occur (ATSDR 2007b).

Lead can be toxic in some chemical forms and may cause metabolic poisoning from a variety of exposure pathways. Lead can be toxic to aquatic biota, especially as ionic lead, at elevated water temperature, at lower pH and hardness, at early life stages, and after longer exposures (Eisler 1988). Chronic exposure to lead may result in a host of adverse effects in fish, including skeletal deformities; anemia; caudal pigmentation and degeneration; damage to the neurological and respiratory systems; enzyme inhibition, chemistry changes, and damage to the blood, spleen, liver, kidney, and gonads; reduced swimming ability and muscular atrophy; and inhibition of reproduction, growth, and survival (Eisler 1988). In adult frogs, lead poisoning may manifest with sluggishness, decreased muscle tone, sloughing of skin, decreases in blood cells, gastric erosion, and neurological signs (Eisler 1988). Effects on physiology, pathology, metamorphosis, and survival have been noted in frogs and salamanders at various concentrations and exposure periods. In birds and mammals, lead compounds may elicit adverse effects on the hematopoietic, nervous, renal, cardiovascular, reproductive, immune, and skeletal systems (Eisler 1988).

Zinc

Zinc is a naturally occurring trace metal that is important in plant and animal nutrition, but as with many other essential elements, the optimal concentration range is narrow (Leland and Kuwabara 1985). Zinc is one of the most ubiquitous and mobile of the heavy metals and occurs in the environment mainly in the +II oxidation state (ATSDR 2005), although it also has oxidation states of 0 and +I. Zinc is transported in natural waters in dissolved forms and associated with suspended particles (ATSDR 2005). In aerobic waters, zinc is partitioned into sediments through sorption onto hydrous iron and manganese oxides, clay minerals, and organic material. Zinc content in sediment is closely correlated with the depth, organic content, and clay content of the sediments. The tendency to sorb is affected by pH, with zinc absorbing more readily at high pH than at low pH.

Zinc is taken up directly from the water by both leaves and stems by the aquatic plant *Potamogeton natans* (Fritioff and Greger 2006). Zinc bioconcentrates moderately in some aquatic organisms; bioconcentration is higher in crustaceans and bivalve species than in fish (WHO 2001). The fact that zinc, as an essential metal, is naturally concentrated by living organisms means that the bioconcentration factor (BCF) for zinc bears no relationship to toxicity (WHO 2001). Additionally, the fact that many organisms are capable of regulating internal zinc concentrations within certain limits means that these organisms can stabilize internal concentrations against perturbations or high concentrations in the external environment (WHO 2001). Therefore, whole-body zinc concentrations do not necessarily reflect ambient concentrations or potential toxicity.

Concentrations of zinc in tissues of aquatic invertebrates are usually in excess of that required for normal metabolism (Eisler 1993). Elevated concentrations of zinc have been associated with behavioral effects, low species richness, and elevated mortality. However, effects are generally not observed until concentrations are quite high. Amphibian embryos have been shown to be more sensitive to zinc than older stages (Eisler

1993). In a controlled mesocosm experiment, concentrations of zinc altered the algal species composition, with communities dominated by green and blue-green algae (Genter et al. 1987). Zinc excess in avian species is associated with decreased body weight, gizzard and pancreatic lesions, and biochemical changes (USEPA 2007). Toxicity studies on avian and mammalian species have quantified biochemical, behavioral, physiological, pathological, reproduction, growth, and survival effects. In mammals, excess zinc is associated with vomiting, depressed growth rate, purgation, and ataxia (USEPA 2007). Absorption of zinc occurs from all segments of the intestine. Following absorption, zinc is rapidly distributed to the liver, kidneys, prostate, muscles, bones, and pancreas. Zinc salts can adversely affect tissues; interfere with the metabolism of other ions such as copper, calcium, and iron; and inhibit erythrocyte production and function (ATSDR 2005; USEPA 2007).

References

ATSDR. 2005. Toxicological Profile for Zinc. U.S. Department of Health and Human Services, Public Health Service. August.

ATSDR. 2007a. Toxicological Profile for Arsenic. U.S. Department of Health and Human Services.

ATSDR. 2007b. Toxicological Profile for Lead. U.S. Department of Health and Human Services, Public Health Service. August.

ATSDR. 2012. Draft Toxicological Profile for Cadmium. US Department of Health and Human Services, Public Health Service. September.

Eisler, R. 1988. Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Biological Report 85(1.14)/Contaminant Hazard Review Report No. 14. US Fish and Wildlife Service. April.

Eisler, R. 1993. Zinc hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 10, Contaminant Hazard Reviews Report 26. 106 pp.

Fritioff, A. and M. Greger. 2006. Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant Potamogeton natans. Chemosphere. 63 (2): 220-227.

Genter, R.B., D.S. Cherry, E.P. Smith, and J. Cairns Jr. 1987. Algal-periphyton population and community changes from zinc stress in stream mesocosms. Hydrobiologia 153: 261-275.

International Programme on Chemical Safety (IPCS). 1992. Environmental Health Criteria 135: Cadmium-Environmental Aspects. World Health Organization. Geneva.

Irwin, R.J. 1997. Environmental contaminants encyclopedia. Arsenic entry. National Park Service. WaterResources Division.

Leland, H.V., and J.S. Kuwabara. 1985. Trace Metals. In: (Eds) G.M. Rand and S.R. Petrocelli. Fundamentals of Aquatic Toxicology. Hemisphere Publishing Corporation. New York, New York. pp. 374-415.

Mason, R.P., J.M. Laporte, and S. Andres. 2000. Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium, and cadmium, by freshwater inverterbrates and fish. Archives of environmental contamination and toxicology. 38: 283-297.

USEPA. 1985. Ambient Aquatic Life Water Quality Criteria for Arsenic. EPA#: 440/5-84-033.

USEPA. 2007. Ecological Soil Screening Levels for Zinc. Interim Final. OSWER Directive 9285.7-73. Office of Solid Waste and Emergency Response. Washington, D.C. June.

World Health Organization (WHO). 2001. Zinc. Environmental Health Criteria 221. Geneva, Switzerland: World Health Organization. [Webpage] Located at: http://www.who.int/ipcs/publications/ehc/ehc_221/en/index.html. Accessed in: March 2013.

Appendix E

Total Allowable Metal Calculation

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Transect 00**		**Transect 01**		**Transect 02**		**Transect 03**		**Transect 04**	
Sample Date			**12/5/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/7/2011**	
Transect			**0**		**1**		**2**		**3**		**4**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	1100		75		1.4	B	6.1		54	B
SEM Lead	mg/kg	SW6010	6400	B	650	B	17	B	18	B	440	B
SEM Cadmium	mg/kg	SW6010	190		29		2		1.3		20	B
SEM Zinc	mg/kg	SW6010	20000	B	4100	B	310	B	150	B	4600	B
SEM Nickel	mg/kg	SW6010	20	B	6.2	B	2.2	JB	7.4	B	15	B
SEM Arsenic	mg/kg	SW6010	74		7.1	B	0.035	U	2	B	1.2	B
SEM Copper	umole/gr	SW6010	17		1.2		0.022	B	0.096		0.85	B
SEM Lead	umole/gr	SW6010	31	B	3.2	B	0.08	B	0.088	B	2.1	B
SEM Cadmium	umole/gr	SW6010	1.7		0.26		0.018		0.011		0.18	B
SEM Zinc	umole/gr	SW6010	310	B	62	B	4.8	B	2.3	B	70	B
SEM Nickel	umole/gr	SW6010	0.34	B	0.11	B	0.037	JB	0.13	B	0.26	B
SEM Arsenic	umole/gr	SW6010	0.99		0.094	B	0.00047	U	0.027	B	0.016	B
Porewater As (Total)	ug/L	SW6020	28		16	B	4.6	J	35	B	4.2	J
Porewater As (Dissolved)	ug/L	SW6020	3.9		4.5		1.2		9.5		0.69	J
Total Recoverable As	mg/kg dw	SW6020	450		230		97		130		160	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	62		37		19		37		32	
Sulfide	mg/kg	SW9034	37	J	9.9	J	3.7	U	68		6.2	J
Total Organic Carbon	mg/kg	LLOYD KAHN	68000		NA		19000		NA		4200	
Calculations												
f_{OC}			0.0680		NA		0.0190		NA		0.0042	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		410.803		0.000		114.783		0.000		25.373	
(B) Allowable As in Water	mg/kg		0.245		0.088		0.035		0.088		0.071	
(A+B) Total Allowable Excess As	mg/kg		411.048		0.088		114.819		0.088		25.444	
Total Allowable Arsenic	**mg/kg**		**411.05**		**0.09**		**114.82**		**0.09**		**25.44**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**YES**		**NO**		**YES**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		279011		NA		1523		NA		413967	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		18973		1577		29		210		1739	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.245		0.088		0.035		0.088		0.071	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.548		67.391		67.338		67.391		67.374	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.5**		**67.4**		**67.3**		**67.4**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**YES**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			1.10		0.11		0.00		0.03		0.02	
Total Recoverable As ≥ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.164		0.031		0.000		0.015		0.008	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
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Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Transect 05**		**Transect 06**		**Transect 08**		**Transect 12**		**Transect 14**	
Sample Date			**6/13/2012**		**12/8/2011**		**12/8/2011**		**12/9/2011**		**12/9/2011**	
Transect			**5**		**6**		**8**		**12**		**14**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	150		8.1	B	4.6		3.7		5.7	
SEM Lead	mg/kg	SW6010	1100	B	55	B	26	B	20	B	36	B
SEM Cadmium	mg/kg	SW6010	10		1.4	B	0.6		0.49		1.9	
SEM Zinc	mg/kg	SW6010	6100	B	180	B	60	B	56	B	250	B
SEM Nickel	mg/kg	SW6010	14	B	5.6	B	5.3	B	3.7	B	5.5	B
SEM Arsenic	mg/kg	SW6010	11	B	0.82	B	0.82	B	0.76	B	0.8	B
SEM Copper	umole/gr	SW6010	2.3		0.13	B	0.072		0.058		0.089	
SEM Lead	umole/gr	SW6010	5.2	B	0.27	B	0.13	B	0.098	B	0.17	B
SEM Cadmium	umole/gr	SW6010	0.091		0.012	B	0.0054		0.0044		0.017	
SEM Zinc	umole/gr	SW6010	93	B	2.7	B	0.92	B	0.85	B	3.8	B
SEM Nickel	umole/gr	SW6010	0.23	B	0.095	B	0.09	B	0.062	B	0.093	B
SEM Arsenic	umole/gr	SW6010	0.15	B	0.011	B	0.011	B	0.01	B	0.011	B
Porewater As (Total)	ug/L	SW6020	12	B	NA		NA		NA		NA	
Porewater As (Dissolved)	ug/L	SW6020	5.9		NA		NA		NA		NA	
Total Recoverable As	mg/kg dw	SW6020	59		9.6		9.9		12		11	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	9		15		25		16		21	
Sulfide	mg/kg	SW9034	15	J	3.6	U	4	U	3.6	U	3.8	U
Total Organic Carbon	mg/kg	LLOYD KAHN	NA		5300		7800		4000		7400	
Calculations												
f_{OC}			NA		0.0053		0.0078		0.0040		0.0074	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		0.000		32.019		47.122		24.165		44.705	
(B) Allowable As in Water	mg/kg		0.015		0.026		0.050		0.029		0.040	
(A+B) Total Allowable Excess As	mg/kg		0.015		32.045		47.172		24.193		44.745	
Total Allowable Arsenic	**mg/kg**		**0.01**		**32.04**		**47.17**		**24.19**		**44.74**	
Total SEM Arsenic > Allowable Arsenic?			**YES**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		NA		NA		NA		NA		NA	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		1864		NA		NA		NA		NA	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.015		0.026		0.050		0.029		0.040	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.318		67.330		67.353		67.332		67.343	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.3**		**67.3**		**67.4**		**67.3**		**67.3**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.16		0.01		0.01		0.01		0.01	
Total Recoverable As ≥ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.186		0.085		0.083		0.063		0.073	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
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Former Altoona Zinc Smelter Site
Altoona, KS

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Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Transect 16**		**Transect 17**		**Transect 18**		**Transect 19**		**Transect 21**	
Sample Date			**6/13/2012**		**6/13/2012**		**6/6/2012**		**6/20/2012**		**6/20/2012**	
Transect			**16**		**17**		**18**		**19**		**21**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	9.9		7.9		6		10		7.2	
SEM Lead	mg/kg	SW6010	61	B	31	B	17	B	51	B	53	B
SEM Cadmium	mg/kg	SW6010	3.9		0.57		0.69		3.1		4	
SEM Zinc	mg/kg	SW6010	490	B	80	B	110	B	300	B	310	B
SEM Nickel	mg/kg	SW6010	3.8	B	7.9	B	5.8	B	4.9	B	6.8	B
SEM Arsenic	mg/kg	SW6010	1.7	B	2.2	B	1.7	B	2.3	B	2.3	B
SEM Copper	umole/gr	SW6010	0.16		0.12		0.094		0.16		0.11	
SEM Lead	umole/gr	SW6010	0.29	B	0.15	B	0.082	B	0.24	B	0.25	B
SEM Cadmium	umole/gr	SW6010	0.035		0.0051		0.0062		0.028		0.035	
SEM Zinc	umole/gr	SW6010	7.4	B	1.2	B	1.7	B	4.6	B	4.8	B
SEM Nickel	umole/gr	SW6010	0.064	B	0.13	B	0.098	B	0.083	B	0.12	B
SEM Arsenic	umole/gr	SW6010	0.022	B	0.029	B	0.023	B	0.031	B	0.031	B
Porewater As (Total)	ug/L	SW6020	10	B	2.1	B	1.9	B	3.1		1.6	
Porewater As (Dissolved)	ug/L	SW6020	7.9		3.3		2.1		4	B	2.6	B
Total Recoverable As	mg/kg dw	SW6020	8.6		7.6		6.7		11		25	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	36		38		33		35		32	
Sulfide	mg/kg	SW9034	150		8.8	J	4.5	U	16	J	5.8	J
Total Organic Carbon	mg/kg	LLOYD KAHN	10000	H	4500	H	3800	H	15000	H	7100	H
Calculations												
f_{OC}			0.0100		0.0045		0.0038		0.0150		0.0071	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		60.412		27.186		22.957		90.618		42.893	
(B) Allowable As in Water	mg/kg		0.084		0.092		0.074		0.081		0.071	
(A+B) Total Allowable Excess As	mg/kg		60.497		27.277		23.031		90.699		42.963	
Total Allowable Arsenic	**mg/kg**		**60.50**		**27.28**		**23.03**		**90.70**		**42.96**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		21463		148012		212903		38297		124527	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		215		666		809		574		884	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.084		0.092		0.074		0.081		0.071	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.388		67.395		67.377		67.384		67.374	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.4**		**67.4**		**67.4**		**67.4**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.03		0.03		0.03		0.03		0.03	
Total Recoverable As ≥ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.198		0.289		0.254		0.209		0.092	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Transect 24**		**Transect 25**		**Transect 25+25**		**Transect 25+50**		**Transect 25+75**	
Sample Date			**6/13/2012**		**6/13/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**	
Transect			**24**		**25**		**25**	**+25**	**25**	**+50**	**25**	**+75**
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	13		12		7.2	B	9.4	B	7	B
SEM Lead	mg/kg	SW6010	160	B	67	B	28	B	54	B	22	B
SEM Cadmium	mg/kg	SW6010	4.5		2.4		2.6	B	2.7	B	1.4	B
SEM Zinc	mg/kg	SW6010	520	B	360	B	340	B	410	B	170	B
SEM Nickel	mg/kg	SW6010	17	B	11	B	7.7	B	8	B	7	B
SEM Arsenic	mg/kg	SW6010	4.2	B	2.9	B	0.57		0.71		0.5	
SEM Copper	umole/gr	SW6010	0.21		0.18		0.11	B	0.15	B	0.11	B
SEM Lead	umole/gr	SW6010	0.8	B	0.32	B	0.14	B	0.26	B	0.11	B
SEM Cadmium	umole/gr	SW6010	0.04		0.022		0.024	B	0.024	B	0.012	B
SEM Zinc	umole/gr	SW6010	8	B	5.6	B	5.1	B	6.3	B	2.6	B
SEM Nickel	umole/gr	SW6010	0.28	B	0.18	B	0.13	B	0.14	B	0.12	B
SEM Arsenic	umole/gr	SW6010	0.056	B	0.038	B	0.0075		0.0095		0.0067	
Porewater As (Total)	ug/L	SW6020	9.1	B	11	B	13		13		15	
Porewater As (Dissolved)	ug/L	SW6020	5.3		4.5		6.4		4.3		5.9	
Total Recoverable As	mg/kg dw	SW6020	20		18		4.5	B	6.1	B	4.1	B
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		380		300		340	
%Moist	%	NA	39		42		45		40		35	
Sulfide	mg/kg	SW9034	160		140		94	B	100	B	54	B
Total Organic Carbon	mg/kg	LLOYD KAHN	14000	H	9500	H	19000		15000		12000	
Calculations												
f_{OC}			0.0140		0.0095		0.0190		0.0150		0.0120	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		84.577		57.392		114.783		90.618		72.495	
(B) Allowable As in Water	mg/kg		0.096		0.109		0.123		0.100		0.081	
(A+B) Total Allowable Excess As	mg/kg		84.673		57.500		114.906		90.718		72.576	
Total Allowable Arsenic	**mg/kg**		**84.67**		**57.50**		**114.91**		**90.72**		**72.58**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		56558		67760		4644		10963		7017	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		792		644		88		164		84	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.096		0.109		0.123		0.100		0.081	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.399		67.412		67.426		67.403		67.384	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.4**		**67.4**		**67.4**		**67.4**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.06		0.04		0.01		0.01		0.01	
Total Recoverable As ≥ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.210		0.161		0.127		0.116		0.122	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Transect 25+100**		**Transect 26**		**Transect 27**		**Off-Property Pond 1-1**		**Off-Property Pond 1-2**	
Sample Date			**11/15/2012**		**11/14/2012**		**11/14/2012**		**12/5/2011**		**12/5/2011**	
Transect			**25**	**+100**	**26**	**CENTER**	**27**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	8.4	B	6.9	B	5.9	B	2.5		3	
SEM Lead	mg/kg	SW6010	36	B	20	B	36	B	200	B	65	B
SEM Cadmium	mg/kg	SW6010	2	B	1.5	B	2.2	B	4.6		1.4	
SEM Zinc	mg/kg	SW6010	260	B	160	B	230	B	700	B	210	B
SEM Nickel	mg/kg	SW6010	7.3	B	7	B	8.1	B	5	B	4.7	B
SEM Arsenic	mg/kg	SW6010	0.93		0.51		0.64		1.3		0.85	
SEM Copper	umole/gr	SW6010	0.13	B	0.11	B	0.093	B	0.039		0.046	
SEM Lead	umole/gr	SW6010	0.17	B	0.099	B	0.18	B	0.97	B	0.31	B
SEM Cadmium	umole/gr	SW6010	0.018	B	0.013	B	0.02	B	0.041		0.012	
SEM Zinc	umole/gr	SW6010	4	B	2.5	B	3.5	B	11	B	3.2	B
SEM Nickel	umole/gr	SW6010	0.13	B	0.12	B	0.14	B	0.085	B	0.08	B
SEM Arsenic	umole/gr	SW6010	0.012		0.0068		0.0086		0.018		0.011	
Porewater As (Total)	ug/L	SW6020	14		15		13		4.4		4.4	
Porewater As (Dissolved)	ug/L	SW6020	7.5		6.5		7.6		2.2		2.2	
Total Recoverable As	mg/kg dw	SW6020	5.5	B	6.1		6.3	B	11		9.9	
Hardness (as CaCO3)	mg/l	SM2340C	380		510		260		NA		NA	
%Moist	%	NA	36		40		35		53		34	
Sulfide	mg/kg	SW9034	56	B	37	B	24	B	690		600	
Total Organic Carbon	mg/kg	LLOYD KAHN	15000		13000		11000		19000		15000	
Calculations												
f_{OC}			0.0150		0.0130		0.0110		0.0190		0.0150	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		90.618		78.536		66.454		114.783		90.618	
(B) Allowable As in Water	mg/kg		0.084		0.100		0.081		0.169		0.077	
(A+B) Total Allowable Excess As	mg/kg		90.703		78.636		66.534		114.952		90.696	
Total Allowable Arsenic	**mg/kg**		**90.70**		**78.64**		**66.53**		**114.95**		**90.70**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		8229		5984		7607		31041		25723	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		123		78		84		590		386	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.084		0.100		0.081		0.169		0.077	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.388		67.403		67.384		67.472		67.380	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.4**		**67.4**		**67.4**		**67.5**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.01		0.01		0.01		0.02		0.01	
Total Recoverable As $\geq$ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.169		0.084		0.102		0.118		0.086	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Off-Property Pond 1-3**		**Off-Property Pond 1-4**		**Off-Property Pond 3-1**		**Off-Property Pond 3-2**		**Off-Property Pond 3-3**	
Sample Date			**12/5/2011**		**12/5/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**	
Transect			**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	25		0.26	J	6.9		8.4		13	
SEM Lead	mg/kg	SW6010	260	B	120	B	56	B	69	B	120	B
SEM Cadmium	mg/kg	SW6010	3.9		3.3		1		1.1		2.2	
SEM Zinc	mg/kg	SW6010	800	B	530	B	190	B	210	B	420	B
SEM Nickel	mg/kg	SW6010	7.3	B	4	B	6	B	4	B	4.9	B
SEM Arsenic	mg/kg	SW6010	2.4		0.6		0.78	B	1.1	B	1	B
SEM Copper	umole/gr	SW6010	0.39		0.004	J	0.11		0.13		0.2	
SEM Lead	umole/gr	SW6010	1.2	B	0.6	B	0.27	B	0.33	B	0.58	B
SEM Cadmium	umole/gr	SW6010	0.035		0.029		0.0091		0.01		0.019	
SEM Zinc	umole/gr	SW6010	12	B	8.1	B	2.9	B	3.2	B	6.4	B
SEM Nickel	umole/gr	SW6010	0.12	B	0.068	B	0.1	B	0.069	B	0.083	B
SEM Arsenic	umole/gr	SW6010	0.032		0.0079		0.01	B	0.014	B	0.014	B
Porewater As (Total)	ug/L	SW6020	4.4		4.4		7.3		7.3		7.3	
Porewater As (Dissolved)	ug/L	SW6020	2.2		2.2		2		2		2	
Total Recoverable As	mg/kg dw	SW6020	15		9.1		9.3		6.5		9.4	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	64		39		42		40		48	
Sulfide	mg/kg	SW9034	1300		400		83		64		60	
Total Organic Carbon	mg/kg	LLOYD KAHN	17000		13000		7400		5400		11000	
Calculations												
f_{OC}			0.0170		0.0130		0.0074		0.0054		0.0110	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		102.701		78.536		44.705		32.623		66.454	
(B) Allowable As in Water	mg/kg		0.267		0.096		0.109		0.100		0.138	
(A+B) Total Allowable Excess As	mg/kg		102.968		78.632		44.814		32.723		66.592	
Total Allowable Arsenic	**mg/kg**		**102.97**		**78.63**		**44.81**		**32.72**		**66.59**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		64067		20930		52605		101728		45371	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		1089		272		389		549		499	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.267		0.096		0.109		0.100		0.138	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.570		67.399		67.412		67.403		67.442	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.6**		**67.4**		**67.4**		**67.4**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.04		0.01		0.01		0.02		0.01	
Total Recoverable As ≥ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.160		0.066		0.084		0.169		0.106	

Notes:
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Appendix E-1
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Sediment Bioavailability Assessment
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Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Off-Property Pond 3-4**		**Off-Property Pond 4-1**		**Off-Property Pond 4-2**		**Northeast Pond-1**		**Northeast Pond-2**	
Sample Date			**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**	
Transect			**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	11	B	4	B	5.7	B	5.8	B	5.7	B
SEM Lead	mg/kg	SW6010	71	B	16	B	29	B	31	B	26	B
SEM Cadmium	mg/kg	SW6010	0.77		0.086	J	0.24		0.43		0.25	
SEM Zinc	mg/kg	SW6010	180	B	22	B	46	B	74	B	51	B
SEM Nickel	mg/kg	SW6010	12	B	7.1	B	8.8	B	3.3	B	3.1	B
SEM Arsenic	mg/kg	SW6010	1.9	B	1.4	B	1.7	B	1.5	B	1.7	B
SEM Copper	umole/gr	SW6010	0.18	B	0.063	B	0.09	B	0.092	B	0.09	B
SEM Lead	umole/gr	SW6010	0.34	B	0.075	B	0.14	B	0.15	B	0.13	B
SEM Cadmium	umole/gr	SW6010	0.0068		0.00077	J	0.0021		0.0038		0.0022	
SEM Zinc	umole/gr	SW6010	2.8	B	0.33	B	0.7	B	1.1	B	0.78	B
SEM Nickel	umole/gr	SW6010	0.21	B	0.12	B	0.15	B	0.057	B	0.053	B
SEM Arsenic	umole/gr	SW6010	0.025	B	0.018	B	0.022	B	0.02	B	0.023	B
Porewater As (Total)	ug/L	SW6020	7.3		5.5		5.5		9.5		9.5	
Porewater As (Dissolved)	ug/L	SW6020	2		2.6		2.6		3.2		3.2	
Total Recoverable As	mg/kg dw	SW6020	9.3		8.5		15		5.8		5	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	44		12		25		42		49	
Sulfide	mg/kg	SW9034	39		3.5	U	4	U	24	J	5.9	U
Total Organic Carbon	mg/kg	LLOYD KAHN	4400		2900		6700		10000		8400	
Calculations												
f_{OC}			0.0044		0.0029		0.0067		0.0100		0.0084	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		26.581		17.520		40.476		60.412		50.746	
(B) Allowable As in Water	mg/kg		0.118		0.020		0.050		0.109		0.144	
(A+B) Total Allowable Excess As	mg/kg		26.699		17.540		40.526		60.521		50.890	
Total Allowable Arsenic	**mg/kg**		**26.70**		**17.54**		**40.53**		**60.52**		**50.89**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		215731		185629		97539		46803		63130	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		949		538		654		468		530	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.118		0.020		0.050		0.109		0.144	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.421		67.324		67.353		67.412		67.447	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.4**		**67.3**		**67.4**		**67.4**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.03		0.02		0.03		0.02		0.03	
Total Recoverable As ≥ SEM As?			YES		YES		YES		YES		YES	
SEM As / Total Recoverable As			0.204		0.165		0.113		0.259		0.340	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**Northeast Pond-3**		**Northeast Pond-4**		**North Pond-1**		**North Pond-2**		**North Pond-3**	
Sample Date			**12/6/2011**		**12/6/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	2	B	8.1	B	21		27		28	
SEM Lead	mg/kg	SW6010	22	B	49	B	140		220		240	
SEM Cadmium	mg/kg	SW6010	0.36		0.61		9.6		23		9.2	
SEM Zinc	mg/kg	SW6010	60	B	110	B	850		1300		830	
SEM Nickel	mg/kg	SW6010	2.8	B	6.3	B	1.9	J	2	J	1.5	J
SEM Arsenic	mg/kg	SW6010	1.3	B	2.5	B	NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.032	B	0.13	B	0.32		0.42		0.45	
SEM Lead	umole/gr	SW6010	0.11	B	0.24	B	0.67		1.1		1.2	
SEM Cadmium	umole/gr	SW6010	0.0032		0.0054		0.085		0.21		0.082	
SEM Zinc	umole/gr	SW6010	0.92	B	1.7	B	13		20		13	
SEM Nickel	umole/gr	SW6010	0.048	B	0.11	B	0.033	J	0.035	J	0.026	J
SEM Arsenic	umole/gr	SW6010	0.017	B	0.034	B	NA		NA		NA	
Porewater As (Total)	ug/L	SW6020	9.5		9.5		3.5		3.5		3.5	
Porewater As (Dissolved)	ug/L	SW6020	3.2		3.2		0.64	J	0.64	J	0.64	J
Total Recoverable As	mg/kg dw	SW6020	5.5		6.1		3.1		16		22	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	40		60		48		48		46	
Sulfide	mg/kg	SW9034	220		35	J	930		120		82	
Total Organic Carbon	mg/kg	LLOYD KAHN	13000		15000		54000		87000		100000	
Calculations												
f_{OC}			0.0130		0.0150		0.0540		0.0870		0.1000	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		78.536		90.618		326.226		525.587		604.123	
(B) Allowable As in Water	mg/kg		0.100		0.225		0.138		0.138		0.128	
(A+B) Total Allowable Excess As	mg/kg		78.636		90.843		326.365		525.725		604.251	
Total Allowable Arsenic	**mg/kg**		**78.64**		**90.84**		**326.36**		**525.73**		**604.25**	
Total SEM Arsenic > Allowable Arsenic?			**NO**		**NO**		**NA**		**NA**		**NA**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		31199		51983		NA		NA		NA	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		406		780		NA		NA		NA	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.100		0.225		0.138		0.138		0.128	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.403		67.528		67.442		67.442		67.431	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.4**		**67.5**		**67.4**		**67.4**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NO**		**NO**		**NA**		**NA**		**NA**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)			0.02		0.04							
Total Recoverable As ≥ SEM As?			YES		YES		NA		NA		NA	
SEM As / Total Recoverable As			0.236		0.410		NA		NA		NA	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-1
Bioavailability Calculations for Arsenic

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Site background concentration, As	mg/kg dw	19.9
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, As	ug/L	150
McDonald et al. consensus-based threshold effect concentration (TEC), As	mg/kg dw	9.79
McDonald et al. consensus-based probable effect concentration (PEC), As	mg/kg dw	33
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), As	mg/kg dw	11.3
Molecular weight, As	ug/umol	74.9
Average Empirical Partition Coef, $K_{d,OC,As}$	L/kg-OC	81,398
Geometric Mean Empirical Partition Coef $K_{d,OC,As}$	L/kg-OC	40,275
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,As}$	L/kg dry sed	449

Transect/Pond ID			**North Pond-4**		**South Pond-1**		**South Pond-2**		**South Pond-3**		**South Pond-4**	
Sample Date			**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	23		1.5	U	0.89	U	1.2	U	0.86	U
SEM Lead	mg/kg	SW6010	160		120		78		58		63	
SEM Cadmium	mg/kg	SW6010	9.2		11		7.5		5.6		4.9	
SEM Zinc	mg/kg	SW6010	1100		1600		1100		890		720	
SEM Nickel	mg/kg	SW6010	1.8	J	1.4	J	0.55	U	3.1	J	2.3	J
SEM Arsenic	mg/kg	SW6010	NA		NA		NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.37		0.023	U	0.014	U	0.019	U	0.014	U
SEM Lead	umole/gr	SW6010	0.76		0.59		0.38		0.28		0.3	
SEM Cadmium	umole/gr	SW6010	0.082		0.096		0.066		0.05		0.044	
SEM Zinc	umole/gr	SW6010	17		25		17		14		11	
SEM Nickel	umole/gr	SW6010	0.031	J	0.024	J	0.0094	U	0.053	J	0.039	J
SEM Arsenic	umole/gr	SW6010	NA		NA		NA		NA		NA	
Porewater As (Total)	ug/L	SW6020	3.5		7.5		7.5		7.5		7.5	
Porewater As (Dissolved)	ug/L	SW6020	0.64	J	4.8		4.8		4.8		4.8	
Total Recoverable As	mg/kg dw	SW6020	22		15		14		7.3		14	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	67		65		45		59		42	
Sulfide	mg/kg	SW9034	150		1500		920		1200		890	
Total Organic Carbon	mg/kg	LLOYD KAHN	53000		30000		26000		11000		17000	
Calculations												
f_{OC}			0.0530		0.0300		0.0260		0.0110		0.0170	
Bioavailability Based on Literature Values												
(A) Allowable As Sorbed to OC in Sediment	mg/kg		320.185		181.237		157.072		66.454		102.701	
(B) Allowable As in Water	mg/kg		0.305		0.279		0.123		0.216		0.109	
(A+B) Total Allowable Excess As	mg/kg		320.490		181.515		157.195		66.669		102.809	
Total Allowable Arsenic	**mg/kg**		**320.49**		**181.52**		**157.19**		**66.67**		**102.81**	
Total SEM Arsenic > Allowable Arsenic?			**NA**		**NA**		**NA**		**NA**		**NA**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,As}$ (Calc'd)	L/kg-OC		NA		NA		NA		NA		NA	
Partition Coefficient, $K_{d,dry\ sed,As}$ (Calc'd)	L/kg dry sed		NA		NA		NA		NA		NA	
(A) Allowable As Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		67.303		67.303		67.303		67.303		67.303	
(B) Allowable As in Water	mg/kg		0.305		0.279		0.123		0.216		0.109	
(A+B) Total Allowable Excess As (empirical Kd for dry sed)	mg/kg		67.608		67.582		67.426		67.519		67.412	
Total Allowable Arsenic (empirical Kd for dry sed)	**mg/kg**		**67.6**		**67.6**		**67.4**		**67.5**		**67.4**	
Total SEM Arsenic > Allowable Arsenic (empirical Kd for dry sed)?			**NA**		**NA**		**NA**		**NA**		**NA**	
Total SEM Arsenic:Total Allowable Arsenic (empirical Kd for dry sed)												
Total Recoverable As $\geq$ SEM As?			NA		NA		NA		NA		NA	
SEM As / Total Recoverable As			NA		NA		NA		NA		NA	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000	*(Carbonaro et al. 2005; ET&C 24: 3007-3019)*
Site background concentration, Cd	mg/kg dw	3.45	
Site hardness (as CaCO3)	mg/l	361.7	
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7	
McDonald et al. consensus-based threshold effect concentration (TEC), Cd	mg/kg dw	0.99	
McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98	
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0	
Molecular weight, Cd	ug/umol	112.4	
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687	
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052	
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438	

Transect/Pond ID			**Transect 00**		**Transect 01**		**Transect 02**		**Transect 03**		**Transect 04**		**Transect 05**		**Transect 06**	
Sample Date			**12/5/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/8/2011**	
Transect			**0**		**1**		**2**		**3**		**4**		**5**		**6**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																
SEM Copper	mg/kg	SW6010	1100		75		1.4	B	6.1		54	B	150		8.1	B
SEM Lead	mg/kg	SW6010	6400	B	650	B	17	B	18	B	440	B	1100	B	55	B
SEM Cadmium	mg/kg	SW6010	190		29		2		1.3		20	B	10		1.4	B
SEM Zinc	mg/kg	SW6010	20000	B	4100	B	310	B	150	B	4600	B	6100	B	180	B
SEM Nickel	mg/kg	SW6010	20	B	6.2	B	2.2	JB	7.4	B	15	B	14	B	5.6	B
SEM Arsenic	mg/kg	SW6010	74		7.1	B	0.035	U	2	B	1.2	B	11	B	0.82	B
SEM Copper	umole/gr	SW6010	17		1.2		0.022	B	0.096		0.85	B	2.3		0.13	B
SEM Lead	umole/gr	SW6010	31	B	3.2	B	0.08	B	0.088	B	2.1	B	5.2	B	0.27	B
SEM Cadmium	umole/gr	SW6010	1.7		0.26		0.018		0.011		0.18	B	0.091		0.012	B
SEM Zinc	umole/gr	SW6010	310	B	62	B	4.8	B	2.3	B	70	B	93	B	2.7	B
SEM Nickel	umole/gr	SW6010	0.34	B	0.11	B	0.037	JB	0.13	B	0.26	B	0.23	B	0.095	B
SEM Arsenic	umole/gr	SW6010	0.99		0.094	B	0.00047	U	0.027	B	0.016	B	0.15	B	0.011	B
SEM/AVS Ratio	none	SEM	310		220		NA		1.2		380		210		NA	
Lab AVS	umole/gr	SW9034	1.1	J	0.31	J	0.58	U	2.1		0.19	J	0.48	J	0.56	U
Porewater Cd (Total)	ug/L	SW6020	3100		40		130		1	J	470		8		NA	
Porewater Cd (Dissolved)	ug/L	SW6020	3400		9		130		0.11	U	460		6		NA	
Total Recoverable Cd	mg/kg dw	SW6020	210		160		100		70		69		59		10	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	62		37		19		37		32		9		15	
Sulfide	mg/kg	SW9034	37	J	9.9	J	3.7	U	68		6.2	J	15	J	3.6	U
Total Organic Carbon	mg/kg	LLOYD KAHN	68000		NA		19000		NA		4200		NA		5300	
Calculations																
ΣSEM	umole/gr		360.04		66.77		4.96		2.63		73.39		100.82		3.21	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.16		0.30		0.00		2.19		0.19		0.48		0.00	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		1.15		0.31		0.12		2.12		0.19		0.47		0.11	
SEM-AVS	umole/gr		358.89		66.46		4.84		0.50		73.20		100.35		3.09	
f_{OC}			0.0680		NA		0.0190		NA		0.0042		NA		0.0053	
Excess Total Metals-OC	umole/gr OC		5,277.74		NA		254.82		NA		17,427.77		NA		583.91	
AVS-Σ Cu,Pb	umole/gr		-46.85		-4.09		0.01		1.94		-2.76		-7.03		-0.29	
Excess SEM Cadmium	umole/gr		1.70		0.26		0.00		0.00		0.18		0.09		0.01	
Excess SEM Cadmium	mg/kg		191		29		1		0		20		10		1	
Excess SEM Cd-OC	umole/gr OC		25		NA		0		NA		43		NA		2	
Excess SEM Cd-OC	mg/kg OC		2,810		NA		27		NA		4,817		NA		254	
AVS-bound SEM Cd	mg/kg		0.0		0.0		1.5		217.7		0.0		0.0		0.0	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.7		0.7		0.7		0.7		0.7		0.7		0.7	
Bioavailability Based on Literature Values																
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		1.881		0.000		0.526		0.000		0.116		0.000		0.147	
(B) Allowable Cd in Water	mg/kg		0.001		NA		0.000		NA		0.000		NA		0.000	
(A+B) Total Allowable Excess Cd	mg/kg		1.882		NA		0.526		NA		0.117		NA		0.147	
Total Allowable Cadmium	**mg/kg**		**1.88**		**0.00**		**2.03**		**217.68**		**0.12**		**0.00**		**0.15**	
Total SEM Cadmium > Allowable Cadmium?			**YES**		**YES**		**NO**		**NO**		**YES**		**YES**		**YES**	
Bioavailability Based on Empirical Values																
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		802		NA		197		NA		10360		NA		NA	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		55		NA		4		NA		44		NA		NA	
AVS-bound SEM Cd	mg/kg		0.0		0.0		1.5		217.7		0.0		0.0		0.0	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.303		0.303		0.303		0.303	
(B) Allowable Cd in Water	mg/kg		0.001		0.000		0.000		0.000		0.000		0.000		0.000	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.304		0.303		0.303		0.303		0.303		0.303		0.303	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**0.3**		**0.3**		**1.8**		**218.0**		**0.3**		**0.3**		**0.3**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			**YES**		**YES**		**YES**		**NO**		**YES**		**YES**		**YES**	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			625.55		95.71		1.11		0.01		66.02		33.04		4.62	
Total Recoverable Cd ≥ SEM Cd?			YES		YES		YES		YES		YES		YES		YES	
SEM Cd / Total Recoverable Cd			0.905		0.181		0.020		0.019		0.290		0.169		0.140	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000
Site background concentration, Cd	mg/kg dw	3.45
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7
McDonald et al. consensus-based threshold effect concentration (TEC), Cd	mg/kg dw	0.99
McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0
Molecular weight, Cd	ug/umol	112.4
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438

Transect/Pond ID			**Transect 08**		**Transect 12**		**Transect 14**		**Transect 16**		**Transect 17**		**Transect 18**		**Transect 19**	
Sample Date			**12/8/2011**		**12/9/2011**		**12/9/2011**		**6/13/2012**		**6/13/2012**		**6/6/2012**		**6/20/2012**	
Transect			**8**		**12**		**14**		**16**		**17**		**18**		**19**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																
SEM Copper	mg/kg	SW6010	4.6		3.7		5.7		9.9		7.9		6		10	
SEM Lead	mg/kg	SW6010	26	B	20	B	36	B	61	B	31	B	17	B	51	B
SEM Cadmium	mg/kg	SW6010	0.6		0.49		1.9		3.9		0.57		0.69		3.1	
SEM Zinc	mg/kg	SW6010	60	B	56	B	250	B	490	B	80	B	110	B	300	B
SEM Nickel	mg/kg	SW6010	5.3	B	3.7	B	5.5	B	3.8	B	7.9	B	5.8	B	4.9	B
SEM Arsenic	mg/kg	SW6010	0.82	B	0.76	B	0.8	B	1.7	B	2.2	B	1.7	B	2.3	B
SEM Copper	umole/gr	SW6010	0.072		0.058		0.089		0.16		0.12		0.094		0.16	
SEM Lead	umole/gr	SW6010	0.13	B	0.098	B	0.17	B	0.29	B	0.15	B	0.082	B	0.24	B
SEM Cadmium	umole/gr	SW6010	0.0054		0.0044		0.017		0.035		0.0051		0.0062		0.028	
SEM Zinc	umole/gr	SW6010	0.92	B	0.85	B	3.8	B	7.4	B	1.2	B	1.7	B	4.6	B
SEM Nickel	umole/gr	SW6010	0.09	B	0.062	B	0.093	B	0.064	B	0.13	B	0.098	B	0.083	B
SEM Arsenic	umole/gr	SW6010	0.011	B	0.01	B	0.011	B	0.022	B	0.029	B	0.023	B	0.031	B
SEM/AVS Ratio	none	SEM	NA		NA		NA		1.7		6.1		NA		10	
Lab AVS	umole/gr	SW9034	0.62	U	0.56	U	0.6	U	4.7		0.28	J	0.7	U	0.51	J
Porewater Cd (Total)	ug/L	SW6020	NA		NA		NA		1.9		0.34	J	0.33	J	1.7	
Porewater Cd (Dissolved)	ug/L	SW6020	NA		NA		NA		0.11	U	0.11	U	0.23	U	0.32	J
Total Recoverable Cd	mg/kg dw	SW6020	6.6		11		11		5.2		5.6	B	5.4	B	9	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	25		16		21		36		38		33		35	
Sulfide	mg/kg	SW9034	4	U	3.6	U	3.8	U	150		8.8	J	4.5	U	16	J
Total Organic Carbon	mg/kg	LLOYD KAHN	7800		4000		7400		10000	H	4500	H	3800	H	15000	H
Calculations																
ΣSEM	umole/gr		1.22		1.07		4.17		7.95		1.61		1.98		5.11	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		0.00		0.00		0.00		4.68		0.26		0.00		0.51	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		0.12		0.11		0.12		4.68		0.27		0.14		0.50	
SEM-AVS	umole/gr		1.09		0.96		4.05		3.27		1.33		1.84		4.61	
f_{OC}			0.0078		0.0040		0.0074		0.0100		0.0045		0.0038		0.0150	
Excess Total Metals-OC	umole/gr OC		140.08		240.03		547.36		327.10		295.70		484.17		307.47	
AVS-Σ Cu,Pb	umole/gr		-0.08		-0.04		-0.14		4.23		0.00		-0.04		0.10	
Excess SEM Cadmium	umole/gr		0.01		0.00		0.02		0.00		0.00		0.01		0.00	
Excess SEM Cadmium	mg/kg		1		0		2		0		0		1		0	
Excess SEM Cd-OC	umole/gr OC		1		1		2		0		0		2		0	
Excess SEM Cd-OC	mg/kg OC		78		124		258		0		16		183		0	
AVS-bound SEM Cd	mg/kg		0.0		0.0		0.0		475.2		0.5		0.0		11.1	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.7		0.7		0.7		0.7		0.7		0.7		0.7	
Bioavailability Based on Literature Values																
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		0.216		0.111		0.205		0.277		0.124		0.105		0.415	
(B) Allowable Cd in Water	mg/kg		0.000		0.000		0.000		0.000		0.000		0.000		0.000	
(A+B) Total Allowable Excess Cd	mg/kg		0.216		0.111		0.205		0.277		0.125		0.105		0.415	
Total Allowable Cadmium	**mg/kg**		**0.22**		**0.11**		**0.20**		**475.50**		**0.62**		**0.11**		**11.54**	
Total SEM Cadmium > Allowable Cadmium?			**YES**		**YES**		**YES**		**NO**		**NO**		**YES**		**NO**	
Bioavailability Based on Empirical Values																
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		NA		NA		NA		ND		149154		797216		ND	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		NA		NA		NA		ND		671		3029		ND	
AVS-bound SEM Cd	mg/kg		0.0		0.0		0.0		475.2		0.5		0.0		11.1	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.303		0.303		0.303		0.303	
(B) Allowable Cd in Water	mg/kg		0.000		0.000		0.000		0.000		0.000		0.000		0.000	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.303		0.303		0.303		0.303	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**0.3**		**0.3**		**0.3**		**475.5**		**0.8**		**0.3**		**11.4**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			**YES**		**YES**		**YES**		**NO**		**NO**		**YES**		**NO**	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			1.98		1.62		6.27		0.01		0.71		2.28		0.27	
Total Recoverable Cd ≥ SEM Cd?			YES		YES		YES		YES		YES		YES		YES	
SEM Cd / Total Recoverable Cd			0.091		0.045		0.173		0.750		0.102		0.128		0.344	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000
Site background concentration, Cd	mg/kg dw	3.45
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7
McDonald et al. consensus-based threshold effect concentration (TEC), Cd	mg/kg dw	0.99
McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0
Molecular weight, Cd	ug/umol	112.4
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438

Transect/Pond ID			**Transect 21**		**Transect 24**		**Transect 25**		**Transect 25+25**		**Transect 25+50**		**Transect 25+75**		**Transect 25+100**	
Sample Date			**6/20/2012**		**6/13/2012**		**6/13/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**	
Transect			**21**		**24**		**25**		**25**	**+25**	**25**	**+50**	**25**	**+75**	**25**	**+100**
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																
SEM Copper	mg/kg	SW6010	7.2		13		12		7.2	B	9.4	B	7	B	8.4	B
SEM Lead	mg/kg	SW6010	53	B	160	B	67	B	28	B	54	B	22	B	36	B
SEM Cadmium	mg/kg	SW6010	4		4.5		2.4		2.6	B	2.7	B	1.4	B	2	B
SEM Zinc	mg/kg	SW6010	310	B	520	B	360	B	340	B	410	B	170	B	260	B
SEM Nickel	mg/kg	SW6010	6.8	B	17	B	11	B	7.7	B	8	B	7	B	7.3	B
SEM Arsenic	mg/kg	SW6010	2.3	B	4.2	B	2.9	B	0.57		0.71		0.5		0.93	
SEM Copper	umole/gr	SW6010	0.11		0.21		0.18		0.11	B	0.15	B	0.11	B	0.13	B
SEM Lead	umole/gr	SW6010	0.25	B	0.8	B	0.32	B	0.14	B	0.26	B	0.11	B	0.17	B
SEM Cadmium	umole/gr	SW6010	0.035		0.04		0.022		0.024	B	0.024	B	0.012	B	0.018	B
SEM Zinc	umole/gr	SW6010	4.8	B	8	B	5.6	B	5.1	B	6.3	B	2.6	B	4	B
SEM Nickel	umole/gr	SW6010	0.12	B	0.28	B	0.18	B	0.13	B	0.14	B	0.12	B	0.13	B
SEM Arsenic	umole/gr	SW6010	0.031	B	0.056	B	0.038	B	0.0075		0.0095		0.0067		0.012	
SEM/AVS Ratio	none	SEM	30		1.9		1.5		1.9		2.2		1.7		2.5	
Lab AVS	umole/gr	SW9034	0.18	J	4.9		4.3		2.9	B	3.2	B	1.7	B	1.8	B
Porewater Cd (Total)	ug/L	SW6020	2.1		3.8		0.72	J	0.66	J	1.3		1.5		0.87	J
Porewater Cd (Dissolved)	ug/L	SW6020	0.46	J	0.35	J	0.11	U	0.11	U	0.11	U	0.11	U	0.11	U
Total Recoverable Cd	mg/kg dw	SW6020	6.4		7.4		24		2.1		2		1.2		1.3	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		380		300		340		380	
%Moist	%	NA	32		39		42		45		40		35		36	
Sulfide	mg/kg	SW9034	5.8	J	160		140		94	B	100	B	54	B	56	B
Total Organic Carbon	mg/kg	LLOYD KAHN	7100	H	14000	H	9500	H	19000		15000		12000		15000	
Calculations																
ΣSEM	umole/gr		5.32		9.33		6.30		5.50		6.87		2.95		4.45	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		0.18		4.91		4.20		2.90		3.12		1.74		1.78	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		0.18		4.99		4.37		2.93		3.12		1.68		1.75	
SEM-AVS	umole/gr		5.13		4.34		1.94		2.57		3.76		1.27		2.70	
f_{OC}			0.0071		0.0140		0.0095		0.0190		0.0150		0.0120		0.0150	
Excess Total Metals-OC	umole/gr OC		723.12		310.01		203.78		135.39		250.36		105.66		180.10	
AVS-Σ Cu,Pb	umole/gr		-0.18		3.98		3.87		2.68		2.71		1.46		1.45	
Excess SEM Cadmium	umole/gr		0.04		0.00		0.00		0.00		0.00		0.00		0.00	
Excess SEM Cadmium	mg/kg		4		0		0		0		0		0		0	
Excess SEM Cd-OC	umole/gr OC		5		0		0		0		0		0		0	
Excess SEM Cd-OC	mg/kg OC		554		0		0		0		0		0		0	
AVS-bound SEM Cd	mg/kg		0.0		447.3		434.6		301.4		304.5		164.6		162.6	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.7		0.7		0.7		0.7		0.6		0.7		0.7	
Bioavailability Based on Literature Values																
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		0.196		0.387		0.263		0.545		0.361		0.317		0.430	
(B) Allowable Cd in Water	mg/kg		0.000		0.000		0.001		0.001		0.000		0.000		0.000	
(A+B) Total Allowable Excess Cd	mg/kg		0.197		0.388		0.263		0.546		0.362		0.317		0.431	
Total Allowable Cadmium	**mg/kg**		**0.20**		**447.72**		**434.82**		**301.95**		**304.82**		**164.88**		**163.01**	
Total SEM Cadmium > Allowable Cadmium?			**YES**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values																
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		1204465		ND		ND		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		8552		ND		ND		ND		ND		ND		ND	
AVS-bound SEM Cd	mg/kg		0.0		447.3		434.6		301.4		304.5		164.6		162.6	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.314		0.263		0.289		0.314	
(B) Allowable Cd in Water	mg/kg		0.000		0.000		0.001		0.001		0.000		0.000		0.000	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.314		0.264		0.289		0.314	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**0.3**		**447.6**		**434.9**		**301.7**		**304.7**		**164.9**		**162.9**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			**YES**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			13.20		0.01		0.01		0.01		0.01		0.01		0.01	
Total Recoverable Cd ≥ SEM Cd?			YES		YES		YES		NO		NO		NO		NO	
SEM Cd / Total Recoverable Cd			0.625		0.608		0.100		1.238		1.350		1.167		1.538	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000
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Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7
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McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0
Molecular weight, Cd	ug/umol	112.4
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438

Transect/Pond ID			**Transect 26**		**Transect 27**		**Off-Property Pond 1-1**		**Off-Property Pond 1-2**		**Off-Property Pond 1-3**		**Off-Property Pond 1-4**		**Off-Property Pond 3-1**	
Sample Date			**11/14/2012**		**11/14/2012**		**12/5/2011**		**12/5/2011**		**12/5/2011**		**12/5/2011**		**12/6/2011**	
Transect			**26**	**CENTER**	**27**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																
SEM Copper	mg/kg	SW6010	6.9	B	5.9	B	2.5		3		25		0.26	J	6.9	
SEM Lead	mg/kg	SW6010	20	B	36	B	200	B	65	B	260	B	120	B	56	B
SEM Cadmium	mg/kg	SW6010	1.5	B	2.2	B	4.6		1.4		3.9		3.3		1	
SEM Zinc	mg/kg	SW6010	160	B	230	B	700	B	210	B	800	B	530	B	190	B
SEM Nickel	mg/kg	SW6010	7	B	8.1	B	5	B	4.7	B	7.3	B	4	B	6	B
SEM Arsenic	mg/kg	SW6010	0.51		0.64		1.3		0.85		2.4		0.6		0.78	B
SEM Copper	umole/gr	SW6010	0.11	B	0.093	B	0.039		0.046		0.39		0.004	J	0.11	
SEM Lead	umole/gr	SW6010	0.099	B	0.18	B	0.97	B	0.31	B	1.2	B	0.6	B	0.27	B
SEM Cadmium	umole/gr	SW6010	0.013	B	0.02	B	0.041		0.012		0.035		0.029		0.0091	
SEM Zinc	umole/gr	SW6010	2.5	B	3.5	B	11	B	3.2	B	12	B	8.1	B	2.9	B
SEM Nickel	umole/gr	SW6010	0.12	B	0.14	B	0.085	B	0.08	B	0.12	B	0.068	B	0.1	B
SEM Arsenic	umole/gr	SW6010	0.0068		0.0086		0.018		0.011		0.032		0.0079		0.01	B
SEM/AVS Ratio	none	SEM	2.4		5.2		0.55		0.19		0.35		0.71		1.3	
Lab AVS	umole/gr	SW9034	1.2	B	0.75	B	21		19		40		12		2.6	
Porewater Cd (Total)	ug/L	SW6020	0.26	J	0.75	J	0.85	J	0.85	J	0.85	J	0.85	J	1.6	
Porewater Cd (Dissolved)	ug/L	SW6020	0.11	U	0.11	U	0.11	U	0.11	U	0.11	U	0.11	U	0.23	U
Total Recoverable Cd	mg/kg dw	SW6020	1.5		1.5		4.7		3		4.8		4.3		2.9	
Hardness (as CaCO3)	mg/l	SM2340C	510		260		NA		NA		NA		NA		NA	
%Moist	%	NA	40		35		53		34		64		39		42	
Sulfide	mg/kg	SW9034	37	B	24	B	690		600		1300		400		83	
Total Organic Carbon	mg/kg	LLOYD KAHN	13000		11000		19000		15000		17000		13000		7400	
Calculations																
ΣSEM	umole/gr		2.84		3.93		12.14		3.65		13.75		8.80		3.39	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.18		0.76		22.06		19.20		39.27		12.40		2.61	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		1.15		0.75		21.52		18.71		40.54		12.47		2.59	
SEM-AVS	umole/gr		1.69		3.18		-9.38		-15.06		-26.80		-3.67		0.80	
f_{OC}			0.0130		0.0110		0.0190		0.0150		0.0170		0.0130		0.0074	
Excess Total Metals-OC	umole/gr OC		129.85		289.50		-493.88		-1,004.27		-1,576.33		-282.59		108.19	
AVS-Σ Cu,Pb	umole/gr		0.94		0.48		20.51		18.36		38.95		11.87		2.21	
Excess SEM Cadmium	umole/gr		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Excess SEM Cadmium	mg/kg		0		0		0		0		0		0		0	
Excess SEM Cd-OC	umole/gr OC		0		0		0		0		0		0		0	
Excess SEM Cd-OC	mg/kg OC		0		0		0		0		0		0		0	
AVS-bound SEM Cd	mg/kg		106.2		53.4		2305.3		2063.2		4378.3		1334.3		248.2	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.9		0.5		0.7		0.7		0.7		0.7		0.7	
Bioavailability Based on Literature Values																
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		0.464		0.238		0.526		0.415		0.470		0.360		0.205	
(B) Allowable Cd in Water	mg/kg		0.001		0.000		0.001		0.000		0.001		0.000		0.001	
(A+B) Total Allowable Excess Cd	mg/kg		0.465		0.239		0.526		0.415		0.472		0.360		0.205	
Total Allowable Cadmium	**mg/kg**		**106.67**		**53.68**		**2,305.83**		**2,063.63**		**4,378.75**		**1,334.62**		**248.44**	
Total SEM Cadmium > Allowable Cadmium?			NO		NO		NO		NO		NO		NO		NO	
Bioavailability Based on Empirical Values																
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		ND		ND		ND		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		ND		ND		ND		ND		ND		ND		ND	
AVS-bound SEM Cd	mg/kg		106.2		53.4		2305.3		2063.2		4378.3		1334.3		248.2	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.390		0.237		0.303		0.303		0.303		0.303		0.303	
(B) Allowable Cd in Water	mg/kg		0.001		0.000		0.001		0.000		0.001		0.000		0.001	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.391		0.237		0.303		0.303		0.304		0.303		0.303	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**106.6**		**53.7**		**2,305.6**		**2,063.5**		**4,378.6**		**1,334.6**		**248.5**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			NO		NO		NO		NO		NO		NO		NO	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			0.01		0.04		0.00		0.00		0.00		0.00		0.00	
Total Recoverable Cd ≥ SEM Cd?			YES		NO		YES		YES		YES		YES		YES	
SEM Cd / Total Recoverable Cd			1.000		1.467		0.979		0.467		0.813		0.767		0.345	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000
Site background concentration, Cd	mg/kg dw	3.45
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7
McDonald et al. consensus-based threshold effect concentration (TEC), Cd	mg/kg dw	0.99
McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0
Molecular weight, Cd	ug/umol	112.4
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438

Transect/Pond ID			**Off-Property Pond 3-2**		**Off-Property Pond 3-3**		**Off-Property Pond 3-4**		**Off-Property Pond 4-1**		**Off-Property Pond 4-2**		**Northeast Pond-1**		**Northeast Pond-2**	
Sample Date			**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**	
Transect			**P**		**P**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																
SEM Copper	mg/kg	SW6010	8.4		13		11	B	4	B	5.7	B	5.8	B	5.7	B
SEM Lead	mg/kg	SW6010	69	B	120	B	71	B	16	B	29	B	31	B	26	B
SEM Cadmium	mg/kg	SW6010	1.1		2.2		0.77		0.086	J	0.24		0.43		0.25	
SEM Zinc	mg/kg	SW6010	210	B	420	B	180	B	22	B	46	B	74	B	51	B
SEM Nickel	mg/kg	SW6010	4	B	4.9	B	12	B	7.1	B	8.8	B	3.3	B	3.1	B
SEM Arsenic	mg/kg	SW6010	1.1	B	1	B	1.9	B	1.4	B	1.7	B	1.5	B	1.7	B
SEM Copper	umole/gr	SW6010	0.13		0.2		0.18	B	0.063	B	0.09	B	0.092	B	0.09	B
SEM Lead	umole/gr	SW6010	0.33	B	0.58	B	0.34	B	0.075	B	0.14	B	0.15	B	0.13	B
SEM Cadmium	umole/gr	SW6010	0.01		0.019		0.0068		0.00077	J	0.0021		0.0038		0.0022	
SEM Zinc	umole/gr	SW6010	3.2	B	6.4	B	2.8	B	0.33	B	0.7	B	1.1	B	0.78	B
SEM Nickel	umole/gr	SW6010	0.069	B	0.083	B	0.21	B	0.12	B	0.15	B	0.057	B	0.053	B
SEM Arsenic	umole/gr	SW6010	0.014	B	0.014	B	0.025	B	0.018	B	0.022	B	0.02	B	0.023	B
SEM/AVS Ratio	none	SEM	1.9		3.9		2.9		NA		NA		1.9		NA	
Lab AVS	umole/gr	SW9034	2		1.9		1.2		0.54	U	0.63	U	0.76	J	0.91	U
Porewater Cd (Total)	ug/L	SW6020	1.6		1.6		1.6		0.13	J	0.13	J	0.16	J	0.16	J
Porewater Cd (Dissolved)	ug/L	SW6020	0.23	U	0.23	U	0.23	U	0.11	U	0.11	U	0.11	U	0.11	U
Total Recoverable Cd	mg/kg dw	SW6020	1.1		3.6		2.1		0.8		0.59		0.77		0.52	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	40		48		44		12		25		42		49	
Sulfide	mg/kg	SW9034	64		60		39		3.5	U	4	U	24	J	5.9	U
Total Organic Carbon	mg/kg	LLOYD KAHN	5400		11000		4400		2900		6700		10000		8400	
Calculations																
ΣSEM	umole/gr		3.74		7.28		3.54		0.59		1.08		1.40		1.06	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.97		1.87		1.22		0.00		0.00		0.74		0.00	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		2.00		1.87		1.22		0.11		0.12		0.75		0.18	
SEM-AVS	umole/gr		1.74		5.41		2.32		0.48		0.96		0.65		0.87	
f_{OC}			0.0054		0.0110		0.0044		0.0029		0.0067		0.0100		0.0084	
Excess Total Metals-OC	umole/gr OC		322.79		491.89		527.39		165.39		142.89		65.43		103.71	
AVS-Σ Cu,Pb	umole/gr		1.54		1.09		0.70		-0.03		-0.11		0.51		-0.04	
Excess SEM Cadmium	umole/gr		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Excess SEM Cadmium	mg/kg		0		0		0		0		0		0		0	
Excess SEM Cd-OC	umole/gr OC		0		0		0		0		0		0		0	
Excess SEM Cd-OC	mg/kg OC		0		0		0		30		35		0		29	
AVS-bound SEM Cd	mg/kg		172.6		122.7		78.3		0.0		0.0		56.9		0.0	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.7		0.7		0.7		0.7		0.7		0.7		0.7	
Bioavailability Based on Literature Values																
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		0.149		0.304		0.122		0.080		0.185		0.277		0.232	
(B) Allowable Cd in Water	mg/kg		0.000		0.001		0.001		0.000		0.000		0.001		0.001	
(A+B) Total Allowable Excess Cd	mg/kg		0.150		0.305		0.122		0.080		0.186		0.277		0.233	
Total Allowable Cadmium	**mg/kg**		**172.79**		**122.96**		**78.38**		**0.08**		**0.19**		**57.21**		**0.23**	
Total SEM Cadmium > Allowable Cadmium?			**NO**		**NO**		**NO**		**YES**		**YES**		**NO**		**YES**	
Bioavailability Based on Empirical Values																
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		ND		ND		ND		271263		320222		ND		267505	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		ND		ND		ND		787		2145		ND		2247	
AVS-bound SEM Cd	mg/kg		172.6		122.7		78.3		0.0		0.0		56.9		0.0	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.303		0.303		0.303		0.303	
(B) Allowable Cd in Water	mg/kg		0.000		0.001		0.001		0.000		0.000		0.001		0.001	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.303		0.303		0.303		0.303	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**172.9**		**123.0**		**78.6**		**0.3**		**0.3**		**57.2**		**0.3**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			0.01		0.02		0.01		0.28		0.79		0.01		0.82	
Total Recoverable Cd ≥ SEM Cd?			YES		YES		YES		YES		YES		YES		YES	
SEM Cd / Total Recoverable Cd			1.000		0.611		0.367		0.108		0.407		0.558		0.481	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000
Site background concentration, Cd	mg/kg dw	3.45
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7
McDonald et al. consensus-based threshold effect concentration (TEC), Cd	mg/kg dw	0.99
McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0
Molecular weight, Cd	ug/umol	112.4
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438

Transect/Pond ID			**Northeast Pond-3**		**Northeast Pond-4**		**North Pond-1**		**North Pond-2**		**North Pond-3**		**North Pond-4**		**South Pond-1**	
Sample Date			**12/6/2011**		**12/6/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																
SEM Copper	mg/kg	SW6010	2	B	8.1	B	21		27		28		23		1.5	U
SEM Lead	mg/kg	SW6010	22	B	49	B	140		220		240		160		120	
SEM Cadmium	mg/kg	SW6010	0.36		0.61		9.6		23		9.2		9.2		11	
SEM Zinc	mg/kg	SW6010	60	B	110	B	850		1300		830		1100		1600	
SEM Nickel	mg/kg	SW6010	2.8	B	6.3	B	1.9	J	2	J	1.5	J	1.8	J	1.4	J
SEM Arsenic	mg/kg	SW6010	1.3	B	2.5	B	NA		NA		NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.032	B	0.13	B	0.32		0.42		0.45		0.37		0.023	U
SEM Lead	umole/gr	SW6010	0.11	B	0.24	B	0.67		1.1		1.2		0.76		0.59	
SEM Cadmium	umole/gr	SW6010	0.0032		0.0054		0.085		0.21		0.082		0.082		0.096	
SEM Zinc	umole/gr	SW6010	0.92	B	1.7	B	13		20		13		17		25	
SEM Nickel	umole/gr	SW6010	0.048	B	0.11	B	0.033	J	0.035	J	0.026	J	0.031	J	0.024	J
SEM Arsenic	umole/gr	SW6010	0.017	B	0.034	B	NA		NA		NA		NA		NA	
SEM/AVS Ratio	none	SEM	0.16		2		1.5		13		13		11		1.9	
Lab AVS	umole/gr	SW9034	7		1.1	J	NA		NA		NA		NA		NA	
Porewater Cd (Total)	ug/L	SW6020	0.16	J	0.16	J	630		630		630		630		2.7	
Porewater Cd (Dissolved)	ug/L	SW6020	0.11	U	0.11	U	710		710		710		710		0.11	U
Total Recoverable Cd	mg/kg dw	SW6020	0.82		0.83		0.27		64		38		26		20	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	40		60		48		48		46		67		65	
Sulfide	mg/kg	SW9034	220		35	J	930		120		82		150		1500	
Total Organic Carbon	mg/kg	LLOYD KAHN	13000		15000		54000		87000		100000		53000		30000	
Calculations																
ΣSEM	umole/gr		1.11		2.19		14.11		21.77		14.76		18.24		25.73	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		6.96		1.09		9.41		1.67		1.14		1.66		13.54	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		6.86		1.09		29.00		3.74		2.56		4.68		46.78	
SEM-AVS	umole/gr		-5.75		1.09		-14.90		18.02		12.20		13.57		-21.05	
f_{OC}			0.0130		0.0150		0.0540		0.0870		0.1000		0.0530		0.0300	
Excess Total Metals-OC	umole/gr OC		-442.14		72.92		-275.84		207.16		122.01		255.94		-701.57	
AVS-Σ Cu,Pb	umole/gr		6.72		0.72		28.01		2.22		0.91		3.55		46.17	
Excess SEM Cadmium	umole/gr		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Excess SEM Cadmium	mg/kg		0		0		0		0		0		0		0	
Excess SEM Cd-OC	umole/gr OC		0		0		0		0		0		0		0	
Excess SEM Cd-OC	mg/kg OC		0		0		0		0		0		0		0	
AVS-bound SEM Cd	mg/kg		755.2		81.1		3148.7		249.8		102.0		398.8		5189.2	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.7		0.7		0.7		0.7		0.7		0.7		0.7	
Bioavailability Based on Literature Values																
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		0.360		0.415		1.494		2.407		2.767		1.466		0.830	
(B) Allowable Cd in Water	mg/kg		0.000		0.001		0.001		0.001		0.001		0.001		0.001	
(A+B) Total Allowable Excess Cd	mg/kg		0.360		0.416		1.495		2.408		2.767		1.468		0.831	
Total Allowable Cadmium	**mg/kg**		**755.58**		**81.52**		**3,150.22**		**252.21**		**104.75**		**400.26**		**5,190.00**	
Total SEM Cadmium > Allowable Cadmium?			NO		NO		NO		NO		NO		NO		NO	
Bioavailability Based on Empirical Values																
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		ND		ND		ND		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		ND		ND		ND		ND		ND		ND		ND	
AVS-bound SEM Cd	mg/kg		755.2		81.1		3148.7		249.8		102.0		398.8		5189.2	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303		0.303		0.303		0.303		0.303	
(B) Allowable Cd in Water	mg/kg		0.000		0.001		0.001		0.001		0.001		0.001		0.001	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.303		0.304		0.303		0.303		0.303		0.304		0.304	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**755.5**		**81.4**		**3,149.0**		**250.1**		**102.3**		**399.1**		**5,189.5**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			NO		NO		NO		NO		NO		NO		NO	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			0.00		0.01		0.00		0.09		0.09		0.02		0.00	
Total Recoverable Cd ≥ SEM Cd?			YES		YES		NO		YES		YES		YES		YES	
SEM Cd / Total Recoverable Cd			0.439		0.735		35.556		0.359		0.242		0.354		0.550	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-2
Bioavailability Calculations for Cadmium

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Cd}$	L/kg-OC	40000
Site background concentration, Cd	mg/kg dw	3.45
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Cd (Average site hardness)	ug/L	0.7
McDonald et al. consensus-based threshold effect concentration (TEC), Cd	mg/kg dw	0.99
McDonald et al. consensus-based probable effect concentration (PEC), Cd	mg/kg dw	4.98
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Cd	mg/kg dw	39.0
Molecular weight, Cd	ug/umol	112.4
Average Empirical Partition Coef, $K_{d,OC,Cd}$	L/kg-OC	335,687
Geometric Mean Empirical Partition Coef $K_{d,OC,Cd}$	L/kg-OC	56,052
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Cd}$	L/kg dry sed	438

Transect/Pond ID			**South Pond-2**		**South Pond-3**		**South Pond-4**	
Sample Date			**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values								
SEM Copper	mg/kg	SW6010	0.89	U	1.2	U	0.86	U
SEM Lead	mg/kg	SW6010	78		58		63	
SEM Cadmium	mg/kg	SW6010	7.5		5.6		4.9	
SEM Zinc	mg/kg	SW6010	1100		890		720	
SEM Nickel	mg/kg	SW6010	0.55	U	3.1	J	2.3	J
SEM Arsenic	mg/kg	SW6010	NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.014	U	0.019	U	0.014	U
SEM Lead	umole/gr	SW6010	0.38		0.28		0.3	
SEM Cadmium	umole/gr	SW6010	0.066		0.05		0.044	
SEM Zinc	umole/gr	SW6010	17		14		11	
SEM Nickel	umole/gr	SW6010	0.0094	U	0.053	J	0.039	J
SEM Arsenic	umole/gr	SW6010	NA		NA		NA	
SEM/AVS Ratio	none	SEM	2		1.9		2.3	
Lab AVS	umole/gr	SW9034	NA		NA		NA	
Porewater Cd (Total)	ug/L	SW6020	2.7		2.7		2.7	
Porewater Cd (Dissolved)	ug/L	SW6020	0.11	U	0.11	U	0.11	U
Total Recoverable Cd	mg/kg dw	SW6020	24		5.7		13	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA	
%Moist	%	NA	45		59		42	
Sulfide	mg/kg	SW9034	920		1200		890	
Total Organic Carbon	mg/kg	LLOYD KAHN	26000		11000		17000	
Calculations								
ΣSEM	umole/gr		17.47		14.40		11.40	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		8.73		7.58		4.96	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		28.69		37.42		27.76	
SEM-AVS	umole/gr		-11.22		-23.02		-16.36	
f_{OC}			0.0260		0.0110		0.0170	
Excess Total Metals-OC	umole/gr OC		-431.63		-2,092.91		-962.30	
AVS-Σ Cu,Pb	umole/gr		28.30		37.12		27.44	
Excess SEM Cadmium	umole/gr		0.00		0.00		0.00	
Excess SEM Cadmium	mg/kg		0		0		0	
Excess SEM Cd-OC	umole/gr OC		0		0		0	
Excess SEM Cd-OC	mg/kg OC		0		0		0	
AVS-bound SEM Cd	mg/kg		3180.7		4172.8		3084.5	
Calculated Kansas chronic aquatic life WQC, Cd (Location Specific)	ug/L		0.7		0.7		0.7	
Bioavailability Based on Literature Values								
(A) Allowable Cd Sorbed to OC in Sediment	mg/kg		0.719		0.304		0.470	
(B) Allowable Cd in Water	mg/kg		0.001		0.001		0.001	
(A+B) Total Allowable Excess Cd	mg/kg		0.720		0.305		0.471	
Total Allowable Cadmium	**mg/kg**		**3,181.38**		**4,173.15**		**3,084.97**	
Total SEM Cadmium > Allowable Cadmium?			**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values								
Partition Coefficient, $K_{d,OC,Cd}$ (Calc'd)	L/kg-OC		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Cd}$ (Calc'd)	L/kg dry sed		ND		ND		ND	
AVS-bound SEM Cd	mg/kg		3180.7		4172.8		3084.5	
(A) Allowable Cd Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		0.303		0.303		0.303	
(B) Allowable Cd in Water	mg/kg		0.001		0.001		0.001	
(A+B) Total Allowable Excess Cd (empirical Kd for dry sed)	mg/kg		0.303		0.304		0.303	
Total Allowable Cadmium (empirical Kd for dry sed)	**mg/kg**		**3,181.0**		**4,173.2**		**3,084.8**	
Total SEM Cadmium > Allowable Cadmium (empirical Kd for dry sed)?			**NO**		**NO**		**NO**	
Total SEM Cadmium:Total Allowable Cadmium (empirical Kd for dry sed)			0.00		0.00		0.00	
Total Recoverable Cd ≥ SEM Cd?			YES		YES		YES	
SEM Cd / Total Recoverable Cd			0.313		0.982		0.377	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-3
Bioavailability Calculations for Lead

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Pb}$	L/kg-OC	4000000	*(Carbonaro et al. 2005; ET&C 24: 3007-3019)*
Site background concentration, Pb	mg/kg dw	96.7	
Site hardness (as CaCO3)	mg/l	361.7	
Kansas chronic aquatic life WQC, Pb (Average site hardness)	ug/L	16.1	
McDonald et al. consensus-based threshold effect concentration (TEC), Pb	mg/kg dw	35.8	
McDonald et al. consensus-based probable effect concentration (PEC), Pb	mg/kg dw	128	
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Pb	mg/kg dw	400	
Molecular weight, Pb	ug/umol	207.2	
Average Empirical Partition Coef, $K_{d,OC,Pb}$	L/kg-OC	6,017,993	
Geometric Mean Empirical Partition Coef $K_{d,OC,Pb}$	L/kg-OC	3,927,449	
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Pb}$	L/kg dry sed	29,206	

Transect/Pond ID			**Transect 00**		**Transect 01**		**Transect 02**		**Transect 03**		**Transect 04**		**Transect 05**		**Transect 06**		**Transect 08**	
Sample Date			**12/5/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/8/2011**		**12/8/2011**	
Transect			**0**		**1**		**2**		**3**		**4**		**5**		**6**		**8**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	1100		75		1.4	B	6.1		54	B	150		8.1	B	4.6	
SEM Lead	mg/kg	SW6010	6400	B	650	B	17	B	18	B	440	B	1100	B	55	B	26	B
SEM Cadmium	mg/kg	SW6010	190		29		2		1.3		20	B	10		1.4	B	0.6	
SEM Zinc	mg/kg	SW6010	20000	B	4100	B	310	B	150	B	4600	B	6100	B	180	B	60	B
SEM Nickel	mg/kg	SW6010	20	B	6.2	B	2.2	JB	7.4	B	15	B	14	B	5.6	B	5.3	B
SEM Arsenic	mg/kg	SW6010	74		7.1	B	0.035	U	2	B	1.2	B	11	B	0.82	B	0.82	B
SEM Copper	umole/gr	SW6010	17		1.2		0.022	B	0.096		0.85	B	2.3		0.13	B	0.072	
SEM Lead	umole/gr	SW6010	31	B	3.2	B	0.08	B	0.088	B	2.1	B	5.2	B	0.27	B	0.13	B
SEM Cadmium	umole/gr	SW6010	1.7		0.26		0.018		0.011		0.18	B	0.091		0.012	B	0.0054	
SEM Zinc	umole/gr	SW6010	310	B	62	B	4.8	B	2.3	B	70	B	93	B	2.7	B	0.92	B
SEM Nickel	umole/gr	SW6010	0.34	B	0.11	B	0.037	JB	0.13	B	0.26	B	0.23	B	0.095	B	0.09	B
SEM Arsenic	umole/gr	SW6010	0.99		0.094	B	0.00047	U	0.027	B	0.016	B	0.15	B	0.011	B	0.011	B
SEM/AVS Ratio	none	SEM	310		220		NA		1.2		380		210		NA		NA	
Lab AVS	umole/gr	SW9034	1.1	J	0.31	J	0.58	U	2.1		0.19	J	0.48	J	0.56	U	0.62	U
Porewater Pb (Total)	ug/L	SW6020	1500		210		590	B	21		230	B	190		NA		NA	
Porewater Pb (Dissolved)	ug/L	SW6020	480	B	2		36	B	0.18	J	17	B	18		NA		NA	
Total Recoverable Pb	mg/kg dw	SW6020	13000		5000		3500		2900	B^	4300	B	1400	B	330	B	190	B
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	62		37		19		37		32		9		15		25	
Sulfide	mg/kg	SW9034	37	J	9.9	J	3.7	U	68		6.2	J	15	J	3.6	U	4	U
Total Organic Carbon	mg/kg	LLOYD KAHN	68000		NA		19000		NA		4200		NA		5300		7800	
Calculations																		
ΣSEM	umole/gr		360.04		66.77		4.96		2.63		73.39		100.82		3.21		1.22	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.16		0.30		0.00		2.19		0.19		0.48		0.00		0.00	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		1.15		0.31		0.12		2.12		0.19		0.47		0.11		0.12	
SEM-AVS	umole/gr		358.89		66.46		4.84		0.50		73.20		100.35		3.09		1.09	
f_{OC}			0.0680		NA		0.0190		NA		0.0042		NA		0.0053		0.0078	
Excess Total Metals-OC	umole/gr OC		5,277.74		NA		254.82		NA		17,427.77		NA		583.91		140.08	
AVS-Σ Cu	umole/gr		-15.85		-0.89		0.09		2.02		-0.66		-1.83		-0.02		0.05	
Excess SEM Lead	umole/gr		31.00		3.20		0.00		0.00		2.10		5.20		0.27		0.08	
Excess SEM Lead	mg/kg		6,423		663		0		0		435		1,077		56		16	
Excess SEM Pb-OC	umole/gr OC		456		NA		0		NA		500		NA		51		10	
Excess SEM Pb-OC	mg/kg OC		94,459		NA		0		NA		103,600		NA		10,555		2,052	
AVS-bound SEM Pb	mg/kg		0.0		0.0		19.4		419.5		0.0		0.0		0.0		10.9	
Calculated Kansas chronic aquatic life WQC, Pb (Location Specific)	ug/L		16.1		16.1		16.1		16.1		16.1		16.1		16.1		16.1	
Bioavailability Based on Literature Values																		
(A) Allowable Pb Sorbed to OC in Sediment	mg/kg		4383.459		0.000		1224.790		0.000		270.743		0.000		341.652		502.809	
(B) Allowable Pb in Water	mg/kg		0.026		NA		0.004		NA		0.008		NA		0.003		0.005	
(A+B) Total Allowable Excess Pb	mg/kg		4383.486		NA		1224.794		NA		270.751		NA		341.655		502.814	
Total Allowable lead (published $K_{d,OC,Pb}$)	**mg/kg**		**4,383.49**		**0.00**		**1,244.14**		**419.52**		**270.75**		**0.00**		**341.65**		**513.74**	
Total SEM lead > Allowable lead? (published $K_{d,OC,Pb}$)			**YES**		**YES**		**NO**		**NO**		**YES**		**YES**		**NO**		**NO**	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Pb}$ (Calc'd)	L/kg-OC		196765		NA		ND		NA		6094006		NA		NA		NA	
Partition Coefficient, $K_{d,dry\ sed,Pb}$ (Calc'd)	L/kg dry sed		13380		NA		ND		NA		25595		NA		NA		NA	
AVS-bound SEM Pb	mg/kg		0.0		0.0		19.4		419.5		0.0		0.0		0.0		10.9	
(A) Allowable Pb Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		470.677		470.677		470.677		470.677		470.677		470.677		470.677		470.677	
(B) Allowable Pb in Water	mg/kg		0.026		0.009		0.004		0.009		0.008		0.002		0.003		0.005	
(A+B) Total Allowable Excess Pb (empirical Kd for dry sed)	mg/kg		470.704		470.687		470.681		470.687		470.685		470.679		470.680		470.683	
Total Allowable lead (empirical Kd for dry sed)	**mg/kg**		**470.7**		**470.7**		**490.0**		**890.2**		**470.7**		**470.7**		**470.7**		**481.6**	
Total SEM Lead > Allowable lead (empirical Kd for dry sed)?			**YES**		**YES**		**NO**		**NO**		**NO**		**YES**		**NO**		**NO**	
Total SEM Lead:Total Allowable Lead (empirical Kd for dry sed)			13.60		1.38		0.03		0.02		0.93		2.34		0.12		0.05	
Total Recoverable Pb ≥ SEM Pb?			YES		YES		YES		YES		YES		YES		YES		YES	
SEM Pb / Total Recoverable Pb			0.492		0.130		0.005		0.006		0.102		0.786		0.167		0.137	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-3
Bioavailability Calculations for Lead

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Pb}$	L/kg-OC	4000000
Site background concentration, Pb	mg/kg dw	96.7
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Pb (Average site hardness)	ug/L	16.1
McDonald et al. consensus-based threshold effect concentration (TEC), Pb	mg/kg dw	35.8
McDonald et al. consensus-based probable effect concentration (PEC), Pb	mg/kg dw	128
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Pb	mg/kg dw	400
Molecular weight, Pb	ug/umol	207.2
Average Empirical Partition Coef, $K_{d,OC,Pb}$	L/kg-OC	6,017,993
Geometric Mean Empirical Partition Coef $K_{d,OC,Pb}$	L/kg-OC	3,927,449
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Pb}$	L/kg dry sed	29,206

Transect/Pond ID			**Transect 12**		**Transect 14**		**Transect 16**		**Transect 17**		**Transect 18**		**Transect 19**		**Transect 21**		**Transect 24**	
Sample Date			**12/9/2011**		**12/9/2011**		**6/13/2012**		**6/13/2012**		**6/6/2012**		**6/20/2012**		**6/20/2012**		**6/13/2012**	
Transect			**12**		**14**		**16**		**17**		**18**		**19**		**21**		**24**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	3.7		5.7		9.9		7.9		6		10		7.2		13	
SEM Lead	mg/kg	SW6010	20	B	36	B	61	B	31	B	17	B	51	B	53	B	160	B
SEM Cadmium	mg/kg	SW6010	0.49		1.9		3.9		0.57		0.69		3.1		4		4.5	
SEM Zinc	mg/kg	SW6010	56	B	250	B	490	B	80	B	110	B	300	B	310	B	520	B
SEM Nickel	mg/kg	SW6010	3.7	B	5.5	B	3.8	B	7.9	B	5.8	B	4.9	B	6.8	B	17	B
SEM Arsenic	mg/kg	SW6010	0.76	B	0.8	B	1.7	B	2.2	B	1.7	B	2.3	B	2.3	B	4.2	B
SEM Copper	umole/gr	SW6010	0.058		0.089		0.16		0.12		0.094		0.16		0.11		0.21	
SEM Lead	umole/gr	SW6010	0.098	B	0.17	B	0.29	B	0.15	B	0.082	B	0.24	B	0.25	B	0.8	B
SEM Cadmium	umole/gr	SW6010	0.0044		0.017		0.035		0.0051		0.0062		0.028		0.035		0.04	
SEM Zinc	umole/gr	SW6010	0.85	B	3.8	B	7.4	B	1.2	B	1.7	B	4.6	B	4.8	B	8	B
SEM Nickel	umole/gr	SW6010	0.062	B	0.093	B	0.064	B	0.13	B	0.098	B	0.083	B	0.12	B	0.28	B
SEM Arsenic	umole/gr	SW6010	0.01	B	0.011	B	0.022	B	0.029	B	0.023	B	0.031	B	0.031	B	0.056	B
SEM/AVS Ratio	none	SEM	NA		NA		1.7		6.1		NA		10		30		1.9	
Lab AVS	umole/gr	SW9034	0.56	U	0.6	U	4.7		0.28	J	0.7	U	0.51	J	0.18	J	4.9	
Porewater Pb (Total)	ug/L	SW6020	NA		NA		29		3		5		6.9	B	4.2	B	72	
Porewater Pb (Dissolved)	ug/L	SW6020	NA		NA		1.9		0.34	J	0.37	J	1.1	B	0.99	JB	9.2	
Total Recoverable Pb	mg/kg dw	SW6020	260		250	B	87		150	B	50	B	160		120	B	210	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	16		21		36		38		33		35		32		39	
Sulfide	mg/kg	SW9034	3.6	U	3.8	U	150		8.8	J	4.5	U	16	J	5.8	J	160	
Total Organic Carbon	mg/kg	LLOYD KAHN	4000		7400		10000	H	4500	H	3800	H	15000	H	7100	H	14000	H
Calculations																		
ΣSEM	umole/gr		1.07		4.17		7.95		1.61		1.98		5.11		5.32		9.33	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		0.00		0.00		4.68		0.26		0.00		0.51		0.18		4.91	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		0.11		0.12		4.68		0.27		0.14		0.50		0.18		4.99	
SEM-AVS	umole/gr		0.96		4.05		3.27		1.33		1.84		4.61		5.13		4.34	
f_{OC}			0.0040		0.0074		0.0100		0.0045		0.0038		0.0150		0.0071		0.0140	
Excess Total Metals-OC	umole/gr OC		240.03		547.36		327.10		295.70		484.17		307.47		723.12		310.01	
AVS-Σ Cu	umole/gr		0.05		0.03		4.52		0.15		0.05		0.34		0.07		4.78	
Excess SEM Lead	umole/gr		0.04		0.14		0.00		0.00		0.04		0.00		0.18		0.00	
Excess SEM Lead	mg/kg		9		29		0		0		7		0		37		0	
Excess SEM Pb-OC	umole/gr OC		11		19		0		0		9		0		25		0	
Excess SEM Pb-OC	mg/kg OC		2,265		3,934		0		0		1,944		0		5,227		0	
AVS-bound SEM Pb	mg/kg		11.2		6.1		936.1		32.0		9.6		70.2		14.7		990.4	
Calculated Kansas chronic aquatic life WQC, Pb (Location Specific)	ug/L		16.1		16.1		16.1		16.1		16.1		16.1		16.1		16.1	
Bioavailability Based on Literature Values																		
(A) Allowable Pb Sorbed to OC in Sediment	mg/kg		257.851		477.024		644.626		290.082		244.958		966.940		457.685		902.477	
(B) Allowable Pb in Water	mg/kg		0.003		0.004		0.009		0.010		0.008		0.009		0.008		0.010	
(A+B) Total Allowable Excess Pb	mg/kg		257.854		477.028		644.635		290.092		244.966		966.948		457.692		902.487	
Total Allowable lead (published $K_{d,OC,Pb}$)	**mg/kg**		**269.10**		**483.14**		**1,580.76**		**322.09**		**254.57**		**1,037.19**		**472.38**		**1,892.88**	
Total SEM lead > Allowable lead? (published $K_{d,OC,Pb}$)			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Pb}$ (Calc'd)	L/kg-OC		NA		NA		ND		ND		5255038		ND		5279935		ND	
Partition Coefficient, $K_{d,dry\ sed,Pb}$ (Calc'd)	L/kg dry sed		NA		NA		ND		ND		19969		ND		37488		ND	
AVS-bound SEM Pb	mg/kg		11.2		6.1		936.1		32.0		9.6		70.2		14.7		990.4	
(A) Allowable Pb Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		470.677		470.677		470.677		470.677		470.677		470.677		470.677		470.677	
(B) Allowable Pb in Water	mg/kg		0.003		0.004		0.009		0.010		0.008		0.009		0.008		0.010	
(A+B) Total Allowable Excess Pb (empirical Kd for dry sed)	mg/kg		470.680		470.682		470.686		470.687		470.685		470.686		470.685		470.688	
Total Allowable lead (empirical Kd for dry sed)	**mg/kg**		**481.9**		**476.8**		**1,406.8**		**502.7**		**480.3**		**540.9**		**485.4**		**1,461.1**	
Total SEM Lead > Allowable lead (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Lead:Total Allowable Lead (empirical Kd for dry sed)			0.04		0.08		0.04		0.06		0.04		0.09		0.11		0.11	
Total Recoverable Pb ≥ SEM Pb?			YES		YES		YES		YES		YES		YES		YES		YES	
SEM Pb / Total Recoverable Pb			0.077		0.144		0.701		0.207		0.340		0.319		0.442		0.762	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-3
Bioavailability Calculations for Lead

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Pb}$	L/kg-OC	4000000
Site background concentration, Pb	mg/kg dw	96.7
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Pb (Average site hardness)	ug/L	16.1
McDonald et al. consensus-based threshold effect concentration (TEC), Pb	mg/kg dw	35.8
McDonald et al. consensus-based probable effect concentration (PEC), Pb	mg/kg dw	128
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Pb	mg/kg dw	400
Molecular weight, Pb	ug/umol	207.2
Average Empirical Partition Coef, $K_{d,OC,Pb}$	L/kg-OC	6,017,993
Geometric Mean Empirical Partition Coef $K_{d,OC,Pb}$	L/kg-OC	3,927,449
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Pb}$	L/kg dry sed	29,206

Transect/Pond ID			**Transect 25**		**Transect 25+25**		**Transect 25+50**		**Transect 25+75**		**Transect 25+100**		**Transect 26**		**Transect 27**		**Off-Property Pond 1-1**	
Sample Date			**6/13/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**		**11/14/2012**		**11/14/2012**		**12/5/2011**	
Transect			**25**		**25**	**+25**	**25**	**+50**	**25**	**+75**	**25**	**+100**	**26**	**CENTER**	**27**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	12		7.2	B	9.4	B	7	B	8.4	B	6.9	B	5.9	B	2.5	
SEM Lead	mg/kg	SW6010	67	B	28	B	54	B	22	B	36	B	20	B	36	B	200	B
SEM Cadmium	mg/kg	SW6010	2.4		2.6	B	2.7	B	1.4	B	2	B	1.5	B	2.2	B	4.6	
SEM Zinc	mg/kg	SW6010	360	B	340	B	410	B	170	B	260	B	160	B	230	B	700	B
SEM Nickel	mg/kg	SW6010	11	B	7.7	B	8	B	7	B	7.3	B	7	B	8.1	B	5	B
SEM Arsenic	mg/kg	SW6010	2.9	B	0.57		0.71		0.5		0.93		0.51		0.64		1.3	
SEM Copper	umole/gr	SW6010	0.18		0.11	B	0.15	B	0.11	B	0.13	B	0.11	B	0.093	B	0.039	
SEM Lead	umole/gr	SW6010	0.32	B	0.14	B	0.26	B	0.11	B	0.17	B	0.099	B	0.18	B	0.97	B
SEM Cadmium	umole/gr	SW6010	0.022		0.024	B	0.024	B	0.012	B	0.018	B	0.013	B	0.02	B	0.041	
SEM Zinc	umole/gr	SW6010	5.6	B	5.1	B	6.3	B	2.6	B	4	B	2.5	B	3.5	B	11	B
SEM Nickel	umole/gr	SW6010	0.18	B	0.13	B	0.14	B	0.12	B	0.13	B	0.12	B	0.14	B	0.085	B
SEM Arsenic	umole/gr	SW6010	0.038	B	0.0075		0.0095		0.0067		0.012		0.0068		0.0086		0.018	
SEM/AVS Ratio	none	SEM	1.5		1.9		2.2		1.7		2.5		2.4		5.2		0.55	
Lab AVS	umole/gr	SW9034	4.3		2.9	B	3.2	B	1.7	B	1.8	B	1.2	B	0.75	B	21	
Porewater Pb (Total)	ug/L	SW6020	12		15	B	76	B	43	B	20	B	6.8	B	42	B	71	
Porewater Pb (Dissolved)	ug/L	SW6020	0.15	J	0.11	JB	0.66	JB	0.24	JB	0.077	JB	0.038	JB	2.7	B	0.43	J
Total Recoverable Pb	mg/kg dw	SW6020	150		26	B	43	B	20	B	24	B	36	B	26	B	210	^
Hardness (as CaCO3)	mg/l	SM2340C	NA		380		300		340		380		510		260		NA	
%Moist	%	NA	42		45		40		35		36		40		35		53	
Sulfide	mg/kg	SW9034	140		94	B	100	B	54	B	56	B	37	B	24	B	690	
Total Organic Carbon	mg/kg	LLOYD KAHN	9500	H	19000		15000		12000		15000		13000		11000		19000	
Calculations																		
ΣSEM	umole/gr		6.30		5.50		6.87		2.95		4.45		2.84		3.93		12.14	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		4.20		2.90		3.12		1.74		1.78		1.18		0.76		22.06	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		4.37		2.93		3.12		1.68		1.75		1.15		0.75		21.52	
SEM-AVS	umole/gr		1.94		2.57		3.76		1.27		2.70		1.69		3.18		-9.38	
f_{OC}			0.0095		0.0190		0.0150		0.0120		0.0150		0.0130		0.0110		0.0190	
Excess Total Metals-OC	umole/gr OC		203.78		135.39		250.36		105.66		180.10		129.85		289.50		-493.88	
AVS-Σ Cu	umole/gr		4.19		2.82		2.97		1.57		1.62		1.04		0.66		21.48	
Excess SEM Lead	umole/gr		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Excess SEM Lead	mg/kg		0		0		0		0		0		0		0		0	
Excess SEM Pb-OC	umole/gr OC		0		0		0		0		0		0		0		0	
Excess SEM Pb-OC	mg/kg OC		0		0		0		0		0		0		0		0	
AVS-bound SEM Pb	mg/kg		867.4		584.6		615.1		326.1		334.9		216.3		135.8		4450.6	
Calculated Kansas chronic aquatic life WQC, Pb (Location Specific)	ug/L		16.1		17.2		12.7		14.9		17.2		25.0		10.6		16.1	
Bioavailability Based on Literature Values																		
(A) Allowable Pb Sorbed to OC in Sediment	mg/kg		612.395		1304.366		762.163		715.048		1029.763		1297.961		465.838		1224.790	
(B) Allowable Pb in Water	mg/kg		0.012		0.014		0.008		0.008		0.010		0.017		0.006		0.018	
(A+B) Total Allowable Excess Pb	mg/kg		612.407		1304.380		762.172		715.056		1029.772		1297.977		465.844		1224.808	
Total Allowable lead (published $K_{d,OC,Pb}$)	**mg/kg**		**1,479.77**		**1,889.00**		**1,377.28**		**1,041.21**		**1,364.70**		**1,514.27**		**601.66**		**5,675.42**	
Total SEM lead > Allowable lead? (published $K_{d,OC,Pb}$)			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Pb}$ (Calc'd)	L/kg-OC		ND		ND		ND		ND		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Pb}$ (Calc'd)	L/kg dry sed		ND		ND		ND		ND		ND		ND		ND		ND	
AVS-bound SEM Pb	mg/kg		867.4		584.6		615.1		326.1		334.9		216.3		135.8		4450.6	
(A) Allowable Pb Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		470.677		501.258		370.998		435.080		501.258		729.010		309.213		470.677	
(B) Allowable Pb in Water	mg/kg		0.012		0.014		0.008		0.008		0.010		0.017		0.006		0.018	
(A+B) Total Allowable Excess Pb (empirical Kd for dry sed)	mg/kg		470.689		501.272		371.007		435.088		501.267		729.026		309.219		470.695	
Total Allowable lead (empirical Kd for dry sed)	**mg/kg**		**1,338.1**		**1,085.9**		**986.1**		**761.2**		**836.2**		**945.3**		**445.0**		**4,921.3**	
Total SEM Lead > Allowable lead (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Lead:Total Allowable Lead (empirical Kd for dry sed)			0.05		0.03		0.05		0.03		0.04		0.02		0.08		0.04	
Total Recoverable Pb ≥ SEM Pb?			YES	NA	NO	NA	NO	NA	NO	NA	NO	NA	YES	NA	NO	NA	YES	
SEM Pb / Total Recoverable Pb			0.447	NA	1.077	NA	1.256	NA	1.100	NA	1.500	NA	0.556	NA	1.385	NA	0.952	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-3
Bioavailability Calculations for Lead

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Pb}$	L/kg-OC	4000000
Site background concentration, Pb	mg/kg dw	96.7
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Pb (Average site hardness)	ug/L	16.1
McDonald et al. consensus-based threshold effect concentration (TEC), Pb	mg/kg dw	35.8
McDonald et al. consensus-based probable effect concentration (PEC), Pb	mg/kg dw	128
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Pb	mg/kg dw	400
Molecular weight, Pb	ug/umol	207.2
Average Empirical Partition Coef, $K_{d,OC,Pb}$	L/kg-OC	6,017,993
Geometric Mean Empirical Partition Coef $K_{d,OC,Pb}$	L/kg-OC	3,927,449
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Pb}$	L/kg dry sed	29,206

Transect/Pond ID			**Off-Property Pond 1-2**		**Off-Property Pond 1-3**		**Off-Property Pond 1-4**		**Off-Property Pond 3-1**		**Off-Property Pond 3-2**		**Off-Property Pond 3-3**		**Off-Property Pond 3-4**		**Off-Property Pond 4-1**	
Sample Date			**12/5/2011**		**12/5/2011**		**12/5/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**	
Transect			**P**		**P**		**P**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	3		25		0.26	J	6.9		8.4		13		11	B	4	B
SEM Lead	mg/kg	SW6010	65	B	260	B	120	B	56	B	69	B	120	B	71	B	16	B
SEM Cadmium	mg/kg	SW6010	1.4		3.9		3.3		1		1.1		2.2		0.77		0.086	J
SEM Zinc	mg/kg	SW6010	210	B	800	B	530	B	190	B	210	B	420	B	180	B	22	B
SEM Nickel	mg/kg	SW6010	4.7	B	7.3	B	4	B	6	B	4	B	4.9	B	12	B	7.1	B
SEM Arsenic	mg/kg	SW6010	0.85		2.4		0.6		0.78	B	1.1	B	1	B	1.9	B	1.4	B
SEM Copper	umole/gr	SW6010	0.046		0.39		0.004	J	0.11		0.13		0.2		0.18	B	0.063	B
SEM Lead	umole/gr	SW6010	0.31	B	1.2	B	0.6	B	0.27	B	0.33	B	0.58	B	0.34	B	0.075	B
SEM Cadmium	umole/gr	SW6010	0.012		0.035		0.029		0.0091		0.01		0.019		0.0068		0.00077	J
SEM Zinc	umole/gr	SW6010	3.2	B	12	B	8.1	B	2.9	B	3.2	B	6.4	B	2.8	B	0.33	B
SEM Nickel	umole/gr	SW6010	0.08	B	0.12	B	0.068	B	0.1	B	0.069	B	0.083	B	0.21	B	0.12	B
SEM Arsenic	umole/gr	SW6010	0.011		0.032		0.0079		0.01	B	0.014	B	0.014	B	0.025	B	0.018	B
SEM/AVS Ratio	none	SEM	0.19		0.35		0.71		1.3		1.9		3.9		2.9		NA	
Lab AVS	umole/gr	SW9034	19		40		12		2.6		2		1.9		1.2		0.54	U
Porewater Pb (Total)	ug/L	SW6020	71		71		71		130		130		130		130		15	
Porewater Pb (Dissolved)	ug/L	SW6020	0.43	J	0.43	J	0.43	J	6.8		6.8		6.8		6.8		0.25	J
Total Recoverable Pb	mg/kg dw	SW6020	160	^	250	^	180	^	170	^	66	B	180	B	91	B	53	B
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	34		64		39		42		40		48		44		12	
Sulfide	mg/kg	SW9034	600		1300		400		83		64		60		39		3.5	U
Total Organic Carbon	mg/kg	LLOYD KAHN	15000		17000		13000		7400		5400		11000		4400		2900	
Calculations																		
ΣSEM	umole/gr		3.65		13.75		8.80		3.39		3.74		7.28		3.54		0.59	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		19.20		39.27		12.40		2.61		1.97		1.87		1.22		0.00	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		18.71		40.54		12.47		2.59		2.00		1.87		1.22		0.11	
SEM-AVS	umole/gr		-15.06		-26.80		-3.67		0.80		1.74		5.41		2.32		0.48	
f_{OC}			0.0150		0.0170		0.0130		0.0074		0.0054		0.0110		0.0044		0.0029	
Excess Total Metals-OC	umole/gr OC		-1,004.27		-1,576.33		-282.59		108.19		322.79		491.89		527.39		165.39	
AVS-Σ Cu	umole/gr		18.67		40.15		12.47		2.48		1.87		1.67		1.04		0.05	
Excess SEM Lead	umole/gr		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.03	
Excess SEM Lead	mg/kg		0		0		0		0		0		0		0		6	
Excess SEM Pb-OC	umole/gr OC		0		0		0		0		0		0		0		10	
Excess SEM Pb-OC	mg/kg OC		0		0		0		0		0		0		0		2,061	
AVS-bound SEM Pb	mg/kg		3867.6		8319.6		2583.9		513.5		386.6		346.3		214.7		9.6	
Calculated Kansas chronic aquatic life WQC, Pb (Location Specific)	ug/L		16.1		16.1		16.1		16.1		16.1		16.1		16.1		16.1	
Bioavailability Based on Literature Values																		
(A) Allowable Pb Sorbed to OC in Sediment	mg/kg		966.940		1095.865		838.014		477.024		348.098		709.089		283.636		186.942	
(B) Allowable Pb in Water	mg/kg		0.008		0.029		0.010		0.012		0.011		0.015		0.013		0.002	
(A+B) Total Allowable Excess Pb	mg/kg		966.948		1095.893		838.025		477.035		348.109		709.104		283.648		186.944	
Total Allowable lead (published $K_{d,OC,Pb}$)	**mg/kg**		**4,834.54**		**9,415.52**		**3,421.95**		**990.58**		**734.73**		**1,055.38**		**498.37**		**196.51**	
Total SEM lead > Allowable lead? (published $K_{d,OC,Pb}$)			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Pb}$ (Calc'd)	L/kg-OC		ND		ND		ND		ND		ND		ND		ND		8244146	
Partition Coefficient, $K_{d,dry\ sed,Pb}$ (Calc'd)	L/kg dry sed		ND		ND		ND		ND		ND		ND		ND		23908	
AVS-bound SEM Pb	mg/kg		3867.6		8319.6		2583.9		513.5		386.6		346.3		214.7		9.6	
(A) Allowable Pb Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		470.677		470.677		470.677		470.677		470.677		470.677		470.677		470.677	
(B) Allowable Pb in Water	mg/kg		0.008		0.029		0.010		0.012		0.011		0.015		0.013		0.002	
(A+B) Total Allowable Excess Pb (empirical Kd for dry sed)	mg/kg		470.686		470.706		470.688		470.689		470.688		470.692		470.690		470.679	
Total Allowable lead (empirical Kd for dry sed)	**mg/kg**		**4,338.3**		**8,790.3**		**3,054.6**		**984.2**		**857.3**		**817.0**		**685.4**		**480.2**	
Total SEM Lead > Allowable lead (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Lead:Total Allowable Lead (empirical Kd for dry sed)			0.01		0.03		0.04		0.06		0.08		0.15		0.10		0.03	
Total Recoverable Pb ≥ SEM Pb?			YES		NO		YES		YES		NO		YES		YES		YES	
SEM Pb / Total Recoverable Pb			0.406		1.040		0.667		0.329		1.045		0.667		0.780		0.302	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-3
Bioavailability Calculations for Lead

Sediment Bioavailability Assessment
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Altoona, KS

Published partition coefficient, $K_{d,OC,Pb}$	L/kg-OC	4000000
Site background concentration, Pb	mg/kg dw	96.7
Site hardness (as CaCO3)	mg/l	361.7
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KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Pb	mg/kg dw	400
Molecular weight, Pb	ug/umol	207.2
Average Empirical Partition Coef, $K_{d,OC,Pb}$	L/kg-OC	6,017,993
Geometric Mean Empirical Partition Coef $K_{d,OC,Pb}$	L/kg-OC	3,927,449
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Pb}$	L/kg dry sed	29,206

Transect/Pond ID			**Off-Property Pond 4-2**		**Northeast Pond-1**		**Northeast Pond-2**		**Northeast Pond-3**		**Northeast Pond-4**		**North Pond-1**		**North Pond-2**		**North Pond-3**	
Sample Date			**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	5.7	B	5.8	B	5.7	B	2	B	8.1	B	21		27		28	
SEM Lead	mg/kg	SW6010	29	B	31	B	26	B	22	B	49	B	140		220		240	
SEM Cadmium	mg/kg	SW6010	0.24		0.43		0.25		0.36		0.61		9.6		23		9.2	
SEM Zinc	mg/kg	SW6010	46	B	74	B	51	B	60	B	110	B	850		1300		830	
SEM Nickel	mg/kg	SW6010	8.8	B	3.3	B	3.1	B	2.8	B	6.3	B	1.9	J	2	J	1.5	J
SEM Arsenic	mg/kg	SW6010	1.7	B	1.5	B	1.7	B	1.3	B	2.5	B	NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.09	B	0.092	B	0.09	B	0.032	B	0.13	B	0.32		0.42		0.45	
SEM Lead	umole/gr	SW6010	0.14	B	0.15	B	0.13	B	0.11	B	0.24	B	0.67		1.1		1.2	
SEM Cadmium	umole/gr	SW6010	0.0021		0.0038		0.0022		0.0032		0.0054		0.085		0.21		0.082	
SEM Zinc	umole/gr	SW6010	0.7	B	1.1	B	0.78	B	0.92	B	1.7	B	13		20		13	
SEM Nickel	umole/gr	SW6010	0.15	B	0.057	B	0.053	B	0.048	B	0.11	B	0.033	J	0.035	J	0.026	J
SEM Arsenic	umole/gr	SW6010	0.022	B	0.02	B	0.023	B	0.017	B	0.034	B	NA		NA		NA	
SEM/AVS Ratio	none	SEM	NA		1.9		NA		0.16		2		1.5		13		13	
Lab AVS	umole/gr	SW9034	0.63	U	0.76	J	0.91	U	7		1.1	J	NA		NA		NA	
Porewater Pb (Total)	ug/L	SW6020	15		22		22		22		22		590		590		590	
Porewater Pb (Dissolved)	ug/L	SW6020	0.25	J	0.22	J	0.22	J	0.22	J	0.22	J	570	B	570	B	570	B
Total Recoverable Pb	mg/kg dw	SW6020	58	B	41	B	37	B	41	B	47	B	13	B	830	B	1100	B
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	25		42		49		40		60		48		48		46	
Sulfide	mg/kg	SW9034	4	U	24	J	5.9	U	220		35	J	930		120		82	
Total Organic Carbon	mg/kg	LLOYD KAHN	6700		10000		8400		13000		15000		54000		87000		100000	
Calculations																		
ΣSEM	umole/gr		1.08		1.40		1.06		1.11		2.19		14.11		21.77		14.76	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		0.00		0.74		0.00		6.96		1.09		9.41		1.67		1.14	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		0.12		0.75		0.18		6.86		1.09		29.00		3.74		2.56	
SEM-AVS	umole/gr		0.96		0.65		0.87		-5.75		1.09		-14.90		18.02		12.20	
f_{OC}			0.0067		0.0100		0.0084		0.0130		0.0150		0.0540		0.0870		0.1000	
Excess Total Metals-OC	umole/gr OC		142.89		65.43		103.71		-442.14		72.92		-275.84		207.16		122.01	
AVS-Σ Cu	umole/gr		0.03		0.66		0.09		6.83		0.96		28.68		3.32		2.11	
Excess SEM Lead	umole/gr		0.11		0.00		0.04		0.00		0.00		0.00		0.00		0.00	
Excess SEM Lead	mg/kg		22		0		7		0		0		0		0		0	
Excess SEM Pb-OC	umole/gr OC		16		0		4		0		0		0		0		0	
Excess SEM Pb-OC	mg/kg OC		3,255		0		888		0		0		0		0		0	
AVS-bound SEM Pb	mg/kg		7.2		136.0		19.5		1415.0		199.2		5943.2		688.4		436.6	
Calculated Kansas chronic aquatic life WQC, Pb (Location Specific)	ug/L		16.1		16.1		16.1		16.1		16.1		16.1		16.1		16.1	
Bioavailability Based on Literature Values																		
(A) Allowable Pb Sorbed to OC in Sediment	mg/kg		431.900		644.626		541.486		838.014		966.940		3480.982		5608.249		6446.264	
(B) Allowable Pb in Water	mg/kg		0.005		0.012		0.015		0.011		0.024		0.015		0.015		0.014	
(A+B) Total Allowable Excess Pb	mg/kg		431.905		644.638		541.502		838.025		966.964		3480.997		5608.264		6446.277	
Total Allowable lead (published $K_{d,OC,Pb}$)	**mg/kg**		**439.10**		**780.66**		**560.98**		**2,253.01**		**1,166.19**		**9,424.24**		**6,296.67**		**6,882.91**	
Total SEM lead > Allowable lead? (published $K_{d,OC,Pb}$)			NO		NO		NO		NO		NO		NO		NO		NO	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Pb}$ (Calc'd)	L/kg-OC		13019952		ND		4036109		ND		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Pb}$ (Calc'd)	L/kg dry sed		87234		ND		33903		ND		ND		ND		ND		ND	
AVS-bound SEM Pb	mg/kg		7.2		136.0		19.5		1415.0		199.2		5943.2		688.4		436.6	
(A) Allowable Pb Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		470.677		470.677		470.677		470.677		470.677		470.677		470.677		470.677	
(B) Allowable Pb in Water	mg/kg		0.005		0.012		0.015		0.011		0.024		0.015		0.015		0.014	
(A+B) Total Allowable Excess Pb (empirical Kd for dry sed)	mg/kg		470.683		470.689		470.693		470.688		470.701		470.692		470.692		470.691	
Total Allowable lead (empirical Kd for dry sed)	**mg/kg**		**477.9**		**606.7**		**490.2**		**1,885.7**		**669.9**		**6,413.9**		**1,159.1**		**907.3**	
Total SEM Lead > Allowable lead (empirical Kd for dry sed)?			NO		NO		NO		NO		NO		NO		NO		NO	
Total SEM Lead:Total Allowable Lead (empirical Kd for dry sed)			0.06		0.05		0.05		0.01		0.07		0.02		0.19		0.26	
Total Recoverable Pb ≥ SEM Pb?			YES	NA	YES		YES		YES		NO		NO		YES		YES	
SEM Pb / Total Recoverable Pb			0.500	NA	0.756		0.703		0.537		1.043		10.769		0.265		0.218	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-3
Bioavailability Calculations for Lead

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Pb}$	L/kg-OC	4000000
Site background concentration, Pb	mg/kg dw	96.7
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Pb (Average site hardness)	ug/L	16.1
McDonald et al. consensus-based threshold effect concentration (TEC), Pb	mg/kg dw	35.8
McDonald et al. consensus-based probable effect concentration (PEC), Pb	mg/kg dw	128
KS Department of Health and Environment risk-based standards for Kansas (KDHE RBSK), Pb	mg/kg dw	400
Molecular weight, Pb	ug/umol	207.2
Average Empirical Partition Coef, $K_{d,OC,Pb}$	L/kg-OC	6,017,993
Geometric Mean Empirical Partition Coef $K_{d,OC,Pb}$	L/kg-OC	3,927,449
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Pb}$	L/kg dry sed	29,206

Transect/Pond ID			**North Pond-4**		**South Pond-1**		**South Pond-2**		**South Pond-3**		**South Pond-4**	
Sample Date			**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	23		1.5	U	0.89	U	1.2	U	0.86	U
SEM Lead	mg/kg	SW6010	160		120		78		58		63	
SEM Cadmium	mg/kg	SW6010	9.2		11		7.5		5.6		4.9	
SEM Zinc	mg/kg	SW6010	1100		1600		1100		890		720	
SEM Nickel	mg/kg	SW6010	1.8	J	1.4	J	0.55	U	3.1	J	2.3	J
SEM Arsenic	mg/kg	SW6010	NA		NA		NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.37		0.023	U	0.014	U	0.019	U	0.014	U
SEM Lead	umole/gr	SW6010	0.76		0.59		0.38		0.28		0.3	
SEM Cadmium	umole/gr	SW6010	0.082		0.096		0.066		0.05		0.044	
SEM Zinc	umole/gr	SW6010	17		25		17		14		11	
SEM Nickel	umole/gr	SW6010	0.031	J	0.024	J	0.0094	U	0.053	J	0.039	J
SEM Arsenic	umole/gr	SW6010	NA		NA		NA		NA		NA	
SEM/AVS Ratio	none	SEM	11		1.9		2		1.9		2.3	
Lab AVS	umole/gr	SW9034	NA		NA		NA		NA		NA	
Porewater Pb (Total)	ug/L	SW6020	590		210		210		210		210	
Porewater Pb (Dissolved)	ug/L	SW6020	570	B	2.5		2.5		2.5		2.5	
Total Recoverable Pb	mg/kg dw	SW6020	520	B	290	B	250	B	74	B	170	B
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	67		65		45		59		42	
Sulfide	mg/kg	SW9034	150		1500		920		1200		890	
Total Organic Carbon	mg/kg	LLOYD KAHN	53000		30000		26000		11000		17000	
Calculations												
ΣSEM	umole/gr		18.24		25.73		17.47		14.40		11.40	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.66		13.54		8.73		7.58		4.96	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		4.68		46.78		28.69		37.42		27.76	
SEM-AVS	umole/gr		13.57		-21.05		-11.22		-23.02		-16.36	
f_{OC}			0.0530		0.0300		0.0260		0.0110		0.0170	
Excess Total Metals-OC	umole/gr OC		255.94		-701.57		-431.63		-2,092.91		-962.30	
AVS-Σ Cu	umole/gr		4.31		46.76		28.68		37.40		27.74	
Excess SEM Lead	umole/gr		0.00		0.00		0.00		0.00		0.00	
Excess SEM Lead	mg/kg		0		0		0		0		0	
Excess SEM Pb-OC	umole/gr OC		0		0		0		0		0	
Excess SEM Pb-OC	mg/kg OC		0		0		0		0		0	
AVS-bound SEM Pb	mg/kg		892.6		9688.0		5942.0		7750.3		5748.2	
Calculated Kansas chronic aquatic life WQC, Pb (Location Specific)	ug/L		16.1		16.1		16.1		16.1		16.1	
Bioavailability Based on Literature Values												
(A) Allowable Pb Sorbed to OC in Sediment	mg/kg		3416.520		1933.879		1676.029		709.089		1095.865	
(B) Allowable Pb in Water	mg/kg		0.033		0.030		0.013		0.023		0.012	
(A+B) Total Allowable Excess Pb	mg/kg		3416.552		1933.909		1676.042		709.112		1095.877	
Total Allowable lead (published $K_{d,OC,Pb}$)	**mg/kg**		**4,309.17**		**11,621.95**		**7,618.07**		**8,459.42**		**6,844.04**	
Total SEM lead > Allowable lead? (published $K_{d,OC,Pb}$)			**NO**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,Pb}$ (Calc'd)	L/kg-OC		ND		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Pb}$ (Calc'd)	L/kg dry sed		ND		ND		ND		ND		ND	
AVS-bound SEM Pb	mg/kg		892.6		9688.0		5942.0		7750.3		5748.2	
(A) Allowable Pb Sorbed to dry sediment (empirical Kd for dry sed)	mg/kg		470.677		470.677		470.677		470.677		470.677	
(B) Allowable Pb in Water	mg/kg		0.033		0.030		0.013		0.023		0.012	
(A+B) Total Allowable Excess Pb (empirical Kd for dry sed)	mg/kg		470.710		470.707		470.690		470.700		470.689	
Total Allowable lead (empirical Kd for dry sed)	**mg/kg**		**1,363.3**		**10,158.8**		**6,412.7**		**8,221.0**		**6,218.9**	
Total SEM Lead > Allowable lead (empirical Kd for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Lead:Total Allowable Lead (empirical Kd for dry sed)			0.12		0.01		0.01		0.01		0.01	
Total Recoverable Pb ≥ SEM Pb?			YES		YES		YES		YES		YES	
SEM Pb / Total Recoverable Pb			0.308		0.414		0.312		0.784		0.371	

Notes:
1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-4
Bioavailability Calculations for Zinc

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Zn}$	L/kg-OC	100	*(Carbonaro et al. 2005; ET&C 24: 3007-3019)*
Site background concentration, Zn	mg/kg dw	402	
Site hardness (as CaCO3)	mg/l	361.7	
Kansas chronic aquatic life WQC, Zn (Average Site hardness)	ug/L	351	
McDonald et al. consensus-based threshold effect concentration (TEC), Zn	mg/kg dw	121	
McDonald et al. consensus-based probable effect concentration (PEC), Zn	mg/kg dw	459	
KS Department of Health and Environment risk-based standards for Kansas (KDHE RSK), Zn	mg/kg dw	23500	
Molecular weight, Zn	ug/umol	65.38	
Average Empirical Partition Coef, $K_{d,OC,Zn}$	L/kg-OC	1,391,725	
Geometric Mean Empirical Partition Coef $K_{d,OC,Zn}$	L/kg-OC	199,572	
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Zn}$	L/kg dry sed	2,416	

Transect/Pond ID			**Transect 00**		**Transect 01**		**Transect 02**		**Transect 03**		**Transect 04**		**Transect 05**		**Transect 06**		**Transect 08**	
Sample Date			**12/5/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/7/2011**		**6/13/2012**		**12/8/2011**		**12/8/2011**	
Transect			**0**		**1**		**2**		**3**		**4**		**5**		**6**		**8**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	1100		75		1.4	B	6.1		54	B	150		8.1	B	4.6	
SEM Lead	mg/kg	SW6010	6400	B	650	B	17	B	18	B	440	B	1100	B	55	B	26	B
SEM Cadmium	mg/kg	SW6010	190		29		2		1.3		20	B	10		1.4	B	0.6	
SEM Zinc	mg/kg	SW6010	20000	B	4100	B	310	B	150	B	4600	B	6100	B	180	B	60	B
SEM Nickel	mg/kg	SW6010	20	B	6.2	B	2.2	JB	7.4	B	15	B	14	B	5.6	B	5.3	B
SEM Arsenic	mg/kg	SW6010	74		7.1	B	0.035	U	2	B	1.2	B	11	B	0.82	B	0.82	B
SEM Copper	umole/gr	SW6010	17		1.2		0.022	B	0.096		0.85	B	2.3		0.13	B	0.072	
SEM Lead	umole/gr	SW6010	31	B	3.2	B	0.08	B	0.088	B	2.1	B	5.2	B	0.27	B	0.13	B
SEM Cadmium	umole/gr	SW6010	1.7		0.26		0.018		0.011		0.18	B	0.091		0.012	B	0.0054	
SEM Zinc	umole/gr	SW6010	310	B	62	B	4.8	B	2.3	B	70	B	93	B	2.7	B	0.92	B
SEM Nickel	umole/gr	SW6010	0.34	B	0.11	B	0.037	JB	0.13	B	0.26	B	0.23	B	0.095	B	0.09	B
SEM Arsenic	umole/gr	SW6010	0.99		0.094	B	0.00047	U	0.027	B	0.016	B	0.15	B	0.011	B	0.011	B
SEM/AVS Ratio	none	SEM	310		220		NA		1.2		380		210		NA		NA	
Lab AVS	umole/gr	SW9034	1.1	J	0.31	J	0.58	U	2.1		0.19	J	0.48	J	0.56	U	0.62	U
Porewater Zn (Total)	ug/L	SW6020	570000	B	15,000		29000	B	110		69000	B	3,500		NA		NA	
Porewater Zn (Dissolved)	ug/L	SW6020	680000		14,000		28000		9.4		69000		2,700		NA		NA	
Total Recoverable Zn	mg/kg dw	SW6020	75000		25000		17000		19000	B	16000		8900		1100		680	B
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	62		37		19		37		32		9		15		25	
Sulfide	mg/kg	SW9034	37	J	9.9	J	3.7	U	68		6.2	J	15	J	3.6	U	4	U
Total Organic Carbon	mg/kg	LLOYD KAHN	68000		NA		19000		NA		4200		NA		5300		7800	
Calculations																		
ΣSEM	umole/gr		360.04		66.77		4.96		2.63		73.39		100.82		3.21		1.22	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.16		0.30		0.00		2.19		0.19		0.48		0.00		0.00	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		1.15		0.31		0.12		2.12		0.19		0.47		0.11		0.12	
SEM-AVS	umole/gr		358.89		66.46		4.84		0.50		73.20		100.35		3.09		1.09	
f_{OC}			0.0680		NA		0.0190		NA		0.0042		NA		0.0053		0.0078	
Excess Total Metals-OC	umole/gr OC		5,277.74		NA		254.82		NA		17,427.77		NA		583.91		140.08	
AVS-Σ Cu,Pb, Cd	umole/gr		-48.55		-4.35		0.00		1.93		-2.94		-7.12		-0.30		-0.08	
Excess SEM Zinc	umole/gr		310.00		62.00		4.80		0.37		70.00		93.00		2.70		0.92	
Excess SEM Zinc	mg/kg		20,268		4,054		314		24		4,577		6,080		177		60	
Excess SEM Zn-OC	umole/gr OC		4,559		NA		253		NA		16,667		NA		509		118	
Excess SEM Zn-OC	mg/kg OC		298,056		NA		16,517		NA		1,089,667		NA		33,307		7,711	
AVS-bound SEM Zn	mg/kg		0.0		0.0		0.0		125.9		0.0		0.0		0.0		0.0	
Calculated Kansas chronic aquatic life WQC, Zn (Location Specific)	ug/L		351.1		351.1		351.1		351.1		351.1		351.1		351.1		351.1	
Bioavailability Based on Literature Values																		
(A) Allowable Zn Sorbed to OC in Sediment (published $K_{d,OC,Zn}$)	mg/kg		2.388		0.000		0.667		0.000		0.147		0.000		0.186		0.274	
(B) Allowable Zn in Water	mg/kg		0.573		NA		0.082		NA		0.165		NA		0.062		0.117	
(A+B) Total Allowable Excess Zn	mg/kg		2.960		NA		0.749		NA		0.313		NA		0.248		0.391	
Total Allowable Zinc (published $K_{d,OC,Zn}$)	**mg/kg**		**2.96**		**0.00**		**0.75**		**125.90**		**0.31**		**0.00**		**0.25**		**0.39**	
Total SEM Zinc > Allowable Zinc (published $K_{d,OC,Zn}$)?			YES		YES		YES		YES		YES		YES		YES		YES	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Zn}$ (Calc'd)	L/kg-OC		414		NA		578		NA		15680		NA		NA		NA	
Partition Coefficient, $K_{d,dry\ sed,Zn}$ (Calc'd)	L/kg dry sed		28		NA		11		NA		66		NA		NA		NA	
AVS-bound SEM Zn	mg/kg		0.0		0.0		0.0		125.9		0.0		0.0		0.0		0.0	
(A) Allowable Zn Sorbed to dry sediment (empirical K_d for dry sed)	mg/kg		848.245		848.245		848.245		848.245		848.245		848.245		848.245		848.245	
(B) Allowable Zn in Water	mg/kg		0.573		0.206		0.082		0.206		0.165		0.035		0.062		0.117	
(A+B) Total Allowable Excess Zn	mg/kg		848.818		848.451		848.328		848.451		848.410		848.280		848.307		848.362	
Total Allowable Zinc (empirical K_d for dry sed)	**mg/kg**		**848.8**		**848.5**		**848.3**		**974.4**		**848.4**		**848.3**		**848.3**		**848.4**	
Total SEM Zinc > Allowable Zinc (empirical K_d for dry sed)?			YES		YES		NO		NO		YES		YES		NO		NO	
Total SEM Zinc:Total Allowable Zinc (empirical K_d for dry sed)	NA		23.56		4.83		0.37		0.15		5.42		7.19		0.21		0.07	
Total Recoverable Zn ≥ SEM Zn?	NA		YES		YES		YES		YES		YES		YES		YES		YES	
SEM Zn / Total Recoverable Zn	NA		0.267		0.164		0.018		0.008	NA	0.288		0.685		0.164		0.088	NA

Notes:

1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-4
Bioavailability Calculations for Zinc

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Zn}$	L/kg-OC	100
Site background concentration, Zn	mg/kg dw	402
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Zn (Average Site hardness)	ug/L	351
McDonald et al. consensus-based threshold effect concentration (TEC), Zn	mg/kg dw	121
McDonald et al. consensus-based probable effect concentration (PEC), Zn	mg/kg dw	459
KS Department of Health and Environment risk-based standards for Kansas (KDHE RSK), Zn	mg/kg dw	23500
Molecular weight, Zn	ug/umol	65.38
Average Empirical Partition Coef, $K_{d,OC,Zn}$	L/kg-OC	1,391,725
Geometric Mean Empirical Partition Coef $K_{d,OC,Zn}$	L/kg-OC	199,572
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Zn}$	L/kg dry sed	2,416

Transect/Pond ID			**Transect 12**		**Transect 14**		**Transect 16**		**Transect 17**		**Transect 18**		**Transect 19**		**Transect 21**		**Transect 24**	
Sample Date			**12/9/2011**		**12/9/2011**		**6/13/2012**		**6/13/2012**		**6/6/2012**		**6/20/2012**		**6/20/2012**		**6/13/2012**	
Transect			**12**		**14**		**16**		**17**		**18**		**19**		**21**		**24**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	3.7		5.7		9.9		7.9		6		10		7.2		13	
SEM Lead	mg/kg	SW6010	20	B	36	B	61	B	31	B	17	B	51	B	53	B	160	B
SEM Cadmium	mg/kg	SW6010	0.49		1.9		3.9		0.57		0.69		3.1		4		4.5	
SEM Zinc	mg/kg	SW6010	56	B	250	B	490	B	80	B	110	B	300	B	310	B	520	B
SEM Nickel	mg/kg	SW6010	3.7	B	5.5	B	3.8	B	7.9	B	5.8	B	4.9	B	6.8	B	17	B
SEM Arsenic	mg/kg	SW6010	0.76	B	0.8	B	1.7	B	2.2	B	1.7	B	2.3	B	2.3	B	4.2	B
SEM Copper	umole/gr	SW6010	0.058		0.089		0.16		0.12		0.094		0.16		0.11		0.21	
SEM Lead	umole/gr	SW6010	0.098	B	0.17	B	0.29	B	0.15	B	0.082	B	0.24	B	0.25	B	0.8	B
SEM Cadmium	umole/gr	SW6010	0.0044		0.017		0.035		0.0051		0.0062		0.028		0.035		0.04	
SEM Zinc	umole/gr	SW6010	0.85	B	3.8	B	7.4	B	1.2	B	1.7	B	4.6	B	4.8	B	8	B
SEM Nickel	umole/gr	SW6010	0.062	B	0.093	B	0.064	B	0.13	B	0.098	B	0.083	B	0.12	B	0.28	B
SEM Arsenic	umole/gr	SW6010	0.01	B	0.011	B	0.022	B	0.029	B	0.023	B	0.031	B	0.031	B	0.056	B
SEM/AVS Ratio	none	SEM	NA		NA		1.7		6.1		NA		10		30		1.9	
Lab AVS	umole/gr	SW9034	0.56	U	0.6	U	4.7		0.28	J	0.7	U	0.51	J	0.18	J	4.9	
Porewater Zn (Total)	ug/L	SW6020	NA		NA		170		59		78		410		150		210	
Porewater Zn (Dissolved)	ug/L	SW6020	NA		NA		19		28		23		200	B	38	B	26	
Total Recoverable Zn	mg/kg dw	SW6020	1100		1200	B	660		820	B	550	B	1000		1100		860	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	16		21		36		38		33		35		32		39	
Sulfide	mg/kg	SW9034	3.6	U	3.8	U	150		8.8	J	4.5	U	16	J	5.8	J	160	
Total Organic Carbon	mg/kg	LLOYD KAHN	4000		7400		10000	H	4500	H	3800	H	15000	H	7100	H	14000	H
Calculations																		
ΣSEM	umole/gr		1.07		4.17		7.95		1.61		1.98		5.11		5.32		9.33	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		0.00		0.00		4.68		0.26		0.00		0.51		0.18		4.91	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		0.11		0.12		4.68		0.27		0.14		0.50		0.18		4.99	
SEM-AVS	umole/gr		0.96		4.05		3.27		1.33		1.84		4.61		5.13		4.34	
f_{OC}			0.0040		0.0074		0.0100		0.0045		0.0038		0.0150		0.0071		0.0140	
Excess Total Metals-OC	umole/gr OC		240.03		547.36		327.10		295.70		484.17		307.47		723.12		310.01	
AVS-Σ Cu,Pb, Cd	umole/gr		-0.05		-0.16		4.19		0.00		-0.04		0.07		-0.21		3.94	
Excess SEM Zinc	umole/gr		0.85		3.80		3.21		1.20		1.70		4.53		4.80		4.06	
Excess SEM Zinc	mg/kg		56		248		210		78		111		296		314		265	
Excess SEM Zn-OC	umole/gr OC		213		514		321		267		447		302		676		290	
Excess SEM Zn-OC	mg/kg OC		13,893		33,574		20,967		17,435		29,249		19,740		44,201		18,961	
AVS-bound SEM Zn	mg/kg		0.0		0.0		274.1		0.0		0.0		4.6		0.0		257.6	
Calculated Kansas chronic aquatic life WQC, Zn (Location Specific)	ug/L		351.1		351.1		351.1		351.1		351.1		351.1		351.1		351.1	
Bioavailability Based on Literature Values																		
(A) Allowable Zn Sorbed to OC in Sediment (published $K_{d,OC,Zn}$)	mg/kg		0.140		0.260		0.351		0.158		0.133		0.527		0.249		0.492	
(B) Allowable Zn in Water	mg/kg		0.067		0.093		0.198		0.215		0.173		0.189		0.165		0.224	
(A+B) Total Allowable Excess Zn	mg/kg		0.207		0.353		0.549		0.373		0.306		0.716		0.415		0.716	
Total Allowable Zinc (published $K_{d,OC,Zn}$)	**mg/kg**		**0.21**		**0.35**		**274.69**		**0.37**		**0.31**		**5.36**		**0.41**		**258.30**	
Total SEM Zinc > Allowable Zinc (published $K_{d,OC,Zn}$)?			**YES**		**YES**		**YES**		**YES**		**YES**		**YES**		**YES**		**YES**	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Zn}$ (Calc'd)	L/kg-OC		NA		NA		1103490		622530		1271564		98666		1163106		729217	
Partition Coefficient, $K_{d,dry\ sed,Zn}$ (Calc'd)	L/kg dry sed		NA		NA		11035		2801		4832		1480		8258		10209	
AVS-bound SEM Zn	mg/kg		0.0		0.0		274.1		0.0		0.0		4.6		0.0		257.6	
(A) Allowable Zn Sorbed to dry sediment (empirical K_d for dry sed)	mg/kg		848.245		848.245		848.245		848.245		848.245		848.245		848.245		848.245	
(B) Allowable Zn in Water	mg/kg		0.067		0.093		0.198		0.215		0.173		0.189		0.165		0.224	
(A+B) Total Allowable Excess Zn	mg/kg		848.312		848.339		848.443		848.460		848.418		848.434		848.410		848.470	
Total Allowable Zinc (empirical K_d for dry sed)	**mg/kg**		**848.3**		**848.3**		**1,122.6**		**848.5**		**848.4**		**853.1**		**848.4**		**1,106.1**	
Total SEM Zinc > Allowable Zinc (empirical K_d for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**NO**	
Total SEM Zinc:Total Allowable Zinc (empirical K_d for dry sed)	NA		0.07		0.29		0.44		0.09		0.13		0.35		0.37		0.47	
Total Recoverable Zn $\geq$ SEM Zn?	NA		YES		YES		YES		YES		YES		YES		YES		YES	
SEM Zn / Total Recoverable Zn	NA		0.051		0.208	NA	0.742		0.098	NA	0.200	NA	0.300		0.282		0.605	

Notes:

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2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-4
Bioavailability Calculations for Zinc

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Zn}$	L/kg-OC	100
Site background concentration, Zn	mg/kg dw	402
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Zn (Average Site hardness)	ug/L	351
McDonald et al. consensus-based threshold effect concentration (TEC), Zn	mg/kg dw	121
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KS Department of Health and Environment risk-based standards for Kansas (KDHE RSK), Zn	mg/kg dw	23500
Molecular weight, Zn	ug/umol	65.38
Average Empirical Partition Coef, $K_{d,OC,Zn}$	L/kg-OC	1,391,725
Geometric Mean Empirical Partition Coef $K_{d,OC,Zn}$	L/kg-OC	199,572
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Zn}$	L/kg dry sed	2,416

Transect/Pond ID			**Transect 25**		**Transect 25+25**		**Transect 25+50**		**Transect 25+75**		**Transect 25+100**		**Transect 26**		**Transect 27**		**Off-Property Pond 1-1**	
Sample Date			**6/13/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**		**11/15/2012**		**11/14/2012**		**11/14/2012**		**12/5/2011**	
Transect			**25**		**25**	**+25**	**25**	**+50**	**25**	**+75**	**25**	**+100**	**26**	**CENTER**	**27**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	12		7.2	B	9.4	B	7	B	8.4	B	6.9	B	5.9	B	2.5	
SEM Lead	mg/kg	SW6010	67	B	28	B	54	B	22	B	36	B	20	B	36	B	200	B
SEM Cadmium	mg/kg	SW6010	2.4		2.6	B	2.7	B	1.4	B	2	B	1.5	B	2.2	B	4.6	
SEM Zinc	mg/kg	SW6010	360	B	340	B	410	B	170	B	260	B	160	B	230	B	700	B
SEM Nickel	mg/kg	SW6010	11	B	7.7	B	8	B	7	B	7.3	B	7	B	8.1	B	5	B
SEM Arsenic	mg/kg	SW6010	2.9	B	0.57		0.71		0.5		0.93		0.51		0.64		1.3	
SEM Copper	umole/gr	SW6010	0.18		0.11	B	0.15	B	0.11	B	0.13	B	0.11	B	0.093	B	0.039	
SEM Lead	umole/gr	SW6010	0.32	B	0.14	B	0.26	B	0.11	B	0.17	B	0.099	B	0.18	B	0.97	B
SEM Cadmium	umole/gr	SW6010	0.022		0.024	B	0.024	B	0.012	B	0.018	B	0.013	B	0.02	B	0.041	
SEM Zinc	umole/gr	SW6010	5.6	B	5.1	B	6.3	B	2.6	B	4	B	2.5	B	3.5	B	11	B
SEM Nickel	umole/gr	SW6010	0.18	B	0.13	B	0.14	B	0.12	B	0.13	B	0.12	B	0.14	B	0.085	B
SEM Arsenic	umole/gr	SW6010	0.038	B	0.0075		0.0095		0.0067		0.012		0.0068		0.0086		0.018	
SEM/AVS Ratio	none	SEM	1.5		1.9		2.2		1.7		2.5		2.4		5.2		0.55	
Lab AVS	umole/gr	SW9034	4.3		2.9	B	3.2	B	1.7	B	1.8	B	1.2	B	0.75	B	21	
Porewater Zn (Total)	ug/L	SW6020	72		76	B	120	B	140	B	100	B	35	B	72	B	160	
Porewater Zn (Dissolved)	ug/L	SW6020	5.3		4	JB	3.3	JB	2.3	JB	1.6	JB	1.8	JB	7.3	B	8.8	
Total Recoverable Zn	mg/kg dw	SW6020	2000		240		290		150		180		180		180		880	
Hardness (as CaCO3)	mg/l	SM2340C	NA		380		300		340		380		510		260		NA	
%Moist	%	NA	42		45		40		35		36		40		35		53	
Sulfide	mg/kg	SW9034	140		94	B	100	B	54	B	56	B	37	B	24	B	690	
Total Organic Carbon	mg/kg	LLOYD KAHN	9500	H	19000		15000		12000		15000		13000		11000		19000	
Calculations																		
ΣSEM	umole/gr		6.30		5.50		6.87		2.95		4.45		2.84		3.93		12.14	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		4.20		2.90		3.12		1.74		1.78		1.18		0.76		22.06	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		4.37		2.93		3.12		1.68		1.75		1.15		0.75		21.52	
SEM-AVS	umole/gr		1.94		2.57		3.76		1.27		2.70		1.69		3.18		-9.38	
f_{OC}			0.0095		0.0190		0.0150		0.0120		0.0150		0.0130		0.0110		0.0190	
Excess Total Metals-OC	umole/gr OC		203.78		135.39		250.36		105.66		180.10		129.85		289.50		-493.88	
AVS-Σ Cu,Pb, Cd	umole/gr		3.84		2.66		2.68		1.45		1.43		0.93		0.46		20.47	
Excess SEM Zinc	umole/gr		1.76		2.44		3.62		1.15		2.57		1.57		3.04		0.00	
Excess SEM Zinc	mg/kg		115		160		236		75		168		103		199		0	
Excess SEM Zn-OC	umole/gr OC		185		129		241		96		171		121		277		0	
Excess SEM Zn-OC	mg/kg OC		12,084		8,405		15,758		6,254		11,209		7,886		18,096		0	
AVS-bound SEM Zn	mg/kg		251.3		173.8		175.5		94.9		93.4		60.9		29.8		1338.2	
Calculated Kansas chronic aquatic life WQC, Zn (Location Specific)	ug/L		351.1		366.1		299.7		333.2		366.1		469.8		265.5		351.1	
Bioavailability Based on Literature Values																		
(A) Allowable Zn Sorbed to OC in Sediment (published $K_{d,OC,Zn}$)	mg/kg		0.334		0.696		0.450		0.400		0.549		0.611		0.292		0.667	
(B) Allowable Zn in Water	mg/kg		0.254		0.300		0.200		0.179		0.206		0.313		0.143		0.396	
(A+B) Total Allowable Excess Zn	mg/kg		0.588		0.995		0.649		0.579		0.755		0.924		0.435		1.063	
Total Allowable Zinc (published $K_{d,OC,Zn}$)	**mg/kg**		**251.92**		**174.75**		**176.17**		**95.52**		**94.15**		**61.85**		**30.21**		**1,339.31**	
Total SEM Zinc > Allowable Zinc (published $K_{d,OC,Zn}$)?			YES		YES		YES		YES		YES		YES		YES		NO	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Zn}$ (Calc'd)	L/kg-OC		2279938		2101111		4775119		2719196		7005286		4381230		2478790		ND	
Partition Coefficient, $K_{d,dry\ sed,Zn}$ (Calc'd)	L/kg dry sed		21659		39921		71627		32630		105079		56956		27267		ND	
AVS-bound SEM Zn	mg/kg		251.3		173.8		175.5		94.9		93.4		60.9		29.8		1338.2	
(A) Allowable Zn Sorbed to dry sediment (empirical K_d for dry sed)	mg/kg		848.245		884.540		723.988		804.987		884.540		1134.987		641.318		848.245	
(B) Allowable Zn in Water	mg/kg		0.254		0.300		0.200		0.179		0.206		0.313		0.143		0.396	
(A+B) Total Allowable Excess Zn	mg/kg		848.499		884.839		724.188		805.166		884.746		1135.300		641.461		848.641	
Total Allowable Zinc (empirical K_d for dry sed)	**mg/kg**		**1,099.8**		**1,058.6**		**899.7**		**900.1**		**978.1**		**1,196.2**		**671.2**		**2,186.9**	
Total SEM Zinc > Allowable Zinc (empirical K_d for dry sed)?			NO		NO		NO		NO		NO		NO		NO		NO	
Total SEM Zinc:Total Allowable Zinc (empirical K_d for dry sed)	NA		0.33		0.32		0.46		0.19		0.27		0.13		0.34		0.32	
Total Recoverable Zn $\geq$ SEM Zn?	NA		YES		NO		NO		NO		NO		YES		NO		YES	
SEM Zn / Total Recoverable Zn	NA		0.180		1.417		1.414		1.133		1.444		0.889		1.278		0.795	

Notes:

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Molecular weight, Zn	ug/umol	65.38
Average Empirical Partition Coef, $K_{d,OC,Zn}$	L/kg-OC	1,391,725
Geometric Mean Empirical Partition Coef $K_{d,OC,Zn}$	L/kg-OC	199,572
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Zn}$	L/kg dry sed	2,416

Transect/Pond ID			**Off-Property Pond 1-2**		**Off-Property Pond 1-3**		**Off-Property Pond 1-4**		**Off-Property Pond 3-1**		**Off-Property Pond 3-2**		**Off-Property Pond 3-3**		**Off-Property Pond 3-4**		**Off-Property Pond 4-1**	
Sample Date			**12/5/2011**		**12/5/2011**		**12/5/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**	
Transect			**P**		**P**		**P**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	3		25		0.26	J	6.9		8.4		13		11	B	4	B
SEM Lead	mg/kg	SW6010	65	B	260	B	120	B	56	B	69	B	120	B	71	B	16	B
SEM Cadmium	mg/kg	SW6010	1.4		3.9		3.3		1		1.1		2.2		0.77		0.086	J
SEM Zinc	mg/kg	SW6010	210	B	800	B	530	B	190	B	210	B	420	B	180	B	22	B
SEM Nickel	mg/kg	SW6010	4.7	B	7.3	B	4	B	6	B	4	B	4.9	B	12	B	7.1	B
SEM Arsenic	mg/kg	SW6010	0.85		2.4		0.6		0.78	B	1.1	B	1	B	1.9	B	1.4	B
SEM Copper	umole/gr	SW6010	0.046		0.39		0.004	J	0.11		0.13		0.2		0.18	B	0.063	B
SEM Lead	umole/gr	SW6010	0.31	B	1.2	B	0.6	B	0.27	B	0.33	B	0.58	B	0.34	B	0.075	B
SEM Cadmium	umole/gr	SW6010	0.012		0.035		0.029		0.0091		0.01		0.019		0.0068		0.00077	J
SEM Zinc	umole/gr	SW6010	3.2	B	12	B	8.1	B	2.9	B	3.2	B	6.4	B	2.8	B	0.33	B
SEM Nickel	umole/gr	SW6010	0.08	B	0.12	B	0.068	B	0.1	B	0.069	B	0.083	B	0.21	B	0.12	B
SEM Arsenic	umole/gr	SW6010	0.011		0.032		0.0079		0.01	B	0.014	B	0.014	B	0.025	B	0.018	B
SEM/AVS Ratio	none	SEM	0.19		0.35		0.71		1.3		1.9		3.9		2.9		NA	
Lab AVS	umole/gr	SW9034	19		40		12		2.6		2		1.9		1.2		0.54	U
Porewater Zn (Total)	ug/L	SW6020	160		160		160		220		220		220		220		28	
Porewater Zn (Dissolved)	ug/L	SW6020	8.8		8.8		8.8		16		16		16		16		9.9	
Total Recoverable Zn	mg/kg dw	SW6020	630		1100		740		670		250		730		400		190	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	34		64		39		42		40		48		44		12	
Sulfide	mg/kg	SW9034	600		1300		400		83		64		60		39		3.5	U
Total Organic Carbon	mg/kg	LLOYD KAHN	15000		17000		13000		7400		5400		11000		4400		2900	
Calculations																		
ΣSEM	umole/gr		3.65		13.75		8.80		3.39		3.74		7.28		3.54		0.59	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		19.20		39.27		12.40		2.61		1.97		1.87		1.22		0.00	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		18.71		40.54		12.47		2.59		2.00		1.87		1.22		0.11	
SEM-AVS	umole/gr		-15.06		-26.80		-3.67		0.80		1.74		5.41		2.32		0.48	
f_{OC}			0.0150		0.0170		0.0130		0.0074		0.0054		0.0110		0.0044		0.0029	
Excess Total Metals-OC	umole/gr OC		-1,004.27		-1,576.33		-282.59		108.19		322.79		491.89		527.39		165.39	
AVS-Σ Cu,Pb, Cd	umole/gr		18.34		38.92		11.84		2.20		1.53		1.07		0.69		-0.03	
Excess SEM Zinc	umole/gr		0.00		0.00		0.00		0.70		1.67		5.33		2.11		0.33	
Excess SEM Zinc	mg/kg		0		0		0		46		109		348		138		22	
Excess SEM Zn-OC	umole/gr OC		0		0		0		95		310		484		480		114	
Excess SEM Zn-OC	mg/kg OC		0		0		0		6,190		20,268		31,667		31,360		7,440	
AVS-bound SEM Zn	mg/kg		1199.3		2544.4		774.2		143.8		99.8		70.1		45.1		0.0	
Calculated Kansas chronic aquatic life WQC, Zn (Location Specific)	ug/L		351.1		351.1		351.1		351.1		351.1		351.1		351.1		351.1	
Bioavailability Based on Literature Values																		
(A) Allowable Zn Sorbed to OC in Sediment (published $K_{d,OC,Zn}$)	mg/kg		0.527		0.597		0.456		0.260		0.190		0.386		0.154		0.102	
(B) Allowable Zn in Water	mg/kg		0.181		0.624		0.224		0.254		0.234		0.324		0.276		0.048	
(A+B) Total Allowable Excess Zn	mg/kg		0.708		1.221		0.681		0.514		0.424		0.710		0.430		0.150	
Total Allowable Zinc (published $K_{d,OC,Zn}$)	**mg/kg**		**1,200.04**		**2,545.66**		**774.89**		**144.31**		**100.19**		**70.81**		**45.51**		**0.15**	
Total SEM Zinc > Allowable Zinc (published $K_{d,OC,Zn}$)?			NO		NO		NO		YES		YES		YES		YES		YES	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Zn}$ (Calc'd)	L/kg-OC		ND		ND		ND		386775		1266655		1979073		1959847		751447	
Partition Coefficient, $K_{d,dry\ sed,Zn}$ (Calc'd)	L/kg dry sed		ND		ND		ND		2862		6840		21770		8623		2179	
AVS-bound SEM Zn	mg/kg		1199.3		2544.4		774.2		143.8		99.8		70.1		45.1		0.0	
(A) Allowable Zn Sorbed to dry sediment (empirical K_d for dry sed)	mg/kg		848.245		848.245		848.245		848.245		848.245		848.245		848.245		848.245	
(B) Allowable Zn in Water	mg/kg		0.181		0.624		0.224		0.254		0.234		0.324		0.276		0.048	
(A+B) Total Allowable Excess Zn	mg/kg		848.426		848.869		848.470		848.499		848.479		848.569		848.521		848.293	
Total Allowable Zinc (empirical K_d for dry sed)	**mg/kg**		**2,047.8**		**3,393.3**		**1,622.7**		**992.3**		**948.2**		**918.7**		**893.6**		**848.3**	
Total SEM Zinc > Allowable Zinc (empirical K_d for dry sed)?			NO		NO		NO		NO		NO		NO		NO		NO	
Total SEM Zinc:Total Allowable Zinc (empirical K_d for dry sed)	NA		0.10		0.24		0.33		0.19		0.22		0.46		0.20		0.03	
Total Recoverable Zn $\geq$ SEM Zn?	NA		YES		YES		YES		YES		YES		YES		YES		YES	
SEM Zn / Total Recoverable Zn	NA		0.333		0.727		0.716		0.284		0.840		0.575		0.450		0.116	

Notes:

1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-4
Bioavailability Calculations for Zinc

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Zn}$	L/kg-OC	100
Site background concentration, Zn	mg/kg dw	402
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Zn (Average Site hardness)	ug/L	351
McDonald et al. consensus-based threshold effect concentration (TEC), Zn	mg/kg dw	121
McDonald et al. consensus-based probable effect concentration (PEC), Zn	mg/kg dw	459
KS Department of Health and Environment risk-based standards for Kansas (KDHE RSK), Zn	mg/kg dw	23500
Molecular weight, Zn	ug/umol	65.38
Average Empirical Partition Coef, $K_{d,OC,Zn}$	L/kg-OC	1,391,725
Geometric Mean Empirical Partition Coef $K_{d,OC,Zn}$	L/kg-OC	199,572
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Zn}$	L/kg dry sed	2,416

Transect/Pond ID			**Off-Property Pond 4-2**		**Northeast Pond-1**		**Northeast Pond-2**		**Northeast Pond-3**		**Northeast Pond-4**		**North Pond-1**		**North Pond-2**		**North Pond-3**	
Sample Date			**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**12/6/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values																		
SEM Copper	mg/kg	SW6010	5.7	B	5.8	B	5.7	B	2	B	8.1	B	21		27		28	
SEM Lead	mg/kg	SW6010	29	B	31	B	26	B	22	B	49	B	140		220		240	
SEM Cadmium	mg/kg	SW6010	0.24		0.43		0.25		0.36		0.61		9.6		23		9.2	
SEM Zinc	mg/kg	SW6010	46	B	74	B	51	B	60	B	110	B	850		1300		830	
SEM Nickel	mg/kg	SW6010	8.8	B	3.3	B	3.1	B	2.8	B	6.3	B	1.9	J	2	J	1.5	J
SEM Arsenic	mg/kg	SW6010	1.7	B	1.5	B	1.7	B	1.3	B	2.5	B	NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.09	B	0.092	B	0.09	B	0.032	B	0.13	B	0.32		0.42		0.45	
SEM Lead	umole/gr	SW6010	0.14	B	0.15	B	0.13	B	0.11	B	0.24	B	0.67		1.1		1.2	
SEM Cadmium	umole/gr	SW6010	0.0021		0.0038		0.0022		0.0032		0.0054		0.085		0.21		0.082	
SEM Zinc	umole/gr	SW6010	0.7	B	1.1	B	0.78	B	0.92	B	1.7	B	13		20		13	
SEM Nickel	umole/gr	SW6010	0.15	B	0.057	B	0.053	B	0.048	B	0.11	B	0.033	J	0.035	J	0.026	J
SEM Arsenic	umole/gr	SW6010	0.022	B	0.02	B	0.023	B	0.017	B	0.034	B	NA		NA		NA	
SEM/AVS Ratio	none	SEM	NA		1.9		NA		0.16		2		1.5		13		13	
Lab AVS	umole/gr	SW9034	0.63	U	0.76	J	0.91	U	7		1.1	J	NA		NA		NA	
Porewater Zn (Total)	ug/L	SW6020	28		40		40		40		40		120000	B	120000	B	120000	B
Porewater Zn (Dissolved)	ug/L	SW6020	9.9		12		12		12		12		140000		140000		140000	
Total Recoverable Zn	mg/kg dw	SW6020	110		150		120		130		150		56		4800		3400	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA		NA		NA		NA	
%Moist	%	NA	25		42		49		40		60		48		48		46	
Sulfide	mg/kg	SW9034	4	U	24	J	5.9	U	220		35	J	930		120		82	
Total Organic Carbon	mg/kg	LLOYD KAHN	6700		10000		8400		13000		15000		54000		87000		100000	
Calculations																		
ΣSEM	umole/gr		1.08		1.40		1.06		1.11		2.19		14.11		21.77		14.76	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		0.00		0.74		0.00		6.96		1.09		9.41		1.67		1.14	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		0.12		0.75		0.18		6.86		1.09		29.00		3.74		2.56	
SEM-AVS	umole/gr		0.96		0.65		0.87		-5.75		1.09		-14.90		18.02		12.20	
f_{OC}			0.0067		0.0100		0.0084		0.0130		0.0150		0.0540		0.0870		0.1000	
Excess Total Metals-OC	umole/gr OC		142.89		65.43		103.71		-442.14		72.92		-275.84		207.16		122.01	
AVS-Σ Cu,Pb, Cd	umole/gr		-0.11		0.50		-0.04		6.72		0.72		27.93		2.01		0.83	
Excess SEM Zinc	umole/gr		0.70		0.60		0.78		0.00		0.98		0.00		17.99		12.17	
Excess SEM Zinc	mg/kg		46		39		51		0		64		0		1,176		796	
Excess SEM Zn-OC	umole/gr OC		104		60		93		0		66		0		207		122	
Excess SEM Zn-OC	mg/kg OC		6,831		3,905		6,071		0		4,288		0		13,518		7,960	
AVS-bound SEM Zn	mg/kg		0.0		32.9		0.0		439.1		46.8		1826.0		131.6		54.0	
Calculated Kansas chronic aquatic life WQC, Zn (Location Specific)	ug/L		351.1		351.1		351.1		351.1		351.1		351.1		351.1		351.1	
Bioavailability Based on Literature Values																		
(A) Allowable Zn Sorbed to OC in Sediment (published $K_{d,OC,Zn}$)	mg/kg		0.235		0.351		0.295		0.456		0.527		1.896		3.055		3.511	
(B) Allowable Zn in Water	mg/kg		0.117		0.254		0.337		0.234		0.527		0.324		0.324		0.299	
(A+B) Total Allowable Excess Zn	mg/kg		0.352		0.605		0.632		0.691		1.053		2.220		3.379		3.810	
Total Allowable Zinc (published $K_{d,OC,Zn}$)	**mg/kg**		**0.35**		**33.47**		**0.63**		**439.77**		**47.87**		**1,828.19**		**134.95**		**57.77**	
Total SEM Zinc > Allowable Zinc (published $K_{d,OC,Zn}$)?			**YES**		**YES**		**YES**		**NO**		**YES**		**NO**		**YES**		**YES**	
Bioavailability Based on Empirical Values																		
Partition Coefficient, $K_{d,OC,Zn}$ (Calc'd)	L/kg-OC		689925		325368		505802		ND		357262		ND		86		48	
Partition Coefficient, $K_{d,dry\ sed,Zn}$ (Calc'd)	L/kg dry sed		4622		3254		4249		ND		5359		ND		7		5	
AVS-bound SEM Zn	mg/kg		0.0		32.9		0.0		439.1		46.8		1826.0		131.6		54.0	
(A) Allowable Zn Sorbed to dry sediment (empirical K_d for dry sed)	mg/kg		848.245		848.245		848.245		848.245		848.245		848.245		848.245		848.245	
(B) Allowable Zn in Water	mg/kg		0.117		0.254		0.337		0.234		0.527		0.324		0.324		0.299	
(A+B) Total Allowable Excess Zn	mg/kg		848.362		848.499		848.583		848.479		848.772		848.569		848.569		848.544	
Total Allowable Zinc (empirical K_d for dry sed)	**mg/kg**		**848.4**		**881.4**		**848.6**		**1,287.6**		**895.6**		**2,674.5**		**980.1**		**902.5**	
Total SEM Zinc > Allowable Zinc (empirical K_d for dry sed)?			**NO**		**NO**		**NO**		**NO**		**NO**		**NO**		**YES**		**NO**	
Total SEM Zinc:Total Allowable Zinc (empirical K_d for dry sed)	NA		0.05		0.08		0.06		0.05		0.12		0.32		1.33		0.92	
Total Recoverable Zn $\geq$ SEM Zn?	NA		YES		YES		YES		YES		YES		NO		YES		YES	
SEM Zn / Total Recoverable Zn	NA		0.418		0.493		0.425		0.462		0.733		15.179		0.271		0.244	

Notes:

1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

Appendix E-4
Bioavailability Calculations for Zinc

Sediment Bioavailability Assessment
Former Altoona Zinc Smelter Site
Altoona, KS

Published partition coefficient, $K_{d,OC,Zn}$	L/kg-OC	100
Site background concentration, Zn	mg/kg dw	402
Site hardness (as CaCO3)	mg/l	361.7
Kansas chronic aquatic life WQC, Zn (Average Site hardness)	ug/L	351
McDonald et al. consensus-based threshold effect concentration (TEC), Zn	mg/kg dw	121
McDonald et al. consensus-based probable effect concentration (PEC), Zn	mg/kg dw	459
KS Department of Health and Environment risk-based standards for Kansas (KDHE RSK), Zn	mg/kg dw	23500
Molecular weight, Zn	ug/umol	65.38
Average Empirical Partition Coef, $K_{d,OC,Zn}$	L/kg-OC	1,391,725
Geometric Mean Empirical Partition Coef $K_{d,OC,Zn}$	L/kg-OC	199,572
Geometric Mean Empirical Partition Coef $K_{d,dry\ sed,Zn}$	L/kg dry sed	2,416

Transect/Pond ID			**North Pond-4**		**South Pond-1**		**South Pond-2**		**South Pond-3**		**South Pond-4**	
Sample Date			**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**		**11/16/2011**	
Transect			**P**		**P**		**P**		**P**		**P**	
Chemical	**Unit**	**Method**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**	**Result**	**Qualifiers**
Input Values												
SEM Copper	mg/kg	SW6010	23		1.5	U	0.89	U	1.2	U	0.86	U
SEM Lead	mg/kg	SW6010	160		120		78		58		63	
SEM Cadmium	mg/kg	SW6010	9.2		11		7.5		5.6		4.9	
SEM Zinc	mg/kg	SW6010	1100		1600		1100		890		720	
SEM Nickel	mg/kg	SW6010	1.8	J	1.4	J	0.55	U	3.1	J	2.3	J
SEM Arsenic	mg/kg	SW6010	NA		NA		NA		NA		NA	
SEM Copper	umole/gr	SW6010	0.37		0.023	U	0.014	U	0.019	U	0.014	U
SEM Lead	umole/gr	SW6010	0.76		0.59		0.38		0.28		0.3	
SEM Cadmium	umole/gr	SW6010	0.082		0.096		0.066		0.05		0.044	
SEM Zinc	umole/gr	SW6010	17		25		17		14		11	
SEM Nickel	umole/gr	SW6010	0.031	J	0.024	J	0.0094	U	0.053	J	0.039	J
SEM Arsenic	umole/gr	SW6010	NA		NA		NA		NA		NA	
SEM/AVS Ratio	none	SEM	11		1.9		2		1.9		2.3	
Lab AVS	umole/gr	SW9034	NA		NA		NA		NA		NA	
Porewater Zn (Total)	ug/L	SW6020	120000	B	280		280		280		280	
Porewater Zn (Dissolved)	ug/L	SW6020	140000		18		18		18		18	
Total Recoverable Zn	mg/kg dw	SW6020	2800		2800		3400		860		1900	
Hardness (as CaCO3)	mg/l	SM2340C	NA		NA		NA		NA		NA	
%Moist	%	NA	67		65		45		59		42	
Sulfide	mg/kg	SW9034	150		1500		920		1200		890	
Total Organic Carbon	mg/kg	LLOYD KAHN	53000		30000		26000		11000		17000	
Calculations												
ΣSEM	umole/gr		18.24		25.73		17.47		14.40		11.40	
Calculated AVS (ΣSEM / SEM/AVS Ratio)	umole/gr		1.66		13.54		8.73		7.58		4.96	
Calculated AVS (Sulfide mg/kg / 32.065 grams/mol)	umole/gr		4.68		46.78		28.69		37.42		27.76	
SEM-AVS	umole/gr		13.57		-21.05		-11.22		-23.02		-16.36	
f_{OC}			0.0530		0.0300		0.0260		0.0110		0.0170	
Excess Total Metals-OC	umole/gr OC		255.94		-701.57		-431.63		-2,092.91		-962.30	
AVS-Σ Cu,Pb, Cd	umole/gr		3.47		46.07		28.23		37.07		27.40	
Excess SEM Zinc	umole/gr		13.53		0.00		0.00		0.00		0.00	
Excess SEM Zinc	mg/kg		885		0		0		0		0	
Excess SEM Zn-OC	umole/gr OC		255		0		0		0		0	
Excess SEM Zn-OC	mg/kg OC		16,695		0		0		0		0	
AVS-bound SEM Zn	mg/kg		226.6		3012.1		1845.8		2424.0		1791.3	
Calculated Kansas chronic aquatic life WQC, Zn (Location Specific)	ug/L		351.1		351.1		351.1		351.1		351.1	
Bioavailability Based on Literature Values												
(A) Allowable Zn Sorbed to OC in Sediment (published $K_{d,OC,Zn}$)	mg/kg		1.861		1.053		0.913		0.386		0.597	
(B) Allowable Zn in Water	mg/kg		0.713		0.652		0.287		0.505		0.254	
(A+B) Total Allowable Excess Zn	mg/kg		2.574		1.705		1.200		0.891		0.851	
Total Allowable Zinc (published $K_{d,OC,Zn}$)	**mg/kg**		**229.18**		**3,013.83**		**1,846.99**		**2,424.85**		**1,792.14**	
Total SEM Zinc > Allowable Zinc (published $K_{d,OC,Zn}$)?			**YES**		**NO**		**NO**		**NO**		**NO**	
Bioavailability Based on Empirical Values												
Partition Coefficient, $K_{d,OC,Zn}$ (Calc'd)	L/kg-OC		81		ND		ND		ND		ND	
Partition Coefficient, $K_{d,dry\ sed,Zn}$ (Calc'd)	L/kg dry sed		4		ND		ND		ND		ND	
AVS-bound SEM Zn	mg/kg		226.6		3012.1		1845.8		2424.0		1791.3	
(A) Allowable Zn Sorbed to dry sediment (empirical K_d for dry sed)	mg/kg		848.245		848.245		848.245		848.245		848.245	
(B) Allowable Zn in Water	mg/kg		0.713		0.652		0.287		0.505		0.254	
(A+B) Total Allowable Excess Zn	mg/kg		848.958		848.897		848.532		848.750		848.499	
Total Allowable Zinc (empirical K_d for dry sed)	**mg/kg**		**1,075.6**		**3,861.0**		**2,694.3**		**3,272.7**		**2,639.8**	
Total SEM Zinc > Allowable Zinc (empirical K_d for dry sed)?			**YES**		**NO**		**NO**		**NO**		**NO**	
Total SEM Zinc:Total Allowable Zinc (empirical K_d for dry sed)	NA		1.02		0.41		0.41		0.27		0.27	
Total Recoverable Zn $\geq$ SEM Zn?	NA		YES		YES		YES		NO		YES	
SEM Zn / Total Recoverable Zn	NA		0.393		0.571		0.324		1.035		0.379	

Notes:

1. Non-detect values reported to the method detection limit.
2. The maximum total recoverable metal concentration used for transects where multiple samples were collected.

C3-103-71601

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