# **Risk Evaluation of Fly Ash-based Controlled Low Strength Material**

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February 19, 2021



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# Abbreviations

ASTM	American Society for Testing and Materials
ССР	Coal Combustion Product
CCR	Coal Combustion Residual
cfs	Cubic Feet per Second
CLSM	Controlled Low Strength Material
COPC	Constituent of Potential Concern
CPInfo	Combustion Product Information
CrVI	Hexavalent Chromium
DAF	Dilution Attenuation Factor
EPACMTP	US EPA Contaminant Migration with Transformation Products
EPRI	Electric Power Research Institute
FGD	Flue Gas Desulfurization
GSI	Groundwater-Surface Water Interface
GWPS	Groundwater Protection Standard
IWEM	Industrial Waste Evaluation Model
LEAF	Leaching Environmental Assessment Framework
MCL	Maximum Contaminant Level
PEF	Particle Emission Factor
PPE	Personal Protective Equipment
RCRA	Resource Conservation and Recovery Act
RSL	Regional Screening Level
TCLP	Toxicity Characteristic Leaching Procedure
US EPA	United States Environmental Protection Agency

This report presents a beneficial use risk evaluation of Controlled Low Strength Material (CLSM, also known as flowable fill) containing coal fly ash for use in construction projects. Currently, the United States Environmental Protection Agency US EPA considers CLSM to be an "unencapsulated" use.

Due to the lack of available data for bulk and leachate concentrations covering the range of potential CLSM characteristics, this risk evaluation cannot follow the step-wise approach described in US EPA's beneficial use risk guidance and example beneficial use risk evaluations (US EPA, 2016a,b). It does, however, rely on the same tools and underlying risk approaches promoted in those beneficial use evaluation documents.

This risk evaluation determines the concentrations of the constituents of potential concern (COPC) in bulk CLSM and CLSM leachate that would not be expected to pose a human health or environmental risk for specific CLSM application scenarios. Such an approach allows for a more practical understanding of CLSM uses that have a low potential to pose a risk *vs*. those uses that may require more project- or product-specific analysis.

While CLSM can be used in a variety of construction applications, this risk evaluation focuses on two key uses: conduit trenches and roadway embankments. These CLSM applications were selected because they offer an opportunity to examine a wide range of potential human health and ecological risks and represent applications that have the greatest potential for exposure. These applications involve CLSM used in the subsurface, which is then covered by a permeable cover, such as soil. While the permeable cover limits direct contact with CLSM, it allows for rainwater to infiltrate, interact with the CLSM, and produce leachate that can subsequently migrate downward and impact groundwater. Additionally, because CLSM embankments can be constructed near surface water bodies, the inclusion of this application in this report offers the opportunity to examine the potential risks to aquatic ecological receptors. Risks to workers involved in the excavation and disposal of CLSM post use was also evaluated. The specific CLSM applications and pathways evaluated in this risk evaluation are summarized in Table ES.1 below.

Application	Description	Exposure Pathway			
Conduit trench	20 ft. by 1 mile	Human Health-Drinking water:			
		Groundwater well located 25, 100, or 1,000 ft.			
		downgradient of the edge of the conduit trench			
Embankment – No nearby	100 ft. by 100 ft.;	Human Health-Drinking water:			
surface water body	300 ft. by 300 ft.	Groundwater well located 100 or 1,000 ft.			
		downgradient of the edge of the embankment			
Embankment – Nearby	100 ft. by 100 ft.;	Human Health-Drinking water:			
surface water body	300 ft. by 300 ft.	Medium-, or large-size surface water body 25 ft.			
		downgradient of edge of embankment			
		Ecological – Contact by aquatic receptors:			
		Small-, medium-, or large-size surface water body			
		25 ft. downgradient of edge of embankment			
Generic CLSM use	Not Applicable	Human Health – Worker via CLSM fugitive dust			
Nietee.					

Table ES.1 Summary of CLSM Applications and Exposure Pathway
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Notes:

CLSM = Controlled Low Strength Material.

This risk evaluation modeled leachate concentrations that would not result in the exceedance of federal drinking water standards under different CLSM application scenarios. The modeling was conducted using the US EPA Contaminant Migration with Transformation Products (EPACMTP), which relies on a probabilistic, Monte Carlo modeling approach that accounts for the diversity of potential climatic, hydrogeologic, and source conditions in a statistical manner. This same model was used by US EPA in the 2014 Coal Combustion Residual (CCR) Risk Assessment and a closely related model (the Industrial Waste Evaluation Model, IWEM) was used in the fly ash concrete beneficial use evaluation (US EPA, 2014a,b). This risk evaluation conservatively used the 90<sup>th</sup> percentile model-predicted dilution attenuation factor (DAF) to derive the health-protective leachate concentration (*i.e.*, the CLSM leachate concentration that will not result in a downgradient groundwater concentration in excess of federal drinking water standards. For the embankment with a nearby surface water body scenario, the discharge of affected groundwater into surface water was modeled using a national distribution of surface water flow rates considered as part of US EPA's 2014 CCR Risk Assessment (US EPA, 2014a).

Workers were assumed to be exposed to particulates or dust generated from activities that involve excavating CLSM from a trench with a backhoe and dumping the CLSM into a dump truck. Health-protective levels protective of worker exposure to CLSM fugitive dust were derived using an approach consistent with the approach used in US EPA's "Regional Screening Levels (RSLs) User's Guide" (US EPA, 2020b). The exposure scenario assumed an exposure frequency of 20 days/year, with an exposure duration of 10 years.

The health-protective levels derived in this report, described in Section 4 and summarized in Table 6.1 can be used by CLSM users as a guide to understand if specific CLSM projects have the potential to pose a risk concern.

Further, to provide perspective on the potential for bulk CLSM and CLSM leachate to pose a risk, the developed CLSM application-specific health-protective levels were conservatively compared to COPC concentrations measured in bulk fly ash and fly ash leachates. Based on this comparison, this evaluation has concluded that:

- The use of CLSM in conduit trenches does not pose a drinking water risk, even for a well as close as 25 ft. downgradient from the edge of the trench.
- Depending on the size of the embankment structure (300 ft. by 300 ft. or larger), it may be advisable to confirm CLSM leachates are below the health-protective levels or conduct project/site-specific modeling if a groundwater drinking water well is located within 1,000 ft. However, such embankments do not pose a drinking water risk for surface waters located as close as 25 ft. of the structure.
- Embankments as a large as 300 ft. by 300 ft. do not pose an ecological risk for surface waters located as close as 25 ft. of the embankment. The one exception for ecological receptors is for selenium and cadmium in high-end leachate concentrations, which can exceed health-protective benchmarks when discharging to a small (10<sup>th</sup> percentile size) water body 25 ft. from the edge of the embankment.

These conclusions are summarized in Table ES.2.

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worker Kisk – Applicable to excavating CLSM under Multiple Applications							
<b>Exposure Duration</b>	Measured Bulk Fly Ash – 50 <sup>th</sup> Percentile	Measured Bulk Fly Ash – 90 <sup>th</sup> Percentile					
20 days/year for	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					
10 years							
Drinking Water Risk – Conduit Trench							
Well Distance	Measured Fly Ash Leachate	Measured Pore Water Leachate					
Wen Distance	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile					
25 ft.	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					
100 ft.	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					
1,000 ft.	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					
Drinking	; Water Risk – Embankment – No Nearby Sur	face Water Body – 100 Ft. x 100 Ft.					
Wall Distance	Measured Fly Ash Leachate	Measured Pore Water Leachate					
wen Distance	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile					
100 ft.	No Risk Concerns <sup>a</sup>	Consider Additional Evaluation <sup>b</sup>					
1,000 ft.	No Risk Concerns <sup>a</sup>	Minimal Risk Concerns <sup>c</sup>					
Drinking Water Risk – Embankment – No Nearby Surface Water Body – 300 Ft. x 300 Ft.							
Wall Distance	Measured Fly Ash Leachate	Measured Pore Water Leachate					
	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile					
100 ft.	Minimal Risk Concerns <sup>c</sup>	Consider Additional Evaluation <sup>b</sup>					
1,000 ft. No Risk Concerns <sup>a</sup>		Consider Additional Evaluation <sup>b</sup>					
Drinking Water Risk – Embankment – Nearby Surface Water Body – 300 Ft. x 300 Ft.							
Surface Water Size	Measured Fly Ash Leachate	Measured Pore Water Leachate					
Surface water Size	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile					
Medium	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					
Large No Risk Concerns <sup>a</sup>		No Risk Concerns <sup>a</sup>					
Ecol	Ecological Risk – Embankment – Nearby Surface Water Body – 300 Ft. x 300 Ft.						
Surface Water Size	Measured Fly Ash Leachate	Measured Pore Water Leachate					
Surface Water Size	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile					
Small	No Risk Concerns <sup>a</sup>	Minimal Risk Concerns <sup>c</sup>					
Medium	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					
Large	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>					

 Table ES.2 Summary of CLSM Application Risk Potential for Evaluated Exposure Scenarios

Notes:

CLSM = Controlled Low Strength Material.

(a) "No risk concerns" indicate that measured fly ash leachates (used as proxies for CLSM leachates) were below the application-specific health-protective leachate levels.

(b) "Consider Additional Evaluation" indicates that measured 50<sup>th</sup> percentile fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was an exceedance at the 90<sup>th</sup> percentile. To address the potential risk concern, CLSM leaching tests and/or project-specific fate and transport modeling should be considered. (c) "Minimal Risk Concerns" indicates that measured 50<sup>th</sup> percent Fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was a small (<3-fold) exceedance at the 90<sup>th</sup> percentile.

## **1** Introduction

CLSM is a mixture of fine aggregates and minerals that has specific strength and flexibility characteristics that make it an ideal material for self-leveling, self-compacting backfill that can be used as an alternative to compacted soil or granular fill (CAMC, 2015; US DOT, 2016). It is a self-consolidating when applied in a wet form. Once it hardens it reaches compressive strengths of typically less than 300 psi, making its potential future excavation possible. Conventional CLSM mixtures often contain fine aggregates such as sand, slag, and fly ash, as well as cement but can also be composed of 100% fly ash (ACI, 2013). Because its self-cementing properties or because it can be mixed with relatively small amounts of portland cement, it will form a bound material that has reduced permeability, as compared to compacted soil, once cured.

Because of its self-leveling and self-consolidating properties, CLSM is often used in construction projects as backfill for conduit trenches and other applications requiring the use of fill in tight areas where it would be difficult to spread and compact by machine or hand. It is also used as a stabilizing layer for roads, bridge abutments, and other applications to save money on materials and labor that would be required to spread and compact the material (CAMC, 2015).

In 2016, US EPA published two guidance documents that describe a methodology and provide resources (*e.g.*, statistical methods, health-based benchmarks, fate and transport models) for evaluating the beneficial use of industrial, non-hazardous secondary materials, which include coal combustion products (CCPs), such as fly ash (US EPA, 2016a,b). The methodology is intended for those performing or reviewing beneficial use evaluations and other stakeholders, including state and local governments, the regulated community, and the general public. The US EPA also published an example beneficial use evaluation of concrete containing fly ash and wallboard containing synthetic gypsum (US EPA, 2014b).

US EPA's risk guidance and the risk evaluation example report take a stepwise approach to compare environmental exposures that may result from the beneficial use of CCPs to health-protective benchmarks. The process involves a screening step followed by a more detailed exposure evaluation, if needed. The risk evaluation described in this report cannot take the stepwise approach presented in the US EPA guidance document, due to a lack of measured CLSM constituent concentration data sufficient to describe the range of potential CLSM characteristics and the variability of site-specific factors that affect leachate generation. Instead, this assessment determines the concentrations of the constituents of potential concern (COPC) in bulk CLSM and CLSM leachate that would not be expected to pose a human health or environmental risk for specific CLSM application scenarios. This approach, which relies on the same tools and underlying risk approaches used in the US EPA guidance document, allows for a more practical understanding of CLSM uses that have a low potential to pose a risk *vs*. those uses that may require more project or product-specific analysis.

While CLSM can be used in a variety of construction applications, this risk evaluation focuses on two key uses: conduit trenches and roadway embankments. These CLSM applications were selected not only because they represent some of the most common CLSM uses, but because they offer an opportunity to examine a wide range of potential human health and ecological risks. These applications involve CLSM used in the subsurface, which is then covered by a permeable cover, such as soil. While the permeable cover limits direct contact with CLSM, it allows for rainwater to infiltrate, interact with the CLSM, and produce leachate that can subsequently migrate downward to groundwater. In contrast, many other CLSM applications involve material that is buried and covered by an impermeable cover (*e.g.*, CLSM used as a road stabilizer is covered by concrete or asphalt, CLSM use in building foundation) or enclosed within other materials (*e.g.*, fill in underground tanks) that prevent interaction with infiltrating precipitation or groundwater. These types of applications evaluated in this report, due to the more limited potential for leachate generation. Additionally, because CLSM embankments are commonly constructed near surface water bodies, the inclusion of this application in this report offers the opportunity to examine the potential risks to aquatic ecological receptors.

The sections below provide more specific information on the potential receptors and exposures pathways associated with the use of CLSM in a conduit trench and in a roadway embankment. A description of the exposure pathways for workers involving the excavation of CLSM is also included. The worker exposure scenario is not specific to any particular CLSM application. A summary of CLSM applications and relevant exposure pathways is also summarized in Table 2.1.

## 2.1 Conduit Trench-Residential Drinking Water

One of the most common uses of CLSM is its use as stabilization material for trenches, particularly long narrow spaces that are more difficult to properly backfill with traditional materials such as soil or gravel. Specific uses include bedding for water pipes and electrical conduits.

This risk evaluation evaluated potential exposures for the use of CLSM in a conduit trench 20 ft. wide and one mile long. This width is significantly larger than the distance needed for most conduit trenches used in more residential settings for fiber optic and cable lines, which are less than 30 inches. Larger trenches, such as those used for oil and gas pipelines, would not typically be located near residential areas. Nonetheless, because conduit trenches may be close to residential areas, it was assumed that a drinking water well could be located as close as 25 ft. from the edge of the trench. For completeness, this risk evaluation also evaluated a drinking water receptor using wells located 100 and 1,000 ft. downgradient of the edge of the trench. Consistent with use specifications, it was assumed that the trench was constructed above the water table.<sup>1</sup> No residents were assumed to have direct exposure to CLSM because the CLSM is buried. A schematic of the conduit trench application scenario is presented in Figure 2.1.

<sup>&</sup>lt;sup>1</sup> The depth to groundwater below the CLSM ranged from 1 to 2,000 ft., based on the national distribution included with the US EPA Contaminant Migration with Transformation Products (EPACMTP) model, and is described in Section 4.1 and Appendix C (US EPA, 1997).



**Figure 2.1** Schematic of the Geometry of the Conduit Trench Set-Up. Concentrations were evaluated at distances (R) of 25, 100, and 1,000 ft.

## 2.2 Roadway Embankments-Residential Drinking Water and Ecological Receptors

Another common application of CLSM is a stabilizer for roadway embankments, and particularly as a bridge abutment to help mitigate settlement or erosion concerns. For this application, two embankment/abutment project sizes were evaluated: a small, 100 ft. by 100 ft. embankment and a larger, 300 ft. by 300 ft. embankment.

To account for different receptors and exposure pathways, two embankment scenarios were considered:

- Embankment with no nearby surface water body: In this scenario, it was assumed that the potential for CLSM leachate from a highway embankment to migrate towards a downgradient drinking water well. It was also assumed that a drinking water well could be located either 100 or 1,000 ft. downgradient of the edge of the embankment (Figure 2.2). The well depth is based on a national distribution of depths (see Appendix C for further information). This risk evaluation did not evaluate a drinking water well within 25 ft. (as was done for a conduit trench) because embankments are typically used on highways that have residential setbacks greater than 25 ft.
- 2. Embankment with a nearby surface water body: Because embankments may be used to help stabilize bridges, CLSM application may be in close proximity to a surface water body. While there is no direct contact between CLSM and the surface water, there is a potential for CLSM

leachate to migrate to groundwater and discharge into a surface water body. Based on this, residential receptors were evaluated using the surface water adjacent to a CLSM embankment as a drinking water source. It was assumed that the surface water was located 25 ft. downgradient from the embankment. The dilution that occurs as groundwater is discharged<sup>2</sup> into different sized surface water bodies was estimated based on a national distribution of surface water sizes considered as part of US EPA's 2014 CCR Risk Assessment (US EPA, 2014a). The medium water body was the 50<sup>th</sup> percentile with a flow rate of 19 cubic feet per second (cfs) and is equivalent to a large creek (or third-order stream). The large water body was the 90<sup>th</sup> percentile with a flow rate of nearly 28,000 cfs and is equivalent to a large river (see Appendix C for further details). Using this scenario, ecological receptors living in the surface water were also evaluated. The ecological evaluation considered a small water body in addition to the medium and large surface water bodies. The small water body was represented using the 25<sup>th</sup> percentile size with a flow rate of 1.8 cfs; this is equivalent to a small stream or headwaters (a first- or second-order stream). The small water body was not included in the drinking water evaluation since this feature would be too small to be used as a drinking water source, but could support aquatic habitat. Example schematics of the scenarios that were evaluated for the 100 ft. by 100 ft. embankment are presented in Figures 2.2 and 2.3.





 $<sup>^{2}</sup>$  Only dilution during discharge into the surface water body was evaluated. This approach is conservative because it does not account for geochemical and sorption reactions that occur at the groundwater-surface water interface (GSI); these reactions may result in reduced concentrations in the surface water body. Further, inclusion of the 50<sup>th</sup> percentile water body is conservative, since this is small enough that it is unlikely to serve as a drinking water source.

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**Figure 2.3 Schematic of the Geometry of the Abutment/Embankment Near Surface Water Set-Up.** Concentrations were evaluated at distances (R) of 25 ft. to small, medium, or large surface water bodies.

## 2.3 CLSM Excavation

Workers are mainly exposed to CLSM during excavation and disposal during the removal of CLSM. The evaluation of worker risks is not specific to a conduit trench or an embankment. Instead, because the activities associated with excavation and disposal would be similar among different CLSM project types, an exposure scenario was developed that would be applicable to any construction project involving the excavation and disposal of CLSM. For this scenario, a worker was assumed to be exposed for 20 days a year (5 days a week for 4 weeks) for 10 years. During these activities, workers can be exposed *via* the incidental ingestion, inhalation, and dermal contact to CLSM fugitive dust. This risk evaluation did not evaluate the placement of CLSM into a conduit trench or embankment because the CLSM is applied in a wet form from a closed system, which limits direct contact and inhalation.

Scenario	Pathways			
Conduit trench	<ul> <li>Human Health</li> <li>Ingestion of residential drinking water from groundwater potentially impacted by CLSM leachate</li> </ul>			
	• Drinking water well located 25, 100, or 1,000 ft. downgradient of the edge of the conduit trench			
	<ul> <li>No direct exposure to CLSM because CLSM is buried/confined</li> </ul>			
Embankments with no nearby surface water body	<ul> <li>Human Health</li> <li>Ingestion of residential drinking water from groundwater potentially impacted by CLSM leachate</li> </ul>			
	• Drinking water well located 100 or 1,000 ft. downgradient of the edge of the embankment			
	<ul> <li>No direct exposure to CLSM because CLSM is buried/confined</li> </ul>			
Embankments nearby surface water body	<ul> <li>Human Health</li> <li>Ingestion of residential drinking water from surface water potentially impacted by CLSM leachate</li> </ul>			
	<ul> <li>Medium- or large-size surface water body assumed to be 25 ft. downgradient of the edge of embankment</li> </ul>			
	<ul> <li>No direct exposure to CLSM because CLSM is buried/confined</li> </ul>			
	<ul> <li>Ecological</li> <li>Aquatic receptors in contact with surface waters potentially impacted by CLSM leachate</li> </ul>			
	<ul> <li>Small-, medium-, or large-size surface water body assumed to be 25 ft. downgradient of edge of embankment</li> </ul>			
	<ul> <li>No direct exposure of terrestrial receptors to CLSM because CLSM is buried/confined</li> </ul>			
CLSM excavation – unspecified application	<ul> <li>Human Health</li> <li>Worker incidental ingestion, inhalation, and dermal contact with CLSM fugitive</li> </ul>			
	dust during excavation or disposal			
	Assumes exposure 20 days/year for 10 years			
	<ul> <li>No significant exposure during placement of CLSM (wet materials from closed system)</li> </ul>			

Table 2.1 Summary of Exposure Pathways for Use of CLSM Applications

Notes:

CLSM = Controlled Low Strength Material.

## 3.1 Literature Review of CLSM Leaching Characteristics

For this risk evaluation, a comprehensive literature evaluation of the COPCs that have the potential to leach from CLSM was conducted. Although the number of studies was limited and information was not available for all COPCs, the literature studies cover a large range of CLSM mixtures and methods to evaluate leaching potential. Tabular results from these studies are included in Appendix A and include results from bulk composition, the US EPA's Toxicity Characteristic Leaching Procedure (TCLP) method, American Society for Testing and Materials' (ASTM) D3987 leaching method, and one study that used US EPA's Leaching Environmental Assessment Framework (LEAF) Method 1315 for monolith testing.<sup>3</sup> The studies that used the TCLP method were generally focused on the eight metals that are regulated using this method under Resource Conservation and Recovery Act (RCRA).<sup>4</sup> The studies that used the ASTM method presented results for approximately 20 metals, and these results were deemed the most reliable for the purposes of this risk evaluation and were used for a preliminary human health and ecological screening. As presented in Appendix A, the only COPCs that leached from CLSM using the ASTM method at levels above the federal drinking water standards (maximum contaminant level [MCL]) were arsenic and molybdenum. No leachate data were available for chromium (VI), lithium, or radium, and the reported detection limits were not low enough to evaluate cobalt (Appendix Table A.7). Generally, the studies that used the TCLP method reported higher results, particularly for arsenic. One isolated study (Türkel et al., 2006) found leachate concentrations that exceeded MCLs for some additional COPCs including barium, cadmium, lead, mercury, and selenium. These values were typically greater<sup>5</sup> than the measured 90<sup>th</sup> percentile concentration from US EPA's CCR constituent database for pore water from impoundments with "whole waste" CCPs (US EPA, 2014a). Two studies evaluated COPC concentrations in bulk CLSM materials made with fly ash (Appendix A). These studies provide some perspective on the COPC levels that can be measured in bulk CLSM, but the limited data on different mixtures are insufficient to understand the variability in COPC concentrations.

Based on this literature review, it was determined that there is insufficient information on the variability of COPC concentrations in bulk CLSM and CLSM leachate to eliminate COPCs from further risk evaluation. Consequently, all of the constituents specified for assessment monitoring in the Federal CCR Rule (*i.e.*, the Appendix IV constituents) were included. Those constituents are listed below in Table 3.1. It is noteworthy that evaluating the potential risk associated with the complete list of Appendix IV constituents is conservative. In fact, the constituents that have the potential to pose a risk from the use of CCPs in CLSM are likely a small subset of these constituents.

<sup>&</sup>lt;sup>3</sup> Both the US EPA's TCLP and ASTM's D3987 methods evaluate leaching of granular materials, although the TCLP requires a pH adjustment to replicate the acidic conditions found in most landfills. In contrast, the LEAF 1315 method performs longer duration leaching tests on a solid, monolith sample.

<sup>&</sup>lt;sup>4</sup> Leaching as determined from the TCLP method is regulated under RCRA for the following eight constituents: arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. All except silver are also included on the Appendix IV list.

<sup>&</sup>lt;sup>5</sup> Only selenium concentrations measured in this TCLP test (0.22 to 0.32 mg/L) were similar to the 90<sup>th</sup> percentile values reported by US EPA (2014a) for impoundment pore water (0.32 mg/L).

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#### Table 3.1 Constituents of Potential Concern

CCR = Coal Combustion Residual.

(a) US EPA (2015a).

(b) Boron was originally listed as an Appendix III constituent in the CCR Federal Rule, but may be added to Appendix IV as part of Phase II.
(c) Hexavalent chromium (Cr[VI]) is not included as an Appendix IV constituent in the CCR Federal Rule, but was included in this analysis.

## 3.2 Reported Leachate and Bulk Concentrations in Fly Ash and Other CCPs

## **3.2.1** COPC Concentrations in Leachate

Fly ash-based CLSM is composed as a mix of fly ash, cement, and aggregate. The proportions of fly ash vary anywhere from 7% to 100% (ACI, 2013). While, as discussed in Section 3.1, data available on the bulk and leachable COPC concentrations in fly ash-based CLSM are limited, substantial data are available for COPC concentrations in fly ash and CCPs (EPRI, 2006, 2010; US EPA, 2014a).

Thus, to provide perspective on potential CLSM leachate concentrations that could pose a risk to downgradient receptors, the 50<sup>th</sup> percentile COPC concentrations in fly ash leachate collected in the various systems at ash containment facilities (EPRI, 2006) were presented as well as the 90<sup>th</sup> percentile concentrations for pore water in impoundments containing "whole waste" that includes fly ash and other CCPs (US EPA, 2014a). Both the Electric Power Research Institute (EPRI) and US EPA data sets report actual measured leachate concentrations from a variety of source types, including pore water, leachate collection systems, and other field samples. These results are not based on estimated leaching characteristics from laboratory studies (such as TCLP or LEAF methods). Information on these two sources of data is summarized below.

- EPRI (2006): The ash field leachate data included samples collected from leachate wells, collection systems, piezometers, lysimeters, impoundment outfalls, and seeps at fly ash and bottom ash containment facilities; flue gas desulfurization (FGD) gypsum was not present in these systems. The median (50<sup>th</sup> percentile) concentration in field-measured leachate from ash are included in this report.
- US EPA (2014a): The US EPA, in its 2014 CCR Risk Assessment, presents the 90<sup>th</sup> percentile concentration from its CCR constituent database for pore water from impoundments with "whole waste" CCPs. The data it presents and uses in the risk assessment are for all CCPs (and not specifically for fly ash).

Using these data as a proxy for COPCs in CLSM leachate is likely conservative and would accurately reflect CLSM composed of 100% fly ash. For CLSM mixtures composed of less than 100% fly ash, these data will likely over-predict the contributions of COPCs from fly ash, due to the presence of other materials in the CLSM (*i.e.*, cement, fine aggregates). This is particularly true for CLSM with sufficient amounts of cement, which will significantly reduce the permeability of the CLSM and, therefore, reduce the leaching potential.<sup>6</sup>

## 3.2.2 COPC Concentrations in Bulk Fly Ash

Similar to the COPC concentrations in fly ash and CCP leachate described above, data on COPC concentrations in fly ash were used to provide perspective on potential COPC levels in bulk CLSM that would not be expected to pose a risk to workers, but were not used to explicitly evaluate risk in this CLSM evaluation. The values can approximate CLSM that is made of 100% fly ash and serve as an upper-bound estimate of fly ash-based CLSM that contains less than 100% fly ash. The 50<sup>th</sup> and 90<sup>th</sup> percentile COPC concentrations are presented in the risk tables in Section 5 (EPRI, 2010, US EPA, 2014a). The values come from two sources:

- EPRI (2010): EPRI compiled bulk concentration data for fly ash, bottom ash, and FGD gypsum from its Combustion Product Information (CPInfo) and PISCES databases. Only the fly ash data are included in this report.
- US EPA (2014a): US EPA presents, in its 2014 CCR Risk Assessment, information for its CCR COPC database on "newly generated" CCPs. The data US EPA presents and uses in the risk assessment are for all CCPs (and not specifically for fly ash).

<sup>&</sup>lt;sup>6</sup> Addition of cement to CLSM is expected to decrease the permeability of the materials and thus reduce the leaching potential (Gaddam *et al.*, 2009 and Inyang and Gaddam, 2006); the addition of cement, which is a very basic material, may also increase the pH of the CLSM. This may alter the leaching characteristics of some constituents from CLSM mixes with cement additions and may potentially increase leaching potential relative to CCPs without cement additives (see Section 5).

## 4 Risk Evaluation

Given the range of materials that can be used in CLSM, the factors that can lead to variability in leachate, and the lack of sufficient measured data in CLSM, this risk analysis was not based on the limited measured COPC concentration data for CLSM leachate and bulk CLSM. Instead, this evaluation focused on developing levels of COPCs in CLSM leachate and bulk CLSM that would not be expected to pose a health risk (herein referred to as "health-protective" levels). This approach provides an understanding of the magnitude of COPC concentrations in CLSM leachate and bulk CLSM that are not likely to result in unacceptable risks to human health or the environment. To provide perspective, the calculated health-protective levels were compared to typical and high-end COPC concentrations measured in fly ash and CCP pore water leachates and bulk fly ash. Given that CLSM often contains less than 100% fly ash, this allows for a "worst-case" understanding of whether COPC concentrations in CLSM made with fly ash are at a level that can pose a potential risk.

## 4.1 Residential-Drinking Water

### 4.1.1 Modeling Approach

To develop the health-protective leachate concentrations, leachate concentrations that could result in the exceedance of a drinking water risk under the different CLSM application scenarios were modeled. Drinking water risk thresholds were based federal drinking water protection levels. Specifically, MCLs were used when available, and if not, US EPA regional screening levels (RSLs) were relied on (Table 4.2). This approach is consistent with how US EPA has established groundwater protection standards (GWPSs) in the 2019 update to the Federal CCR Rule (US EPA, 2018a).

There is no GWPS for hexavalent chromium (CrVI). While there is an RSL for CrVI, that level is based on a toxicity value developed in 2010 that was never finalized by US EPA (2010). Since then, a vast amount of research on CrVI toxicity has emerged that suggests the value developed by US EPA in 2010 is not wellsupported (*e.g.*, Thompson *et al.*, 2014, Cullen *et al.*, 2015). In the absence of an updated assessment from US EPA, this risk evaluation relied on a drinking water guideline developed by Health Canada that has more fully considered the developing CrVI research. Specifically, in 2016, Health Canada developed a drinking water guideline for CrVI of 50  $\mu$ g/L based on a comprehensive evaluation of current CrVI toxicity data (Health Canada, 2016). All drinking water risk thresholds for CLSM COPCs are presented in Table 4.2.

СОРС	Level (mg/L) <sup>a</sup>	Basis
Antimony	0.006	MCL
Arsenic	0.01	MCL
Barium	2	MCL
Beryllium	0.004	MCL
Boronª	4	RSL
Cadmium	0.005	MCL
Chromium	0.1	MCL
Chromium (VI) <sup>c</sup>	0.05	Health Canada
Cobalt	0.006	RSL
Fluoride	4	MCL
Lead	0.015	RSL
Lithium	0.04	RSL
Mercury	0.002	MCL
Molybdenum	0.1	RSL
Selenium	0.05	MCL
Thallium	0.002	MCL
Radionuclides	(pCi/L)	
Radium 226+228	5	MCL

Table 4.1 Dillking water Flotection Level	Table 4.1	Drinking	Water	Protection	Levels
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Notes:

CCR = Coal Combustion Residual; COPC = Constituent of Potential Concern; CrVI = Hexavalent Chromium; MCL = Maximum Contaminant Level; RSL = Residential Tap Water Regional Screening Level; US EPA = United States Environmental Protection Agency.

(a) Drinking water protection levels are from MCLs and US EPA RSLs, where available (US EPA (2018b, 2020a).

(b) Boron was originally listed as an Appendix III constituent in the Federal CCR Rule, but will be added to Appendix IV as part of Phase II.

(c) Health Canada developed a drinking water guideline for CrVI based on a comprehensive evaluation of current CrVI toxicity data (Health Canada, 2016).

Leachate concentrations that could result in an exceedance of a drinking water risk threshold at potential downgradient groundwater receptor locations were calculated using the US EPA Contaminant Migration with Transformation Products (EPACMTP) model (US EPA, 1997). This model was developed by US EPA to simulate the fate and transport of COPCs leaching from land-based waste management units through the underlying unsaturated and saturated zones. The model simulates infiltration and dissolved COPC transport through the unsaturated zone, and is coupled with a three-dimensional transport in the saturated zone. EPACMTP is the same model used by US EPA to evaluate risks associated with disposal in the 2014 CCR risk assessment (US EPA, 2014a); it is also the same model engine used by the Industrial Waste Evaluation Model (IWEM), which is a common model used to evaluate potential environmental impacts associated with the beneficial uses of CCPs (US EPA, 2015b).

EPACMTP relies on a probabilistic, Monte Carlo modeling approach, which accounts for the diversity of potential climatic, hydrogeologic, and source conditions in statistical evaluations (Appendix C). The Monte Carlo modeling approach was similar to the approach developed and used by US EPA in the 2014 CCR risk assessment and in the fly ash concrete beneficial use evaluation (US EPA, 2014 a,b). For each CLSM source scenario, 10,000 unique runs were conducted using national distributions for the climatic and hydrogeologic parameters, as well as other necessary input parameters. Each realization resulted in a predicted maximum contaminant concentration at the specified downgradient receptor location over the model simulation period. The dilution attenuation factor (DAF) was calculated as the ratio of source leachate concentration and the maximum model-predicted concentration at the receptor location. A statistical distribution of DAFs for each specific CLSM source application scenario was generated based

on the results from all 10,000 realizations. The  $90^{th}$  percentile model-predicted DAF was conservatively used to derive the health-protective leachate concentration (*i.e.*, the CLSM leachate concentrations will not result in a downgradient groundwater concentration in excess of a drinking water risk in groundwater). Further details about the modeling approach and the parameters used are given in Appendix B.

For the embankment scenario with a nearby surface water body, it was also necessary to model the effect of groundwater discharge into surface water. To estimate this, dilution into two surface water body sizes was evaluated based on a national distribution of surface water flow rates considered as part of US EPA's 2014 CCR risk assessment (US EPA, 2014a). The medium water body represents a 50<sup>th</sup> percentile flowrate and is considered a large creek, and the large water body represents the 90<sup>th</sup> percentile flow rate and is a large river (see Appendix C for further details). This approach is conservative because it does not account for geochemical and sorption reactions that occur at the groundwater-surface water interface (GSI); these reactions may result in reduced concentrations in the surface water body.

## 4.1.2 Conduit Trenches

## **Health-Protective Leachate Concentrations**

This risk evaluation developed COPC leachate concentrations for CLSM that are not expected to pose a residential drinking water risk based on the 90<sup>th</sup> percentile EPACMTP modeling results for CLSM used in a large conduit trench project (20 ft. wide, 1 mile long; Appendix C). These health-protective leachate concentrations are presented in Table 4.2. Results are presented for potential residential wells located 25, 100, and 1,000 ft. downgradient of the trench. For perspective, these health-protective leachate concentrations are compared to median fly ash COPC leachate concentrations measured in field samples and the 90<sup>th</sup> percentile pore water concentrations, as described in Section 3.2.

### **Risk Conclusions**

Based on modeling of CLSM leachate from a conduit trench and a comparison with both typical fly ash leachate concentrations and high end CCP pore water concentrations, it is implausible that COPCs from this CLSM application scenario could result in exceedances of drinking water protection levels.

As presented in Table 4.2, even at a groundwater drinking water well as close as 25 ft. away from a conduit trench, CLSM leachate concentrations would need to be significantly higher than measured 50<sup>th</sup> percentile leachate concentrations (>400-fold) and the 90<sup>th</sup> percentile pore water concentration (at least 20-fold) (US EPA, 2014a). For a well located 100 or 1,000 ft. away, the differential between the health-based leachate concentrations and concentrations measured in leachates is even more pronounced. Risk conclusions for each well distance compared to each measured leachate dataset are presented in Table 4.3. Although results are not presented, it is noteworthy that the conclusions for conduit trenches longer than 1 mile are similar as long as the conduit trench is approximately 20 ft. wide or smaller (data not shown).

	Health-Protective Leachate Concentrations <sup>a</sup>			EPRI <sup>b</sup>	US EPA <sup>c</sup>		
	Well Distance			Leachate Data	Impoundment Pore Water		
	25 Ft.	100 Ft.	1,000 Ft.	Median <sup>d</sup>	90 <sup>th</sup> Percentile		
COPCs (mg/L)							
Antimony	10	14	85	0.0024	0.04		
Arsenic (III) <sup>e</sup>	17	23	142	0.00037	0.78		
Barium	3,546	4,662	>10,000	1.08	0.21		
Beryllium	8	10	65	0.0004	0.001		
Boron <sup>f</sup>	6,475	9,810	>10,000	2.16	97.8		
Cadmium	11	14	101	0.0015	0.06		
Chromium Total <sup>e,g</sup>	>10,000	>10,000	>10,000	0.0006	0.2		
Chromium VI	86	113	704	0.0007	NA		
Cobalt	13	16	111	0.001	0.05		
Fluoride	6,658	9,040	>10,000	NA	21.3		
Lead	>10,000	>10,000	>10,000	0.0002	0.1		
Lithium <sup>h</sup>	71	99	581	0.129	0.45		
Mercury	4	5	31	0.0000038	0.000007		
Molybdenum	169	224	1,404	0.405	7.1		
Selenium <sup>e</sup>	84	111	702	0.019	0.32		
Thallium	3	5	28	0.00036	0.003		
Radionuclides (pCi/l	Radionuclides (pCi/L)						
Radium <sup>i</sup>	>10,000	>10,000	>10,000	NA	NA		

#### Table 4.2 Groundwater to Drinking Water – Conduit Trench

Notes:

COPC = Constituent of Potential Concern; DAF = Dilution Attenuation Factor; EPRI = Electric Power Research Institute; Kd = Soil-Water Partitioning Coefficient; NA = Not Available; US EPA = United States Environmental Protection Agency.

(a) Health-protective leachate concentrations are calculated as the COPC-specific-drinking water standard multiplied by the DAFs presented in Appendix C.

(b) Median field leachate concentrations from fly ash and bottom ash containment facilities (EPRI, 2006).

(c) 90<sup>th</sup> percentile pore water concentrations from whole waste impoundments (US EPA, 2014a).

(d) Beryllium and lead were not detected in the median samples; the detection limits are shown.

(e) United States Environmental Protection Agency Composite Model for Leachate Migration with Transformation Products (EPACMTP) does not model total arsenic, chromium, or selenium. Instead total concentrations for these metals were modeled using arsenite (As[III]), trivalent chromium (Cr[III]), and selenite Se(IV).

(f) Distribution of Kd value for boron was adopted from US EPA (2014a) Table H-3-1.

(g) Benchmarks for total chromium are based on values for trivalent chromium.

(h) No sorption was simulated for lithium.

(i) Kd value was calculated for radium using equation from Sheppard *et al.* (2009).

Well Distance	Measured Fly Ash Leachate – 50 <sup>th</sup> Percentile	Measured Pore Water Leachate – 90 <sup>th</sup> Percentile
25 ft.	No Risk Concerns: <sup>a</sup>	No Risk Concerns:
	Measured fly ash leachate concentrations are 400 to >10,000 times lower than modeled CLSM health- protective leachate concentrations	Measured pore water leachate concentrations are 22 to >10,000 times lower than modeled CLSM health- protective leachate concentrations
100 ft.	No Risk Concerns:	No Risk Concerns:
	Measured fly ash leachate concentrations are 550 to >10,000 times lower than modeled CLSM health- protective leachate concentrations	Measured pore water leachate concentrations are 29 to >10,000 times lower than modeled CLSM health- protective leachate concentrations
1,000 ft.	No Risk Concerns:	No Risk Concerns:
	Measured fly ash leachate concentrations are nearly 3,500 to >10,000 times lower than modeled CLSM health-protective leachate concentrations	Measured pore water leachate concentrations are 180 to >10,000 times lower than modeled CLSM health- protective leachate concentrations

# Table 4.3 Modeled Health-Protective Leachate at Different Well Distances vs. Measured Leachates – Conduit Trench

Notes:

CLSM = Controlled Low Strength Material.

(a) "No risk concerns" indicate that measured leachates (used as proxies for CLSM leachates) were below the application-specific health-protective leachate levels.

## 4.1.3 Embankments with No Nearby Surface Water Body

## **Health-Protective Leachate Concentrations**

This risk evaluation developed COPC leachate concentrations for CLSM that are not expected to pose a residential drinking water risk based on the 90<sup>th</sup> percentile EPACMTP modeling results for CLSM used in embankments (Appendix C). These health-protective leachate concentrations are presented in Table 4.4. Results are presented for potential residential wells located 100 and 1,000 ft. downgradient of the embankment. For this evaluation, two different embankment sizes were considered: 100 ft. by 100 ft. and 300 ft. by 300 ft. For perspective, these health-protective leachate concentrations are compared to median fly ash COPC leachate concentrations measured in field samples and the 90<sup>th</sup> percentile pore water concentrations, as described in Section 3.2.

### Risk Conclusions – 100 Ft. by 100 Ft. Embankment

Constituent-specific health-protective leachate levels for a 100 ft. by 100 ft. embankment (with no nearby surface water body) and a summary of risk implications are described below and summarized in Tables 4.5 and 4.6.

The modeled health-protective leachate values for the well located 100 ft. from a 100 ft. by 100 ft. CLSM embankment are greater (at least 2-fold, but typically more than 10-fold) than the 50<sup>th</sup> percentile leachate concentrations reported in the EPRI report (2006), meaning that typical CLSM leachates are unlikely to result in downgradient groundwater concentrations above the drinking water standard (Table 4.4). The modeled health-protective leachate values, however, are comparable to the 90<sup>th</sup> percentile pore water impoundment sample data reported in the 2014 CCR risk assessment (US EPA, 2014a). The 90<sup>th</sup> percentile arsenic and molybdenum pore water concentrations (0.78 and 7.1 mg/L, respectively) are about 10-fold greater than modeled health-protective leachate concentrations (0.07 and 0.65 mg/L) for a well located 100 ft. from an embankment. The 90<sup>th</sup> percentile pore water concentrations for boron, cadmium, lithium, and antimony are also higher than the modeled health-protective leachate concentrations for an exceedance of the drinking

water standard at a receptor well located 100 ft. downgradient of an embankment. No other COPCs had measured 90<sup>th</sup> percentile pore water concentrations greater than the modeled health-protective leachate concentrations.

For the well located 1,000 ft. from the 100 ft. by 100 ft. embankment, modeled health-protective leachate concentrations are typically 10-fold greater than for the closer well. The 90<sup>th</sup> percentile measured pore water arsenic and molybdenum concentrations are slightly greater than the modeled health-protective concentrations (0.78 *vs.* 0.69 mg/L and 6.78 *vs.* 7.1 mg/L, respectively). No other COPCs had measured 90<sup>th</sup> percentile pore water concentrations greater than the modeled health-protective concentrations.

	Health-Protective Leachate Concentrations <sup>a</sup>				EPRI <sup>b</sup>	US EPA <sup>c</sup>
	100 Ft. x	100 Ft.	300 Ft. x 300 Ft.		Leachate Data	Impoundment Pore Water
Well Distance	100 Ft.	1,000 Ft.	100 Ft.	1,000 Ft.	Median <sup>d</sup>	90 <sup>th</sup> Percentile
COPCs (mg/L)						
Antimony	0.04	0.42	0.010	0.075	0.0024	0.04
Arsenic (III) <sup>e</sup>	0.066	0.69	0.017	0.13	0.00037	0.78
Barium	14	158	3.7	29	1.08	0.21
Beryllium	0.034	0.37	0.0081	0.067	0.0004	0.001
Boron <sup>f</sup>	25	314	7.0	57	2.16	97.8
Cadmium	0.056	0.67	0.012	0.125	0.0015	0.06
Chromium Total <sup>e, g</sup>	3,315	3,520	467	1,372	0.0006	0.2
Chromium VI	0.33	3.5	0.086	0.62	0.0007	NA
Cobalt	0.016	0.70	0.013	0.128	0.001	0.05
Fluoride	26	273	6.9	49	NA	21.3
Lead	4,920	>10,000	1,348	>10,000	0.0002	0.1
Lithium <sup>h</sup>	0.38	4.0	0.081	0.70	0.129	0.45
Mercury	0.014	0.17	0.0037	0.031	0.000038	0.000007
Molybdenum	0.65	6.8	0.17	1.22	0.405	7.1
Selenium <sup>e</sup>	0.33	3.41	0.086	0.61	0.019	0.32
Thallium	0.013	0.14	0.0035	0.025	0.00036	0.003
Radionuclides (pCi/L)						
Radium <sup>i</sup>	>10,000	>10,000	>10,000	>10,000	NA	NA

Table 4.4	Groundwater to	Drinking	Water –	<b>Embankments</b>
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Notes:

**Bolding** = Indicates values less than the 90<sup>th</sup> percentile pore water concentrations; *Italics* = Indicates values less than the median field leachate; COPC = Constituent of Potential Concern; EPRI = Electric Power Research Institute; Kd = Soil-Water Partitioning Coefficient; NA = Not Available; US EPA = United States Environmental Protection Agency.

(a) Health-protective leachate concentrations are calculated as the COPC-specific-drinking water standard multiplied by the DAFs presented in Appendix C.

(b) Median field leachate concentrations from fly ash and bottom ash containment facilities (EPRI, 2006).

(c) 90<sup>th</sup> percentile pore water concentrations from whole waste impoundments (US EPA, 2014a).

(d) Beryllium and lead were not detected in the median samples; the detection limits are shown.

(e) United States Environmental Protection Agency Composite Model for Leachate Migration with Transformation Products (EPACMTP) does not model total arsenic, chromium, or selenium. Instead total concentrations for these metals were modeled using arsenite (As[III]), trivalent chromium (Cr[III]), and selenite Se(IV).

(f) Distribution of Kd value for boron was adopted from US EPA (2014a) Table H-3-1.

(g) Benchmarks for total chromium are based on values for trivalent chromium.

(h) No sorption was simulated for lithium.

(i) Kd value was calculated for radium using Equation from Sheppard et al. (2009).

#### Risk Conclusions – 300 Ft. by 300 Ft. Embankment

Constituent-specific health-protective leachate levels for a 300 ft. by 300 ft. embankment (with no nearby surface water body) and a summary of risk implications are described below and summarized in Tables 4.5 and 4.6.

Health-protective leachate concentrations are lower for the larger embankment (300 ft. by 300 ft.), but typically remain below the comparison values (Table 4.4). The modeled health-protective leachate values for a well located 100 ft. from a 300 ft. by 300 ft. CLSM embankment are greater (typically more than 3-fold) than the 50<sup>th</sup> percentile leachate concentrations reported in the EPRI report (2006), meaning that typical CLSM leachates are unlikely to result in downgradient groundwater concentrations above the drinking water standard (Table 4.4). However, median lithium and molybdenum leachate concentrations (0.13 and 0.4 mg/L, respectively) are about 2- fold greater than the modeled health-protective leachate concentrations for boron, cadmium, cobalt, fluoride, lithium, molybdenum, antimony, and selenium are greater than the modeled health-protective leachate concentrations. No other COPCs had measured 90<sup>th</sup> percentile pore water concentrations greater than the modeled health-protective concentrations.

For the well located 1,000 ft. from the 300 ft. by 300 ft. embankment, modeled health-protective concentrations are typically 7-fold greater than for the closer well. The modeled health-protective leachate values for all COPCs are greater (typically more than 25-fold) than the 50<sup>th</sup> percentile leachate concentrations reported in the EPRI report (2006), meaning that typical CLSM leachates are unlikely to result in concentrations above the drinking water standard. The 90<sup>th</sup> percentile measured pore water arsenic, boron, and molybdenum concentrations are slightly greater than the modeled health-protective concentration. No other COPCs had measured 90<sup>th</sup> percentile pore water concentrations greater than the modeled concentrations.

 Table 4.5 Embankments with No Nearby Surface Water Body – Modeled Health-Protective Leachate at Different Well Distances vs. Measured

 Leachates

	100 Ft. x 100 Ft.		300 Ft	t. x 300 Ft.
Well Distance-	Measured Fly Ash Leachate – 50 <sup>th</sup> Percentile	Measured Pore Water Leachate – 90 <sup>th</sup> Percentile	Measured Fly Ash Leachate – 50 <sup>th</sup> Percentile	Measured Pore Water Leachate - 90 <sup>th</sup> Percentile
100 ft.	No Risk Concerns: <sup>a</sup> Measured fly ash leachate concentrations are 1.6 to >10,000 times lower than modeled CLSM health- protective leachate concentrations.	<b>Consider Additional Evaluation:</b> <sup>b</sup> Measured pore water leachate concentrations for many COPCs are similar to the measured leachate concentration. Arsenic and molybdenum leachate are about 10 times higher, and boron is about 4 times higher than modeled CLSM health-protective leachate concentrations.	Minimal Risk Concerns: <sup>c</sup> Measured fly ash leachate concentrations are 3 to >10,000 times lower than modeled CLSM health-protective leachate concentrations. The exceptions are lithium and molybdenum leachate concentrations, which are about 2-fold greater than modeled CLSM health-protective leachate concentrations.	Consider Additional Evaluation: Measured pore water leachate concentrations for many COPCs (arsenic, boron, cadmium, cobalt, fluoride, lithium, molybdenum, antimony, and selenium) are higher (3-40 times) than modeled CLSM health-protective leachate concentrations. Leachate concentrations for the remaining COPCs are lower than modeled CLSM health-protective leachate concentrations.
1,000 ft.	No Risk Concerns: Measured fly ash leachate concentrations are 16 to >10,000 times lower than modeled CLSM health- protective leachate concentrations.	Minimal Risk Concerns: Measured pore water leachate concentrations are 3 to >10,000 times lower than modeled CLSM health-protective leachate concentrations. The exceptions are arsenic and molybdenum leachate concentrations, which are similar to modeled CLSM health-protective leachate concentrations.	No Risk Concerns: Measured fly ash leachate concentrations are 3 to >10,000 times lower than modeled CLSM health-protective leachate concentrations	Consider Additional Evaluation: Measured pore water leachate concentrations for many COPCs (arsenic, boron, and molybdenum) are higher (1.5-6 times) than modeled CLSM health-protective leachate concentrations. Leachate concentrations for the remaining COPCs are lower than modeled CLSM health-protective leachate concentrations

Notes:

CLSM = Controlled Low Strength Material; COPC = Constituent of Potential Concern.

(a) "No risk concerns" indicates that measured leachates (used as proxies for CLSM leachates) were below the application-specific health-protective leachate levels.

(b) "Consider Additional Evaluation:" indicates that measured 50<sup>th</sup> percentile fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was an exceedance at the 90<sup>th</sup> percentile measured pore water level. To address the potential risk concern, CLSM leaching tests and/or project-specific fate and transport modeling should be considered.

(c) "Minimal Risk Concerns" indicates that measured 50<sup>th</sup> percent fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was a small (<3-fold) exceedance at the 90<sup>th</sup> percentile for pore water.

#### GRADIENT

The practical implication of these conclusions is that CLSM containing fly ash used as stabilization material for embankments has the potential to leach COPCs at concentrations that could result in exceedances of drinking water standards for projects located near residential wells (100 ft. by 100 ft. size with a well within 100 ft. or the 300 ft. by 300 ft. size with a well within 1,000 ft.; see Table 4.5). If projects of this size are proposed to be located near residential drinking water wells, it would be prudent to consider product-specific leaching tests of the CLSM material and/or site-specific groundwater modeling to assess the project-specific risk potential.

### 4.1.4 Embankments Near a Surface Water Body

### Health-Protective Leachate Concentration

This risk evaluation developed health-protective leachate concentrations for the use of surface water as a drinking water source for two embankment sizes that are constructed with CLSM containing fly ash: 100 ft. by 100 ft. and 300 ft. by 300 ft. Specifically, this evaluation calculated health-based leachate concentrations that would not be expected to result in an exceedance of drinking water standards in a surface water body located 25 ft. from an embankment for 90% of the EPACMTP modeling scenarios. The dilution that occurs as groundwater is discharged into a surface water body was calculated for three different sizes of surface water bodies based on a national distribution of surface water body was represented using the 25<sup>th</sup> percentile size with a flow rate of 1.8 cfs, medium was represented using the 50<sup>th</sup> percentile size with a flow rate of nearly 28,000 cfs (see Appendix C for further details). For perspective, these health-protective leachate concentrations were compared to median fly ash COPC leachate concentrations measured in field samples and the 90<sup>th</sup> percentile pore water concentrations, as described in the Section 3.2.

### Risk Conclusions – 100 Ft. by 100 Ft. Embankment

Constituent-specific health-protective leachate levels for a 100 ft. by 100 ft. embankment (with a nearby surface water body) and a summary of risk implications are described below and summarized in Tables 4.6 and 4.7.

As presented in Table 4.6, for a drinking water source in a medium stream just 25 ft. downgradient of the 100 ft. by 100 ft. embankment, the health-protective CLSM leachate concentrations are at least 500 times greater than median fly ash leachate concentration and at least 28 times greater than the US EPA-reported 90<sup>th</sup> percentile CCP pore water concentrations (EPRI, 2006 and US EPA, 2014a). The health-protective CLSM leachate concentrations for a drinking water source in a large stream are more than 10,000 times greater than the measured leachates.

		Health-P	EPRI <sup>b</sup>	US EPA <sup>c</sup>		
	100 Ft. 3	x 100 Ft.	300 Ft. 2	300 Ft. x 300 Ft.		Impoundment Pore Water
Surface Water Size	Medium (50 <sup>th</sup> )	Large (90 <sup>th</sup> )	Medium (50 <sup>th</sup> )	Large (90 <sup>th</sup> )	Median <sup>d</sup>	90 <sup>th</sup> Percentile
COPCs (mg/L)						
Antimony	13	>10,000	1.65	2,433	0.0024	0.04
Arsenic (III) <sup>e</sup>	22	>10,000	2.76	4,066	0.00037	0.78
Barium	4,723	>10,000	562	>10,000	1.08	0.21
Beryllium	10	>10,000	1.18	1,739	0.0004	0.001
Boron <sup>f</sup>	8,760	>10,000	1,101	>10,000	2.16	97.8
Cadmium	16	>10,000	1.61	2,366	0.0015	0.06
Chromium Total <sup>e, g</sup>	>10,000	>10,000	>10,000	>10,000	0.0006	0.2
Chromium VI	108	>10,000	13.71	>10,000	0.0007	NA
Cobalt	18	>10,000	1.85	2,724	0.001	0.05
Fluoride	8,799	>10,000	1,089	>10,000	NA	21.3
Lead	>10,000	>10,000	>10,000	>10,000	0.0002	0.1
Lithium <sup>h</sup>	120	>10,000	12.34	>10,000	0.129	0.45
Mercury	4.6	6,839	0.57	838	0.000038	0.000007
Molybdenum	218	>10,000	27.19	>10,000	0.405	7.1
Selenium <sup>e</sup>	109	>10,000	14	>10,000	0.019	0.32
Thallium	4.4	6,466	0.55	806	0.00036	0.003
Radionuclides (pCi/L	.)					
Radium <sup>i</sup>	>10,000	>10,000	>10,000	>10,000	NA	NA

Table 4.6 S	Surface Water to	Drinking Water -	<b>Embankments</b>
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Notes:

COPC = Constituent of Potential Concern; DAF = Dilution Attenuation Factor; EPRI = Electric Power Research Institute; Kd = Soil-Water Partitioning Coefficient; NA = Not Available; US EPA = United States Environmental Protection Agency.

(a) Health-protective leachate concentrations are calculated as the COPC-specific-drinking water standard multiplied by the DAFs presented in Appendix C.

(b) Median field leachate concentrations from fly ash and bottom ash containment facilities (EPRI, 2006).

(c) 90<sup>th</sup> percentile pore water concentrations from whole waste impoundments (US EPA, 2014a).

(d) Beryllium and lead were not detected in the median samples; the detection limits are shown.

(e) United States Environmental Protection Agency Composite Model for Leachate Migration with Transformation Products (EPACMTP) does not model total arsenic, chromium, or selenium. Instead total concentrations for these metals were modeled using arsenite (As[III]), trivalent chromium (Cr[III]), and selenite Se(IV).

(f) Distribution of Kd value for boron was adopted from US EPA (2014a) Table H-3-1.

(g) Benchmarks for total chromium are based on values for trivalent chromium.

(h) No sorption was simulated for lithium.

(i) Kd value was calculated for radium using Equation from Sheppard *et al.* (2009).

#### Risk Conclusions – 300 Ft. by 300 Ft. Embankment

Constituent-specific health-protective leachate levels for a 300 ft. by 300 ft. embankment (with a nearby surface water body) and a summary of risk implications are described below and summarized in Tables 4.6 and 4.7.

Median concentrations in leachate are all less than the modeled health-protective concentrations for all surface water body sizes. This means an embankment constructed with CLSM containing fly ash with typical leachate concentrations would not result in concentrations above the drinking water standard in a nearby surface water body. The health-protective leachate concentrations for all COPCs in medium and large surface water bodies are also far greater than the US EPA-reported 90<sup>th</sup> percentile pore water concentrations. This means that, even for an embankment constructed with CLSM containing fly ash with high-end leachate concentrations, there would not be any resulting surface water concentrations above the drinking water standard for medium and large surface water bodies. Health-protective leachate concentrations for the medium surface water body are at least 67 times greater than median observed concentrations and 3.5-fold greater than the 90<sup>th</sup> percentile pore water concentrations. Health-protective leachate concentrations and 3.6-fold greater than the 90<sup>th</sup> percentile pore water concentrations. Health-protective leachate concentrations for the large surface water body are at least 5,000 times greater than the 90<sup>th</sup> percentile pore water concentrations.

	100 Ft. x 100 Ft.		300 Ft. x 300 Ft.		
Surface	Measured Fly Ash	Measured Pore	Measured Fly Ash	Measured Pore	
Water Body	Leachate	Water Leachate	Leachate –	Water Leachate	
Size	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile	50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile	
Medium	No Risk Concerns: <sup>a</sup>	No Risk Concerns:	No Risk Concerns:	No Risk Concerns:	
	Measured fly ash	Measured pore	Measured fly ash	Measured pore water	
	leachate	water leachate	leachate	leachate	
	concentrations are	concentrations are	concentrations are 67	concentrations are	
	540 to >10,000 times	28 to >10,000 times	to >10,000 times	3.5 to >10,000 times	
	lower than modeled	lower than modeled	lower than modeled	lower than modeled	
	CLSM health-	CLSM health-	CLSM health-	CLSM health-	
	protective leachate	protective leachate	protective leachate	protective leachate	
	concentrations	concentrations	concentrations	concentrations	
Large	No Risk Concerns:	No Risk Concerns:	No Risk Concerns:	No Risk Concerns:	
	Measured fly ash	Measured pore	Measured fly ash	Measured pore water	
	leachate	water leachate	leachate	leachate	
	concentrations are	concentrations are	concentrations are	concentrations are	
	>10,000 times lower	>10,000 times lower	>10,000 times lower	>5,000 times lower	
	than modeled CLSM	than modeled CLSM	than modeled CLSM	than modeled CLSM	
	health-protective	health-protective	health-protective	health-protective	
	leachate	leachate	leachate	leachate	
	concentrations	concentrations	concentrations	concentrations	

Table 4.7	Modeled Health-Protective Leachate (Human Health) for Different-Size Surface V	Vater Bodies
vs. Measu	ured Leachates – Embankments	

Notes:

CLSM = Controlled Low Strength Material.

(a) "No risk concerns" indicates that measured leachates (used as proxies for CLSM leachates) were below the application-specific health-protective leachate levels.

The practical implication of these conclusions is that CLSM used as stabilization material for embankments is highly unlikely to leach COPCs at concentrations that could result in exceedances of drinking water standards for projects located near surface water bodies of a medium or large size (Table 4.7).

## 4.2 Ecological

### 4.2.1 Embankments (Near a Surface Water Body)

#### **Health-Protective Leachate Concentration**

This risk evaluation developed health-protective leachate concentrations for aquatic receptors in surface water for two embankment sizes that are constructed with CLSM containing fly ash: 100 ft. by 100 ft. and 300 ft. by 300 ft. Specifically, this evaluation calculated health-based leachate concentrations that would not be expected to result in an exceedance of ecological standards (Table 4.8) in a surface water body located 25 ft. from an embankment for 90% of the EPACMTP modeling scenarios. The dilution that occurs as groundwater is discharged into a surface water body was calculated for three different sizes of surface water bodies based on a national distribution of surface water body sizes considered as part of US EPA's 2014 CCR Risk Assessment (US EPA, 2014a). The small water body was represented using the 25<sup>th</sup> percentile size with a flow rate of 1.8 cfs, medium was represented using the 50<sup>th</sup> percentile with a flow rate of 19 cfs, and large was represented using the 90<sup>th</sup> percentile with a flow rate of nearly 28,000 cfs (see Appendix C for further details). For perspective, these health-protective leachate concentrations were compared to median fly ash leachate concentrations and the US EPA-reported 90<sup>th</sup> percentile CCP pore water concentrations, as described in Section 3.2.

СОРС	Level (mg/L)	Basis <sup>a</sup>
Antimony	0.19	EPA R4
Arsenic	0.15	EPA R4
Barium	0.22	EPA R4
Beryllium	0.011	EPA R4
Boron <sup>b</sup>	7.2	EPA R4
Cadmium	0.00072	NRWQC
Chromium	0.074	NRWQC
Chromium (VI)	0.011	NRWQC
Cobalt	0.019	EPA R4
Fluoride	2.7	EPA R4
Lead	0.0032	NRWQC
Lithium	0.44	EPA R4
Mercury	0.00077	NRWQC
Molybdenum	0.80	EPA R4
Selenium	0.0050	EPA R4
Thallium	0.0060	EPA R4
Radionuclides <sup>c</sup>	(pCi/L)	
Radium 226+228	3	US DOE

Table 4.8 E	Ecological P	Protection	Levels
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Notes:

COPC = Constituent of Potential Concern; EPA R4 = US EPA Agency Region IV; ESV = Ecological Screening Value; NRWQC = National Recommended Water Quality Criterion; US DOE = United States Department of Energy; US EPA = United States Environmental Protection Agency.

(a) Ecological benchmarks (cadmium, total chromium, chromium IV, lead, and mercury) are from the ecological NRWQC for freshwaters (US EPA, 2019). In the absence of NRWQC, US EPA Region IV ESVs were used (US EPA Region IV, 2018).

(b) Boron was originally listed as an Appendix III constituent in the CCR Federal Rule, but will be added to Appendix IV as part of Phase II.

(c) For the radionuclides, the chronic benchmarks are from US DOE (2019).

#### Risk Conclusions – 100 Ft. by 100 Ft. Embankment

As presented in Table 4.9, for all surface water body sizes located 25 ft. downgradient of a 100 ft. by 100 ft. embankment constructed with CLSM containing fly ash, the health-protective leachate concentrations are at least 45 times greater than median fly ash leachate concentration and at least 3 times greater than the US EPA-reported 90<sup>th</sup> percentile CCP pore water concentrations (EPRI, 2006 and US EPA, 2014a).

#### Risk Conclusions – 300 Ft. by 300 Ft. Embankment

Constituent-specific health-protective leachate levels for a 100 by ft. 100 ft. embankment (with a nearby surface water body) and a summary of risk implications are described below and summarized in Tables 4.9 and 4.10.

Health-protective leachate concentrations for all COPCs are less than the modeled health-protective leachate concentrations. This means an embankment constructed with CLSM containing fly ash with typical leachate concentrations would not result in concentrations above standards protective of aquatic receptors in a nearby surface water body. The only COPCs for which the US EPA-reported 90<sup>th</sup> percentile pore water concentrations are greater than the modeled health-protective concentrations in a small surface water body are cadmium and selenium (0.06 vs. 0.02 mg/L and 0.32 vs. 0.13 mg/L, respectively). The health-protective leachate concentrations for all COPCs in medium and large surface water bodies are far greater than the US EPA-reported 90<sup>th</sup> percentile pore water concentrations. This means that even for an embankment constructed with CLSM containing fly ash with high-end leachate concentrations, there would not be any resulting surface water concentrations above standards protective of aquatic receptors for medium and large surface water bodies. For the medium surface water body, the health-protective CLSM leachate concentrations are at least 57 times greater than median fly ash leachate concentrations and at least four times greater than the US EPA-reported 90<sup>th</sup> percentile CCP pore water concentrations (EPRI, 2006 and US EPA, 2014a). For the large surface water body, the health-protective CLSM leachate concentrations are at least 5,000 times greater than the US EPA-reported 90<sup>th</sup> percentile CCP pore water concentrations (EPRI, 2006 and US EPA, 2014a).

	Health-Protective					<b>FPRI</b> <sup>b</sup>	LIS FPA <sup>c</sup>	
			Leachate Con	centrations <sup>a</sup>				
		100 Ft. x 100 Ft.			300 Ft. x 300 Ft	t.	Leachate	Impoundment
Steam Size	Small	Medium	Large	Small	Medium	Large	Median <sup>d</sup>	90 <sup>th</sup> Percentile
COPCs (mg/L)	Sinan	Mediam	Luige	Shan	inculum	Luige	inculari	50 Tercentile
Antimony	39	417	>10,000	5.0	52	>10,000	0.0024	0.04
Arsenic (III) <sup>e</sup>	31	330	>10,000	3.9	41.4	>10,000	0.00037	0.78
Barium	49	520	>10,000	5.86	61.8	>10,000	1.08	0.21
Beryllium	2.7	28	>10,000	0.31	3.2	4,782	0.0004	0.001
Boron <sup>f</sup>	1,494	>10,000	>10,000	188	1,982	>10,000	2.16	97.8
Cadmium	0.22	2.4	3,481	0.02	0.2	341	0.0015	0.06
Chromium	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000		
Total <sup>e,g</sup>							0.0006	0.2
Chromium VI	2.3	24	>10,000	0.29	3.0	4,438	0.0007	NA
Cobalt	5.4	57	>10,000	0.56	5.9	8,627	0.001	0.05
Fluoride	563	5,939	>10,000	69.63	735	>10,000	NA	21.3
Lead	>10,000	>10,000	>10,000	8,835	>10,000	>10,000	0.0002	0.1
Lithium <sup>h</sup>	126	1,325	>10,000	12.9	136	>10,000	0.129	0.45
Mercury	0.17	1.8	2,633	0.02	0.22	322	0.0000038	0.000007
Molybdenum	165	1,744	>10,000	20.6	218	>10,000	0.405	7.1
Selenium <sup>e</sup>	1.0	11	>10,000	0.13	1.4	2,003	0.019	0.32
Thallium	1.2	13	>10,000	0.16	1.6	2,417	0.00036	0.003
Radionuclides (p	Ci/L)							
Radium <sup>i</sup>	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	NA	NA

#### Table 4.9 Surface Water to Ecological Receptors – Embankments

Notes:

**Bolding** = Indicates values less than the 90<sup>th</sup> percentile pore water concentrations; COPC = Constituent of Potential Concern; DAF = Dilution Attenuation Factor; EPRI = Electric Power Research Institute; Kd = Soil-Water Partitioning Coefficient; NA = Not Available; US EPA = United States Environmental Protection Agency.

(a) Health-protective leachate concentrations are calculated as the COPC-specific-drinking water standard multiplied by the DAFs presented in Appendix C.

(b) Median field leachate concentrations from fly ash and bottom ash containment facilities (EPRI, 2006).

(c) 90<sup>th</sup> percentile pore water concentrations from whole waste impoundments (US EPA, 2014a).

(d) Beryllium and lead were not detected in the median samples; the detection limits are shown.

(e) United States Environmental Protection Agency Composite Model for Leachate Migration with Transformation Products (EPACMTP) does not model total arsenic, chromium, or selenium. Instead total concentrations for these metals were modeled using arsenite (As[III]), trivalent chromium (Cr[III]), and selenite Se(IV).

(f) Distribution of Kd value for boron was adopted from US EPA (2014a) Table H-3-1.

(g) Benchmarks for total chromium are based on values for trivalent chromium.

(h) No sorption was simulated for lithium.

(i) Kd value was calculated for radium using Equation from Sheppard *et al.* (2009).

	100 Ft. x 100 Ft.		300 Ft. x 300 Ft.		
Surface Water Body Size	Measured Fly Ash Leachate – 50 <sup>th</sup> Percentile	Measured Pore Water Leachate — 90 <sup>th</sup> Percentile	Measured Fly Ash Leachate – 50 <sup>th</sup> Percentile	Measured Pore Water Leachate — 90 <sup>th</sup> Percentile	
Small	No Risk Concerns: <sup>a</sup> Measured fly ash leachate concentrations are 45 to >10,000 times lower than modeled CLSM health-protective leachate concentrations.	No Risk Concerns: Measured pore water leachate concentrations are 3 to >10,000 times lower than modeled CLSM health- protective leachate concentrations.	No Risk Concerns: Measured fly ash leachate concentrations are 5 to >10,000 times lower than modeled CLSM health- protective leachate concentrations.	Minimal Risk Concerns: <sup>b</sup> Measured pore water leachate concentrations for cadmium and selenium are higher (about 2.5 times) than modeled CLSM health- protective leachate concentrations. For the remaining COPCs, the measured fly ash leachate concentrations are 2 to >10,000 times lower than CLSM health- protective leachate concentrations.	
Medium	No Risk Concerns: Measured fly ash leachate concentrations are 480 to >10,000 times lower than modeled CLSM health-protective leachate concentrations.	No Risk Concerns: Measured pore water leachate concentrations are 34 to >10,000 times lower than modeled CLSM health- protective leachate concentrations.	No Risk Concerns: Measured fly ash leachate concentrations are 57 to >10,000 times lower than modeled CLSM health- protective leachate concentrations.	No Risk Concerns: Measured pore water leachate concentrations are 4-10,000 times lower than modeled CLSM health- protective leachate concentrations.	
Large	No Risk Concerns: Measured fly ash leachate concentrations are >10,000 times lower than modeled CLSM health- protective leachate concentrations.	No Risk Concerns: Measured pore water leachate concentrations are >10,000 times lower than modeled CLSM health-protective leachate concentrations.	No Risk Concerns: Measured fly ash leachate concentrations are > 10,000 times lower than modeled CLSM health-protective leachate concentrations.	No Risk Concerns: Measured pore water leachate concentrations are >5,000 times lower than modeled CLSM health- protective leachate concentrations.	

Table 4.10 Modeled Health-Protective (Ecological) Leachate for Different-Size Surface Water Bodies vs. Measured Leachates – Embankments

Notes:

CLSM = Controlled Low Strength Material; COPC = Constituent of Potential Concern.

(a) "No risk concerns" indicate that measured leachates (used as proxies for CLSM leachates) were below the application-specific health-protective leachate levels.

(b) "Minimal Risk Concerns" indicates that measured 50<sup>th</sup> percent fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was a small (<3-fold) exceedance at the 90<sup>th</sup> percentile for pore water.

The practical implication of these conclusions is that CLSM used as stabilization material for embankments are highly unlikely to leach COPCs at concentrations that could result in exceedances of ecological standards for projects located near surface water bodies of a medium or large size (Table 4.10). For large embankments located near small surface water bodies, and using the US EPA-reported 90<sup>th</sup> percentile pore water concentration data as a proxy for what could leach from CLSM, only cadmium and selenium have the potential to exceed ecological benchmarks. If projects of this size are proposed to be located near a surface water body, it was concluded that this would present minimal risk concerns.

## 4.3 Worker Exposure-Fugitive Dust

## 4.3.1 Conduit Trenches and Embankments

## **Health-Protective Screening Levels**

Workers were assumed to be exposed to particulates or dust generated from activities that involve excavating CLSM from a trench with a backhoe and dumping the CLSM into a truck. The health-protective levels protective of worker exposure to CLSM fugitive dust were derived using an approach consistent with the approach used for US EPA RSLs for construction workers, and using the equations in the US EPA "Regional Screening Levels (RSLs) User's Guide" (US EPA, 2020b 220-10708) (Appendix Table B.1). The only difference was the focus on dumping and excavating (*i.e.*, grading, dozing, and tilling were not considered when calculating fugitive dust air concentrations). The exposure scenario used an exposure frequency of 20 days/year, with an exposure duration of 10 years and was specific to the excavating and dumping activities.

In order to estimate potential exposures to dust generated by these periodic construction activities, a sitespecific particulate emissions factor (PEF) was derived using the equations presented in US EPA's soil screening guidance (US EPA, 2002) (Appendix Table B.2). The PEF for excavating and dumping activities depends on several factors, including the areal extent of the activity, the frequency of the activity, and the soil characteristics (*e.g.*, moisture content, soil density, silt content). This risk evaluation assumed a daily excavation area of approximately 44,000 square feet (one acre), and that construction activities occur on 25% of the project at one time (10,890 sq. ft). CLSM-specific estimates were used for the moisture content and material density (Rhodes, 2020). It was assumed that excavation of the project would occur to a depth of three ft. (approximately one meter). US EPA default values were used for the other inputs. Based on these assumptions, a PEF of  $1.0 \times 10^{11} \text{ m}^3/\text{kg}$  was calculated. It is noteworthy that while CLSM-specific activities were used to calculate fugitive dust concentrations, we used the default incidental ingestion rate for a construction worker of 330 mg/day.

### **Risk Conclusions**

As demonstrated in Table 4.11, both the 50<sup>th</sup> and 90<sup>th</sup> percentile CCP concentrations are nearly all lower than the COPC concentrations in CLSM that are protective of human health. The one exception is thallium, where the 90<sup>th</sup> percentile concentration in fly ash reported by EPRI is 1 mg/kg higher than the CLSM health-protective screening level; however the US EPA reported 90<sup>th</sup> percentile CCP concentrations in fly ash (50<sup>th</sup> percentile) are over 20 times lower than the health-protective screening level for workers. Bulk concentrations of several fly ash samples and one CLSM mixture (with 13% fly ash) were identified during the CLSM literature review are included in Appendix A.

COPC (mg/kg)	Construction Worker Health-Protective Bulk CLSM Screening Level (mg/kg)	50 <sup>th</sup> Percentile <sup>a</sup> (mg/kg)	90 <sup>th</sup> Percentile <sup>a</sup> (mg/kg)	90 <sup>th</sup> Percentile CCPs <sup>b</sup> (mg/kg)
Antimony	1,770	7	16	47
Arsenic	297	71	261	106
Barium	884,564	923	5,064	1,103
Beryllium	8,848	11	26	18.3
Boron	884,841	322	1,018	388
Cadmium	3,921	1	6	3.8
Chromium (Total)	6,636,364	133	298	153
Chromium VI	619	NA	NA	NA
Cobalt	168	8	101	65.9
Fluoride	176,969	NA	NA	25
Lead	800	49	143	75.3
Lithium	8,848	NA	NA	NA
Mercury	1,327	0	1	1.1
Molybdenum	22,121	19	60	31
Selenium	22,121	11	18	18.2
Thallium	44	2	45	33.9
Radionuclides (pCi/	/kg)			
Radium 226	7,000	NA	NA	NA
Radium 228	12,600	NA	NA	NA
Notes				

Table 4.11 Worker Risks – Conduit Trench and Embankment Excavation

Notes:

CCP = Coal Combustion Product; CCR = Coal Combustion Residual; CLSM = Controlled Low Strength Material; COPC = Constituent of Potential Concern; EPRI = Electric Power Research Institute; NA = Not Analyzed; US EPA = United States Environmental Protection Agency.

(a) EPRI (2010). EPRI's reported bulk concentration data for fly ash are included here.

(b) US EPA (2014a). Values for "whole waste" from US EPA (2014a). Data from CCPs at the time of generation from US EPA CCR constituent database.
# 5 Limitations, Uncertainties, and Additional Discussion Points

While CLSM can be used in a variety of construction applications, this risk evaluation focuses on two key uses: conduit trenches and roadway embankments. Because of the lack of a robust data set for CLSM leachate, this risk evaluation developed health-protective CLSM bulk and leachate concentrations that are protective of human health and ecological receptors for representative construction scenarios. The section below provides further perspective on the approach and the evaluation methods. In general, uncertainties inherent in the risk characterization were accounted for by overestimating risks with health-protective assumptions. Several sources of uncertainty and their potential impact on the risk characterization are discussed below.

#### **CLSM Construction Scenarios**

- Health-protective leachate levels were presented for a conduit trench scenario 20 ft. wide and one mile long. In an analysis not presented in this report, it was determined that the length of a conduit trench does not cause a meaningful impact on calculated health-protective leachate concentrations. Consequently, the results presented in this evaluation can be considered applicable to conduit trenches longer than 1 mile. Health-protective leachate concentrations are more sensitive to the width of the trench. A conduit trench with a 20 ft. width is significantly larger than a trench that would be typical in a residential area. Condit trenches wider than 20 ft. may require site-specific analysis if CLSM leachate concentrations are similar or higher than the 90<sup>th</sup> percentile US EPA-reported pore water concentrations for CCPs.
- This risk evaluation calculates and presents health-protective leachate concentrations for the specific use of CLSM in a conduit trench or embankment, which are expected to be the CLSM applications that have the greatest potential environmental impact because the CLSM is not covered with or contained within an impermeable barrier. Other CLSM applications that include a cover or containment of the CLSM by an impermeable barrier, would be associated with lower potential drinking water and ecological risks (*i.e.*, have higher health-protective leachate concentrations). Additionally, uses with smaller surface areas (particularly with respect to width perpendicular to a downgradient well) than modeled here would also be associated with less risk (*i.e.*, have higher health-protective leachate concentrations).

#### **Constituents of Potential Concern**

This evaluation developed health-protective bulk CLSM and CLSM leachate concentrations for all of the Appendix IV constituents. Based on the limited available CLSM data as well as fly ash constituent concentrations data, it is likely that only a small set of these constituents have the potential to pose a risk. Based on the literature review of CLSM data, the constituents that were most likely to pose a risk are arsenic and molybdenum, which were measured in CLSM leachates using the ASTM method above drinking water standards. Interestingly, this observation (from the laboratory studies) was also consistent with the results of this risk evaluation, which suggested arsenic and molybdenum are the two constituents most likely to exceed a human health-protective value.

#### **Modeling Approach**

- The EPACMTP modeling approach estimates the loading of the constituents into the subsurface based on the surface area of the CLSM and infiltration and does not expressly consider the volume of the CLSM. This is a conservative approach because it assumes that the CLSM provides an infinite source of leachate (*i.e.*, that the constituents will not fully leach out within the model simulation period). If leaching were limited by the total mass available, downgradient groundwater concentrations would likely decline over time as the concentrations in the leachate would also declined.
- A probabilistic, Monte Carlo modeling approach was used in EPACMTP to evaluate the dilution and attenuation of CCP constituents between the CLSM source and receptor location. The Monte Carlo approach is a statistical evaluation accounting for a range of hydrogeological characteristics, climate, and chemical properties (*i.e.*, model inputs). While these model inputs are inherently uncertain, the statistical approach considers all plausible conditions under which CLSM may be used. Using the 90<sup>th</sup> percentile modeled DAF based on 10,000 individual simulations provides a conservative estimate of likely dilution and attenuation that will occur between a CLSM source and receptor location. In more simple terms, the DAFs modeled here are developed for large majority of possible environmental conditions. Most environments will actually results in even higher DAFs and higher health-protective values.
- The health-protective leachate concentrations are based on the results of probability distributions at the 90<sup>th</sup> percentile, which provide a conservative estimate of worst-case potential risks. This is consistent with US EPA's guidance for conducting probabilistic risk assessments and evaluating probabilistic data distributions (US EPA, 2001). US EPA does not suggest using data from the extreme tails since such estimates "may be neither accurate nor plausible" (US EPA, 2001).

#### Drinking Water Risks

- Health-protective leachate concentrations were calculated as the COPC-specific drinking water standard multiplied by the DAFs presented in Appendix C. However the DAF for many COPCs in various scenarios were very high, resulting in implausible leachate concentrations. Instead of calculating plausible maximum leachate concentrations based on CLSM mass and COPC-specific solubility limits, this risk evaluation simply reports a maximum leachate concentration of >10,000 mg/L for calculated leachate concentrations of 10,000 mg/L or higher, with no consideration of mass in the CLSM or solubility limits.
- Due to the lack of a robust data on constituents in CLSM leachate, risk potential was evaluated by comparing health-protective CLSM levels to constituent levels in two measured leachate data sets median concentration data from a field study (EPRI, 2006) of fly ash leachates and US EPA-reported 90<sup>th</sup> percentile concentrations of pore water from impoundments containing "whole waste," which included fly ash and other CCPs. CLSM often contains less than 100% fly ash; thus the actual CLSM concentrations may be lower than the comparative values. Further, the addition of cement to a CLSM mixture will create a mixture that is less permeable, which will limit the leaching potential (Gaddam *et al.*, 2009, and Inyang and Gaddam, 2006). Based on a review of independent CLSM-specific LEAF data, leaching potential also decreased with the addition of more cement.
- Addition of cement to CLSM may increase the pH of the CLSM, which may alter the leaching characteristics of some constituents. Based on a limited review of independent LEAF data, a range

of chemical-specific changes in leaching potential between CLSM with no cement and samples with 5% cement was observed. For a subset of COPCs the leaching potential slightly increased; however, broad conclusions about the nature and magnitude of these changes cannot be evaluated without further investigation.

#### **Worker Risks**

- The potential for worker risks was based on CLSM excavation and disposal activities. It was assumed a worker could excavate CLSM 20 days a year (4 weeks a year) for 10 years. This exposure scenario rests on the assumption that a worker involved in excavation only occasionally encounters CLSM, and that the majority of annual work activities would involve the movement of other construction materials. This assumption was informed by practical experience with industry experts. To the extent that workers may work more than 20 days a years excavating CLSM, it is noteworthy that more typical COPC concentrations in bulk fly ash (*i.e.*, 50<sup>th</sup> percentile) are at least four times lower than health-protective levels. This suggests that under most circumstances, workers may work additional days without a risk concern.
- Due to the lack of robust data on constituents in bulk CLSM, risk potential was evaluated by comparing health-protective CLSM levels to constituent levels in CCPs. Comparing CCP to health-protective CLSM levels is conservative because CLSM often contains less than 100% fly ash. Further, the addition of cement to a CLSM mixture will create a composite in which the CLSM constituents are more "bound," which will limit the potential for fugitive dust emissions during excavation by increasing the particle sizes and by retaining moisture.
- The health-protective CLSM levels do not consider mitigation by any personal protective equipment (PPE). The health-protective levels that were developed are largely driven by incidental ingestion rates. PPE and hygiene practices that prevent incidental ingestion would allow for a greater margin of safety.

# 6 Conclusions

This report presents a beneficial use risk evaluation for the use of fly ash-based CLSM in several key construction applications. Relevant human health and ecological risks were evaluated using approaches consistent with US EPA risk evaluation guidance. The limited information on COPC concentrations (*i.e.*, Appendix IV constituents) in CLSM or CLSM leachate, the range of potential CLSM characteristics, and the variability of site-specific factors that affect leachate generation prevent the explicit use of the step-wise risk assessment approach presented in the US EPA beneficial use risk evaluation guidance. Instead, theoretical levels of constituents in bulk CLSM and CLSM leachate were developed that are protective of human health and the environment. This was accomplished using applicable human health and ecological-based benchmarks in conjunction with a US EPA probabilistic modeling approach for predicting environmental concentrations of constituents of interest (90<sup>th</sup> percentile). Table 6.1 presents a summary of the developed health-protective levels across all evaluated CLSM projects and exposure scenarios.

The health-protective levels reported here can be used by CLSM users as a guide to understand if specific CLSM projects have the potential to pose a risk concern (Table 6.2). These risk conclusions are based on a comparison of health-protective levels to COPC concentrations measured in bulk fly ash and fly ash leachate. These concentrations would be expected to be similar to CLSM comprised of 100% fly ash and are likely higher than CLSM composed of less than 100% fly ash,<sup>7</sup> particularly if the CLSM contains sufficient levels of cement, which can limit leaching.<sup>8</sup>

Overall, this evaluation reached the following key conclusions (See Table 6.2).

- The excavation and disposal of post use CLSM, does not pose a risk concern. This conclusion is based on a worker excavating and disposing of CLSM 20 days a year (*i.e.*, 4 weeks a year). While, based on typical COPC concentration in fly ash (*e.g.*, 50<sup>th</sup> percentile) it is unlikely that longer work periods would pose a risk concern, it is advisable to conduct a project and/or CLSM-specific evaluation to assess risk potential for CLSM excavation work conducted for >20 days a year for 10 years.
- The use of CLSM in conduit trenches does not pose a drinking water risk, even for a well as close as 25 ft. downgradient from the edge of the conduit trench. This conclusion is based on a conduit trench 20 ft. wide and 1 mile long. It is noteworthy that longer trenches are also unlikely be associated with a risk concern. For trenches significantly wider than 20 ft. and less than 100 ft. from a potential drinking water well, it is advisable to conduct a project and/or CLSM-specific evaluation to assess risk potential.
- The use of CLSM in embankments 100 ft. by 100 ft. without a nearby surface water body has the potential to pose a drinking water risk (for arsenic and molybdenum), if a drinking water well is as close as 100 ft. Based on this, it is advisable to confirm CLSM leachates are below the health-protective levels or conduct project/site-specific modeling. If a well is as close as 1,000 ft. from the downgradient end of the impoundment, a risk concern is less (approximately 10-fold less). It is advisable to conduct a project and/or CLSM-specific leachate assessment for larger

<sup>&</sup>lt;sup>7</sup> For CLSM mixtures composed of less than 100% fly ash, these data will likely over-predict the contributions of COPCs from fly ash, due to the presence of other materials in the CLSM (*i.e.*, cement, aggregates).

<sup>&</sup>lt;sup>8</sup> For CLSM mixtures with sufficient amounts of cement the permeability of the CLSM is reduced, which reduce the leaching potential (See Sections 3.2 and 5).

embankments (300 ft. by 300 ft. or more) that will be located within 1,000 ft. of a drinking water well.

- The use of CLSM in embankments (up to 300 ft. by 300 ft.) with a nearby surface water body does not pose a drinking water risk, even for a surface water body as close as 25 ft. downgradient from the edge of the embankment. This is applicable to embankments near medium and large surface water bodies.
- The use of CLSM in embankments (up to 300 ft. by 300 ft.) with a nearby surface water body does not pose a risk to aquatic ecological receptors, even for a surface water body as close as 25 ft. downgradient from the edge of the embankment. This is applicable to embankments near small, medium, and large surface water bodies. The one exception is for selenium and cadmium in high-end leachate concentrations (*e.g.*, those consistent with measured 90<sup>th</sup> percentile pore water leachate concentrations), which can exceed health-protective benchmarks when discharging to a small water body 25 ft. from the edge of the embankment. It is noteworthy, however, that more typical (50<sup>th</sup> percentile) leachate concentrations of selenium and cadmium do not pose a risk.

	Worker		ondit Tron	~h	Embai	nkment	Embar	nkment	Embankment		Embankment (300 Ft x 300 Ft )		
СОРС	HPL	Drin	king Water	. HPL	No Nea	arby SW	– No Nearby SW		– Near	by SW	– Nearby SW		
	(mg/kg)		(mg/L)⁵		Drinking	Drinking Water HPL		Drinking Water HPL		Vater HPL	E	cological HP	L
					(mg	g/L) <sup>⊾</sup>	(mg	ς/L) <sup>♭</sup>	(mg/L) <sup>b</sup>		(mg/L) <sup>b</sup>		
		25 Ft.	100 Ft.	1,000 Ft.	100 Ft.	1,000 Ft.	100 Ft.	1,000 Ft.	Medium SW	Large SW	Small SW	Medium SW	Large SW
Antimony	1,770	10	14	85	0.04	0.42	0.01	0.07	1.65	2,433	5.0	52	>10,000
Arsenic	297	17	23	142	0.07	0.7	0.02	0.13	2.76	4,066	3.9	41.4	>10,000
Barium	883,940	3,546	4,662	>10,000	14	158	4	29	562	>10,000	5.86	61.8	>10,000
Beryllium	8,846	8	10	65	0.03	0.4	0.008	0.067	1.18	1,739	0.31	3.2	4,782
Boron	884,826	6,475	9,810	>10,000	25	314	7	57	1,101	>10,000	188	1,982	>10,000
Cadmium	3,920	11	14	101	0.06	0.7	0.012	0.125	1.61	2,366	0.02	0.2	341
Chromium (Total)	6,636,364	>10,000	>10,000	>10,000	3315	3520	467	1372	>10,000	>10,000	>10,000	>10,000	>10,000
Chromium VI	619	86	113	704	0.3	3.5	0.1	0.6	13.71	>10,000	0.29	3.0	4,438
Cobalt	168	13	16	111	0.06	0.7	0.013	0.128	1.85	2,724	0.56	5.9	8,627
Fluoride	176,968	6,658	9,040	>10,000	26	273	7	49	1,089	>10,000	69.63	735	>10,000
Lead	800	>10,000	>10,000	>10,000	4920	>10,000	1348	>10,000	>10,000	>10,000	8,835	>10,000	>10,000
Lithium	8,848	71	99	581	0.4	4	0.08	0.70	12.34	>10,000	12.9	136	>10,000
Mercury	1,327	4	5	31	0.01	0.17	0.004	0.03	0.57	838	0.02	0.22	322
Molybdenum	22,121	169	224	1,404	0.65	7	0.17	1.22	27.19	>10,000	20.6	218	>10,000
Selenium	22,121	84	111	702	0.33	3.41	0.09	0.61	14	>10,000	0.13	1.4	2,003
Thallium	44	3	5	28	0.01	0.14	0.003	0.025	0.55	806	0.16	1.6	2,417
Radionuclides	(pCi/kg)												
Radium 226	7,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
Radium 228	13,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000

Table 6.1 Summary of Health-Protective Levels for Evaluated Exposure Scenarios<sup>a</sup>

COPC = Constituent of Potential Concern; HPL = Health-Protective Level; SW = Surface Water.

(a) Health-protective concentrations for each scenario are presented in full in Section 4.

(b) Units in pCi/L for radionuclides.

worker Risk – Applicable to Excavating CLSW under Multiple Applications									
<b>Exposure Duration</b>	Measured Bulk Fly Ash – 50 <sup>th</sup> Percentile	Measured Bulk Fly Ash – 90 <sup>th</sup> Percentile							
20 days/year for	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
10 years									
Drinking Water Risk – Conduit Trench									
Well Distance	Measured Fly Ash Leachate	Measured Pore Water Leachate							
Well Distance	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile							
25 ft.	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
100 ft.	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
1,000 ft.	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
Drinking	; Water Risk – Embankment – No Nearby Sur	face Water Body – 100 Ft. x 100 Ft.							
Well Distance	Measured Fly Ash Leachate	Measured Pore Water Leachate							
	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile							
100 ft.	No Risk Concerns <sup>a</sup>	Consider Additional Evaluation <sup>b</sup>							
1,000 ft.	No Risk Concerns <sup>a</sup>	Minimal Risk Concerns <sup>c</sup>							
Drinking	; Water Risk – Embankment – No Nearby Sur	face Water Body – 300 Ft. x 300 Ft.							
Wall Distance	Measured Fly Ash Leachate	Measured Pore Water Leachate							
	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile							
100 ft.	Minimal Risk Concerns <sup>c</sup>	Consider Additional Evaluation <sup>b</sup>							
1,000 ft.	No Risk Concerns <sup>a</sup>	Consider Additional Evaluation <sup>b</sup>							
Drinkir	ng Water Risk – Embankment – Nearby Surfa	ce Water Body – 300 Ft. x 300 Ft.							
Surface Water Size	Measured Fly Ash Leachate	Measured Pore Water Leachate							
Surface Water Size	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile							
Medium	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
Large	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
Ecol	ogical Risk – Embankment – Nearby Surface	Water Body – 300 Ft. x 300 Ft.							
Surface Water Size	Measured Fly Ash Leachate	Measured Pore Water Leachate							
Surface Water Size	– 50 <sup>th</sup> Percentile	– 90 <sup>th</sup> Percentile							
Small	No Risk Concerns <sup>a</sup>	Minimal Risk Concerns <sup>c</sup>							
Medium	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							
Large	No Risk Concerns <sup>a</sup>	No Risk Concerns <sup>a</sup>							

 Table 6.2 Summary of CLSM Application Risk Potential for Evaluated Exposure Scenarios

CLSM = Controlled Low Strength Material.

(a) "No risk concerns" indicate that measured fly ash leachates (used as proxies for CLSM leachates) were below the application-specific health-protective leachate levels.

(b) "Consider Additional Evaluation" indicates that measured 50<sup>th</sup> percentile fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was an exceedance at the 90<sup>th</sup> percentile measured pore water level. To address the potential risk concern, performance of CLSM leaching tests and/or project-specific fate and transport modeling should be considered.

(c) "Minimal Risk Concerns" indicates that measured 50<sup>th</sup> percent Fly ash leachate (used as a proxy for CLSM leachate) was below the application-specific health-protective leachate level, but there was a small (<3-fold) exceedance at the 90<sup>th</sup> percentile.

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# Appendix A

Literature Review of CLSM Leaching Studies

# List of Tables

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	Bland,	Naik, 1998			
Appendix IV Constituents (mg/kg)	Ready-Fill	Heskett		Ach P	
	S Grade	Fly Ash	ASILA	ASILD	
Antimony	< 0.1	< 0.1	7.9	2.9	
Arsenic	6.95	21.65	306	113.7	
Barium	NA	NA	187.4	61.7	
Beryllium	0.26	1.5	3.7	19	
Boron	68	464	79	78	
Cadmium	0.13	0.33	<1520.5	<585.6	
Chromium	6.6	10.2	75.5	26.7	
Chromium VI	NA	NA	NA	NA	
Cobalt	2.9	3.45	46.4	7	
Fluoride	NA	NA	2.5	13	
Lead	4.55	11.8	33	18	
Lithium	NA	NA	NA	NA	
Mercury	< 0.123	0.6058	27.3	4	
Molybdenum	1.95	3	<66.3	125.7	
Selenium	< 0.2	1.78	673	223.3	
Thallium	< 0.1	0.2	1.3	<0.3	
Radionuclides (pCi/kg)					
Radium 226+228	0.39	0.275	NA	NA	

Table A.1 Bulk Concentrations Reported in CLSM Leaching Literature Review

NA= Not Analyzed. Values that were not detected are reported as less than the detection limit.

Bolding indicates the concentration is above health-protective screening level for the construction worker, see Table 4.11.

(a) Bland (2003). Reported bulk concentrations in the fly ash used as well as in the structural fill material made with 13% fly ash.

(b) Naik (1998). Reported bulk concentrations in fly ash used in various CLSM mixtures tested.

#### Table A.2 Leaching Study Literature Review

			CLSMs Tested		Observations			
Method	Studies	Fly Ash	Cement	Agg.	Method	Exceedance of Potential Screening Limit (SL)?		
TCLP (Granular <i>,</i>	Do <i>, et al .,</i> 2019 (Korea)	93-94%*	6-7%	None	<ul> <li>Only As, Cd, Cr, Pb reported</li> <li>Ponded Ash (~75%) + Fly Ash (~20%)</li> </ul>	•Most are significantly higher		
Solution pH = 5)	Türkel <i>,</i> 2006 (Turkey)	15- 25%	1%	75-86%	•8 RCRA metals reported	<ul> <li>All except chromium above potential drinking water SL</li> <li>Silver was ND</li> </ul>		
	Bland, 2003 (North Dakota)	13-14%	2-6%	81-84%	•8 RCRA metals reported	<ul> <li>Select mixtures above As SL</li> <li>Cr and Se detection limits too high</li> </ul>		
ASTM (Granular, no pH adjustment)	Naik, <i>et al .,</i> 1998 and 2001 (Wisconsin)	14-100%	2-5%	0-84%	•25 metals reported	<ul> <li>Most below, only As and Mo above</li> <li>Ash itself has high As</li> </ul>		
	Bland, 2003 (North Dakota)	13-14%	2-6%	81-84%	<ul> <li>19 metals + radioactivity reported</li> <li>Aids in comparison to TCLP</li> </ul>	•As is below, Mo not included		
Modified LEAF 1315 (Monolith)	Mneina, 2017	8%	3-5%	74-85%	<ul> <li>Shortened US EPA method (28 vs 63 days)</li> <li>Also contains 5-15% treated oil sand waste</li> </ul>	•None for 6 metals		

#### Notes:

Agg. = Aggregate; As = Arsenic; ASTM = American Society for Testing and Materials; Cd = Cadium; CLSM = Controlled Low Strength Material; Cr = Chromium; Mo = Molybdenum; LEAF = Leaching Environmental Assessment Framework; ND = Not Detected; Pb = Lead; RCRA = Resource Conservation and Recovery Act; SL = Drinking water protective level; TCLP = Toxicity Characteristic Leaching Procedure; US EPA = United States Environmental Protection Agency.

#### Table A.3 TCLP Study Results

Composition	Do et al ., 2019	Türkel, 2006	Bland, 2003		
% Elv Ach	75% Ponded;	15 to 25%	~15% Ely Ash		
70 FIY ASI	20% Fly Ash	Class C Fly Ash	1370 Fly ASI		
% Cement	6-7% Varied	1% Pozzolanic	2-6% Portland		
Constituent (mg/L)					
Arsenic	0.06- <b>0.21</b>	2.08-2.54	0.06- <b>0.016</b>		
Barium	Not Reported	17.06-17.84	0.4-0.75		
Cadmium	<0.01-0.03	0.09-0.12	<0.01		
Chromium	0.16 - 0.54	0.03-0.08	<0.008-0.021		
Lead	0.01- <b>0.28</b>	0.28-0.39	<0.01		
Mercury	Not Reported	0.085-0.11	<0.002		
Selenium	Not Reported	0.22-0.32	<0.2		
Silver	Not Reported	ND	<0.01		
Study Information					
Number of Samples	12	3	2		
Country	Korea	Turkey	US		

Notes:

ND = Not Detected; TCLP = Toxicity Characteristic Leaching Procedure.

Bolding indicates concentrations above drinking water protection level, see Table 4.1.

Table A.4 TCLP and ASTM Study Results<sup>a</sup>

	TCLP F	Results	ASTM Results						
Constituent	MDU Grade	MDU Grade	Heskett Fly	WRI	Ready-Fill E	Ready-Fill S			
	E	S	Ash	(20:1)	(4:1)	(4:1)			
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)			
Fly Ash (%)	14%	13%	100%	Not given	7%	11%			
Cement (%)	2%	6%	None	None Not given		2-5%			
Arsenic	0.016	0.006	<0.002	<0.002	0.0064	0.0076			
Barium	0.444	0.753	0.215	0.465	0.2	0.12			
Cadmium	All ND	<0.01	All ND <0.0002						
Chromium	<0.008	0.021	0.009	0.019*	0.0021	0.0091			
Lead	<0.1	<0.1	0.0111	0.0078	< 0.002	<0.002			
Mercury			All ND <0.0002						
Selenium	<0.2	<0.2	0.0149	<0.002	0.0056	0.0099			

ASTM = American Society for Testing and Materials; MDU = Montana-Dakota Utilities; ND = Not Detected;

TCLP = Toxicity Characteristic Leaching Procedure; WRI = Western Research Institute.

Bolding indicates concentrations above drinking water protection level, see Table 4.1.(a) Bland (2003). Overall results for 19 constituents are presented, see Table A.7.

Table A.5	ASTM Stuc	ly Results <sup>a</sup>
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Constituent (mg/L)			Fly Ash 1 (F1)		Fly Ash 2 (F2)			
	Mix 2	Mix 5	F1	S1-2	S4-2	F2	P1-8	P3-2
Fly Ash (%)	50% Ash A + 50% Ash B	25% Ash B + 75% Ash A	100% Ash	64%	24%	100% Ash	53%	35%
Cement (%)	None	None	None	3%	2%	None	5%	3%
Arsenic	<0.005	<0.005	NR	<0.001	<0.001	0.074	0.042	0.055
Barium	0.13	0.11	NR	0.79	0.43	0.12	0.039	0.037
Cadmium	0.0001	0.0001	NR		/	All ND <0.0002	2	
Chromium	0.0016	0.0027	NR	0.036	0.036	0.051	0.01	0.014
Lead	0.006	<0.005	NR	<0.001	< 0.001	< 0.001	<0.001	< 0.001
Mercury			NR		/	All ND <0.0002	2	
Selenium			NR	0.008	0.005	0.014	0.033	0.022

ASTM = American Society for Testing and Materials; ND = Not Detected; NR = Not Reported.

Bolding indicates concentrations above drinking water protection level, see Table 4.1.

(a) Naik et al . (1998, 2001).

Leachate (mg/L)	G260W15	G290W15
Arsenic	0.00167	0.00111
Barium	0.11808	0.32043
Cadmium	ND	ND
Chromium	0.03029	0.02132
Lithium	0.02197	0.03803
Strontium	1.14803	0.97709

Table A.6	Modified IFAF	Method 1315	Study Results <sup>a</sup>
	WIDUITIEU LLAI	INICLIIUU IJIJ	Judy nesults

LEAF = Leaching Environmental Assessment Framework; ND = Not Detected.

(a) Mneina, 2017.

Table A.7	<b>Human Health Screenin</b>	g Using ASTM Results
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	Human Health	100% Ash Mixtures <sup>a</sup>				Mixtures <sup>b</sup>						
Appendix IV Constituents <sup>c</sup>	Drinking Water Protection Level <sup>d</sup>	Mix 1	Mix 3	Mix 5	Fly ash, F2	S1-2	S4-2	P1-8	P3-2	WRI Flowable Fill 20:1 Extract	Ready-Fill E 4:1 Extract	Ready-Fill S 4:1 Extract
Metals (mg/L)												
Antimony	0.0060	<0.004	<0.004	<0.004							<0.002	<0.002
Arsenic	0.010	<0.005	<0.005	<0.005	0.074	<0.001	<0.001	0.042	0.055	<0.002	0.0064	0.0076
Barium	2.0	0.19	0.13	0.11	0.12	0.79	0.43	0.039	0.037	0.465	0.2	0.12
Beryllium	0.0040	<0.001	<0.001	<0.001						<0.0002	< 0.0002	<0.0002
Boron	4.0	<0.004	<0.004	<0.004						0.14	0.76	0.42
Cadmium	0.0050	<0.0001	<0.0001	<0.0001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	< 0.0002
Chromium <sup>e</sup>	0.10	0.0021	0.0016	0.0027	0.051	0.036	0.036	0.01	0.014	0.19	0.0021	0.0091
Chromium VI <sup>f</sup>	0.050											
Cobalt	0.0060	<0.008	<0.008	<0.008						<0.002	<0.1	<0.1
Fluoride	4.0	0.92	0.61	<0.25						0.16	0.43	0.49
Lead	0.015	<0.005	0.006	<0.005	< 0.001	<0.001	<0.001	<0.001	<0.001	0.0078	<0.002	<0.002
Lithium	0.040											
Mercury	0.0020	<0.0002	<0.0002	<0.0002						<0.0002	<0.0002	<0.0002
Molybdenum	0.10	0.65	0.61	0.38								
Selenium	0.050	<0.0008	<0.0008	<0.0008	0.014	0.008	0.005	0.033	0.022	<0.002	0.0056	0.0099
Thallium	0.0020	<0.001	<0.001	<0.001							< 0.002	<0.002
Radionuclides (pCi/L)												
Combined Radium 226 + 228 <sup>g</sup>	5.0											

Blank = Not analyzed; ASTM = American Society for Testing and Materials; CCR = Coal Combustion Residual; crit = Criteria; GWPS = Groundwater Protection Standard; MCL = Maximum Contaminant Level; NA = Not Analyzed; NRWQC = National Recommended Water Quality Criterion; RSL = US EPA Regional Screening Level; Rule = US EP Alternative Risk-based GWPS; US EPA = United States Environmental Protection Agency; WRI = Western Research Institute.

Concentrations are presented with the following formats to show cases where concentration exceeds a benchmark. In cases where a constituent is not detected, the detection was used in the screening.

**Bold** = Constituents with concentrations > Drinking Water Protection Levels.

(a) 100% Ash mixtures (Naik, 1998).

(b) Mixtures with cement (Naik, 2001; Bland, 2003).

(c) Constituents listed in Appendix IV of the Federal CCR Rule (US EPA, 2015).

(d) Drinking Water Protection Standards are from the following hierarchy of sources: Maximum Contaminant Levels (MCLs; US EPA, 2018); US EPA alternative risk-based GWPS (Rule; US EPA, 2015); US EPA residential tap water Regional Screening Levels (RSLs; US EPA, 2020).

(e) Benchmarks for total chromium are based on values for trivalent chromium.

(f) Hexavalent chromium (Cr[VI]) is not included as an Appendix IV constituent in the CCR Federal Rule, but was included in this analysis. The potential screening value is based on the approach described by Health Canada (2016).

(g) GWPS for combined radium 226+228 is the MCL for radium. For all other benchmarks, the more stringent benchmark of radium-226 and radium-228 was used.

Table A.8	Fcological	<b>Risk Screening</b>	g Using ASTM Results	
	LUDIUSICAI			

<u>_</u>	<u> </u>													
	Ecolo	gical Protection	Levels		100%	6 Ash <sup>a</sup>					Mi	xtures <sup>b</sup>		
Appendix IV Constituent <sup>c</sup>	FW Acute	FW Chronic	Basis <sup>d</sup>	Mix 1	Mix 3	Mix 5	Fly ash, F2	S1-2	S4-2	P1-8	P3-2	WRI Flowable Fill 20:1 Extract	Ready-Fill E 4:1 Extract	Ready-Fill S 4:1 Extract
Metals (mg/L)						1								
Antimony	0.90	0.19	EPA R4	< 0.004	< 0.004	< 0.004							< 0.002	< 0.002
Arsenic	0.34	0.15	EPA R4	<0.005	<0.005	<0.005	0.074	<0.001	< 0.001	0.042	0.055	< 0.002	0.0064	0.0076
Barium	2.0	0.22	EPA R4	0.19	0.13	0.11	0.12	0.79	0.43	0.039	0.037	0.465	0.2	0.12
Beryllium	0.093	0.011	EPA R4	< 0.001	< 0.001	<0.001						< 0.0002	< 0.0002	< 0.0002
Boron	34	7.2	EPA R4	<0.004	< 0.004	<0.004						0.14	0.76	0.42
Cadmium	0.0018	0.00072	NRWQC	< 0.0001	< 0.0001	< 0.0001	< 0.0002	<0.0002	<0.0002	<0.0002	<0.0002	< 0.0002	< 0.0002	< 0.0002
Chromium <sup>e</sup>	0.57	0.074	NRWQC	0.0021	0.0016	0.0027	0.051	0.036	0.036	0.01	0.014	0.19	0.0021	0.0091
Chromium VI <sup>f</sup>	0.016	0.011	EPA R4											
Cobalt	0.12	0.019	EPA R4	<0.008	<0.008	<0.008						<0.002	<0.1	<0.1
Fluoride	9.8	2.7	EPA R4	0.92	0.61	<0.25						0.16	0.43	0.49
Lead	0.082	0.0032	NRWQC	<0.005	0.006	<0.005	< 0.001	<0.001	< 0.001	< 0.001	< 0.001	0.0078	< 0.002	< 0.002
Lithium	0.91	0.44	EPA R4											
Mercury	0.0014	0.00077	NRWQC	< 0.0002	<0.0002	< 0.0002						< 0.0002	< 0.0002	< 0.0002
Molybdenum	7.2	0.80	EPA R4	0.65	0.61	0.38								
Selenium	0.020	0.0050	EPA R4	<0.0008	<0.0008	<0.0008	0.014	0.008	0.005	0.033	0.022	< 0.002	0.0056	0.0099
Thallium	0.054	0.0060	EPA R4	<0.001	<0.001	<0.001							< 0.002	< 0.002
Radionuclides (pCi/L)														
Combined Radium 226+228 <sup>g</sup>	NC	3.0	US DOE											
Radium-226	NC	4.0	US DOE											
Radium-228	NC	3.0	US DOE											
Madaa						-				-				

ASTM = American Society for Testing and Materials; CCR = Coal Combustion Residual; EPA R4 = US EPA Region IV; ESV = Ecological Screening Value; FW = Freshwater; NC = No Criteria; NRWQC = National Recommended Water Quality Criterion; US DOE = United States Department of Energy; US EPA = United States Environmental Protection Agency; WRI = Western Research Institute.

Concentrations are presented with the following formats to show cases where concentration exceeds a benchmark. In cases where a constituent is not detected, the detection was used in the screening.

**Bold** = Constituents with concentrations > Acute Benchmark

(a) 100% ash mixtures (Naik, 1998).

(b) Mixtures with cement (Naik, 2001; Bland (2003).

(c) Constituents listed in Appendix IV of the Federal CCR Rule (US EPA, 2015).

(d) Ecological benchmarks (cadmium, total chromium, chromium III, lead, and mercury) are from the ecological NRWQC for freshwaters (US EPA, 2019). In the absence of NRWQC, US EPA Region IV ESVs were used (US EPA Region IV, 2018). For the radionuclides, the chronic benchmarks are from US DOE (2019).

(e) Benchmarks for total chromium are based on values for trivalent chromium.

(f) Hexavalent chromium (Cr[VI]) is not included as an Appendix IV constituent in the CCR Federal Rule, but was included in this analysis.

(g) The more stringent benchmark for radium-226 and radium-228 was used for combined radium 226+228.

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# **Appendix B**

**Construction Worker Health-Protective Screening Level Calculations** 

# List of Tables

- Table B.1Construction Worker Health-Protective Screening Levels for Fly Ash/Soil Mixture, Based<br/>on Excavation and Dumping Only
- Table B.2Particulate Emissions Factor Calculation

			Cai	ncer						Non	-Cancer					
	Тох	cicity Reference Val	ues	Incidental		la halati an	Cancer	То	xicity Reference	Values	Incidental	Damaal	la halatian	Non-Cancer	Screening	
Chemical COIs	CSF (mg/kg-d) <sup>-1</sup>	Derm. CSF (mg/kg-d) <sup>-1</sup>	IUR (μg/m <sup>3</sup> ) <sup>-1</sup>	Ingestion SL <sub>ing</sub> (mg/kg)	Dermal Contact SL <sub>derm</sub> (mg/kg)	SL <sub>inh</sub> (mg/kg)	SL (mg/kg)	RfD (mg/kg-d)	Derm. RfD (mg/kg-d)	RfC (mg/m <sup>3</sup> )	Ingestion SL <sub>ing</sub> (mg/kg)	Contact SL <sub>derm</sub> (mg/kg)	SL <sub>inh</sub> (mg/kg)	SL (mg/kg)	Benchmark (mg/kg)	Basis
Antimony	NC	NC	NC	NC	NC	NC	NC	4.0E-04	6.0E-05	3.0E-04	1.8E+03	NA	1.7E+10	1.8E+03	1.77E+03	nc
Arsenic	1.5E+00	1.5E+00	4.3E-03	3.4E+02	2.1E+03	9.2E+08	3.0E+02	3.0E-04	3.0E-04	1.5E-05	2.2E+03	1.4E+04	8.4E+08	1.9E+03	2.97E+02	С
Barium	NC	NC	NC	NC	NC	NC	NC	2.0E-01	1.4E-02	5.0E-04	8.8E+05	NA	2.8E+10	8.8E+05	8.85E+05	nc
Beryllium	NC	NC	2.4E-03	NC	NC	1.6E+09	1.6E+09	2.0E-03	1.4E-05	2.0E-05	8.8E+03	NA	1.1E+09	8.8E+03	8.85E+03	nc
Boron	NC	NC	NC	NC	NC	NC	NC	2.0E-01	2.0E-01	2.0E-02	8.8E+05	NA	1.1E+12	8.8E+05	8.85E+05	nc
Cadmium	NC	NC	1.8E-03	NC	NC	2.2E+09	2.2E+09	1.0E-03	2.5E-05	1.0E-05	4.4E+03	3.4E+04	5.6E+08	3.9E+03	3.92E+03	nc
Chromium (Total)	NC	NC	NC	NC	NC	NC	NC	1.5E+00	2.0E-02	NC	6.6E+06	NA	NC	6.6E+06	6.64E+06	nc
Chromium (Hexavalent)	5.0E-01	2.0E+01	8.4E-02	6.2E+02	NA	4.7E+07	6.2E+02	3.0E-03	7.5E-05	1.0E-04	1.3E+04	NA	5.6E+09	1.3E+04	6.19E+02	С
Cobalt	NC	NC	9.0E-03	NC	NC	4.4E+08	4.4E+08	3.0E-04	3.0E-04	6.0E-06	1.7E+02	NA	3.4E+08	1.7E+02	1.68E+02	nc
Fluoride	NC	NC	NC	NC	NC	NC	NC	4.0E-02	4.0E-02	1.3E-02	1.8E+05	NA	7.3E+11	1.8E+05	1.77E+05	nc
Lead	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	8.00E+02	BLM
Lithium	NC	NC	NC	NC	NC	NC	NC	2.0E-03	2.0E-03	NC	8.8E+03	NA	NC	8.8E+03	8.85E+03	nc
Mercury	NC	NC	NC	NC	NC	NC	NC	3.0E-04	2.1E-05	3.0E-04	1.3E+03	NA	1.7E+10	1.3E+03	1.33E+03	nc
Molybdenum	NC	NC	NC	NC	NC	NC	NC	5.0E-03	5.0E-03	NC	2.2E+04	NA	NC	2.2E+04	2.21E+04	nc
Selenium	NC	NC	NC	NC	NC	NC	NC	5.0E-03	5.0E-03	2.0E-02	2.2E+04	NA	1.1E+12	2.2E+04	2.21E+04	nc
Thallium	NC	NC	NC	NC	NC	NC	NC	1.0E-05	1.0E-05	NC	4.4E+01	NA	NC	4.4E+01	4.42E+01	nc
			Cai	ncer							Cancer					
			Toxicity Refe	erence Values											<b>C</b>	
Radionuclide COIs	Soil Ingestior (risk	n Slope Factor :/pCi)	Inha Slope (risk	lation Factor /pCi)	Exter Expos Slope F (risk/yr pe	nal ure actor r pCi/g)	Incidental In	gestion (pCi/g)	Inh (F	alation oCi/g)	External (pC	Exposure Ci/g)	Ca (pi	ncer SL Ci/g)	Benchmark (pCi/g)	Basis
Radium - 226	6.8	E-10	2.8	E-08	8.4E-	06	2.2	2E+02	9.	2E+13	7.3	E+00	7.0	E+00	7.04E+00	с
Radium - 228	2.0	E-09	4.4	E-08	4.0E-	06	7.7	7E+01	5.	8E+13	1.5	E+01	1.3	E+01	1.26E+01	С

#### Table B.1 Construction Worker Health-Protective Screening Levels for Fly Ash/Soil Mixture, Based on Excavation and Dumping Only

Notes:

ABS = Dermal Absorption; ACF = Area Correction Factor; COI = Constituent of Interest; CSF = Cancer Slope Factor; derm = Dermal Contact; ext = External; ing = Ingestion; inh = Inhalation Unit Risk; GSF = Gamma Shielding Factor; NA = Not Applicable; NC = No Criterion Available; PEF = Particulate Emission Factor; RfC = Reference Concentration; RfD = Reference Dose; SF = Slope Factor; SL = Screening Level.

Health Benchmark defined as the lower of the Screening Levels for cancer and non-cancer. The basis of the Health Benchmark presented as c = based on cancer endpoint or nc = based on non-cancer endpoint.

Screening Benchmark =		1			Radionuclide Screening Benchmark =		
	1 + SL <sub>ing</sub>	SL <sub>derm</sub>	+	1 SL <sub>inb</sub>		1 SL <sub>ing</sub>	
Non-cancer SL <sub>ing</sub> =	THQ * RfD Intake	_	Cancer SL <sub>ing</sub> =	TR Intake * CSF	Radionuclide Cancer SL <sub>ing</sub> =	Tf Intake * Adult S	
Non-cancer SL <sub>derm</sub> =	THQ * RfD Intake * ABS	_	Cancer SL <sub>derm</sub> =	TR Intake * ABS * CSF	Radionuclide Cancer SL <sub>inh</sub> =	TI Intake * Inhalati	
Non-cancer SL <sub>inh</sub> =	THQ * RfC Intake * (1/PEF)	_	Cancer SL <sub>inh</sub> =	TR Intake * IUR * (1/PEF)	Radionuclide Cancer $SL_{ext}$ =	TF Intake * ACF * G	
Target C Target Hazard C	Cancer Risk (TR) = 1E-05 Quotient (THQ) = 1						

Target Hazard Quotient (THQ) =



oil Ingestion SF

ion SF \* (1/PEF)

SF \* External SF

#### Soil – Ingestion (Chemical)

Intake Eactor (IE) -		IR x FR x EF x ED x CF	2.3E-07	3.2E-08	Bacic
		BW x AT	Non-Cancer	Cancer	
	IR	Ingestion Rate (mg/day)	330	330	Default value for Construction Worker (US EPA, 202
	FR	Fraction from Contaminated Source	1	1	
	EF	Surface Soil Exposure Frequency (days/year)	20	20	Assumed value
	ED	Exposure Duration (years)	10	10	Assumed value
	CF	Conversion Factor (kg/mg)	0.000001	0.000001	
	BW	Body Weight (kg)	80	80	Default value for worker (Stalcup, 2014)
	AT	Averaging Time (d)	3,650	25,550	Default value for worker (Stalcup, 2014)

#### Soil – Dermal Contact (Chemical)

-							
Intake Factor (IE) -	SA x AF x EF x ED x CF		_	7.2E-07	1.0E-07	Basic	
		BW x AT	_	Non-Cancer	Cancer	D0313	
	SA	Surface Area Exposed to Soil (cm <sup>2</sup> /day)		3,527	3,527	Default value for worker (Stalcup, 2014)	
	AF	Soil Skin Adherence Factor (mg/cm <sup>2</sup> )		0.3	0.3	Default value for Construction Worker (US EPA, 202	
	EF	Surface Soil Exposure Frequency (days/year)		20	20	Assumed value	
	ED	Exposure Duration (years)		10	10	Assumed value	
	CF	Conversion Factor (kg/mg)		0.000001	0.000001		
	BW	Body Weight (kg)		80	80	Default value for Construction Worker (US EPA, 202	
	AT	Averaging Time (d)		3,650	25,550	Default value for worker (Stalcup, 2014)	

#### Soil – Inhalation (Chemical)

Intake Factor (IE) -		EF x ED x ET x CF1 x CF2	1.8E-02	2.6E+00	Bacic
		AT	Non-Cancer	Cancer	
	EF	Exposure Frequency (days/year)	20	20	Assumed value
	ED	Exposure Duration (years)	10	10	Assumed value
	ET	Exposure Time (hours/day)	8	8	Default value for worker (Stalcup, 2014)
	CF1	Conversion Factor (day/hour)	0.042	0.042	
	CF2	Conversion Factor (μg/mg)		1,000	
	AT	Averaging Time (days)	3,650	25,550	Default value for Construction Worker (US EPA, 202
	PEF	Particulate Emissions Factor (PEF) (m <sup>3</sup> /kg)	1.0E+12	1.0E+12	Calculated - Appendix Table B.2.

#### Soil – Ingestion (Radionuclide)

Intake Eactor (IE) -			=	6.6E+01	Basis
	•		-		
	IR	Ingestion Rate (mg/day)		330	Default value for Construction Worker (US EPA, 202
	EF	Surface Soil Exposure Frequency (days/year)		20	Assumed value
	ED	Exposure Duration (years)		10	Assumed value
	CF	Conversion Factor (g/mg)		0.001	

#### Soil – Inhalation (Radionuclide)

Intake Factor (IE) -		4.0E+00	Basis
		Radionuclide	
Inh	Inhalation Rate (m <sup>3</sup> /d)	60	Default value for worker (US EPA, 2019)
EF	Surface Soil Exposure Frequency (days/year)	20	Assumed value
ED	Exposure Duration (years)	10	Assumed value
ET	Exposure Time (hr/d)	8	Default value for worker (US EPA, 2019)
CF1	Conversion Factor (d/hr)	0.042	
CF2	Conversion Factor (g/kg)	0.001	
PEF	Particulate Emissions Factor (m <sup>3</sup> /kg)	1.0E+12	Calculated - Appendix Table B.2.

#### Soil – External exposure to ionizing radiation (Radionuclide)

Intake Factor (IE) -		1.8E-01	Basis
		Radionuclide	
EF	Surface Soil Exposure Frequency (days/year)	20	Assumed value
ED	Exposure Duration (years)	10	Assumed value
ET	Exposure Time (hr/d)	8	Default value for worker (US EPA, 2019)
CF1	Conversion Factor (d/hr)	0.04	
CF2	Conversion Factor (yr/d)	0.0027	
ACF	Area Correction Factor (unitless)	0.9	Default value (US EPA, 2000).
GCF	Gamma Shielding Factor (unitless)	1	Assumed no shielding

2020)
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2020)

#### Table B.2 Particulate Emissions Factor Calculation

Particulate Emissions Factor (PEF) (m <sup>3</sup> /kg) =	$\frac{Q}{C_{sa}} \left( \frac{\left(\frac{g}{m^2 - s}\right)}{\left(\frac{kg}{m^3}\right)} \right) \times \frac{1}{F_D} \times \frac{1}{ \left(\frac{g}{m^2 - s}\right)} =$	1.0E+12	
A <sub>s</sub>	Area (acres)	1	Trench Area
A <sub>c</sub>	Area of Contamination (acres)	1	Same as Trench Area
A <sub>excav</sub>	Area of excavation site (m <sup>2</sup> )	1012	Assumed construction activities occur on 25% of trench at one time
М	Gravimetric soil moisture content (%)	100.0	Controlled low strength material (CLSM)-specific (Rhodes, 2020)
N <sub>A-dump</sub>	Number of times soil is dumped	2	Default value
d <sub>excav</sub>	Average depth of excavation site (m)	1.00	Assumed depth
P <sub>soil</sub>	In situ soil density (g/cm <sup>3</sup> )	1.00	CLSM-specific (Rhodes, 2020)
U	Mean annual wind speed (m/s)	4.69	Default value
υm		4.05	
٨	DEE dispersion constant	16 2202	Default value (US ERA 2002)
B	PEF dispersion constant	18 7762	Default value (US EPA, 2002)
C	PEF dispersion constant	216 108	Default value (US EPA, 2002)
Δ	Areal extent of site $(m^2)$	4.047	$A_r \times CF (1 \text{ acre} = 4046.86 \text{ m2})$
' 'surf		<b>,</b> -	
J' <sub>T</sub>	Total time-averaged $PM_{10}$ emissions flux (g/m <sup>2</sup> s)	4.4E-10	Calculated ( $(M_{excav})/(A_{surf} \times T_t)$ )
$M_{excav}$	Dust emitted from excavation soil dumping operations (g)	13	Calculated (0.35 x 0.0016 x (( $U_m/2.2$ ) <sup>1.3</sup> /( $M/2$ ) <sup>1.4</sup> )) x P <sub>soil</sub> x A <sub>excav</sub> x d <sub>excav</sub> x N <sub>A</sub> x 1,000 g/kg
Q/C <sub>sa</sub>	Inverse of the ratio of the geometric mean air concentration to the emissions influx at the center of a square source $(g/m^2-s \text{ per } kg/m^3)$	82.9	Calculated value. A x exp[( $\ln A_s-B$ ) <sup>2</sup> /C)]
t <sub>c</sub>	Total hours that pass (hr)	87,360	Calculated (ED x 52 wk/yr x 7 d/wk x 24 h/d)
F <sub>D</sub>	Dispersion correction factor (unitless)	0.19	Calculated (0.1852+(5.3537/ $t_c$ )+(-9.6318/ $t_c^2$ ))
T <sub>t</sub>	Total time of which exposure occurs (s)	7,200,000	Calculated (ED x EF x ET x 3,600 s/hr)
EF	Exposure Frequency (days/year)	25	
ED	Exposure Duration (years)	10	
ET	Exposure Time (hours/day)	8	
CF	sec/hour	3600	
T <sub>t</sub>	Total time of which exposure occurs (s)	7,200,000	
t <sub>c</sub>	Total hours that pass (hr)	87,360	
CF	Weeks/yr	52	
CF	Days/week	/	
	nours/day	24 4047	
LF	ווב/מנוכ	4047	

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# Appendix C

Groundwater Modeling and Surface Water Dilution Estimation

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# **Abbreviations**

ССР	Coal Combustion Product
CCR	Coal Combustion Residual
cfs	Cubic Feet per Second
CLSM	Controlled Low Strength Material
DAF	Dilution Attenuation Factor
EPACMTP	US EPA Composite Model for Leachate Migration with Transformation Products
GSI	Groundwater-Surface Water Interface
IWEM	Industrial Waste Management Evaluation Model
K <sub>d</sub>	Soil-Water Partitioning Coefficient
US EPA	United States Environmental Protection Agency

#### C.1 Model Overview

Numerical modeling was conducted to evaluate the dilution and attenuation of coal combustion product (CCP) constituents that occur between the controlled low strength material (CLSM) source application (*i.e.*, conduit trench or embankment) and downgradient receptor locations. United States Environmental Protection Agency's (US EPA) Composite Model for Leachate Migration with Transformation Products (EPACMTP) was used for this evaluation (US EPA, 1997). EPACMTP is designed to simulate the fate and transport of contaminants that leach from waste management units through the underlying unsaturated and saturated zones. The model simulates a variety of transport-related processes, including advection, dispersion, and sorption. EPACMTP uses a one-dimensional unsaturated zone module to evaluate the downward vertical infiltration of constituents through the unsaturated zone and a three-dimensional saturated zone module to evaluate constituent transport in groundwater.

A probabilistic, Monte Carlo approach was used in EPACMTP to evaluate the dilution and attenuation of CCP constituents between the source and receptor location. The Monte Carlo approach is a statistical evaluation accounting for a range of hydrogeological characteristics, climate, and chemical properties (*i.e.*, model inputs) that are reflective of all conditions under which CLSM may be used. For this approach, 10,000 individual model simulations were evaluated in EPACMTP for each CLSM application; each simulation represents a potential scenario (*i.e.*, a set of model inputs – hydrogeological characteristics, climate, and chemical properties) at an individual site where CLSM may be used. Model output for each simulation is the concentration of a CCP constituent at the downgradient receptor location. By ranking all model output, one can statistically evaluate the dilution and attenuation that occur between a CLSM source and a downgradient receptor on a national scale. Note that this type of Monte Carlo evaluation is the same approach used by US EPA in the 2014 Coal Combustion Residual (CCR) Risk Assessment (US EPA, 2014a).

Geochemical interactions are important factors affecting the fate and transport of metals. EPACMTP uses sorption isotherms generated by MINTEQA2 (US EPA, 1991) to account for geochemical interactions. MINTEQA2 uses combinations of geochemical conditions, including pH and the concentration of iron oxide, dissolved organic carbon, and organic matter, to generate a set of concentration-dependent soil-water partitioning coefficients (K<sub>d</sub>s; "isotherms"). EPACMTP selects the appropriate isotherm to use for each model simulation based on the Monte Carlo model input values. A total of 22 metals can be simulated in EPACMTP using the MINTEQA2 generated isotherms (US EPA, 2003).

### C.2 Model Selection

EPACMTP was selected to perform the modeling because:

- It is capable of efficiently performing a large number of simulations using a probabilistic, Monte Carlo approach (HydroGeoLogic, Inc., and Resource Management Concepts, Inc., 2003);
- It has a built-in metal sorption module that uses isotherms generated by MINTEQA2 to simulate the adsorption onto soil particles (US EPA, 2003);
- It was specifically designed to simulate the infiltration of constituents leaching from waste management units (HydroGeoLogic, Inc., and Resource Management Concepts, Inc., 2003);
- It was the modeling package used by US EPA for the national CCR Risk Assessment (US EPA, 2014a) as well as the US EPA's beneficial use evaluation for fly ash concrete (US EPA, 2014b); and

• EPACMTP is the fate and transport model used by the Industrial Waste Management Evaluation Model (IWEM; US EPA, 2015). IWEM is commonly used to evaluate the beneficial uses of CCPs.

EPACMTP is a publicly available program from US EPA.<sup>1</sup> The input parameters are specified in the data input file in order to set up an EPACMTP simulation. Three types of parameters are required: control parameters and specific physical and chemical parameters. Control parameters govern the execution of the simulation, such as the number of Monte Carlo runs to be conducted, type of waste source (land application unit), and the type of metal sorption isotherm (*i.e.*, linear or non-linear). Physical parameters govern the physics of the simulation and include the vertical infiltration rate and saturated zone horizontal hydraulic conductivity. Chemical parameters determine the subsurface geochemical environments, which impact the adsorption of metals.

For each CLSM source scenario, 10,000 unique runs were conducted using national distributions for the climatic and hydrogeologic parameters, as well as other necessary input parameters. Each realization results in a predicted maximum contaminant concentration at the specified downgradient receptor location over the model simulation period. The dilution attenuation factor (DAF) was calculated as the ratio of source leachate concentration and the maximum model-predicted concentration at the receptor location. A statistical distribution of DAFs for each specific CLSM source application scenario was generated based on the results from all 10,000 realizations.

### C.3 Model Inputs and Parameter Distribution

The Monte Carlo simulation approach in EPACMTP can be used to perform probabilistic analysis based on specific waste unit characteristics and regional climatic and hydrogeologic conditions. There are several groups of parameters required in the input data file, including source specific parameters, sorption parameters, unsaturated zone parameters, and saturated zone parameters. The characteristics and parameter distributions used in the simulations are summarized in Table C.1. A total of 17 inorganic constituents were evaluated in this report (Table C.2); constituents were selected based on their inclusion in Appendix IV of the Federal CCR Rule (US EPA, 2014a) and are constituents that are generally associated with CCPs.

Parameters	Туре	Distribution	Values
Dimensions of CLCM	Source parameter	Application-specific	Utility trench: 1 mile × 20 ft.
applications	Source parameter	Application-specific	Embankment: 100 ft. × 100 ft.; 300 ft. × 300 ft.
Leachate concentration	Source parameter	Constant	1 (unitless)
Leaching duration/model simulation period	Source parameter	Constant	100 years
Recharge rate	Source parameter	Regional distribution from EPACMTP	$1.0 \times 10^{-5}$ m/yr to 0.75 m/yr
Infiltration rate from CLSM application	Source parameter	Regional distribution from EPACMTP (same as recharge rate)	1.0 × 10 <sup>-5</sup> m/yr to 0.75 m/yr
Soil pH	Sorption parameter	Empirical distribution from EPACMTP	3.2 to 9.7

 Table C.1 Key Parameters and Distributions Used in EPACMTP Simulations

<sup>&</sup>lt;sup>1</sup> https://www.epa.gov/smm/epas-composite-model-leachate-migration-transformation-products-epacmtp

 $G: \label{eq:closed} G: \label{eq:closed} G: \label{eq:closed} CLSM \label{eq:closed} WorkingFiles \label{eq:closed} Report \label{eq:closed} Appendix \label{eq:closed} C_Modeling write up_revised. dock and the closed of the$ 

Parameters	Туре	Distribution	Values	
Fraction iron hydroxide in	Sorption parameter	Uniform distribution	0.0126% to 1.115%	
soil		from EPACMTP		
Leachate organic matter	Sorption parameter	Uniform distribution	105 mg/L to 467 mg/L	
concentration in soil		from EPACMTP		
Percent natural organic	Sorption parameter	Johnson SB distribution	4.08 × 10 <sup>-3</sup> % to 1.8%	
matter in soil		from EPACMTP		
Fraction organic carbon in	Sorption parameter	Johnson SB distribution	1.61 × 10 <sup>-5</sup> to 0.0124	
soil		from EPACMTP		
Unsaturated zone hydraulic	Unsaturated zone	Regional distribution	4.3 × 10 <sup>-5</sup> cm/hr to	
conductivity	parameter	from EPACMTP	27.9 cm/hr	
Saturated water content	Unsaturated zone	Regional distribution	0.41 to 0.45	
Saturated water content	parameter	from EPACMTP		
Depth to water table	Unsaturated zone	Regional distribution	0.205 m to 610 m	
	parameter	from EPACMTP	0.305 111 (0 010 11)	
Aquifer hydraulic	Saturated zone	Regional distribution	3.15 m/yr to	
conductivity	parameter	from EPACMTP	4.29 × 10 <sup>6</sup> m/yr	
Hydraulic gradient	Saturated zone	Regional distribution	2 0 x 0 <sup>-6</sup> to 0 491 m/m	
	parameter from EPACMTP		2.0 × 0 10 0:491 11/11	
	Saturated zone	Derived from particle		
Porosity	narameter	diameter and bulk	0.05 to 0.43	
	parameter	density		
Aquifer thickness	Saturated zone	Regional distribution	0.305 m to 914 m	
	parameter	from EPACMTP	0.000 m to 914 m	

CLSM = Controlled Low Strength Material; EPACMTP = US EPA's Composite Model for Leachate Migration with Transformation Products; US EPA = United States Environmental Protection Agency. Source: US EPA (2003).

Constituents	MINTEQA2 Isotherms Included in EPACMTP	Metal ID in EPACMTP
Arsenic (As III)	Yes	13
Boron (B)	No	NA
Barium (Ba)	Yes	1
Beryllium (Be)	Yes	11
Cadmium (Cd)	Yes	2
Cobalt (Co)	Yes	18
Chromium (Cr VI)	Yes	14
Chromium (Cr total)	Yes	3
Fluoride (F)	Yes	20
Mercury (Hg)	Yes	4
Lithium (Li)	No	NA
Molybdenum (Mo)	Yes	12
Lead (Pb)	Yes	6
Radium 226+228 (Ra)	No	NA
Antimony (Sb)	Yes	17
Selenium (Se)	Yes	22
Thallium (Tl)	Yes	16
Notes:		

#### Table C.2 List of Constituents Modeled

EPACMTP = US EPA's Composite Model for Leachate Migration with Transformation Products; NA = Not Available; ID = Identification; US EPA = United States Environmental Protection Agency. Source: US EPA (2003).

Constituent sorption was simulated using the MINTEQA2 sorption isotherms that are incorporated into EPACMTP. Because sorption isotherms were not available for boron, lithium, and radium, different approaches were used to simulate these three constituents. The sorption of boron was simulated based on the distribution of  $K_{dS}$  in the unsaturated and saturated zones used by US EPA in the CCR Risk Assessment (US EPA, 2014a). Sorption of radium was calculated using an equation<sup>2</sup> from Sheppard *et al.* (2009) based on the average clay content in the soils. Lithium was simulated as a conservative tracer, and no sorption mechanism was included in either the unsaturated or saturated zones. This approach was consistent with the approach used by US EPA in the CCR Risk Assessment (US EPA, 2014a).

Groundwater concentrations were evaluated at three receptor wells located 25, 100, and 1,000 ft. downgradient of the CLSM application boundary (*i.e.*, edge of the conduit trench or embankment). While the receptor wells were not required to be located along the centerline of the plume, they were constrained to be within the plume. The vertical depth of the receptor well screen was set to be uniformly distributed between the water table and the saturated aquifer thickness. A unitless CLSM leachate concentration of 1 was assumed for each constituent and CLSM application scenario.

For each CLSM application (*i.e.*, conduit trench or embankment), the DAFs between source leachate concentrations and receptor locations were calculated. In addition, for the CLSM embankment applications (*i.e.*, 100 ft. by 100 ft. and 300 ft. by 300 ft.), which may be located adjacent or near surface water bodies, a second DAF was calculated for each constituent representing the dilution that occurs when groundwater discharges into surface water. These DAFs were calculated based on the ratio of surface water flow to the ratio of groundwater flow. This is a conservative approach because it does not account for the attenuation that may occur due to geochemical reactions at the groundwater-surface water interface (GSI). Streamflow rates were estimated based on mean annual flow rate data from surface water bodies near CCR disposal facilities contained in the 2014 CCR Risk Assessment (US EPA, 2014a). Surface water flow rates at the 25<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles, based on the US EPA data, were chosen to represent small, medium, and large surface water bodies, respectively. The groundwater discharge rates were derived from simulated cross-sectional areas, and the calculated Darcy flux was based on the modeled parameters. The 90<sup>th</sup> percentile Darcy flux discharge rates were conservatively used to calculate the DAFs from groundwater discharging into surface water.

#### C.4 Model Results

#### C.4.1 Groundwater Results

The DAFs for each CLSM application (*i.e.*, conduit trench or embankment), representing dilution and attenuation that occur between the application area and a potential downgradient receptor well, are summarized below. Figures C.1-C.5 show the model-predicted DAF distributions for arsenic and molybdenum, two common CCP-related constituents. Tables C.3-C.5 present the model-predicted DAFs for all constituents and all CLSM application scenarios.

DAF plots for arsenic and molybdenum for a large conduit trench (1 mile long, 20 ft. wide) are shown in Figures C.1 and C.2. The DAFs for arsenic were 1,700, 2,272, and 14,221 at the 90<sup>th</sup> percentile for receptor

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 $<sup>^{2}</sup>$ Log ( $K_{d}$ ) = 1.56 + 0.0599 × (*clay content*)
wells located 25, 100, and 1,000 ft. downgradient, respectively. The DAFs for molybdenum were 1,693, 2,238, and 14,039 at the 90<sup>th</sup> percentile for receptor wells located 25, 100, and 1,000 ft. downgradient, respectively.



**Figure C.1 Probabilistic Distribution of Arsenic DAFs for CLSM Application in a Conduit Trench.** CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor. Assumes that there is a receptor well located 25, 100, and 1,000 ft. downgradient of a conduit trench. Note that DAFs are infinite below 25<sup>th</sup> percentile, and, thus, no data points are shown.



**Figure C.2** Probabilistic Distribution of Molybdenum DAFs for CLSM Application in a Conduit Trench. CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor. Assumes that there is a receptor well located 2, 100, and 1,000 ft. downgradient of a conduit trench. Note that DAFs are infinite below 25<sup>th</sup> percentile, and, thus, no data points are shown.

The DAF plots for the two embankment scenarios (100 ft. by 100 ft. and 300 ft. by 300 ft.) for arsenic and molybdenum are presented in Figures C.2-C.5. As shown in Figures C.3 and C.4, the DAFs for arsenic were 3.5, 6.6, and 69.5 for a 100 ft. by 100 ft. embankment at the 90<sup>th</sup> percentile for receptor wells located 25, 100, and 1,000 ft. downgradient, respectively; the DAFs for arsenic were 1.2, 1.7, and 12.5 for a 300 ft. by 300 ft. embankment at the 90<sup>th</sup> percentile for receptor wells located 25, 100, and 1,000 ft. downgradient, respectively. As shown in Figures C.5 and C.6, the DAFs for molybdenum were 3.5, 6.5, and 67.8 for a 100 ft. by 100 ft. embankment at the 90<sup>th</sup> percentile for receptor wells located 25, 100, and 1,000 ft. downgradient, respectively. As shown in Figures C.5 and C.6, the DAFs for molybdenum were 3.5, 6.5, and 67.8 for a 100 ft. by 100 ft. embankment at the 90<sup>th</sup> percentile for receptor wells located 25, 100, and 1,000 ft. downgradient, respectively; the DAFs for molybdenum were 1.2, 1.7, and 12.2 for a 300 ft. by 300 ft. embankment at the 90<sup>th</sup> percentile for receptor wells located 25, 100, and 1,000 ft. downgradient, respectively. Note, for some of the low percentile results, the DAFs decrease as the downgradient receptor well distance increases; this is because at distances close to the embankment, the concentrations of CCP constituents may not be well-mixed over the entire aquifer depth, and thus, the vertical depths of some receptor well locations selected in the Monte Carlo simulations may be located outside of the vertical depth range of the plume.



**Figure C.3 Probabilistic Distribution of Arsenic DAFs for CLSM Application in a 100 Ft. x 100 Ft. Embankment.** CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor. Assumes that there is a receptor well located 25, 100, and 1,000 ft. downgradient of an embankment. Note that some DAFs are infinite at the low percentiles, and, thus, no data points are shown.



**Figure C.4 Probabilistic Distribution of Arsenic DAFs for CLSM Application in a 300 Ft. x 300 Ft. Embankment.** CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor. Assumes



that there is a receptor well located 25, 100, and 1,000 ft. downgradient of an embankment. Note that some DAFs are infinite at the low percentiles, and, thus, no data points are shown.

**Figure C.5 Probabilistic Distribution of Molybdenum DAFs for CLSM Application in a 100 Ft. x 100 Ft. Embankment.** CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor. Assumes that there is a receptor well located 25, 100, and 1,000 ft. downgradient of an embankment. Note that some DAFs are infinite at the low percentiles, and, thus, no data points are shown.



**Figure C.6 Probabilistic Distribution of Molybdenum DAFs for CLSM Application in a 300 Ft. x 300 Ft. Embankment.** CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor. Assumes that there is a receptor well located 25, 100, and 1,000 ft. downgradient of an embankment. Note that some DAFs are infinite at the low percentiles, and, thus, no data points are shown.

Constituents	Percentiles						
Constituents	10	25	50	75	85	90	
Arsenic (As III)	Infinite	4.1+16	2.0E+06	25,069	4,415	1,700	
Boron (B)	Infinite	Infinite	7.0E+06	31,153	4,498	1,619	
Barium (Ba)	Infinite	7.3E+16	2.9E+06	28,616	4,653	1,773	
Beryllium (Be)	Infinite	Infinite	5.3E+06	32,760	5,332	1,935	
Cadmium (Cd)	Infinite	Infinite	1.8E+07	46,555	6,766	2,277	
Cobalt (Co)	Infinite	Infinite	1.1+07	40,269	6,215	2,151	
Chromium (Cr VI)	Infinite	Infinite	2.0E+06	24,558	4,413	1,714	
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	1.2E+09	3.0E+06	
Fluoride (F)	Infinite	1.7E+15	1.8E+06	24,331	4,331	1,665	
Mercury (Hg)	Infinite	Infinite	4.2+06	30,381	4,793	1,768	
Lithium (Li)	Infinite	2.5E+17	4.1E+06	28,531	4,896	1,777	
Molybdenum (Mo)	Infinite	1.6E+15	1.8E+06	24,588	4,380	1,693	
Lead (Pb)	Infinite	Infinite	Infinite	1.4E+25	2.3E+09	2.1E+07	
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	
Antimony (Sb)	Infinite	8.6+16	2.0E+06	24,600	4,351	1,705	
Selenium (Se)	Infinite	1.7E+15	1.8E+06	24,606	4,401	1,685	
Thallium (Tl)	Infinite	4.2E+18	2.0E+06	25,050	4,364	1,712	

Table C.3	Modeled DAF Distributions for CLSM Application in a Conduit Trench – Assumes a Recept	or
Well is Lo	cated 25 Ft. Downgradient of the Conduit Trench	

Notes:

Constituents	Percentiles							
constituents	10	25	50	75	85	90		
Arsenic (As III)	Infinite	2.6E+09	343,407	18,512	4,380	2,272		
Boron (B)	Infinite	4.7E+10	608,365	21,704	4,826	2,452		
Barium (Ba)	Infinite	7.1E+09	418,323	20,676	4,567	2,331		
Beryllium (Be)	Infinite	2.7E+11	580,804	24,301	5,513	2,538		
Cadmium (Cd)	Infinite	2.1E+14	1.3E+06	33,245	6,660	2,859		
Cobalt (Co)	Infinite	3.1E+12	958,926	29,630	6,160	2,726		
Chromium (Cr VI)	Infinite	2.3E+11	338,295	17,999	4,371	2,255		
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	8.1+08	9.5E+05		
Fluoride (F)	Infinite	1.9E+09	325,998	17,754	4,353	2,260		
Mercury (Hg)	Infinite	8.1E+11	485,437	21,718	4,751	2,369		
Lithium (Li)	Infinite	2.0E+10	470,976	19,039	4,726	2,471		
Molybdenum (Mo)	Infinite	1.7E+09	325,415	17,646	4,301	2,238		
Lead (Pb)	Infinite	Infinite	Infinite	9.3E+15	2.9E+09	9.1E+06		
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite		
Antimony (Sb)	Infinite	2.6E+09	341,491	18,411	4,380	2,266		
Selenium (Se)	Infinite	1.9E+09	327,869	17,743	4,318	2,229		
Thallium (Tl)	Infinite	4.4+09	348,614	18,692	4,399	2,268		

Table C.4 Modeled DAF Distributions for CLSM Application in a Conduit Trench – Assumes a ReceptorWell is Located 100 Ft. Downgradient of the Conduit Trench

Notes:

CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor.

Table C.5	Modeled DAF Distrib	outions for CLSM Application	on in a Conduit Tr	ench – Assumes a Re	ceptor
Well is Lo	cated 1,000 Ft. Down	gradient of the Conduit Tre	ench		

Constituents	Percentiles						
constituents	10	25	50	75	85	90	
Arsenic (As III)	Infinite	1.4E+08	525,762	44,643	18,818	14,221	
Boron (B)	Infinite	4.5E+09	908,471	55,363	21,243	14,793	
Barium (Ba)	Infinite	8.8E+08	704,722	53,505	20,587	15,004	
Beryllium (Be)	Infinite	1.0E+10	1.0E+06	70,859	24,126	16,300	
Cadmium (Cd)	Infinite	1.2E+13	3.1E+06	123,335	35,842	20,276	
Cobalt (Co)	Infinite	2.6E+11	1.8E+06	100,150	29,985	18,479	
Chromium (Cr VI)	Infinite	1.2E+08	511,876	44,248	18,643	14,077	
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	3.2E+09	1.9E+06	
Fluoride (F)	Infinite	8.2E+07	489,057	42,969	18,366	14,035	
Mercury (Hg)	Infinite	4.4E+09	831,947	60,350	21,964	15,408	
Lithium (Li)	Infinite	2.5E+09	760,601	49,176	19,831	14,530	
Molybdenum (Mo)	Infinite	8.1E+07	487,092	42,535	18,208	14,039	
Lead (Pb)	Infinite	Infinite	Infinite	Infinite	2.9E+13	1.5E+10	
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	
Antimony (Sb)	Infinite	1.3E+08	521,286	44,577	18,791	14,154	
Selenium (Se)	Infinite	8.8E+07	499,500	43,328	18,423	14,049	
Thallium (Tl)	Infinite	1.5E+08	540,249	45,496	19,048	14,245	

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Notes: CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor.

Constituents	Percentiles							
Constituents	10	25	50	75	85	90		
Arsenic (As III)	Infinite	Infinite	1.8E+07	248	14	3.5		
Boron (B)	Infinite	Infinite	6.1E+07	401	14	3.5		
Barium (Ba)	Infinite	Infinite	2.7E+07	294	15	3.8		
Beryllium (Be)	Infinite	Infinite	6.8E+07	367	18	4.1		
Cadmium (Cd)	Infinite	Infinite	2.8E+08	686	25	5.2		
Cobalt (Co)	Infinite	Infinite	1.5E+08	524	22	4.8		
Chromium (Cr VI)	Infinite	Infinite	3.5E+07	246	14	3.4		
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	1.9E+09	1.0E+06		
Fluoride (F)	Infinite	Infinite	1.5E+07	243	14	3.5		
Mercury (Hg)	Infinite	Infinite	6.7E+07	310	17	3.7		
Lithium (Li)	Infinite	Infinite	1.4E+08	556	22	4.8		
Molybdenum (Mo)	Infinite	Infinite	1.5E+07	240	14	3.5		
Lead (Pb)	Infinite	Infinite	Infinite	Infinite	2.6E+08	1.2E+06		
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite		
Antimony (Sb)	Infinite	Infinite	1.9E+07	248	14	3.5		
Selenium (Se)	Infinite	Infinite	1.6E+07	241	14	3.5		
Thallium (TI)	Infinite	Infinite	2.2E+07	244	14	3.5		

Table C.6 Modeled DAF Distributions for CLSM Application in a 100 Ft. x 100 Ft. Embankment – Assumes a Receptor Well is Located 25 Ft. Downgradient of the Embankment

Notes:

CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor.

Table C.7 Modeled DAF Distributions for CLSM Application in a 100 Ft. x 100 Ft. Embankment – Assumes
a Receptor Well is Located 100 Ft. Downgradient of the Embankment

Constituents	Percentiles							
Constituents	10	25	50	75	85	90		
Arsenic (As III)	Infinite	2.9E+09	21,763	116	18	6.6		
Boron (B)	Infinite	2.5E+10	36,166	143	18	6.2		
Barium (Ba)	Infinite	9.8E+09	28,944	133	19	7.1		
Beryllium (Be)	Infinite	1.9E+12	50,994	169	24	8.5		
Cadmium (Cd)	Infinite	5.5E+16	149,566	266	33	11.1		
Cobalt (Co)	Infinite	7.8E+13	93,124	218	29	10.2		
Chromium (Cr VI)	Infinite	2.4E+12	21,432	115	18	6.6		
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	2.0E+07	33,146		
Fluoride (F)	Infinite	1.6E+09	20,141	113	18	6.5		
Mercury (Hg)	Infinite	9.5E+12	37,313	139	20	7.2		
Lithium (Li)	Infinite	4.5E+14	136,565	230	29	9.5		
Molybdenum (Mo)	Infinite	1.8E+09	20,008	112	18	6.5		
Lead (Pb)	Infinite	Infinite	Infinite	1.0E+18	7.4E+07	32,8012		
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite		
Antimony (Sb)	Infinite	3.9E+09	21,614	116	18	6.6		
Selenium (Se)	Infinite	1.8E+09	20,483	114	18	6.5		
Thallium (Tl)	Infinite	1.7E+10	22,121	118	19	6.7		

Notes:

Constituents	Percentiles						
Constituents	10	25	50	75	85	90	
Arsenic (As III)	Infinite	2.6E+06	7,831	468	136	69	
Boron (B)	Infinite	9.4E+07	13,976	600	166	78	
Barium (Ba)	Infinite	1.6E+07	10,799	560	157	79	
Beryllium (Be)	Infinite	3.1E+08	19,743	751	201	92	
Cadmium (Cd)	Infinite	5.0E+11	70,077	1,318	320	134	
Cobalt (Co)	Infinite	8.5E+09	40,431	1,067	266	116	
Chromium (Cr VI)	Infinite	3.2E+06	7,527	461	136	69	
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	2.7E+07	35,199	
Fluoride (F)	Infinite	1.7E+06	7,148	447	132	68	
Mercury (Hg)	Infinite	1.1E+08	14,114	642	173	84	
Lithium (Li)	Infinite	4.2E+09	37,524	887	210	99	
Molybdenum (Mo)	Infinite	1.7E+06	7,143	444	132	68	
Lead (Pb)	Infinite	Infinite	Infinite	Infinite	2.6E+11	1.3E+08	
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	
Antimony (Sb)	Infinite	2.5E+06	7,702	463	136	69	
Selenium (Se)	Infinite	1.8E+06	7,203	448	132	68	
Thallium (Tl)	Infinite	2.9E+06	8,035	477	137	70	

Table C.8 Modeled DAF Distributions for CLSM Application in a 100 Ft. x 100 Ft. Embankment – Assumes a Receptor Well is Located 1,000 Ft. Downgradient of the Embankment

Notes:

CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor.

Table C.9 Modeled DAF Distributions for CLSM Application in a 300 Ft. x 300 Ft. Embankment – Assumes
a Receptor Well is Located 25 Ft. Downgradient of the Embankment

Constituents	Percentiles							
constituents	10	25	50	75	85	90		
Arsenic (As III)	Infinite	Infinite	4.2E+07	18	2.0	1.2		
Boron (B)	Infinite	Infinite	2.0E+08	25	2.1	1.2		
Barium (Ba)	Infinite	Infinite	7.2E+07	22	2.1	1.2		
Beryllium (Be)	Infinite	Infinite	3.9E+08	28	2.5	1.3		
Cadmium (Cd)	Infinite	Infinite	2.8E+09	49	3.0	1.4		
Cobalt (Co)	Infinite	Infinite	1.1E+09	39	2.8	1.3		
Chromium (Cr VI)	Infinite	Infinite	2.1E+08	18	1.9	1.2		
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	2.1E+09	99,305		
Fluoride (F)	Infinite	Infinite	3.2E+07	18	1.9	1.2		
Mercury (Hg)	Infinite	Infinite	4.0E+08	23	2.1	1.2		
Lithium (Li)	Infinite	Infinite	2.9E+09	59	3.0	1.3		
Molybdenum (Mo)	Infinite	Infinite	3.1E+07	17	1.9	1.2		
Lead (Pb)	Infinite	Infinite	Infinite	Infinite	9.7E+07	127,226		
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite		
Antimony (Sb)	Infinite	Infinite	4.4E+07	18	2.0	1.2		
Selenium (Se)	Infinite	Infinite	3.3E+07	18	2.0	1.2		
Thallium (Tl)	Infinite	Infinite	6.6E+07	19	1.9	1.2		

Notes:

Constituents	Percentiles						
Constituents	10	25	50	75	85	90	
Arsenic (As III)	Infinite	3.7E+11	12,157	18	3.0	1.7	
Boron (B)	Infinite	1.3E+12	30,984	20	3.2	1.8	
Barium (Ba)	Infinite	9.9E+11	19,157	19	3.2	1.8	
Beryllium (Be)	Infinite	1.1E+15	37,209	24	3.7	2.0	
Cadmium (Cd)	Infinite	Infinite	135,759	38	5.0	2.3	
Cobalt (Co)	Infinite	7.2E+18	75,729	32	4.5	2.2	
Chromium (Cr VI)	Infinite	8.2E+14	11,916	18	3.0	1.7	
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	7.8E+06	4,671	
Fluoride (F)	Infinite	6.8E+10	10,406	17	2.9	1.7	
Mercury (Hg)	Infinite	1.5E+16	28,539	21	3.3	1.8	
Lithium (Li)	Infinite	3.9E+17	172,936	36	4.6	2.0	
Molybdenum (Mo)	Infinite	7.1E+10	10,738	17	2.9	1.7	
Lead (Pb)	Infinite	Infinite	Infinite	4.4E+17	1.8E+07	89,874	
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	
Antimony (Sb)	Infinite	5.2E+11	11,998	18	3.0	1.7	
Selenium (Se)	Infinite	8.5E+10	11,256	17	2.9	1.7	
Thallium (Tl)	Infinite	3.0E+12	12,469	18	3.0	1.7	

Table C.10 Modeled DAF Distributions for CLSM Application in a 300 Ft. x 300 Ft. Embankment – Assumes a Receptor Well is Located 100 Ft. Downgradient of the Embankment

Notes:

CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor.

Table C.11	Modeled DAF	<b>Distributions for</b>	CLSM	Application	in a	a 300	Ft. :	x 300	Ft.	Embankmen	t –
Assumes a F	Receptor Well is	Located 1,000 Ft	. Down	gradient of t	the E	Embar	nkm	ent			

Constituents	Percentiles								
constituents	10	25	50	75	85	90			
Arsenic (As III)	Infinite	1.1E+06	2,161	90	25	13			
Boron (B)	Infinite	4.5E+07	4,364	121	30	14			
Barium (Ba)	Infinite	6.3E+06	3,514	112	29	15			
Beryllium (Be)	Infinite	1.7E+08	6,433	154	37	17			
Cadmium (Cd)	Infinite	3.4E+11	26,867	275	60	25			
Cobalt (Co)	Infinite	7.0E+09	14,221	218	48	21			
Chromium (Cr VI)	Infinite	1.7E+06	2,074	88	25	12			
Chromium (Cr total)	Infinite	Infinite	Infinite	Infinite	8.2E+06	13,716			
Fluoride (F)	Infinite	7.8E+05	1,947	86	24	12			
Mercury (Hg)	Infinite	6.7E+07	4,447	125	32	15			
Lithium (Li)	Infinite	4.1E+09	14,959	184	41	18			
Molybdenum (Mo)	Infinite	7.8E+05	1,920	85	24	12			
Lead (Pb)	Infinite	Infinite	Infinite	Infinite	9.6E+10	2.5E+07			
Radium 226+228 (Ra)	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite			
Antimony (Sb)	Infinite	1.1E+06	2,158	89	25	12			
Selenium (Se)	Infinite	8.6E+05	1,992	87	25	12			
Thallium (Tl)	Infinite	1.3E+06	2,261	92	26	13			

Notes:

## C.4.2 Surface Water Results

The distribution of groundwater discharge rates and average stream flow rates are presented in Tables C.12 and C.13. Groundwater discharge rates are based on the EPACMTP-predicted plume width and the 90<sup>th</sup> percentile Darcy flux for a CLSM embankment located 25 ft. from a surface water body. Plume dimensions were based on the transport of arsenic; there may be minor differences in the plume dimensions and resulting groundwater discharge rates for other constituents. Surface water flow rates are based on data presented in the 2014 CCR Risk Assessment (US EPA, 2014a). The DAFs from groundwater discharging into a surface water body, based on the data presented in Tables C.12 and C.13, are summarized in Table C.14 below. Note, values presented in Table C.14 only represent the dilution and attenuation associated with groundwater discharge into surface water and do not account for dilution and attenuation that occur during constituent migration in the unsaturated and saturated (*i.e.*, groundwater) zones. Thus, to evaluate the dilution and attenuation that occur between a CLSM embankment and a surface water body, the DAFs in Table C.14 would need to be used together with the DAFs in Tables C.3-C.5.

## Table C.12 Groundwater Discharge Rates Used to Calculate Groundwaterto Surface Water DAF

Groundwater Discharge (cfs) for a 100 Ft. × 100 Ft. Embankment	Groundwater Discharge (cfs) for a 300 Ft. × 300 Ft. Embankment
0.03	0.08
distant.	

Notes:

cfs = Cubic Feet per Second; CLSM = Controlled Low Strength Material; DAF = Dilution Attenuation Factor.

Groundwater discharge rates were calculated based on the model-predicted plume width and the 90<sup>th</sup> percentile model-predicted Darcy flux for a CLSM embankment located 25 ft. from the surface water body. Plume dimensions were based on the transport of arsenic; there may be minor differences in the plume dimensions and resulting groundwater discharge rates for other constituents.

## Table C.13 Surface Water Flow Rates Used to Calculate Groundwater to Surface Water DAF

Percentiles	Annual Mean Surface Water Flow Rates (cfs)				
25	1.8				
50	19				
90	27,963				

Notes:

cfs= Cubic Feet per Second; CCR = Coal Combustion Residual; DAF = Dilution Attenuation Factor.

Surface water flow rates are based on data presented in the 2014 CCR Risk Assessment (US EPA, 2014a).

Embankment Size	Dilution Attenuation Factor					
(Length × Width in	Small Surface Water	Large Surface Water				
Ft.)	Body	Body	Body			
100 × 100	60	629	935,873			
300 × 300	22	229	337,132			

Note:

CCR = Coal Combustion Residual; DAF = Dilution Attenuation Factor.

Flow rates for small, medium, and large surface water bodies were based on the 25<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentile flow rates, respectively, in the 2014 CCR Risk Assessment (US EPA, 2014a).

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