Technical Considerations Regarding the Addition of Boron as an Appendix IV Constituent for Assessment Monitoring

Prepared for
Utility Solid Waste Activities Group
Ash Management Committee

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Executive Summary

Pursuant to a settlement agreement entered into by the United States Environmental Protection Agency (US EPA) in litigation challenging the Federal Rule that regulates the disposal of coal combustion residuals (CCR) (hereinafter referred to as Federal CCR Rule), EPA has agreed to propose and take comment on the addition of boron to the list of constituents in Appendix IV of the Federal CCR Rule which can trigger assessment monitoring and corrective action. (See §II.3.C of Settlement Agreement between US EPA, Earthjustice & and the Utility Solid Waste Activities Group *et al.*, dated April 18, 2016). The proposal to add Boron to the list of Appendix IV assessment monitoring constituents, however, has several limitations. Namely, adding boron will be impractically expensive, will not provide any human health benefit, and will undercut the rationale developed by US EPA when creating the detection monitoring and assessment programs in the Federal CCR Rule. Specifically:

- Because the groundwater protection standard (GWPS) for boron would be set to background in absence of a federal Maximum Contaminant Level (MCL) and because most of the other Appendix IV constituents have a health-based GWPS, a greater level of treatment would required for boron than for other Appendix IV constituents. Consequently, boron is likely to become the driver, and in some cases, the sole driver, of many groundwater corrective actions. For example, groundwater corrective actions would have to reduce boron concentrations by a factor of 62 to 2,458, respectively for the median and 95th percentile leachate concentrations, which equates to a treatment efficiency ranging from 98.4% to 99.96% – an impractically difficult standard to achieve. This is in contrast to arsenic, for which typical median leachate concentrations would need to be reduced by about 2.5 fold, equating to a treatment efficiency of 60%.
- Remediating boron to background requires expensive technologies that will likely need to be implemented in addition to any remedy needed for the key human health risk drivers, such as arsenic. Remediation of boron will typically require *ex-situ* remediation technologies, which have capital costs that are approximately 3 to 5.8 times higher than for *in-situ* permeable reactive barrier (PRB) treatment systems. Moreover, operations and maintenance (O&M) costs for boron-specific treatment systems are approximately 2.3 to 6.8 times more expensive than arsenic treatment systems.
- The risk assessment conducted by US EPA in support of the Federal CCR Rule demonstrated that boron did not pose a human health risk both overall and under the more specific waste disposal scenarios for surface impoundments (SIs) and landfills. The only exception was for the risk evaluation of flue-gas desulfurization (FGD) waste in surface impoundments, in which the 90th percentile drinking water risk was slightly above the acceptable risk level (Hazard Index = 2). This value was derived using conservative assumptions and was based on a limited dataset that may not be representative of FGD surface impoundments.
- The inclusion of boron on both Appendix III and Appendix IV is nonsensical. If added to Appendix IV, the detection of boron in groundwater above background during Appendix III detection monitoring would also be an exceedance of the Appendix IV assessment monitoring GWPS and, consequently, would trigger the implementation of corrective action, even though there may be no associated risks to human health. Adding boron to the Appendix IV constituent list would thus undercut the rationale for the entire tiered monitoring process developed by US EPA in the Federal CCR Rule.

1 Introduction

On April 17, 2015, the United States Environmental Protection Agency (US EPA) published a final rule to regulate the disposal of coal combustion residuals (CCR) as solid waste under subtitle D of the Resource Conservation and Recovery Act (RCRA) (US EPA, 2015). This rule (hereinafter referred to as the Federal CCR Rule) established a groundwater monitoring and corrective action program consisting of three phases: *detection monitoring*, *assessment monitoring*, and *corrective action*.

The *detection monitoring* program requires monitoring for constituents in groundwater whose presence at statistically significant levels above background conditions may indicate a release from a CCR disposal facility. US EPA chose a set of parameters, listed on Appendix III,[1] that would indicate a potential release from a CCR disposal facility. The Appendix III constituents include boron, calcium, chloride, fluoride, pH, sulfate, and total dissolved solids (TDS).

The *assessment monitoring* program is triggered when a statistically significant concentration increase over background is detected for any Appendix III constituent.[2] Assessment monitoring includes a different set of analytes, known as the Appendix IV constituents, and generally includes CCR constituents that are more routinely identified as human health risk drivers. The Appendix IV constituents include antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, and radium.

A *corrective action* remedy is required whenever assessment monitoring results indicate a statistically significant concentration exceeding the groundwater protection standard (GWPS) for any Appendix IV constituent. The Federal CCR Rule defines the GWPS as the Maximum Contaminant Level (MCL). For constituents that have no established MCL, the rule sets the GWPS as the background concentration. Corrective actions are required until concentrations decline below the relevant GWPS.

US EPA has recently considered seeking comment for adding boron, a naturally occurring element already listed on Appendix III, to the Appendix IV constituent list. Because of its high mobility, low toxicity, and relatively low analytical detection limit relative to typical background concentrations, boron in groundwater is a good indicator of potential releases from CCR disposal facilities, and thus, its inclusion on the Appendix III constituent list is valid. However, because boron is not associated with risks to human health at levels typically detected in groundwater, US EPA did not establish a Federal MCL (US EPA, 2008). Thus, if boron were added to Appendix IV, its relevant GWPS would be background and corrective action would be required if boron concentrations in groundwater downgradient of a CCR disposal facility exceeded background regardless of any human health risk. Moreover, a corrective action would remain in place until groundwater concentrations have returned to background levels.

The sections below provide more technical details on why adding boron to Appendix IV would be both nonsensical given the goals of the tiered monitoring program and impractically expensive without providing any public health benefit.

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[1] Appendix III to 40 CFR Part 257

[2] Appendix IV to 40 CFR Part 257

2 Inclusion of Boron on the Appendix IV Constituent List and Remediating Groundwater to Background Would be Impractical and Cost-Prohibitive

Removing boron from groundwater is a challenging process without many commercially-proven and tested technologies. Due to its unique chemical characteristics, including high solubility, low propensity to adsorb, and low propensity to precipitate, conventional inorganic groundwater treatment systems are ineffective for boron. US EPA Office of Water reported that among eight technologies potentially capable of removing boron, only three technologies successfully reduced boron levels to below 300 µg/L. Of these three, only boron-specific ion exchange resins were determined to be a commercially-viable technology (US EPA, 2008), albeit at a high cost. Thus, if boron were added to the Appendix IV constituent list, as proposed by US EPA, there would be significant cost implications for utilities forced to install expensive remediation systems. Moreover, corrective action would have to continue until concentrations have returned to background, an impractical standard that requires a significantly higher level of treatment than the current Appendix IV constituents. This section further summarizes the technical challenges associated with removing boron from groundwater, details the high level of treatment that would be required to remediate boron to background, and presents costs analyses comparing treatment costs for boron to other current Appendix IV constituents.

2.1 Remediating boron to background would require greater level of treatment than currently required for existing Appendix IV constituents

There is no federally-established MCL for boron. Thus, if boron were added to the Appendix IV constituent list, groundwater corrective actions would be triggered if boron's concentration in groundwater was detected above its site-specific background concentration. Furthermore, groundwater corrective actions, once instituted, would be required to continue operating until the background concentration is achieved. These requirements will increase the level of treatment efficiency required for, and consequently the cost associated with, groundwater corrective actions.

To provide perspective on the level of treatment required by a corrective action for individual CCR constituents, the ratio of each constituent's CCR leachate concentration to its relevant GWPS was calculated.[3] For this analysis, data from the Electric Power Research Institute (EPRI) Characterization of Field Leachates at Coal Combustion Product Management Sites (2006; Table 2.1) was used, specifically the field ash leachate data reported by EPRI (2006; Table 4-1). This data is based on a dataset consisting of 67 samples and includes data collected from multiple sources including wells screened within CCR, drive point piezometers, seep samplers, core extracts, leachate collection systems, and pond water samples collected from near the CCR-water interface, sluice lines, and impoundment outfalls. Because a significant portion of this dataset comes from impoundment water samples which likely contain lower CCR constituent concentrations than interstitial water samples from within the CCR, this dataset is likely biased low and, thus, conservative. Nonetheless, data presented in this report are consistent with data

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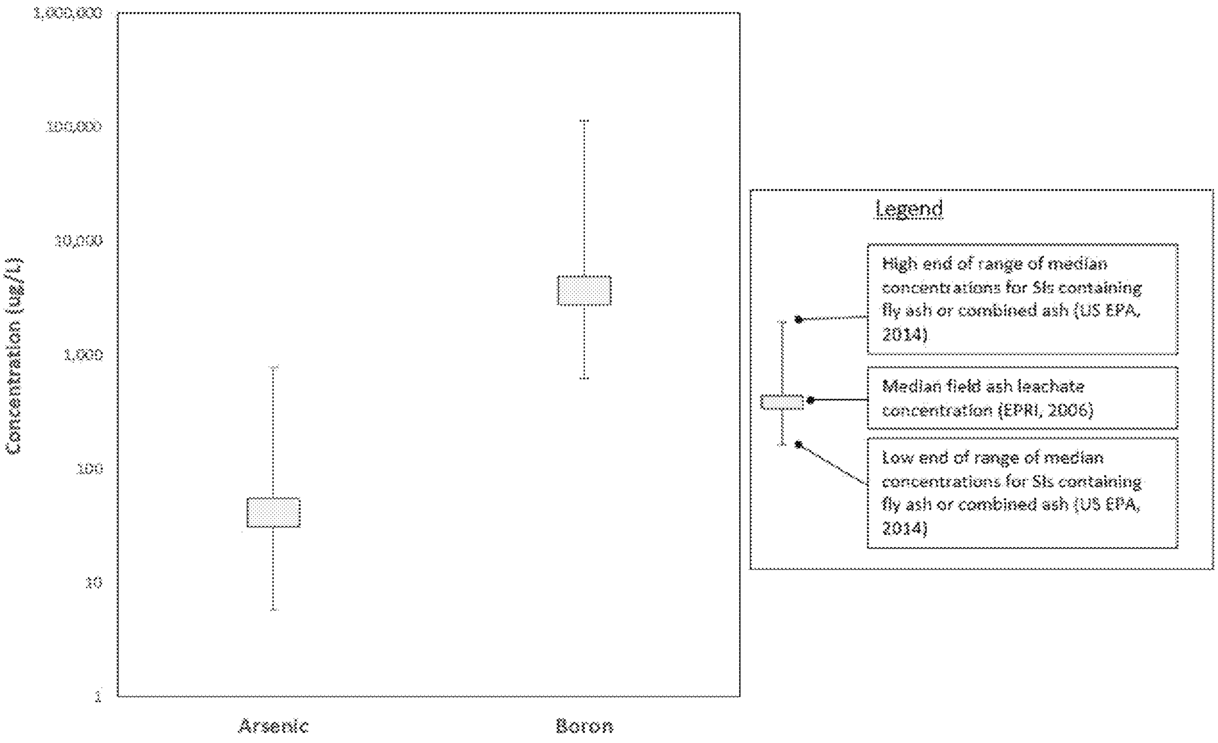
[3] This approach neglects the attenuation that would occur due to leachate mixing with groundwater and subsequent transport processes. However, one can assume that a similar level of attenuation will occur for each constituent.

used by US EPA in the 2014 Final Human and Ecological Risk Assessment for Coal Combustion Residuals (Figure 2.1; US EPA, 2014). For example, in the EPRI dataset (2006), the median boron and arsenic ash leachate concentrations in SIs and landfills are 2,160 µg/L and 25 µg/L, respectively. In the US EPA risk assessment (2014), the range of 50th percentile porewater concentrations at individual sites with surface impoundments (SIs) containing fly ash or combined ash is 620 to 109,000 µg/L[4] for boron and 5.8 to 721 µg/L for arsenic (Figure 2.1).

Figure 2.1: Comparison of EPRI (2006) and US EPA (2014) Leachate Dataset



For this analysis, the median field ash leachate concentration reported by EPRI (2006; Table 4-1) and the 95th percentile leachate concentration were used (Table 2.1). The 95th percentile leachate concentration was calculated based on an analysis of the 67 field ash leachate samples reported by EPRI (2006; Appendix A).

For most of the current Appendix IV constituents, the GWPS is its MCL. However, because boron does not have a federal MCL, its GWPS, according to the Federal CCR Rule, is background (Table 2.1). Because of this, the ratio of leachate concentration to GWPS is significantly higher for boron than for any other Appendix IV constituent with an MCL (Table 2.2). For example, the median boron leachate concentration is approximately 62 times higher than the typical background boron concentration in groundwater, whereas the median arsenic leachate concentration is only 2.5 times higher than the MCL (Table 2.2). The 95th percentile boron leachate concentration is 2,458 times higher than the typical background boron concentration in groundwater, whereas the 95th percentile arsenic leachate concentration is only 22 times higher than the MCL (Table 2.2).

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[4] The highest median boron concentration cited by US EPA (109,000 µg/L; 2014) came from a site where only one sample was collected. The concentration of boron in this one sample was assumed to be the median concentration. Due to the limited data and lack of corroboration, this value may not be an appropriate approximation of the median boron concentration at the site.

Thus, if boron is added to the Appendix IV constituent list, a much higher level of treatment would be required for most groundwater corrective actions than what is currently required for the existing Appendix IV constituents (Table 2.2). For example, groundwater corrective actions would have to reduce boron concentrations by a factor of 62 to 2,458, respectively for the median and 95th percentile leachate concentrations, which equates to a treatment efficiency ranging from 98.4% to 99.96% – an impractically difficult standard to achieve. However, for arsenic, which is the typical risk-driving constituent associated with CCR, groundwater corrective actions would have to reduce concentrations only by a factor of 2.5 to 22. Furthermore, after accounting for the attenuation that occurs due to mixing of leachate with groundwater and during fate and transport (*e.g.*, dispersion), groundwater corrective action may be unnecessary in many circumstances for all current Appendix IV constituents but would be required for boron. Thus, if listed on Appendix IV, boron would most likely become the driver, and in some cases the sole driver, of many groundwater corrective actions.

Table 2.1 Comparison of Typical Coal Ash Constituent Concentrations to Their Groundwater Protection Standards

Constituent	**Ash Leachate Concentrations (EPRI, 2006)**		**GWPS (µg/L)**
	Median (µg/L)	95th Percentile (µg/L)	
Boron	2,160	86,040	35[b]
Current Appendix IV Constituents[a]			
Antimony	2.4	27	6[c]
Arsenic	25	221	10[c]
Barium	108	347	2,000[c]
Beryllium	<0.4	0.7	4[c]
Cadmium	1.5	24	5[c]
Chromium	0.6	121	100[c]
Mercury	0.0038	0.039	2[c]
Selenium	19	315	50[c]
Thallium	0.36	11	2[c]

Notes:

a) While fluoride has an MCL, it was not characterized in EPRI's report (2006) and, consequently, is not listed in this table. Lithium, cobalt, molybdenum, and lead are not shown in this table because they have no federally-established MCL.

b) GWPS is based on typical groundwater background concentration (USGS, 2011). The boron GWPS at individual sites would be based on site-specific background concentrations.

c) GWPS is based on the MCL.

Table 2.2 Groundwater Corrective Action Treatment Efficiency Required to Achieve GWPS

Constituent	Median Leachate Concentration		95th Percentile Leachate Concentration	
	Fold Reduction (Ratio of Leachate Concentration to GWPS)	Required Treatment Efficiency	Fold Reduction (Ratio of Leachate Concentration to GWPS)	Required Treatment Efficiency
Boron	62	98.4%	2,458	99.96%
Current Appendix IV Constituents				
Antimony	---[a]	---[a]	4.5	77.8%
Arsenic	2.5	60%	22	95.5%
Barium	---[a]	---[a]	---[a]	---[a]
Beryllium	---[a]	---[a]	---[a]	---[a]
Cadmium	---[a]	---[a]	4.8	79.2%
Chromium	---[a]	---[a]	1.2	17.4%
Mercury	---[a]	---[a]	---[a]	---[a]
Selenium	---[a]	---[a]	6.3	84.1%
Thallium	---[a]	---[a]	5.5	81.8%

Notes:

a) For these constituents, the leachate concentration is already below the GWPS and, thus, no treatment is necessary.

2.2 Remediating boron would require additional and/or different treatment systems than required for existing Appendix IV constituents

Groundwater corrective actions designed to address boron will be significantly more expensive than corrective actions designed to address other Appendix IV constituents. Due to boron's high solubility, low sorption affinity, low propensity to precipitate, and the higher treatment efficiency required (Section 2.1), many typical groundwater treatment technologies will be ineffective at treating boron. There is no evidence that boron and boron compounds are significantly affected by typical groundwater treatments for inorganic constituents such as coagulation/flocculation, sedimentation, and inert media filtration. US EPA Office of Water reported that among eight technologies potentially capable of removing boron, only three technologies successfully reduced boron levels to below 300 µg/L (US EPA, 2008)– a level which is still approximately an order of magnitude higher than typical background concentrations. Also, since boron is a non-metallic element that is very weakly ionized in neutral waters (EPRI, 2007), the working treatment technologies are boron-specific approaches that include significant pretreatment requirements, including drastic pH adjustment and filtration, and will not be effective at addressing the other Appendix IV constituents. Thus, multiple treatment systems may be required to comply with the Federal CCR Rule requirements if boron is added to the Appendix IV constituent list.

Likewise, groundwater corrective actions that are typically used to address the current Appendix IV constituents are not effective at treating boron. Selected remedial technologies that are commonly used to treat the Appendix IV constituents in groundwater are summarized below (US EPA, 2002a). For this analysis, we have used arsenic, a common CCR risk-driver, as a surrogate to evaluate typical *ex-situ* and *in-situ* treatment technologies for all current Appendix IV constituents.

Ex-Situ Treatment Technologies – Arsenic

- *Precipitation and coprecipitation:* This is an established treatment technology that involves the addition of chemicals that transform constituents into a form that will precipitate or adsorb to another precipitating species (US EPA, 2002a). Oxidants are often used to transform arsenic (III) into the less soluble arsenic (V). Following chemical addition, precipitate solids are removed *via* coagulation, flocculation, and/or filtration. This technology can be effective at reducing arsenic concentrations in water below the MCL.

- *Membrane filtration:* This is an established technology that involves removing contaminants from water using a semi-permeable barrier or membrane (US EPA, 2002a). Membrane filtration includes microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. This technology can be effective at reducing arsenic concentrations in water below the MCL.
- *Adsorption:* This is an established technology that involves removing contaminants from water using a fixed bed of sorbent material (US EPA, 2002a). Common sorbents used to remove arsenic include activated alumina and greensand, but other sorbents may also be used. This technology can be effective at reducing arsenic concentrations in water below the MCL.
- *Ion exchange:* This is an established technology that involves routing water through an ion exchange bed, which contains a resin with functional ionic groups (US EPA, 2002a). Arsenic in the water is removed and replaces the functional ionic groups in the ion exchange bed. This technology can be effective at reducing arsenic concentrations in water below the MCL.

In-Situ Treatment Technologies – Arsenic

- *Permeable reactive barriers (PRBs):* This is a technology whereby a wall of reactive media is installed such that it intersects impacted groundwater (US EPA, 2002a). As groundwater flows through the wall arsenic is removed *via* precipitation, adsorption, or ion exchange. Reactive media used in PRBs include zero-valent iron (ZVI), limestone, zeolite, and ion exchange resins.

Because none of the corrective action technologies discussed above will address boron in groundwater, additional corrective actions specifically designed for boron may be necessary. Treatment systems identified by US EPA as potentially capable of removing boron to levels below 300 µg/L are summarized below. Each technology listed is a boron-specific technology and may not address other Appendix IV constituents. Additionally, not every technology has been demonstrated to successfully remove boron to background levels. Moreover, there are no *in-situ* treatment technologies that have been demonstrated to be effective at treating boron in groundwater. The only proven effective treatment technologies involving pumping and treating groundwater *ex-situ*.

Treatment Technologies (Ex-Situ) - Boron

- *Boron selective ion exchange*: This ion exchange process, similar to an arsenic ion exchange system, involves the use of a specific resin that selectively removes boron. When all of the resin's available exchange sites have been used, the resin is exhausted and must be regenerated or replaced (US EPA, 2008). Boron-selective ion exchange resins with both anionic and polyhydroxyl groups are commercially available and the technology has been demonstrated to achieve greater than 99% boron removal efficiencies, with resulting effluents containing boron at less than 50 µg/L (EPRI, 2005). More recent studies in oil industry wastewater treatment (*e.g.* Rodarte and Smith, 2014), flue gas desulfurization (FGD) wastewater treatment (*e.g.* Goltz *et al.*, 2012), and drinking water treatment technologies (*e.g.* Chillon Arias, *et al.*, 2011) are consistent in the conclusion that the boron-specific ion exchange technology is possibly the only technology capable of treating boron in water to a background level.

- *Chemical addition plus coagulation, precipitation, and filtration*: A wide range of chemicals and materials, such as amorphous aluminum hydroxide, amorphous magnesium hydroxide, activated carbon, and activated alumina have been used to adsorb boron out of a solution. Excessive chemical dosage requirements and high operating costs are currently preventing commercial use of this process. (US EPA, 2008).
- *Reverse osmosis*: Reverse osmosis (RO) can also be used to remove boron from water but has limited capabilities (US EPA, 2008). Commercial applications of RO have shown only partial boron removal when influent concentrations are high. Boron removal to levels lower than 90 µg/L has not been demonstrated (US EPA, 2008).

2.3 Boron remediation is cost-prohibitive

Groundwater corrective actions designed to remediate boron are significantly more expensive than those designed for the other Appendix IV constituents. Due to boron's unique chemical characteristics, it is not readily treated by conventional groundwater remedial technologies that are used to treat the other Appendix IV constituents (Section 2.2). Additionally, because boron treatment technologies will not address the existing Appendix IV constituents, boron treatment costs are additive to other treatment costs that may be required for the existing Appendix IV constituents. This section presents an estimate of cost increases that would result if boron were added the Appendix IV constituent list.

In-situ remediation systems cannot be used to remediate boron in groundwater, which is a potential significant cost increase. There are no existing *in-situ* technologies that effectively address boron. If boron is added to the Appendix IV constituent list and is detected above background, this limitation will restrict treatment technology options to those that involve pumping and treating (P&T), whereas most of the other Appendix IV constituents are treatable with *in-situ* methods, such as PRBs. Due to high capital infrastructure costs, *ex-situ* treatment technologies are often more expensive than *in-situ* remedies. Table 2.3 presents a summary of capital costs associated with *ex-situ* P&T systems and *in-situ* PRB systems, though it does not provide information related to specific technologies (*i.e.* ion exchange, adsorption, *etc.*). Data show that PRB *in-situ* technologies have capital costs that range from 3 to 5.8 times lower than for *ex-situ* P&T systems.

Table 2.3 Comparison of *In-Situ* and *Ex-Situ* Remediation System Costs (US EPA, 2001)

Treatment Approach	Capital Costs (million dollars)		
	25th Percentile	50th Percentile	75th Percentile
P&T (*ex-situ*)	3.0	3.6	10.5
PRB (*in-situ*)	0.8	1.2	1.8

Note: All costs are adapted from US EPA (2001; Exhibit 6); an average annual inflation rate of 3.07% (USACE, 2017) was used to convert the costs from 1999 dollars to 2017 dollars.

In addition to capital costs, potential operation & maintenance (O&M) costs associated with a boron treatment system as well as systems designed for the other Appendix IV constituents were evaluated. For this analysis, costs were estimated for several remedial technologies designed specifically to address boron and arsenic including an arsenic precipitation system, an arsenic adsorption system using greensand filtration, an arsenic ion exchange system, and a boron-specific ion exchange system. We used arsenic as a surrogate for the existing Appendix IV constituents since arsenic is a common risk driver associated with CCR disposal facilities. Because each technology evaluated involves pumping groundwater and treating it in a centralized location, the capital costs, which include the installation of pumping wells, construction of a treatment building, procurement of equipment, and installation of piping network, are similar for each scenario; thus, this evaluation focuses solely on the O&M costs for each system.

Assumptions made for each cost evaluation are described below.

- Costs were estimated for treatment systems based on an influent flowrate of 100 gallons per minute (gpm). Site-specific treatment system flowrates will depend on a number of factors including, but not limited to, plume size and aquifer hydraulic conductivity.
- For arsenic treatment technologies, costs were based on data presented in US EPA (2002a). This report presents typical O&M costs for each technology for a range of flowrates. Costs were scaled from these flowrates in order to estimate costs at the assumed flowrate of 100 gpm. Additionally, costs were adjusted using an average annual inflation rate of 2.87% (USACE, 2017) to convert the costs from 1998 dollars to 2017 dollars.
- For the boron ion exchange treatment system, costs were estimated based on a study of boron treatment in FGD wastewater using an ion exchange system incorporating a boron selective resin (Goltz *et al.*, 2012). The study found that O&M costs for the system were approximately $5 per lb of boron removed by the ion exchange resin. For this analysis, we assumed an influent boron concentration of 86,000 µg/L, equivalent to the 95th percentile concentration for field ash leachate reported by EPRI (2006). Costs were inflated from 2012 dollars to 2017 dollars using an annual average inflation rate of 2.02%. (USACE, 2017).

A comparison of O&M costs for each treatment technology is provided below (Table 2.4). Note that these estimates should not be used in lieu of site-specific cost evaluations. Remedial costs will vary depending on many site-specific factors including flowrate, plume size, influent concentrations, pH, and groundwater geochemistry. Further, these O&M costs only represent costs associated with the individual treatment approach. Typical O&M costs such as equipment repair and replacement, well redevelopment, labor, permitting, sampling, laboratory analysis, electricity, and reporting are not included in the costs summarized below.

Table 2.4 Annual Operation and Maintenance (O&M) Cost Comparison of Treatment Technologies

Groundwater Treatment System	Estimated Annual O&M Cost for 100-gpm System
Arsenic Precipitation (US EPA, 2002a)	$88,750
Arsenic Adsorption - Greensand (US EPA, 2002a)	$33,700
Arsenic Ion Exchange (US EPA, 2002a)	$30,700
Boron-Specific Ion Exchange (Goltz, *et al.*, 2012)	$208,120 (86 mg/L influent)

Based on the cost analysis in Table 2.4, O&M costs for boron-specific treatment systems range from 2.3 to 6.8 times more expensive than arsenic treatment systems. However, because boron ion exchange systems will not address arsenic, if boron is added to Appendix IV, many facilities will require both arsenic and boron treatment systems. Thus, the cost impacts of adding boron to Appendix IV are even higher.

To illustrate the overall cost impacts of adding boron to the Appendix IV list, the following hypothetical example has been prepared detailing costs associated with the installation of a groundwater corrective action to address arsenic impacts. A similar estimate has been prepared for the same system to address both arsenic and boron impacts. Both estimates are consistent with the current GWPS requirements of the

Federal CCR Rule. It was assumed that, if just arsenic remediation were required, an *in-situ* PRB would be the selected remedy. However, if the corrective action were required to address both arsenic and boron impacts, an *ex-situ* remedy would be required. For this scenario, it was assumed that an arsenic adsorption system using greensand and a boron-specific ion exchange system would be installed.

For this analysis, it was assumed that the corrective actions would treat an influent flow of 100 gpm with a boron concentration equal to the 95th percentile value based on the EPRI (2006) dataset (86,000 µg/L). O&M costs were assumed for 10 years; no discount factor was applied to future costs. Additionally, O&M costs listed in Table 2.5 below only include technology-specific costs and do not include typical O&M costs such as equipment repair and replacement, well redevelopment, labor, permitting, sampling, electricity, laboratory analysis, and reporting that would be expected for both the *in-situ* and *ex-situ* approaches. Finally, it should be emphasized that this is simply an example of potential costs and is not reflective of costs for any specific site or any specific remedial action.

Based on this hypothetical scenario, the cost to remediate arsenic using a PRB would be approximately $1,565,600. The cost to treat arsenic and boron *ex-situ* would be approximately $6,018,200. Thus, the cost impact of adding boron to the Appendix IV constituent list for this individual hypothetical scenario would be more than $4,452,600.

Table 2.5 Hypothetical Cost Scenario

Corrective Action Approach	Estimated Capital Costs	Estimated O&M Costs	Total
In-Situ PRB to address arsenic impacts	$1,565,600[1,2]	--[4]	$1,565,600
Ex-Situ P&T System; arsenic-greensand and boron ion exchange	$3,600,000[3]	$2,418,200[5] ($241, 820 per year)	$6,018,200

Note:

1. Capital costs are based on a 1,000-foot long zero-valent iron (ZVI) PRB installed to a depth of 20 feet. PRB thickness is 6 inches – half of which is sand and half of which is ZVI. Thus, 5,000 ft^3 of ZVI assumed for the PRB. ZVI unit cost assumed to be $0.45/lb (high end cost for coarse ZVI in ITRC, 2011). ZVI density assumed to be 6.7 g/cm^3 [420 lb/ft^3] (average of Fe^0 and Fe_3O_4; Keane, 2009). Emplacement costs assumed to be $350 per linear foot (average of costs presented in ITRC, 2011).
2. An average annual inflation rate of 2.4% (USACE, 2017) was used to convert the costs from 2009 dollars to 2017 dollars.
3. Capital costs are adapted from median cost information presented in US EPA (2001); an average annual inflation rate of 3.07% (USACE, 2017) was used to convert the costs from 1999 dollars to 2017 dollars.
4. Assumed no O&M costs for the PRB since typical coarse ZVI PRBs have longevity of more than 15 years (ITRC, 2011).
5. O&M costs based on flow of 100 gpm, system operation for 10 years, and an influent boron concentration of 86,000 µg/L. Boron treatment costs estimated based on Goltz, *et al.* (2012); arsenic treatment costs based on US EPA (2002a). No discount factor was applied to future costs.

2.4 Remediating boron to a risk-based level instead of background is still a significant expense

US EPA standard risk assessment methodology for site-based clean-ups involves achieving acceptable risk-based environmental media concentrations, not background concentrations (US EPA, 1989).[5] The costs associated with boron treatment, however, will be significant even if the remedial goal is a risk-based standard rather than background. A regional screening level (RSL) of 4,000 µg/L has been set for boron (US EPA, 2016); even though the risk-based standard is over an order of magnitude higher than

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[5] Note that according to US EPA's Risk Assessment Guidance for Superfund, clean-up goals may be set to background, if site-specific background are higher than a health-based benchmark (US EPA, 2002b).

typical boron background concentrations in groundwater (35 µg/L; USGS, 2011), it will still be an expensive standard to meet. Chillon Arias *et al*. (2011) stated that the cost difference between treating boron to 500 µg/L and to non-detectable levels is insignificant. Based on Goltz *et al*. (2012), boron-specific ion exchange system costs are dependent upon the mass of boron removed by the resin. A system designed to meet the RSL will remove less boron and, thus, have lower costs than a system designed to achieve background. However, the cost differences are minimal; a system designed to achieve the RSL would have only 4.7% lower O&M costs than a system designed to achieve background (Table 2.6)

Table 2.6 Estimated Annual O&M Costs for Boron-Specific Ion Exchange Treatment System for Different Remedial Goals

Influent Conditions	**Remedial Goal**	
	Background, 35 µg/L (USGS, 2011)	RSL, 4 mg/L (US EPA, 2016)
Influent Boron Concentration = 86,000 µg/L	$208,120	$198,440

3 According to the US EPA Risk Assessment, Boron Does Not Pose a Human Health Risk at CCR Storage Facilities

In support of the Federal CCR Rule, US EPA conducted a risk assessment to characterize the potential risks to human health and ecological receptors associated with leachate from CCR surface impoundments and landfills in the US (US EPA, 2014). In terms of human health, the risk assessment focused on possible risks resulting from CCR disposal related to using groundwater as a source of drinking water and the ingestion of fish caught from nearby freshwater lakes or streams (US EPA, 2014). This part of the analysis considered possible exposures to CCR constituents to groundwater for a hypothetical off-site individual living within 1 mile of the landfill or surface impoundment. In addition to the groundwater pathways assessment, the EPA also evaluated potential risks from fugitive dust at landfills (US EPA, 2010a). Previous risk assessments determined that other exposure pathways posed a negligible human health risk, and therefore, were not re-assessed in connection with the CCR Rule.

The risk assessment, which focused on groundwater pathways and was first released as a draft in 2007, is well vetted – it has undergone multiple rounds of public comments, and has been updated with relevant information under various NODA actions (US EPA, 2007; US EPA, 2013). The risk assessment, which was conducted using a probabilistic design, was comprehensive, utilizing data from 953 surface impoundments and 341 landfills (US EPA, 2014; Table 2-1). Previous versions of the risk assessment (RTI, 2007; US EPA, 2010b) contained conservative assumptions that likely led to an overestimate of risk. Upon receiving public comment, US EPA made some refinements that resulted in more realistic data inputs and better characterization of uncertainty. While these refined inputs led to an overall reduction in risks, it is noteworthy that US EPA noted some lingering conservative assumptions that were likely to overestimate risks. These included assumptions that may have led to an overestimate of drinking water risks, including the use of inputs that overestimate drinking water intake, and underestimate of receptor weight, and an overestimate of infiltration rate based on inability to account for CCR compaction. Moreover, the probabilistic design of the risk assessment generates hypothetical exposure scenarios that are likely to overestimate risks at the high end of the risk distribution. While US EPA noted these biases, it also concluded, that at least individually, these assumptions were not likely to have a substantive impact on risk estimates.

Despite these conservative assumptions, the risk assessment demonstrated that boron did not pose a human health risk overall or for the specific waste disposal scenarios explored in the sensitivity analysis (*e.g.*, different types water types, lined/unlined) (see Table 3.1) for both surface impoundments and landfills. The exception was for the risk evaluation of FGD waste in surface impoundments. For FGD waste, the 90th percentile hazard index associated with the ingestion of drinking water was 2; however, this risk value, which is only slightly above the acceptable risk level, was based on a limited dataset (5 samples). In addition, based on the discussion above, this risk estimate involved some assumptions that likely led to an overestimate of risk.

The boron result is in contrast to several other CCR constituents (*e.g.*, Arsenic (III), Arsenic (V), lithium, molybdenum) that did show elevated risk at the 90th percentile overall and across waste disposal multiple scenarios. In particular, arsenic (III), the most significant risk driver, showed elevated cancer and non-cancer risks across the different disposal scenarios.

Table 3.1: Human Health Risk Exceedances[a] in 2014 US EPA Risk Assessment (US EPA, 2014)

	All	Unlined SI	Combined Ash	Ash & Coal Refuse	FGD
Arsenic (III)[b]	**2x10^{-4}/5**	**3 x 10^{-4}/8**	**2 x 10^{-4}/4**	**1 x 10^{-3}/26**	**2 x 10^{-4}/5**
Arsenic (V)[b]	1 x 10^{-5}/0.4	**4 x 10^{-5}/1**	1 x 10^{-5}/0.3	**4 x 10^{-4} /14**	**2 x 10^{-5}** /0.5
Lithium	2	3	**3**	<1	<1
Molybdenum	2	4	**2**	<1	<1
Thallium	<1	2	<1	<1	<1
Cobalt	<1	<1	<1	**13**	
Fluoride	<1	<1	<1		**2**
Mercury	<1	<1	<1	**5**	<1
Boron	0.6	<1	0.6	0.2	**2**

[a] Exceedances are for surface impoundments at the 90th percentile. There were no risk exceedances for landfills and surface impoundments at the 50th percentile and landfills at the 90th percentile for all the evaluated constituents.

[b] Cancer/non-cancer risks presented.

Bold fonts indicate a risk exceedance

Given the lack of risk to off-site receptors associated with boron from both landfill and surface impoundment coal ash disposal, adding boron to the list of Appendix IV constituents, and requiring corrective action if an on-site GWPS is exceeded, will not provide a meaningful public health benefit.

4 Listing of Boron Both as an Appendix III and Appendix IV Monitoring Constituent is Nonsensical

Listing boron as an Appendix IV constituent will undercut the US EPA's intent for the 2015 Federal CCR Rule. The detection monitoring program requires monitoring for constituents (Appendix III) in groundwater whose presence, at statistically significant levels above background conditions, may indicate a release from a CCR disposal facility. Because it is highly mobile, does not precipitate, and has a low affinity for sorbing to soil particulates (EPRI, 2005), boron may be a good indicator of potential releases from CCR disposal facilities and, consequently, a good constituent for inclusion on the Appendix III list.

However, the assessment monitoring program, designed by US EPA, serves a different purpose than the detection monitoring program. When an Appendix III constituent is detected at a statistically significant level above background, Appendix IV assessment monitoring is triggered. The goal of assessment monitoring is to evaluate whether there are any risks to human health associated with CCR constituents in groundwater and to determine whether corrective action is necessary. Thus, constituents on the Appendix IV assessment monitoring list include those constituents that are more likely to present a risk to human health. Because boron poses no meaningful risk from CCR disposal according to the US EPA risk assessment, and has no federally-established MCL, it is unnecessary to include it on Appendix IV.

In the draft version of the Federal CCR Rule, boron was included on the Appendix IV constituent list, but it was removed in the final version. The justification for removing boron from the final Appendix IV list was because it was already listed in Appendix III. Several other constituents, including aluminum, copper, iron, manganese, and sulfide, were removed from the Appendix IV list because they lacked MCLs – a justification that also applies to boron. The complete text of US EPA's rationale for removing boron from Appendix IV is provided below (US EPA, 2015):

> EPA has also revised the list of constituents in appendix IV by deleting the following constituents and parameters: aluminum, boron, chloride, copper, iron, manganese, pH, sulfate, sulfide, and TDS; and adding the following constituents: cobalt, lithium, and radium 226 and 228 combined. The following constituents and parameters are being removed from appendix IV because they are on appendix III and therefore will continue to be monitored throughout assessment monitoring: boron, chloride, pH, sulfate and TDS. Although fluoride is on appendix III, we are also retaining it on appendix IV because it does have an MCL and was found to pose risks in the 2014 risk assessment, and therefore is appropriately considered to be a constituent that is relevant for purposes of corrective action. Aluminum, copper, iron, manganese, and sulfide have been removed because they lack maximum contaminant levels (MCLs) and were not shown to be constituents of concern based on either the risk assessment conducted for this rule or the damage cases.

The inclusion of boron on both Appendix III and Appendix IV is nonsensical. Because there is no MCL for boron, the Federal CCR Rule requires that the background concentration be used as the Appendix IV GWPS. Thus, if added to Appendix IV, the detection of boron in groundwater above background during Appendix III detection monitoring would also be an exceedance of the Appendix IV assessment monitoring GWPS and, consequently, would trigger the implementation of corrective action, even though there may be no associated risks to human health. Adding boron to the Appendix IV constituent list would thus undercut the rationale for the entire tiered monitoring process developed by US EPA in the Federal CCR Rule.

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