

An Analysis of Potentially Exposed Populations Living Near Coal Combustion Waste Facilities and Associated Cancer Risks

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ABSTRACT

In 2010, the US Environmental Protection Agency (US EPA) published the results of a probabilistic risk assessment examining risks associated with the leaching of constituents in coal combustion residues (CCR) from different types of waste management units (WMUs), finding that exposure to arsenic *via* drinking water posed the most significant risk. Based on these results, US EPA conducted a Regulatory Impact Analysis (RIA) to estimate the regulatory benefits associated with avoiding excess cancer cases from arsenic exposure. In this paper, we present an alternative approach for determining the estimated number of excess cancer cases through a refined analysis of the size of the population that could potentially be exposed to arsenic leaching from WMUs. To perform this assessment, we located 511 coal-fired power plants on aerial imagery, mapped known or estimated groundwater flow direction, and counted apparent dwellings within one mile downgradient from the plant (excluding areas served by public water supplies) to identify the number of potentially exposed individuals. From the 511 identified power plants, we determined that 73 had potential downgradient receptors that are not on a municipal water supply. These 73 plants had 2,659 apparent dwellings, with an estimated population of 6,913 individuals. Although we took a markedly different approach, our evaluation was in reasonable agreement with US EPA's. Our evaluation provides a refined assessment of the population that may be potentially exposed to CCR leachate and further informs risk management decisions regarding the safe storage of CCRs.

INTRODUCTION

The United States Environmental Protection Agency (US EPA) conducted a probabilistic risk assessment examining risks from chemical constituents in coal combustion residues (CCRs) managed in several types of waste management units (WMUs) located at US power plants.¹ The risk assessment estimated the arsenic cancer risk associated with drinking water and fish consumption for the population living within one mile of a WMU. The results of the risk assessment are one of the criteria being used to distinguish between various regulatory alternatives in the Proposed Rule for the

regulation of CCRs.² Specifically, the Regulatory Impact Analysis (RIA) used the risk assessment results to estimate the regulatory benefits associated with avoiding excess cancer cases (monetized) under different regulatory options.³

Important steps in determining the number of cancer cases that could be avoided under different regulatory options involves 1) estimating the population that could potentially be exposed to CCRs and 2) calculating the number of hypothetical excess cancer cases that could be expected, given the size of the population and the toxicity of CCR constituents. This paper describes an independent population risk assessment evaluating the potential for excess cancers in the population living in the vicinity of WMUs. For this specific population risk assessment, we focused on potential risk from groundwater as a source of drinking water downgradient of CCR WMUs, and specifically risks from arsenic (the only CCR constituent that was associated with elevated risk in the 2010 US EPA risk assessment).¹ When appropriate, we compared our independent evaluation to the population risk assessment conducted by US EPA for the RIA, which also evaluated potential excess cancer cases from arsenic in groundwater used for drinking water.

DETERMINING THE POPULATION POTENTIALLY EXPOSED LIVING DOWNGRADIENT OF CCR LANDFILLS AND IMPOUNDMENTS

Our approach to estimating the number of potential groundwater receptors downgradient of CCR WMUs was based on a review of aerial imagery and evaluation of potential groundwater flow directions. This information was used to define an arc covering possible directions for groundwater flow for each WMU. Once this arc was determined, all dwellings were counted within the arc within one mile of the WMU unless there was a major surface water body within one mile, in which case the arc extended only to that distance. Dwellings within areas served by public water supplies were then excluded from the final count of groundwater receptors. More details on defining the potentially exposed population are presented below.

Our analysis was performed for coal-fired power plants used in US EPA's RIA and included a number of plants that were not included in the RIA. All of the 415 coal-fired power plants with nameplate capacity > 100 MW and most of the 96 plants with nameplate capacity < 100 MW* that were used in the RIA (total of 511 plants) were located using Google Earth Pro (see Table 1). For each plant, we identified the following:

- WMUs on or close to the power plant property.
- The distance to the nearest body of water.
- The potential for off-site groundwater flow and potential receptors downgradient of the WMU, the number of potential receptors, and the distance from the WMU to the nearest potential receptor.

* Three of the small plants could not be identified on the aerial images at the coordinates listed in the EGRID2007 database published by US EPA.

- Adjacent land use, whether rural, urban, developed, undeveloped, or industrial.

Potential for off-site flow was determined based on the following criteria:

- If the WMU was immediately adjacent to a large lake or river in a humid climate, and in a rural or undeveloped location, such that the likely direction of groundwater flow was to the lake or river, then it was determined that the site had low potential for off-site groundwater flow, and, by extension, low potential for downgradient receptors, unless the following conditions were observed:
 - The lake was man-made and the WMU was near the dam, or where there was lower land nearby, where groundwater flow may be outward from the lake around the dam;
 - The lake or river was small in scale, where it could not be assumed that all groundwater flow was toward the lake;
 - The power plant property was orientated perpendicular to the lake or river, potentially allowing groundwater flowing beneath a WMU on the upgradient portion of the property to flow off the property before discharging to the lake or river; or
 - There were dwellings immediately adjacent to the WMU in a position where a component of groundwater flow toward that property may be possible.
- If the WMU was not immediately adjacent to a large lake or river, and there could be dwellings between the WMU and the lake or river, then it was deemed to have potential for off-site groundwater flow because the power plant property boundaries were not known in most cases.
- If the facility was adjacent to a large lake or river, but in an area with dry climate, where groundwater flow to the lake or river could not be assumed, then it was deemed to have potential for off-site flow.

For WMUs with potential for off-site groundwater flow, the arc covering possible directions for groundwater flow was estimated based on the location of groundwater sinks (e.g., lakes and rivers) and land surface topography. This arc covered between 35 and 220 degrees, with smaller arcs used for WMUs where groundwater flow data were available and for WMUs in humid climates with uncomplicated landscapes where flow to rivers could be reasonably assumed. Larger arcs were used in areas where river bends and other topographic features (such as dams) complicated interpretation. In cases where land surface information was inconclusive (often in western states where groundwater discharge to lakes and rivers could not be assumed), a 360-degree arc was used. As noted above, all dwellings within this arc were counted under the assumption that it could be downgradient of the WMU and that each dwelling potentially had a groundwater supply well.

The presence of dwellings was determined by searching the aerial image for rooftops. If multiple rooftops were clustered around a single driveway (*e.g.*, a house with detached garage or outbuildings on a farm), they were counted as a single dwelling. Dwellings typically appeared to be residences, but also included other types of buildings that may or may not be inhabited.

A follow-up analysis was then performed to identify WMUs in areas served by municipal water. Water utilities were identified and called to determine service areas. Dwellings within areas served by public water supplies were then excluded from the final count of potential groundwater receptors.

As presented in Table 1, 364 of 511 plant locations we assessed had apparent WMUs. Of these, 73 had potential for downgradient receptors. A total of 2,659 dwellings that were not serviced by public water were found downgradient of these plants. We multiplied the number of dwellings by an average of 2.6 persons/dwelling (based on data from the US Census Bureau) to obtain an estimated population of 6,913, which represents an approximation of the number of individuals in the US who can potentially be exposed to constituents that leach from CCR WMUs *via* groundwater used as drinking water.

**Table 1
Tabulation of Receptor Analysis Results**

Plant Capacity	Number of Plants/RIA Plants	Could not Locate	Plants with Apparent WMUs	Plants with Potential for Off-Site GW Flow*	Plants with Potential Downgradient Dwellings on Private Water**	Number of Potential Downgradient Dwellings on Private Water	Number of Potential Downgradient Receptors on Private Water***
>100 MW	415/399	0	339	232	73	2,653 ± 292	6,898
50-100 MW	54/54	0	17	9	0	0 ± 0	0
<50 MW	42/42	3	8	2	1	6 ± 1	13
All Plants	511/495	3	364	243	74	2,659 ± 292	6,913

* Plants with potential for off-site groundwater flow have WMUs in locations where off-site flow may be possible.

** Potential downgradient dwellings reflects dwellings in areas not served by public water supplies.

*** Potential downgradient receptors reflects number of people living in downgradient dwellings in areas not served by public water supplies.

Our methodology to define the potential exposure population differed substantially from US EPA's approach in the RIA, and includes several refinements that increase the confidence of population estimates. Key advantages of our analysis were that each site was examined visually to estimate groundwater flow direction and flow arc, potential receptors were manually counted, and we factored in the limiting effect of major rivers and other water bodies on groundwater flow and contaminant transport. In contrast, US EPA used a generic assumption for all sites that half the population within one mile of the WMU lived downgradient of the source, and it did not account for groundwater interception by a surface water body in this step of the analysis.[†] Without accounting for interception by a surface water body, US EPA estimated a potentially exposed population of 34,533 people.

Additionally, our population estimate is a more refined analysis due to the consideration of site-specific factors for each site and a more recent evaluation of dwellings on city water *versus* using private wells. On the other hand, US EPA's use of census tract data, and adjustments for present population size (based on older data) and population growth over time, is a more refined approach than simply multiplying the number of dwellings by the average number of persons per dwelling based on current census data. However, US EPA's population adjustments would have only a minor effect on the population estimate.

Our site-specific analysis provided more realistic information about the distance of potential downgradient receptors from WMUs. We noted that, out of all the sites, the closest receptor is 250 feet from a WMU, 75% of the receptors are more than 1,000 feet from a WMU, and 53% of receptors are more than 2,000 feet from a WMU. This provides more realistic information than US EPA's 2010 risk assessment, which used a well distance input distribution ranging from 0.6 meters (2 feet) to 1,610 meters (1 mile), with a 50th percentile of 427 meters (1,400 feet) (see Appendix C, US EPA, 2010a).¹ Our analysis reveals that, on the whole, private wells are generally farther from the WMU than US EPA has assumed. Although we cannot use this analysis quantitatively to inform the estimate of the number of potential excess cancer cases from exposure to CCRs in groundwater, this analysis does demonstrate that, qualitatively, potential excess cancer cases estimated in our evaluation (below) and in US EPA's RIA (which are based on risk estimates assuming drinking water wells are closer than they actually are) are overestimated.

[†] This was accounted for in a later stage of US EPA's RIA.

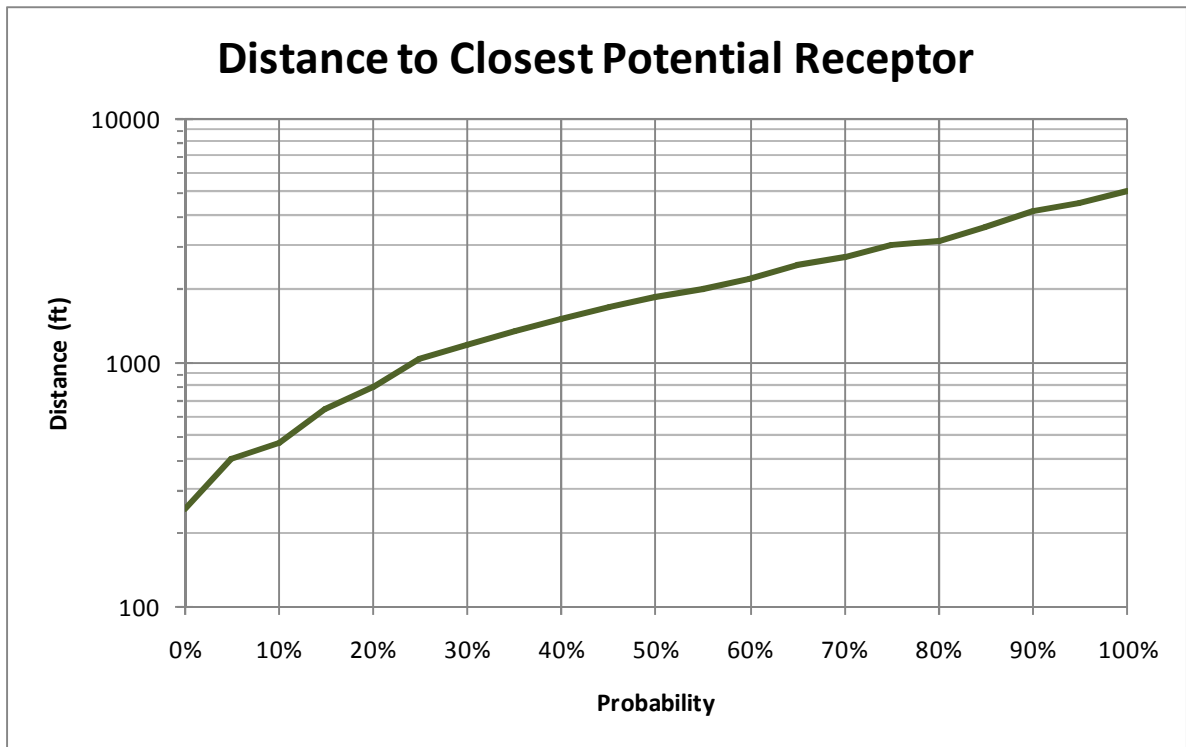


Figure 1. Probability plot showing distance to the closest potential receptor. Distance was determined for each WMU. For power plants with multiple WMUs, the shortest distance was used in this compilation.

POPULATION RISK

To determine the potential excess cancer cases in the defined population, we used US EPA's 50th and 90th percentile risks for landfills and surface impoundments, as presented in US EPA's Human Health Risk Assessment.¹ These are the cancer risks associated with drinking water risks from groundwater at the peak groundwater concentration and were calculated assuming a cancer slope factor (CSF) of $(1.5 \text{ mg/kg-d})^{-1}$, which is the current CSF for arsenic in US EPA's Integrated Risk Information System (IRIS). To obtain the average yearly increment of risk, we then divided the risks by the average adult exposure duration of 16 years.¹ We multiplied this risk by our population estimate of 6,913 potential receptors to estimate the potential number of excess cancer cases per year. This value was then multiplied by 75 years to estimate the number of excess cases over 75 years. Using this method, at the 90th percentile risk level (which is based on the IRIS CSF), we estimated 5 and 161 hypothetical excess cancer cases for landfills and surface impoundments, respectively (166 total). At the 50th percentile risk (also based on the IRIS CSF), we estimated 0.1 and 5 excess cases for landfills and surface impoundments, respectively (5 total) (see Table 2 below).

Table 2
Hypothetical Excess Cancer Cases Using Refined Population Estimate

Groundwater to DW Pathway	US EPA Risk*	Risk/Year**	Est. Population Exposed to Groundwater***	Cases/Year	Cases Over 75 Years
90 th Percentile					
Landfills	3.20E-04	2.00E-05	3,058	0.06	5
Surface Impoundments	8.90E-03	5.56E-04	3,856	2.1	161
TOTAL				2.2	166
50 th Percentile					
Landfills	7.70E-06	4.81E-07	3,058	0.0013	0.1
Surface Impoundments	2.80E-04	1.75E-05	3,856	0.067	5
TOTAL				0.068	5.1

* Average risks for landfills and surface impoundments calculated based on information in US EPA's Human Health Risk Assessment;¹ as a conservative measure, average risk excludes risks associated with synthetic liners.

** Risk/year is the risk divided by the average exposure duration of 16 years.

*** When the same population was exposed to both a landfill and surface impoundment, we present the excess cancer cases based on the surface impoundment (which is more conservative).

Due to the probabilistic nature of the risk assessment, it was not possible for us to re-create US EPA's analysis using the more refined population estimates exactly, but the calculations described above are parallel to the approach used by US EPA in the RIA. Some differences with our analysis are that we used an average risk and average exposure duration (instead of individual model runs and associated exposure durations) to calculate a peak one-year risk. Also, our analysis assumes that the population is exposed to the peak well concentration for 75 years, which is more conservative than US EPA's approach. US EPA's estimated number of excess cancer cases over a 75-year period was 145 cancers using the IRIS CSF. The estimates we calculated (5 to 166) bound the cancer cases estimated by US EPA. In both analyses, even on the high-end (using 90th percentile risks), this would equate to less than two cancer cases per year over a 75-year period; using 50th percentile risks yearly cancer cases would be less than 0.07 cases per year. However, as mentioned in more detail in the "Discussion of Uncertainties," it is critical to appreciate that any estimate of excess cancer cases is hypothetical and based on assumptions that are intended to overestimate risk. Also, these estimates of potential excess cancer cases do not assume any remediation of CCR contamination. For these reasons, the estimates of potential excess cancer cases should be considered a worst-case scenario. In reality, there may be zero excess cancer cases associated with exposure to CCRs in groundwater.

Although our estimates of potential hypothetical excess cancer cases are in the range of the estimate present in the RIA using the IRIS CSF of 1.5 mg/kg-d. US EPA also performed an alternative assessment using a CSF of 26 (mg/kg-d)⁻¹, a value that was developed in 2001 by the National Research Council (NRC) (based on bladder and lung cancer).^{4,5} Using a CSF of 26 (mg/kg-d)⁻¹ resulted in a significantly higher number of

excess cancer cases over a 75-year period (*i.e.*, 2,509 cases[‡]). While it is widely recognized that the CSF for arsenic in IRIS is outdated, the methodology used to derive this CSF is the source of scientific debate. The arsenic CSF reported in IRIS is currently being reviewed by US EPA and by scientific advisory panels. US EPA's most recent evaluation of the arsenic CSF is similar to the NRC (2001) analysis, sharing a similar overall approach and key assumptions.⁵ There are several outstanding scientific issues in the IRIS analysis, however, and, until the CSF assessment undergoes the full peer-review process and is finalized, it is not appropriate to use a value that lacks a scientific consensus.

DISCUSSION OF UNCERTAINTIES

Some of the uncertainties associated with our assessment are summarized below:

- There is uncertainty in the groundwater flow direction assumed for each facility, because it is based solely on surface elevation; this could result in either an over- or underestimate of the number of dwellings downgradient from each facility. However, the width of the downgradient arc was a conservative overestimate, so as not to underestimate the number of downgradient dwellings.
- This analysis applies to current conditions, because current information was used to count the number of dwellings and determine reliance on municipal water. Additional residential development and changes to reliance on municipal water around these facilities in the future could change the calculated population risk. It should be noted that, given the increased attention on potential risks from CCRs, it is more likely that reliance on municipal wells will increase, which would reduce the population risk.
- To estimate the number of potential excess cancer cases from arsenic in communities living in the vicinity of CCR storage facilities, we relied on the risk estimates presented in the US EPA risk assessment.¹ These risks are hypothetical and were derived using a conservative approach that tends to overestimate risk (for example, conservative assumptions regarding arsenic mobility, arsenic leachate concentrations, distance to the receptor, and toxicity benchmarks). Thus, excess cancer cases calculated in this analysis should also be considered a conservative, hypothetical estimate. In fact, exposure to CCRs in drinking water may not be associated with any increase in cancer. Determining any actual increase in disease rates in communities living within the vicinity of CCR storage units would require a properly designed epidemiological study.
- The hypothetical cancer cases we estimated are in the absence of any groundwater monitoring or remediation; both activities would limit receptor exposure to CCR constituents in groundwater. Considering these activities are

[‡] Again, this value reflects estimated excess cancer cases in the absence of no groundwater monitoring or remediation to limit receptor exposure.

routinely practiced in the management of CCRs, our estimations of hypothetical excess cancer cases are overestimates.

CONCLUSIONS

Using our refined approach to estimate the population living in the vicinity of WMUs and hypothetical cancer risks calculated in US EPA's risk assessment [with a CSF of $1.5 \text{ (mg/kg-d)}^{-1}$], in the absence of any remediation, we would estimate between 5 and 166 hypothetical excess cancer cases over a 75-year period based on the 50th and 90th percentile cancer risks presented in the US EPA risk assessment. On the high end (at 90th percentile) and using risk estimates designed to over-predict health effects, this translates into approximately two excess cancer cases per year on average. Using 50th percentile risks, hypothetical excess cancer cases are significantly less than per year on average. To put these values into perspective, the National Cancer Institute estimated that there would be 290,420 newly diagnosed bladder and lung cancers in the US in 2009.⁶

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