Groundwater Monitoring and Data Analysis under the Coal Combustion Residuals Rule†

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Introduction

The presentation that is summarized in this article focused on two topics: statistical analyses of groundwater monitoring data collected under the coal combustion residuals (CCR) rule and alternative source demonstrations.

Statistical Analyses of Groundwater Monitoring Data Collected under the CCR Rule

This presentation summary provides a high-level overview of the statistical methods that can be used for evaluation of groundwater monitoring data collected under the CCR Rule. Implementation of these procedures requires greater understanding of the topic than is presented here, and the reader is referred to the CCR Rule, U.S. Environmental Protection Agency’s Unified Guidance (USEPA, 2009), and other documents on groundwater monitoring, such as those referenced at the end of this summary. The CCR Rule provides the criteria under which groundwater monitoring and statistical analyses are performed, while the Unified Guidance provides a methodology that can be used to meet statistical criteria. The discussion that follows assumes three definitions:

- Statistically significant increase (SSI): detection monitoring—when downgradient concentrations are higher than a statistically determined background level
- Statistically significant level (SSL): assessment monitoring—when downgradient concentrations are at a level statistically determined to be higher than the groundwater protection standard (GWPS)
- Groundwater protection standard: a threshold concentration, based on the chemical constituent’s maximum contaminant level (MCL) or on a statistically determined background concentration if it is higher than the MCL

Detection monitoring

The first phase of groundwater monitoring performed for a CCR facility under the CCR Rule is detection monitoring. Detection monitoring continues at least 30 years postclosure and can continue for longer periods if the facility is in assessment monitoring (40 CFR 257.94).

Purpose:
- Detection of a release

Approach:
- Monitor for relatively mobile indicator (Appendix III) constituents (see Table 1)
- Frequency is semiannual, although exceptions are possible
- Compare downgradient concentrations to a statistically determined background level

Outcome if there is an SSI relative to background:
- Alternative source demonstration if the SSI is not due to a release from the facility, or
- Establish assessment monitoring program

Assessment monitoring

If a release is verified under detection monitoring, then assessment monitoring is initiated. Detection monitoring continues...
Table 1
Constituents monitored under the coal combustion residuals rule

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Appendix III</th>
<th>Appendix IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>Antimony</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>Arsenic</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>Beryllium</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>Cadmium</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>Chromium</td>
<td></td>
</tr>
<tr>
<td>Sulfate</td>
<td>Cobalt</td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>Fluoride</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lead</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lithium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mercury</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Molybdenum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selenium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thallium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radium 226/228</td>
<td></td>
</tr>
</tbody>
</table>

1 As of November 2016; the U.S. Environmental Protection Agency has filed notice that it intends to add boron to the Appendix IV list. Because boron does not have a maximum contaminant level (MCL), the groundwater protection standard (GWPS) for boron would be based on background.

2 These constituents do not have an MCL, and their GWPS would be based on background.

during this period. Postclosure groundwater (detection) monitoring continues as long as a facility is in assessment monitoring. Assessment monitoring continues until all detection and assessment monitoring constituents are lower than background (using detection monitoring statistics) for two consecutive sample events (40 CFR 257.95).

Purpose:
• Determine if corrective action is needed

Approach:
• Use detection monitoring system

• Monitor semiannually for Appendix III and detected Appendix IV constituents; annually for all Appendix IV constituents (Table 1)
• Assessment monitoring statistics performed on detected Appendix IV constituents
• Statistically compare downgradient concentrations to GWPS

Outcome if there is an SSL relative to the GWPS:
• Alternative source demonstration if the SSL is not due to a release from the facility, or
• Initiate assessment of corrective action measures and close or retrofit the facility if it is an unlined CCR impoundment

The Unified Guidance recommends a different statistical approach for assessment monitoring than for detection monitoring using confidence intervals around the downgradient data set, where the interval defines the range in which the mean (or median for a nonparametric data set) is expected to occur—given a specified confidence. These statistics assume a null hypothesis that groundwater is not contaminated; therefore, an SSL occurs only if the lower confidence level (or bound) is higher than the GWPS (Figure 2).

Corrective action monitoring

If there is a confirmed SSL at a facility, then the CCR Rule requires corrective action. Corrective action monitoring begins after the corrective action is implemented and may use a different set of monitoring wells than the detection/assessment system. Detection and assessment monitoring continue during this period using the detection/assessment monitoring system. Corrective action monitoring continues until concentrations of Appendix IV constituents in all corrective action monitoring wells that are not part of the detection/assessment monitoring system have concentrations...
Fig. 2. An example statistical evaluation flow chart for evaluation of assessment monitoring data showing an approach capable of meeting criteria of the coal combustion residuals rule and the recommendations of the Unified Guidance. Other statistical tests/approaches may be acceptable. GWPS = groundwater protection standard; LCL = lower confidence level; LCB = lower confidence bound (for confidence bands around trend lines); MCL = maximum contaminant level; SSL = statistically significant level.

statistically lower than the GWPS for three consecutive years (40 CFR 257.98).

Purpose:
- Determine effectiveness of selected remedy
- Determine if GWPS attained for Appendix IV constituents

Approach:
- The CCR Rule assumes that there will be corrective action monitoring wells downgradient from the detection/assessment monitoring system
- Monitor semiannually for Appendix III and detected Appendix IV constituents; annually for all Appendix IV constituents (Table 1)
- Corrective action monitoring statistics performed on detected Appendix IV constituents
- Statistically compare downgradient concentrations to GWPS

Outcomes, based on statistical analysis of corrective action monitoring wells downgradient from the detection/assessment monitoring system:
- Modify corrective action if concentrations do not decrease
- Continue corrective action monitoring if concentrations decreasing but statistically higher than GWPS
- Return to assessment monitoring when GWPS attained for three consecutive years

The Unified Guidance recommends a similar statistical approach for corrective action monitoring to assessment monitoring using confidence intervals around the corrective action (downgradient) monitoring data set, where the interval defines the range in which the mean (or median for a nonparametric data set) is expected to occur—given a specified confidence. However, per the Unified Guidance, corrective action statistics assume a null hypothesis that groundwater is contaminated; therefore, compliance is achieved when the upper confidence level (or bound) is lower than the GWPS (Figure 3).

Alternative Source Demonstrations

The CCR Rule allows for alternative source demonstrations (ASDs) when an SSI or SSL occurs due to a cause other than a release from the CCR facility, including:
- Laboratory causes (e.g., interferences)
- Sample causes (e.g., high turbidity)
- Statistical evaluation causes (e.g., change from parametric to nonparametric)
- Natural variation that is not accounted for in the basic detection or assessment monitoring statistics
- Other anthropogenic sources

Laboratory, sample, and statistical evaluation causes may be more straightforward to demonstrate than natural variation and alternative sources. When a straightforward demonstration is not possible, groundwater quality signatures (forensics) provide a tool to make a demonstration in a weight-of-evidence–based approach. The Electric Power Research Institute (EPRI, 2012) documented three tiers for water quality signatures that are useful for evaluation of groundwater monitoring data for inorganic constituents at CCR facilities (Figure 4). In many cases, tiers 1 or 2 may be sufficient. This tiered
approach can be combined with the site conceptual model and hydrogeologic information to build an ASD.

An example ASD is summarized in Table 2. In this example, the tier 1 and tier 2 lines of evidence supported the conclusion that the source of the molybdenum exceedance was not the CCR facility; however, there were technical issues with each of these lines of evidence, such that none were conclusive. As a result, isotope sampling (tier 3) was performed, which provided strong evidence that the CCR facility was not the source.

Table 2
Example summary for an alternative source demonstration, where molybdenum is the constituent of interest

<table>
<thead>
<tr>
<th>Source of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogeology: No hydraulic connection; there is 100+ feet of clay separating coal combustion residuals (CCR) from the uppermost aquifer, but not conclusive because vertical fracture flow could not be ruled out</td>
</tr>
<tr>
<td>Groundwater flow: Highest Mo concentrations far upgradient of the CCR facility monitoring system, but concentrations also elevated downgradient, and not conclusive because other migration pathways could not be ruled out</td>
</tr>
<tr>
<td>Mo distribution: See above and Mo concentrations increased with depth (a decrease with depth expected if CCR facility is the source), but not conclusive due to limited number of vertical monitoring points</td>
</tr>
<tr>
<td>Distribution of other CCR indicators: No evidence of a release based on other indicators, particularly boron, but not conclusive because background boron concentration was higher than typically found in groundwater</td>
</tr>
<tr>
<td>Major ion ratios: Pieper diagrams indicated no evidence of mixing between background groundwater and leachate, but some mixing could be interpreted from a small percentage of sample points on the diagram</td>
</tr>
<tr>
<td>Tritium: Highest Mo concentrations in water with low tritium levels (meaning groundwater recharged prior to construction of the facility)</td>
</tr>
<tr>
<td>Boron isotopes: No evidence of a release from CCR facilities</td>
</tr>
<tr>
<td>Strontium isotopes: No evidence of a release from CCR facilities</td>
</tr>
</tbody>
</table>

Sources of Information

Below are sources of information that can be consulted when implementing a groundwater monitoring and data analysis program for a CCR facility. This list is not all-inclusive, and other sources may provide similar information.

Groundwater monitoring and data analysis under the CCR Rule (including statistical analysis)


Hydrogeologic field investigation and monitoring well design/installation

ASTM International, numerous documents related to groundwater monitoring and groundwater systems (e.g., D5092, D6286, D5979). https://www.astm.org/search/


Groundwater sampling


