Coal Combustion Residual Statistical Method Certification for the CCR Landfill at the Boardman Power Plant Boardman, Oregon

Prepared for

Portland General Electric

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Contents

Section Page

Certification v

1 Introduction 1-1
1.1 Groundwater Analysis Requirements 1-1
1.2 Performance Standard for Selecting Statistical Method 1-1

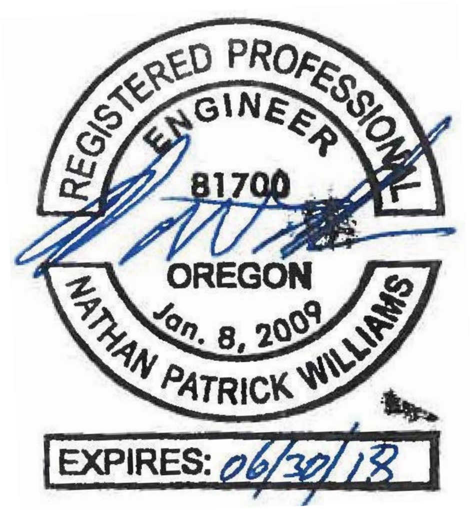
2 Exploratory Data Evaluation and Selection of Statistical Method 2-1
2.1 Graphical (Qualitative) Data Analysis 2-1
2.2 Quantitative Statistical Data Analysis 2-1
2.2.1 Descriptive Statistics 2-1
2.2.2 Statistical Outlier Analysis 2-2
2.2.3 Evaluating Data for Temporal Independence 2-2
2.2.4 Data Distribution Analysis 2-2
2.2.5 Temporal Variability Analysis 2-2
2.2.6 Spatial Variability Analysis 2-3
2.3 Selection of Statistical Method 2-3
2.3.1 Statistical Methods for Appendix III Constituents 2-3
2.3.2 Statistical Methods for Appendix IV Constituents 2-3
2.3.3 Rationale for Statistical Method Selection 2-3
2.4 Narrative Description of Groundwater Monitoring Evaluation Using the Selected Statistical Methods 2-4
2.4.1 Detection Monitoring Evaluation 2-4
2.4.2 Assessment Monitoring Evaluation 2-5

3 Summary 3-1

4 References 4-1

Certification

"I hereby certify that the **statistical method** described in this document is appropriate for evaluating the groundwater monitoring data for the CCR Landfill at the Boardman site located at 73334 Tower Road, Boardman, Oregon, as described herein, and meets the regulatory requirements of the Coal Combustion Residual Rule, Title 40 *Code of Federal Regulations* §257.93(f). I am a duly licensed Professional Engineer under the laws of the State of Oregon."



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SECTION 1

Introduction

On April 17, 2015, the U.S. Environmental Protection Agency (EPA) updated the *Code of Federal Regulations* (CFR) rules and regulations regarding disposal of Coal Combustion Residual (CCR). In accordance with the updated CFR, any facility that disposes of CCR must implement groundwater monitoring plan in accordance with CFR §257.90 under the Resource Conservation and Recovery Act (RCRA). This document has been prepared on behalf of Portland General Electric (PGE) to provide documentation for public record of the selected statistical method per CCR Rule §257.93(f).

PGE manages the Boardman Power Plant (Plant) located approximately 11 miles southwest of Boardman, Oregon. The Plant burns coal for power generation, which generates residual ash waste that is disposed of into the CCR Landfill south of the Plant.

1.1 Groundwater Analysis Requirements

The owner of a CCR unit needs to initiate a groundwater monitoring and evaluation program and select one of the statistical procedures specified in §257.93(f)(1) through (f)(5) of CCR Rule for evaluating groundwater monitoring data. The five statistical methods from which one method needs to be selected for evaluating groundwater monitoring data as listed in CCR Rule §257.93(f) are listed below:

- *(f)(1): A parametric analysis of variance followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent.*
- *(f)(2): An analysis of variance based on ranks followed by multiple comparison procedures to identify statistically significant evidence of contamination; The method must include estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent.*
- *(f)(3): A tolerance or prediction interval procedure in which an interval for each constituent is established from the distribution of the background data and the level of each constituent in each compliance well is compared to the upper tolerance or prediction limit.*
- *(f)(4): A control chart approach that gives control limits for each constituent.*
- *(f)(5): Another statistical method that meets the performance standards specified in Rule §257.93 paragraph (g).*

— EPA (2015)

The owner of the CCR unit must obtain PE certification stating the selected statistical method is appropriate for evaluating the groundwater monitoring data, and include a narrative description of the selected statistical method.

1.2 Performance Standard for Selecting Statistical Method

The statistical methods under CCR Rule §257.93(f) must comply with the following performance standards as described under paragraphs (1) through (6) of CCR Rule §257.93(g):

- *(g)(1): Non-normal distributions shall use non-parametric methods. If the distribution of the constituents is shown by the owner or operator of the CCR unit to be inappropriate for a normal theory test, then the data must be transformed or a distribution-free (non-parametric) theory test* *must be used. If the distributions for the constituents differ, more than one statistical method may be needed.*

- *(g)(2): If an individual well comparison procedure is used to compare an individual compliance well constituent concentration with background constituent concentrations or a groundwater protection standard, the test shall be done at a Type I error level no less than 0.01 for each testing period. If a multiple comparison procedure is used, the Type I experiment wise error rate for each testing period shall be no less than 0.05. This performance standard does not apply to tolerance intervals, prediction intervals, or control charts.*
- *(g)(3): If a control chart approach is used to evaluate groundwater monitoring data, the specific type of control chart and its associated parameter values shall be such that this approach is at least as effective as any other approach of CCR Rule §257.93(f) for evaluating groundwater data. The parameter values shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.*
- *(g)(4): If a tolerance interval or a prediction interval is used to evaluate groundwater monitoring data, the levels of confidence and, for tolerance intervals, the percentage of the population that the interval must contain, shall be such that this approach is at least as effective as any other approach of CCR Rule §257.93(f) for evaluating groundwater data. These parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.*
- *(g)(5): The statistical method must account for data below the limit of detection with one or more statistical procedures that shall be at least as effective as any other approach described under CCR Rule §257.93(f) for evaluating groundwater data.*
- *(g)(6): If necessary, the statistical method must include procedures to control or correct for seasonal and spatial variability as well as temporal correlation in the data.*

— EPA (2015)

SECTION 2

Exploratory Data Evaluation and Selection of Statistical Method

To determine an appropriate statistical method for the detection monitoring program, the CCR background data were evaluated using both graphical (qualitative) and quantitative data exploratory procedures to support their statistical characterization. The main objective of the data exploratory analysis was to determine the following characteristics as described herein:

- Statistical independence of the background measurements
- Temporal stationarity
- Statistical outliers
- Distribution of various constituents at different water quality compliance wells
- Temporal variability
- Spatial variability

The methods and analysis of these data characteristics generally followed the Part I (statistical design) and Part II (diagnostic evaluations) approach described in *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance* (Unified Guidance) (EPA, 2009).

2.1 Graphical (Qualitative) Data Analysis

Graphical plots are useful tools to qualitatively review essential data characteristics in support of, and prior to, conducting quantitative statistical evaluations. The following graphs were developed with the eight rounds of CCR background data as supporting evaluations described herein:

- Time series plots: These are used to evaluate and identify potential inferred trends, seasonal phenomenon, inconsistencies (such as outliers), or a combination thereof. While plotting data on a time-series graph, it is important to distinguish detected values versus nondetects.
- Box and whiskers plots: The basic box plot graphically locates the median, 25th, and 75th percentiles, while the "whiskers" extend to the minimum and maximum values. Box plots are used to illustrate central tendency and spread, to compare characteristics of wells or among well groups, or both, and to identify potential outliers.
- Histograms: These are used to determine underlying distributions.
- Probability plots: These are used to determine distribution and identify potential outliers.

2.2 Quantitative Statistical Data Analysis

Quantitative data analysis includes various statistical diagnostic methods, including descriptive statistics, outlier analysis, temporal independence, data distribution, trend analysis, temporal variability analysis, and spatial variability analysis. These analyses are described below, and the results from these analyses were used to support the selected method as described in Section 2.3.

2.2.1 Descriptive Statistics

Descriptive statistics were calculated for the designated CCR wells using the background data. For each unique well-constituent combination, the mean, standard deviation, skewness, coefficient of variation, minimum concentration, maximum concentration, and frequency of detects (or nondetects) were determined.

2.2.2 Statistical Outlier Analysis

According to the Unified Guidance (EPA, 2009), statistical outliers are observations not derived from the same population as the rest of the samples and violate the basic statistical assumption of identically distributed measurements. The Dixon's test and other applicable outlier test methods were used to evaluate potential statistical outliers in the CCR background data.

2.2.3 Evaluating Data for Temporal Independence

One of the most important assumptions background data should pass is statistical independence. Each measurement should be randomly representative of the target population and its value should not be influenced by any other measurement (that is, each measurement should be independent of every other measurement), because dependent measurements exhibit less variability. Values which are temporally dependent may lead to an underestimation of the population variance, which in turn affects the estimated upper (compliance) limit from a given statistical method. The Rank Von Neumann test was the method used to determine whether the background data for a given monitoring well are serially correlated.

2.2.4 Data Distribution Analysis

Determining the nature of the underlying population from which samples are drawn is important, because it governs whether parametric (or nonparametric) test procedures can be employed in subsequent statistical analyses. The parametric statistical tests require a much smaller dataset than those required by nonparametric statistical tests to achieve the same level of statistical power and false-positive error rate. For relatively small datasets, a test of significance for normality may lack power to detect the deviation of the variable from normality. In this situation, it is advisable to consider a theoretical distribution that appears reasonably logical to the data under consideration and to also review the descriptive statistics (that is, mean, median, mode, range, and quartile deviation while deciding the type of distribution). While conducting the distributional analyses for characterizing the underlying distribution of various constituents, three distributions namely the normal, lognormal, and gamma distributions were used.

One of the important requirements when determining background groundwater quality levels for the constituent(s) of concern is determining whether temporal stationarity exists. If background groundwater constituent concentrations are not temporally stationary, then background conditions are undefined and setting a compliance level for comparison is not statistically valid and can lead to erroneous results. To confirm this understanding, the Mann-Kendall test was used on the CCR background data to determine whether a statistical trend exists within the CCR background monitoring period.

2.2.5 Temporal Variability Analysis

Temporal variability exists when the distribution of measurements varies with the times at which sampling or analytical measurement occurs. To conduct temporal variability analysis, a nonparametric, one-way analysis of variance (ANOVA) analysis test was performed on the CCR background data using the Kruskal-Wallis test. Before applying the Kruskal-Wallis test, the equality of variance was tested using the Levene's test.

2.2.6 Spatial Variability Analysis

To characterize spatial variability, a nonparametric, one-way ANOVA Kruskal-Wallis test was used. To validate the Kruskal-Wallis test results, the equality of variance was tested using the Levene's test before the one-way ANOVA.

2.3 Selection of Statistical Method

In order to implement the CCR Rule §257.93(f), one must establish background levels for both Appendix III and Appendix IV constituents and compare downgradient concentrations to their respective established background levels to determine compliance. Thus, statistical methods need to be selected for both Appendix III and Appendix IV constituents. For the Boardman Power Plant CCR Landfill, the selected statistical methods are summarized in the following sections.

2.3.1 Statistical Methods for Appendix III Constituents

Based on the site-specific groundwater conditions and results of the exploratory evaluation, the selected statistical method for evaluating groundwater detection monitoring data is a prediction interval, which is a statistical method option per CCR Rule §257.93(f)(3) as summarized previously in Section 1.1. The background data characteristics were reviewed to establish a specific approach for each constituent as given below:

- Boron, parametric prediction interval method
- Calcium, nonparametric prediction interval method
- Chloride, parametric prediction interval method
- Fluoride, parametric prediction interval method
- pH, parametric prediction interval method
- Sulfate, parametric prediction interval method
- Total dissolved solids, parametric prediction interval method

The prediction interval method will be conducted separately for each well-constituent pair. Thus, an individual well comparison, also known as intrawell, approach will be used for the statistical analysis. An intrawell approach was selected because all Appendix III constituents except boron indicate significant spatial variability, making an upgradient versus downgradient, also known as interwell, comparison infeasible. For boron, both intrawell and interwell approaches are applicable. For the sake of consistency, it was decided to use the intrawell approach for boron.

2.3.2 Statistical Methods for Appendix IV Constituents

The statistical method selected for Appendix IV constituents is a tolerance interval procedure as specified under §257.93(f)(3) of the CCR Rule. Based on detection frequency and distribution characteristics of each well-constituent pair, either a parametric or a nonparametric tolerance interval procedure will be used.

2.3.3 Rationale for Statistical Method Selection

The prediction interval method specified in CCR Rule §257.93(f)(3) was selected because it is exceptionally versatile, can be used with both parametric and non-parametric data, and can be designed to accommodate a wide variety of potential site monitoring conditions. Furthermore, it has been extensively researched, and provide a straightforward interpretation of test results. The prediction interval approach offers the most effective means of accounting for the cumulative site-wide false positive rate (SWFPR) and the effective power to identify real exceedances. The Unified Guidance (EPA, 2009) strongly encourages the use of a comprehensive design strategy to account for these two criteria.

The prediction interval approach has been constructed to formally include a retesting strategy as part of the overall statistical test.

The analysis of variance (ANOVA) methods specified in CCR Rule §257.93(f)(1) and §257.93(f)(2) were not selected for several reasons. First, these methods assume stringent assumptions that both background and detection monitoring data sets have similar distributions and equal variances, a condition that almost never occurs in practice. Second, because §257.93(g)(2) of the CCR Rule mandates a minimum Type I error of 0.05 when using ANOVA, it would be difficult to maintain the annual SWFPR of 10 percent recommended by the EPA Unified Guidance (EPA, 2009). Finally, the Unified Guidance (EPA, 2009) does not recommend the use of ANOVA for detection monitoring because it is more sensitive to spatial variability than prediction interval or tolerance interval methods.

The control chart method specified in CCR Rule §257.93(f)(4) was not selected for several reasons. First, this method cannot be used for nonparametric datasets, which would preclude the use of a control chart approach for calcium background data. Second, this method cannot be used when nondetects exceed 50 percent of the dataset, a condition that may apply to several of the Appendix IV constituents. Third, control charts usually provide less flexibility than prediction intervals when designing a statistical monitoring program. And lastly, the statistical performance of control charts is not well understood (i.e., false positive rates and statistical power).

The “other” statistical method specified in CCR Rule §257.93(f)(5) was not chosen because prediction intervals and tolerance intervals were determined to be the most appropriate methods for monitoring groundwater at the site.

2.4 Narrative Description of Groundwater Monitoring Evaluation Using the Selected Statistical Methods

The narrative description required by CCR Rule §257.93(f)(6) for conducting groundwater monitoring evaluations using the selected statistical methods for the Appendix III and Appendix IV constituents are summarized below.

2.4.1 Detection Monitoring Evaluation

To determine if there has been a “statistically significant increase” (SSI) over background for each detection monitoring parameter, the detection monitoring results will be compared to upper prediction limits for all detection monitoring constituents except pH for which both lower and upper prediction limits will be used as required by CCR Rule §257.93(f)(3). The lower and upper prediction limits, also referred to as established background values, are determined as part of the statistical analysis used to select the appropriate statistical method. Using the individual well comparisons approach of prediction interval as the selected method, the following general process is used to establish background levels for each well-constituent pair:

- For constituents with 100 percent nondetects, the Double Quantification Rule (EPA, 2009) is used. According to this rule “A confirmed exceedance is registered if any well-constituent pair in the ‘100 percent nondetect’ group exhibits quantified measurements (i.e., at or above the reporting limit in two consecutive sample and resample events.”
- For constituents exhibiting a nondetect frequency greater than 50 percent, the nonparametric prediction interval method is used to compute background levels.
- For constituents exhibiting a nondetect frequency less than or equal to 50 percent, the Kaplan-Meier censored estimation technique is used to estimate the background mean and standard deviation to determine the parametric prediction interval.

- For constituents that do fit a normal, a lognormal, or a gamma distribution, a parametric prediction interval is used.
- For constituents that do not fit a normal, a lognormal, or a gamma distribution, the data is transformed using an appropriate transformation to comply with the normality assumption so that a parametric prediction interval can be constructed. The goal is to find a transformation to approximate a normal distribution.
- For constituents that cannot be transformed into a normal distribution, a nonparametric prediction interval is used to compute background levels.

These methods used to establish background levels for Appendix III constituents are consistent with the methods recommended in the Unified Guidance (EPA, 2009) and the CCR Rule. With the selected statistical method, a statistically-significant increase over background values cannot be confirmed or denied until the results of the retesting, if required, have been obtained. Retesting during detection monitoring is an integral part of the statistical methodology for control of the SWFPR when multiple monitoring locations and constituents are being evaluated. The Unified Guidance (EPA, 2009) recommends that prediction intervals be combined with retesting to maintain a low SWFPR while providing high statistical power.

Due to the complex behavior of groundwater and the need for sufficiently large sample sizes, the Unified Guidance recommends that background may be updated every four to eight observations (EPA, 2009). Using this principle with semi-annual sampling, the Boardman Plant CCR Landfill background values should be updated using statistical analysis every 2 to 4 years assuming no confirmed statistically significant increase is identified. In addition, if hydrogeologic conditions change, then background should be updated to match the latest conditions.

2.4.2 Assessment Monitoring Evaluation

In accordance with §257.94(e) and §257.95 of CCR Rules, if a statistically-significant increase is detected, assessment monitoring must be initiated within 90 days. During each sampling event, at least one sample from each well in the groundwater monitoring system will be collected, analyzed for Appendix III and Appendix IV constituents and statistically evaluated within 90 days of receiving the analytical results from the laboratory. The results from the assessment monitoring will be compared to the groundwater protection standard (GWPS) established per §257.95(h) of the CCR Rule. According to this rule, the GWPS is the maximum contaminant level (MCL) or established background for each Appendix IV constituents, whichever is higher. The assessment monitoring background levels will be established using appropriate parametric and nonparametric tolerance interval procedures based on detection frequency and distributional characteristics of various Appendix IV constituents. If any Appendix IV constituents are detected at statistically significant levels above the GWPS, then necessary action must be taken as required by §257.96 of the CCR Rule.

SECTION 3

Summary

Based on site-specific groundwater conditions and the exploratory data analysis described in Section 2, the selected statistical methods are:

- A prediction interval per CCR Rule §257.93(f)(3) to test for a SSI over background for each CCR Appendix III constituent. Due to evidence of significant spatial variability, an individual well comparisons approach of prediction interval is selected.
- If needed, a tolerance interval per CCR Rule §257.93(f)(3) to test for statistically significant levels above the established GWPS for each CCR Appendix IV constituent.

The statistical method will be implemented to meet the performance specifications of CCR Rule §257.93(g) and in accordance with the Unified Guidance (EPA, 2009).

SECTION 4

References

U.S. Environmental Protection Agency (EPA). 2009. *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance*. EPA 350/R-09-007. March.

U.S. Environmental Protection Agency (EPA). 2015. *“Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule.”* Federal Register, Vol. 80, No. 74. April 17.