Grounded in Groundwater Statistics

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ABSTRACT

In 2017, many power agencies implemented various statistical methods to help them comply with the Environmental Protection Agency’s Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule. With the passing of the January 30, 2018 deadline for active impoundments to submit results from the detection monitoring rounds and issuing of public notices of Statistically Significant Increases (SSI) of Appendix III constituents over background concentration levels, many CCR Unit facilities with noted SSI’s have completed or are in the process of completing the statistical evaluation of Appendix IV and III constituents for assessment monitoring and possibly corrective actions or closure. The groundwater sampling and analysis requirements of Parts 257.95, 297.98, and 257.102 form critical steps in the compliance process; however, the implementation is challenging since the language in subsections 257.95 (e),(f),(g),(h), 257.98 (1),(2), and 257.102(c) does not clearly spell out what statistical tests to use for determining SSIs over background and statistically significant levels (SSL) over groundwater protection standards (GWPS). The purpose of this paper is to breakdown the language in these parts in understandable terms and demonstrate correct structures for hypothesis testing for SSIs over background and SSLs over GWPS. The paper will use examples to help practitioners apply the correct hypothesis framework using well-established test statistics such as the upper prediction limits, upper and lower confidence limits, and upper tolerance limits. In doing so, they will have confidence that their statistical test results appropriately determine whether the CCR unit can remain in assessment monitoring, return to detection monitoring or be required to assess corrective measures to remedy the identified releases.

INTRODUCTION

Part 257.93 of the Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule (CCR Rule) describes the sampling and analytical requirements to ensure monitoring results can provide accurate representation of groundwater quality at the background and downgradient wells. A key requirement in the CCR Rule is for background sample results to be analyzed to test
results from downgradient wells for statistically significant increases (SSI) over background levels.

An important point, which is not readily apparent in the CCR Rule is that the statistically derived background levels are themselves components of statistical tests of hypothesis or statistical conjectures of random events. Parts 257.95, 257.98, and 257.102 of the CCR Rule continue the process of statistically evaluating for increases over background concentration levels for both Appendix III and Appendix IV constituents and exceedances over GWPS such as maximum contaminant levels (MCLs) for Appendix IV constituents. However, the statistical criteria for meeting the requirements in Parts 257.95, 257.98, and 257.102 are different than what was required in Part 257.93 due to differing hypotheses as to the distributional tendencies of downgradient concentrations relative to background concentration levels or fixed standards such as the GWPS.

This paper provides an overview how to formulate the appropriate hypotheses for Parts 257.95, 257.98, and 257.102 using test statistics as the upper prediction limits, upper tolerance limits and lower and upper confidence limits. While other test statistics are available to test for SSIs and SSLs, this author has chosen these statistics since they are well described in the U.S. Environmental Protection Agency’s (U.S. EPA) “Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance” (Unified Guidance) and accessible to most through licensed software and freeware. The examples used in this paper represent possible test scenarios during assessment and compliance monitoring and offer insight as how practitioners can use the statistical test results to determine whether the CCR unit can remain in assessment monitoring, return to detection monitoring or be required to assess corrective measures to remedy the identified releases.

HYPOTHESIS-TESTING FRAMEWORK

The groundwater quality samples taken over time at the upgradient, background well(s) and the downgradient, monitoring wells represent a snapshot of the true or ‘population’ frequencies and variability in the concentrations of the constituents of interest (COI) found near the wells. The act of using a sample to draw conclusions about the population is termed statistical inference. Using the correct distribution that best describes the data and adherence to data assumptions allows practitioners to obtain valid inferences and to quantify the precision of those estimates.

Statistical inference can take on two forms. The first uses formal hypothesis frameworks to test assumptions about a population’s location parameter(s) (e.g., mean or median) and the second one assesses the risk of observing certain values within a population.

To test if the mean or median concentrations of a COI ($\theta$) per downgradient well during detection or assessment monitoring phases is larger than background concentration levels; one establishes a hypothesis of the form:

$$H_0: \theta_C \leq \theta_B \text{ vs. } H_a: \theta_C > \theta_B$$

[1]
Where $\theta_C$ and $\theta_B$ represent parameters of interest estimated from samples collected at the compliance and background wells, respectively. If the test statistic selected for this hypothesis framework provides evidence to reject the null hypothesis $H_0$ in favor of the alternative hypothesis $H_a$, then an SSI over background has occurred.

A modification to the hypothesis framework in Equation 1 is necessary if the goal is so test whether sampled compliance concentrations per COI at a downgradient well are below a fixed standard such as a GWPS or MCL. In this situation, the hypothesis statement can take on one of the two following forms depending on the original assumptions:

$$H_0: \theta_C \leq \mu \text{ vs. } H_a: \theta_C > \mu \tag{2}$$

$$H_0: \theta_C \geq \mu \text{ vs. } H_a: \theta_C < \mu \tag{3}$$

Where $\mu$ represents the risk-based standard for a given COI. Note that $\mu$ is a fixed valued and not a statistical estimate. Equations 2 and 3 are essentially testing if either the distributional tendencies as often represented by the sampled mean or median is different from a known scalar. Equation 1 tests if one population’s central tendency is greater or smaller than another’s is.

The differences in the two hypothesis frameworks in Equations 2 and 3 capture the differences in assumptions as to groundwater quality conditions in the compliance area before and after corrective action has been implemented, respectively. Equation 2 assumes that concentrations are below risk-based standards at the onset. Hence, sufficient evidence must be collected before one can reject the null hypothesis and conclude that an Appendix IV constituent at a downgradient monitoring well has exceeded the standard $\mu$. If there has been an exceedance of at least one Appendix IV constituent at any downgradient well, then costly corrective action is required.

Assuming that an agency has had to implement corrective actions, and to ensure the outcomes of the clean-up efforts are as unambiguous as possible, the status quo, as represented by the null hypothesis in Equation 2, assumes that clean-up efforts were not successful. If evidence from the collected samples is contrary to the null hypothesis based on the statistical test values, then the alternative hypothesis is accepted; that is, the groundwater sample quality for Appendix IV constituents met the standard.

SELECTING APPROPRIATE TEST STATISTICS

Varieties of statistical tests are available to test the assumptions in Equations 1, 2 and 3. Examples include but are not limited to the student’s t-test, one-way analysis of variance (ANOVA), Wilcoxon Signed Rank test, and the Kruskal-Wallis (K-W). A confidence interval around the mean or median estimate from a sample captures the plausible range for the estimate with a set probability (e.g., 95 percent). The selection of the appropriate test depends on whether the data follow parametric or non-parametric distributions, the presence of non-detects, and whether one or multiple sample estimates are being compared.
In order to assess the risk of observing higher groundwater quality concentrations than expected from a population, one can use the method of determining prediction or tolerance intervals or control charts. A prediction interval is a range of concentrations that is likely to contain a value of one or more new observations assuming the same background distributional properties for the process that generated the new observations. As with the confidence interval, a probability (e.g., 95 percent) of observing future values that lie in that range is specified. In essence, when one defines a prediction interval, one is making a statistical conjecture of the likelihood random events.

A tolerance interval captures the range that is likely to contain a specified proportion of the population with a specified confidence level. For example, an 85 percent tolerance interval with 95 percent confidence level indicates a range such that 85 percent of the observations will lie with 95 percent probability.

Finally, control charts set both upper and lower bounds to a data process and use variance properties of the historical data to set different levels of controls. The variations in observations collected over time that remain in the control limits suggest common causes (e.g., natural variability) and the process is said to be ‘in control’. When data points fall outside the bounds, then the process is said to be out of control and a special cause (e.g., environmental spill) has caused the perturbation.

Values that exceed the upper limits of the aforementioned methods are assumed to happen with a predetermined, low probability such as but not limited to 10, 5, 1 percent, or less. This probability level is referred to as the test significance level. When values exceed the upper limits, they do so based on higher probabilities than expected for the background distribution in question. Hence, practitioners deem them as SSIs over the background concentration levels.

For purpose of this document, the upper prediction limit estimated from background is used to demonstrate the application of the hypothesis framework in Equation 1. Both the EPA’s Unified Guidance and ProUCL Version 5.0.00 Technical Guide recommend the upper prediction limit to test for exceedances over background concentration levels. The reports provide ample examples and specifications as to which form of the UPL is appropriate depending on the distributional properties of the background groundwater quality samples. Documentation is also provided as how to adjust the UPL’s test significance level to adjust for the site-wide false positive rate (SWFPR) due to multiple constituent-well pair comparisons, semi-annual testing phases and alternative source demonstration re-testing strategies.

APPLICATION OF HYPOTHESIS-TESTING FRAMEWORK

With respect to hypothesis frameworks in Equations 2 and 3, rejecting the null hypothesis in favor of the alternative is indicative of statistically significant levels (SSLs) over the GWPS. This is an important distinction from the notion of statistically significant increases (SSIs) over background used in detection monitoring and parts of
assessment monitoring. The risk-based standards for Appendix IV constituents provided by various governing bodies are independent of observed background concentration levels for those same constituents. Because of this fact, and of the high expense related to corrective action, it is appropriate to assume as the null hypothesis in Equation 2 that the detected Appendix IV constituents downgradient to the CCR unit have tendencies less than the standards.

The null hypotheses in Equation 1 is not rejected as long as there is a chance of sufficient probability that the central tendency of the sampled downgradient concentrations resides below the GWPS. In other words, as long as the mean or median of the sampled compliance concentrations can reside below the GWPS with sufficient probability, even if some individual samples are observed to exceed the standard, the null hypothesis is not rejected. If the applicable test statistics indicate otherwise, then the tendencies have a level set higher than the standard.

Equation 3, which can be seen as the complement to Equation 2, assumes that the status quo at the compliance wells shows groundwater quality concentrations having central tendencies higher than the GWPS. With this framework, the null hypothesis is rejected if there is evidence to indicate that the central tendencies of either the mean or median of the downgradient samples are within the bounds of the GWPS. If the framework in Equation 2 is used, there is still a level of ambiguity as to how 'clean' the corrective action methods were.

The Unified Guidance recommends the use of the confidence intervals to conduct the tests for SSLs, specifically confidence intervals at the 95 percent level of significance.

When applying the hypothesis framework in Equation 2, the Unified Guidance indicates that when the 95 percent lower confidence limit (95LCL) estimated from the samples collected at the compliance wells is higher than the GWPS, the null hypothesis is rejected. This outcome then precipitates the regulatory process to move into corrective action. Since the entire 95 percent confidence interval is above the GWPS, we say that the constituent has exceeded the standard at a statistically significant level.

The hypothesis framework in Equation 3 seeks evidence against the null hypothesis, post corrective action, that is, after the source(s) of contamination has been removed. The challenge after a clean-up activity is that one must almost unequivocally prove that standards have been met. Hence, the null hypothesis assumes clean-up activities were not successful. In this situation, the Unified Guidance recommends the use of the 95 percent upper confidence limit (95UCL) to test the validity of the null hypothesis. If the 95UCL is below the GWPS, which implies that the entire 95 percent confidence interval is below the standard, the null hypothesis is rejected in favor of the alternative, that is, clean-up activities have met the standard.
TESTING FOR STATISTICALLY SIGNIFICANT INCREASES

This section highlights the two parts in the CCR Rule, which require testing for SSIs relative to background as part of assessment monitoring. They are as follows:

257.95 Assessment monitoring program. (e) If the concentrations of all constituents listed in appendices III and IV to this part are shown to be at or below background values, using the statistical procedures in § 257.93(g), for two consecutive sampling events, the owner or operator may return to detection monitoring of the CCR unit.

257.95 Assessment monitoring program. (f) If the concentrations of any constituent in appendices III and IV to this part are above background values, but all concentrations are below the groundwater protection standard established under paragraph (h) of this section, using the statistical procedures in § 257.93(g), the owner or operator must continue assessment monitoring in accordance with this section.

For context Part 257.93 contains the language indicating that the statistical tests described in Part 257.93(g) show whether or not there has been an SSI over background:

(h) The owner or operator of the CCR unit must determine whether or not there is a statistically significant increase over background values for each constituent required in the particular groundwater monitoring program that applies to the CCR unit, as determined under § 257.94(a) or § 257.95(a).

In Part 257.95 (e), one must already have estimated a background concentration level as the reference test statistic. As long as test significance level has been adjusted to test two sampling events in succession and if the concentrations of Appendix III and IV constituents from the downgradient well-constituent pairs across these two sampling events are less than their respective background test statistics, the CCR Unit may return to detection monitoring.

Figure 1 displays the statistically derived background concentration levels relative to sampled background concentrations as represented by the UPLs using three example constituents, boron, total dissolved solids and barium.
Boron from a hypothetical site and documented in the first row of Table 1 below is used as an example of how to test for SSI as required in 257.95 (e). In this situation, the site has one upgradient, background well and three downgradient, monitoring wells. The distribution of the eight samples collected at the background well is tested to be gamma and the resulting test significance level at this site for this constituent is 2 percent. The 98 percent upper prediction limit is calculated to be 0.11 mg/L.

The boron concentrations (mg/L) from each of the downgradient wells from the two semi-annual events are (0.034, 0.071, and 0.038) and (0.088, 0.053 and 0.055), respectively. Since all three wells over the two events had concentrations for boron below the 98UPL of 0.11 mg/L, this particular Appendix III constituent passed the requirement; however, with 20 more constituents to test, the chances that all will pass are remote, though possible.

For example, at the same site, total dissolved solids (TDS) with a 98UPL of 1454 (mg/L) did not pass the requirement of Part 257.95 (e) and had an SSI over background with values from the two sampling events at the three downgradient wells of (5700, 1500, and 2400) and (4600, 1450, and 2500). The value of 5700 mg/L from the first well exceeded the 98UPL.

Barium from this same site is used to demonstrate Part 257.95 (f). In this situation, if at any sampling event period, one of the barium-well pair samples exceeds background but is less than the MCL, then for at least for this Appendix IV constituent, a positive outcome with respect to 257.95 (f) occurs. Values of (0.091, 0.67 and 0.61) mg/L were observed at the three downgradient wells. Since all values are below the (approximately) 99 percent UPL test statistic from the background sample and all are clearly below the MCL of 2 mg/L for barium, then there is a positive outcome for this constituent in reference to 257.95(f). As with 257.95(e), the chances for all 22 Appendix IV constituents at all downgradient wells to meet this condition is low, yet possible.
Table 1: Upper Prediction Limits from Background Samples

<table>
<thead>
<tr>
<th>Constituent (mg/L)</th>
<th>Type</th>
<th>Mean</th>
<th>Median</th>
<th>UPL</th>
<th>Background Distribution</th>
<th>Test Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>III</td>
<td>0.096</td>
<td>0.097</td>
<td>0.11</td>
<td>Gamma</td>
<td>0.02</td>
</tr>
<tr>
<td>TDS</td>
<td>III</td>
<td>1,250</td>
<td>1,238</td>
<td>1,454</td>
<td>Lognormal</td>
<td>0.02</td>
</tr>
<tr>
<td>Barium (mg/L)</td>
<td>IV</td>
<td>0.42</td>
<td>0.31</td>
<td>0.93</td>
<td>Nonparametric</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Note that the comparison of barium’s concentrations (0.091, 0.67 and 0.61) mg/L to the MCL is not a statistical test. It is simply a comparison of the concentrations to the GWPS. Herein is an example of the ambiguity at times in the CCR Rule. The phrase in Part 257.95(f) “but all concentrations are below the groundwater protection standard established” indicates that all the values in that sampling event are below the GWPS. Apparently, no inferential statistics are required.

Part 257.95(f)’s reference back to Part 257.95(h) warrants a discussion. In 257.95(h), the CCR Rule explains how one can establish a GWPS. In simple terms, one has three possible methods to set a fixed, risk-based standard. The obvious standard is to use the recognized MCL for that constituent. If background for that constituent is higher than the MCL, then the background becomes the standard. If there is no established MCL for a constituent, then background can be used to establish the GWPS. The content of 257.95(h) is as follows:

257.95 Assessment monitoring program. (h) The owner or operator of the CCR unit must establish a groundwater protection standard for each constituent in appendix IV to this part detected in the groundwater. The groundwater protection standard shall be: (1) For constituents for which a maximum contaminant level (MCL) has been established under §§ 141.62 and 141.66 of this title, the MCL for that constituent; (2) For constituents for which an MCL has not been established, the background concentration for the constituent established from wells in accordance with § 257.91; or (3) For constituents for which the background level is higher than the MCL identified under paragraph (h)(1) of this section, the background concentration.

The question arises as how one would use samples collected from the background well(s) to establish a non-statistical entity such as a risk-based standard. The Unified Guidance proposes to use the UTL for such purpose. Similar to the UPL, the UTL flags if outliers are from population distributions different from that of background. However, UTLs are different from UPLs because they lack the statistical properties that allow practitioners to modify the tests in order to control the site-wide false positive rate. The Unified Guidance has recommended that the UTL is a more appropriate statistic to develop ‘fixed’ reference values that can be used as a type of groundwater protection standard (GWPS) where one does not currently exist.
TESTING FOR STATISTICALLY SIGNIFICANT LEVELS

This section highlights the two parts in the CCR Rule, which require testing for SSLs relative to background as part of assessment and compliance (i.e., corrective action) monitoring. They are as follows

257.95 Assessment monitoring program. (g) If one or more constituents in appendix IV to this part are detected at statistically significant levels above the groundwater protection standard established under paragraph (h) of this section in any sampling event, the owner or operator must prepare a notification identifying the constituents in appendix IV to this part that have exceeded the groundwater protection standard.

257.98 Implementation of the corrective action program. (c) Remedies selected pursuant to § 257.97 shall be considered complete when: (1) The owner or operator of the CCR unit demonstrates compliance with the groundwater protection standards established under § 257.95(h) has been achieved at all points within the plume of contamination that lie beyond the groundwater monitoring well system established under § 257.91. (2) Compliance with the groundwater protection standards established under § 257.95(h) has been achieved by demonstrating that concentrations of constituents listed in appendix IV to this part have not exceeded the groundwater protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in § 257.93(f) and (g).

257.102 Criteria for conducting the closure or retrofit of CCR units. (c) Closure by removal of CCR. An owner or operator may elect to close a CCR unit by removing and decontaminating all areas affected by releases from the CCR unit. CCR removal and decontamination of the CCR unit are complete when constituent concentrations throughout the CCR unit and any areas affected by releases from the CCR unit have been removed and groundwater monitoring concentrations do not exceed the groundwater protection standard established pursuant to § 257.95(h) for constituents listed in appendix IV to this part.

To demonstrate an application of hypothesis framework in Equation 2 as it applies to Part 257.95 (g), beryllium from a site with one background well and three downgradient wells is analyzed. Each of the three downgradient wells has eight samples with 100 percent detected values. The gamma distribution provided the best fit for the data. While the MCL for beryllium is 0.0040 mg/L, the UTL from site’s background data for beryllium is 0.0050 mg/L. According to part 257.95(h), the background concentration level can be used to represent this site’s GWPS for beryllium. Assuming a gamma distribution, the estimate 95 percent LCL for each well is provided in Table 2. Based on the test results, beryllium in Well 1 has a SSL since 0.0097 > 0.0050.

<table>
<thead>
<tr>
<th>Well ID</th>
<th>MCL</th>
<th>Background 95%UTL</th>
<th>Mean</th>
<th>Median</th>
<th>95%LCL</th>
<th>Downgradient Distribution</th>
<th>SSL Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0040</td>
<td>0.0050</td>
<td>0.0105</td>
<td>0.0109</td>
<td>0.0097</td>
<td>Gamma</td>
<td>True</td>
</tr>
<tr>
<td>2</td>
<td>0.0040</td>
<td>0.0050</td>
<td>0.0048</td>
<td>0.0049</td>
<td>0.0044</td>
<td>Gamma</td>
<td>False</td>
</tr>
<tr>
<td>3</td>
<td>0.0040</td>
<td>0.0050</td>
<td>0.0044</td>
<td>0.0042</td>
<td>0.0041</td>
<td>Gamma</td>
<td>False</td>
</tr>
</tbody>
</table>
It is important to note that unlike the testing framework in Equation 1, it is not necessary to adjust the test significance level for the confidence intervals for hypothesis frameworks denoted in Equations 2 and 3. The Unified Guidance see computation of the cumulative SWFPR rate during assessment and compliance programs to be complicated as it is not always known what the exact number of tests to conduct are. As a workable compromise, the Unified Guidance recommends to set a fixed significance level such as 5 percent to ensure adequate power to detected impacted groundwater quality. Having a too small test significance level runs the risk of failing to detect an exceedance when one actually exists.

Parts 257.98 (c) and 257.102 (c) provide statements to guide agencies as to whether or not their corrective action activities have complied with GWPSs. While 257.98 specifically references back to the statistical methods in 257.93 and 257.95 and in this author’s opinion, implicitly is requiring correct statistical methods to test for SSLs above risk-based standards, part 257.102 does not.

Using the hypothesis framework in Equation 3, Molybdenum samples from a site are analyzed to confirm if corrective action has been met for this particular Appendix IV constituent. The estimated 95 percent UCLs from each well’s samples are provided in Table 3. Each downgradient well has eight samples all collected after corrective actions have been completed. All observations were detects. Recently, the CCR Rule was amended in July 30, 2018, which included an MCL for Molybdenum of 0.10 mg/L whereas before, none existed. Since all the 95 percent UCLs are lower than the MCL, the null hypothesis is rejected in favor of the alternative, that is, no exceedance above GWPS. If this test had been done prior to the amendment to the CCR Rule, the 95 percent UTL from the background well would have been used to represent the GWPS for Molybdenum at this site. In that situation, the concentrations at Wells 2 and 3 would have an SSL as 0.0047 and 0.014 are greater than the 95 percent UTL of 0.0033.

In order for this site to be compliant and meet all applicable GWPS, no detected Appendix IV constituents can have an SSL at any downgradient well.
Figure 3 indicates the level of the 95 percent UCL relative to the sampled concentrations per well.

Table 3: Upper Confidence Limits from Molybdenum Samples (mg/L)

<table>
<thead>
<tr>
<th>Well ID</th>
<th>MCL</th>
<th>Background 95% UTL</th>
<th>Mean</th>
<th>Median</th>
<th>95% UCL</th>
<th>Downgradient Distribution</th>
<th>SSL Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.10</td>
<td>0.0033</td>
<td>0.00036</td>
<td>0.00020</td>
<td>0.00065</td>
<td>Lognormal</td>
<td>False</td>
</tr>
<tr>
<td>2</td>
<td>0.10</td>
<td>0.0033</td>
<td>0.0025</td>
<td>0.0016</td>
<td>0.0047</td>
<td>Gamma</td>
<td>False</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.0033</td>
<td>0.0077</td>
<td>0.0076</td>
<td>0.014</td>
<td>Gamma</td>
<td>False</td>
</tr>
</tbody>
</table>

Figure 3: Molybdenum Downgradient Samples

In the situations where agencies are in the process of conducting clean closures or retrofits of the CCR Unit, part 257.102 is applicable. Technically, if the statements in sub-part (c) are taken literally, exceedances occur by simply comparing a sampled concentration at a sampling event to the GWPS. If that one sample for a particular Appendix IV constituent at a particular downgradient well is higher than the GWPS, then there is an exceedance. While it may be simpler to conduct this two number comparison, the correct method to use which upholds the intentions of Parts 257.93 and 257.95 is to estimate the upper confidence limits from the monitoring wells post clean-up and compare these statistics to the GWPS. The former method does run the risk of observing one sample with a concentration higher than the GWPS that can occur simply because of random variation. Testing for SSLs instead mitigates this risk.

CONCLUSION

The language in the CCR Rule concerning the testing of SSIs over background and SSLs over GWPS is cumbersome. Significant amount of time is required for practitioners to link the sequence and timing of sampling events and tests due to the recursive-like nature of the statements. Nonetheless, the statements when followed as intended do support one of the key objectives of the CCR Rule concerning protecting human health. The chances that all Appendix III and IV constituents are less than
background or all Appendix IV constituents meet GWPSs is remote for many CCR Units.

This paper clarifies the statistical requirements and tests in Parts 257.95, 257.98 and 257.102 of the CCR Rule using realistic examples. Its brief overview of testing frameworks, statistical tests, and concepts of SSIs and SSLs provides a grounding for other practitioners as they embark on fulfilling the statistical requirements of the CCR Rule. Considering the costs entailed in corrective action, and semi-annual and annual sampling events, being grounded in groundwater statistics will bring efficiencies to the management of the CCR Unit as decisions are based on good statistical practices and scientific evidence.
REFERENCES

