ECF-200PO1-19-0008
Revision 0

# Statistical Evaluation of Assessment Sampling Results for WMA A-AX

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

**P.O. Box 1600**
**Richland, Washington 99352**

Approved for Public Release;
Further Dissemination Unlimited

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APPROVED
By Janis D. Aardal at 1:48 pm, Jun 04, 2019

Release Approval | Date

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# ENVIRONMENTAL CALCULATION COVER PAGE

**SECTION 1 - Completed by the Responsible Manager**

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## ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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**SECTION 2 - Completed by Preparer**

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## ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

**SECTION 5 - Applicable if Calculation is a Risk Assessment or Uses an Environmental Model**

**Prior to Initiating Modeling:**

Required training for modelers completed:
Integration Lead:

| N/A | | |
|---|---|---|
| *Print First and Last Name* | *Signature* | *Date* |

Safety Software Approved:
Integration Lead:

| N/A | | |
|---|---|---|
| *Print First and Last Name* | *Signature* | *Date* |

**Calculation Approved:**
Risk/Modeling Integration Manager:

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|---|---|---|
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# Terms

| | |
|---|---|
| ANOVA | analysis of variance |
| csv | comma separated value |
| ECF | environmental calculation file |
| HISI | Hanford Information System Inventory |
| ROS | regression on order statistics |
| STHDA | *Statistical tools for high-throughput data analysis* |
| WMA | waste management area |

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# 1 Purpose

The purpose of this environmental calculation file (ECF) is to document the process for statistical evaluation of upgradient versus downgradient constituent data for assessment first determination at the waste management area A-AX (WMA A-AX; Figures 1 and 2). Statistical comparison allows for the spatial determination of differentiation of groundwater constituent data between well locations.

# 2 Background

## 2.1 Site Monitoring History

WMA A-AX was placed in groundwater quality assessment monitoring (40 CFR 265.93[d] , "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," "Preparation, Evaluation, and Response") in 2005 because the indicator parameter specific conductance showed an exceedance relative to the statistical comparison value between upgradient and downgradient wells (PNNL-15315, *RCRA Assessment Plan for Single-Shell Tank Waste Management Area A-AX at the Hanford Site*) (40 CFR 265.93[b]). Quadruplicate measurements of specific conductance collected in June 2005 from downgradient well 299-E25-93 averaged 536 µS/cm, which exceeded the critical mean value of 522 µS/cm (PNNL-15315). Under the assessment monitoring plan DOE/RL-2015-49, *Interim Status Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area A-AX*, the WMA A-AX monitoring well network was sampled on a quarterly basis between March of 2016 and June of 2018. The groundwater sampling constituent list and frequency requirements are outlined in DOE/RL-2015-49. Nine quarterly assessment groundwater sampling events were completed for WMA A-AX first determination. The objective of the first determination is to identify any dangerous waste constituents that may have triggered the critical means violations and/or to identify any dangerous waste constituents from WMA A-AX that could have impacted groundwater.

## 2.2 Data Screening

Dangerous waste detections in downgradient wells that were carried forward for further evaluation in the initial data compilation and screening process (ECF-200PO1-19-0007, *Data Screening Procedure for the WMA A-AX RCRA First Determination*) were evaluated for statistical significance relative to concentrations detected in upgradient wells. Dangerous waste constituents data screening resulted in seven constituents for further evaluation and five for statistical comparison (ECF-200PO1-19-0007). Further evaluated constituents included chloroform, chromium, copper, nickel, octachlorodibenzo-p-dioxin, sulfide, and vanadium. Octachlorodibenzo-p-dioxin and sulfide were excluded from the statistical analysis since both constituents were only present for one well after the screening in ECF-200PO1-19-0007. Filtered metals results values were chosen because unfiltered results can be elevated from particulate matter originating from within the well and therefore not being representative of actual aquifer conditions.

## 2.3 Hypothesis Testing

Comparison of assessment sampling data using statistical hypothesis testing allows for the detection of impact to the groundwater by quantitatively establishing differences or similarities in constituent datasets between upgradient and downgradient sampling locations. Hypothesis testing utilized t-tests instead of analysis of variance (ANOVA) because detected dangerous waste constituent concentrations were variable between upgradient wells, suggesting different population means between upgradient sources.

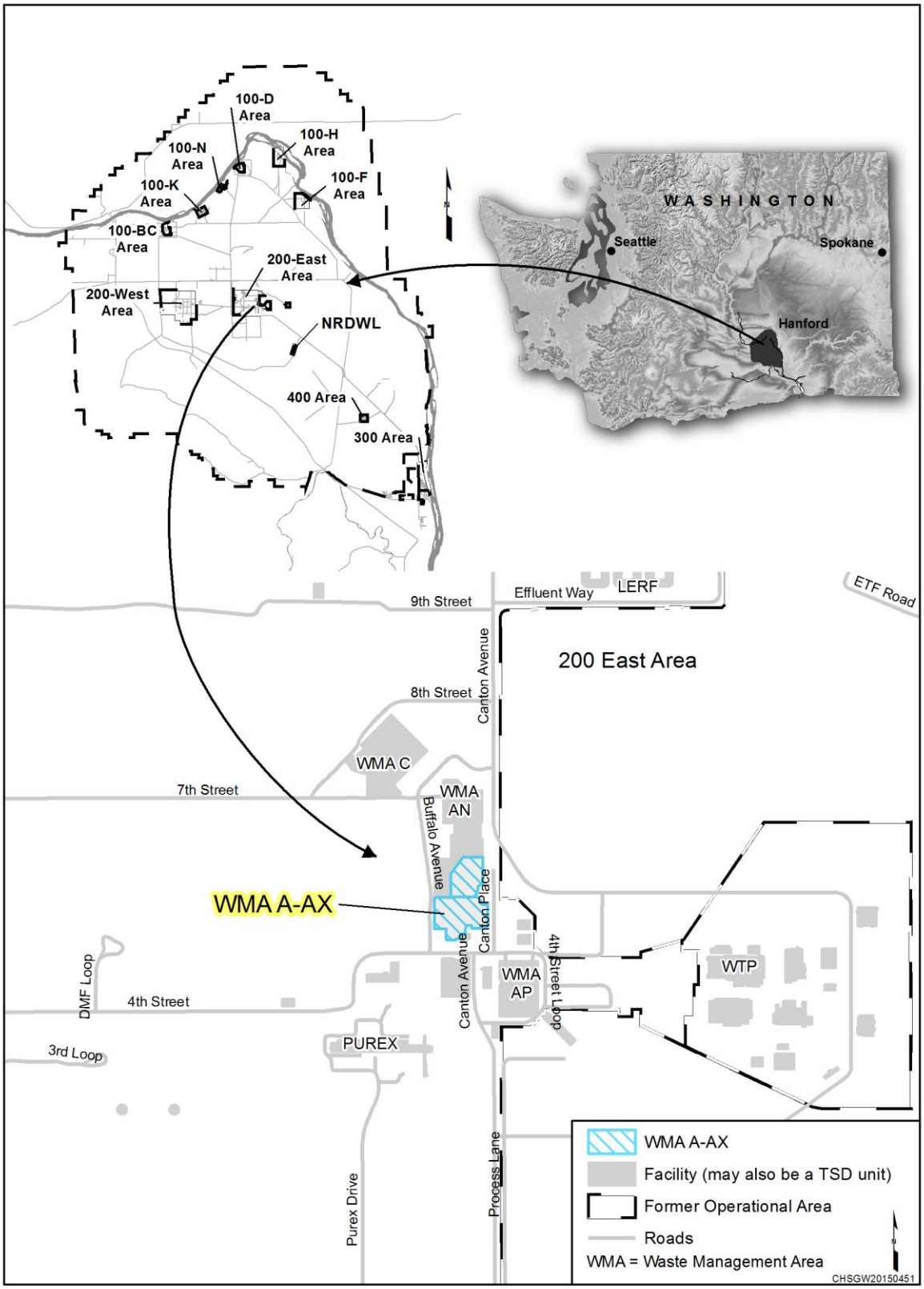


**Figure 1. WMA A-AX Location Map**

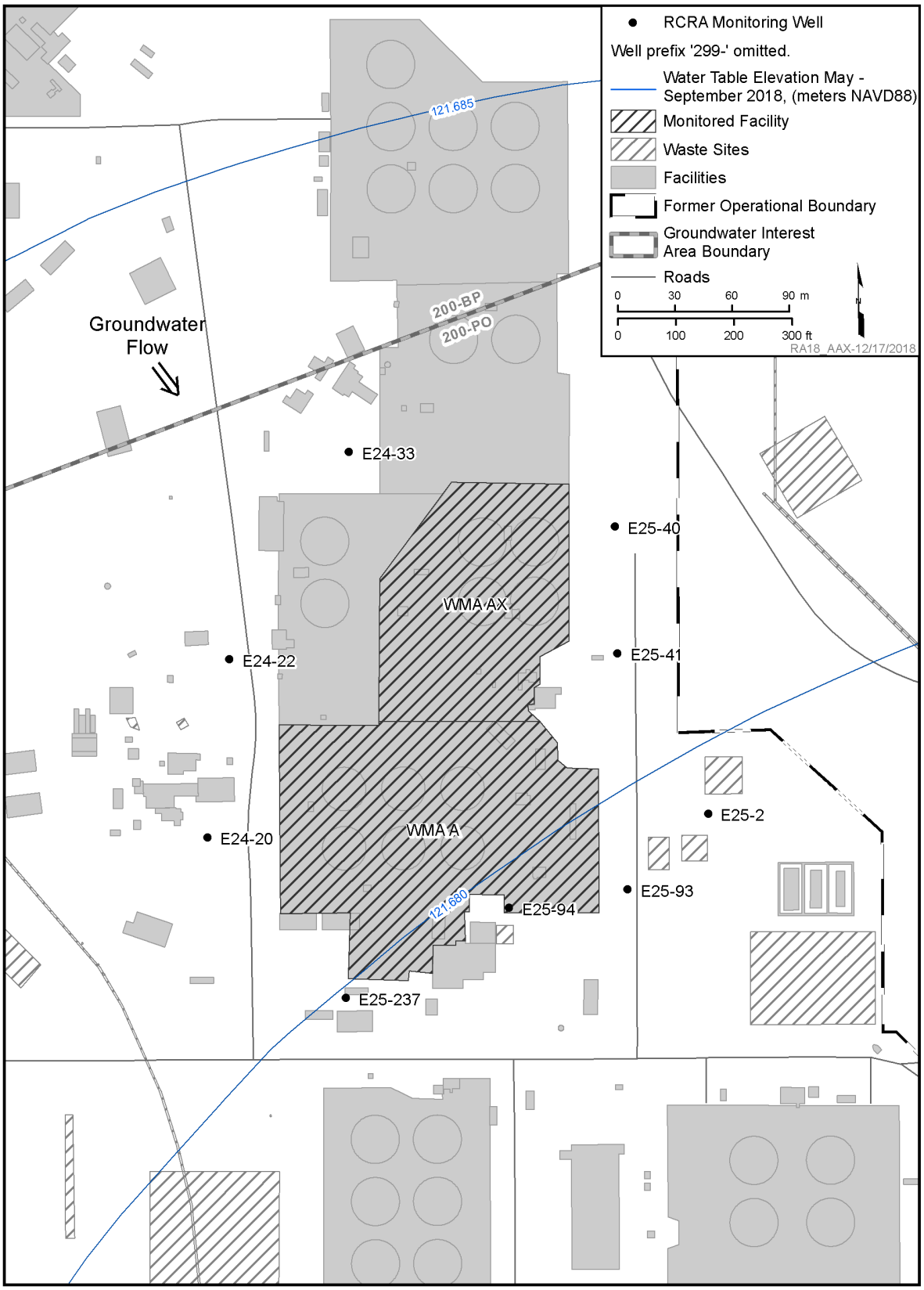


**Figure 2. WMA A-AX Monitoring Well Network Location Map**

The t-tests compared upgradient and downgradient constituent concentrations on a well-by-well basis. For example, each downgradient well detecting a given constituent had the detected constituent concentrations tested against the concentrations of that constituent in each upgradient well where the constituent was detected. Dangerous waste constituents that were detected at downgradient locations only were evaluated in DOE/RL-2019-21, *Groundwater Assessment First Determination Report for Waste Management Area A-AX* to determine if they were attributable to WMA A-AX.

Prior to hypothesis testing, datasets were subjected to Shapiro-Wilke tests for normality. If compared constituent concentration datasets were normally distributed, a Two-Sample t-test was performed. If compared constituent concentration datasets were normally distributed but had different numbers of values or unequal variances, a Welch's Two Sample t-test was performed. If one or both of the two constituent datasets being compared were not normally distributed, then a non-parametric Wilcoxon test was performed. Results sets shown by statistical hypothesis testing as having a low relational probability are statistically significant and therefore the null hypothesis can be rejected. The null hypothesis states that a population parameter (such as the mean, the standard deviation, and so on) is equal to a hypothesized value. The null hypothesis is often an initial claim that is based on previous analyses or specialized knowledge.

If the null hypothesis is accepted, the compared populations are related by having the same sample means. If the null hypothesis is rejected, the compared populations have differing sample means and are therefore unrelated. Thus, an alternative hypothesis is needed to explain the difference in population means.

Statistical significance suggests that the population means of upgradient and downgradient constituent concentrations are different and therefore indicating different sources of a given constituent for both populations. If the downgradient concentration is not statistically significant and has a sample mean less than upgradient well sample means, then the dangerous waste constituent is not considered attributable to WMA A-AX. If downgradient sample means are greater and are statistically significant when compared to upgradient results, then the possibility exists that the dangerous waste constituent is attributable to WMA A-AX.

T-tests assume samples of a given constituent for each well are independent of one another, requiring that duplicate samples be averaged or otherwise addressed prior to hypothesis testing (EPA 530/R-09-007, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance*).

Datasets having >50% non-detect values pose a problem for routine statistical hypothesis tests in that non-detect data are censored on the low or left end of a sample concentration range. Simpler methods, such as substituting the non-detect value with one-half the detection limit value, are imperfect because they ignore two realities of left censored data. First, non-detects are a product of both the underlying distribution of actual concentrations and the measurement process used to estimate these concentrations. Second, non-detects must be considered with respect to other, detected measurements, as well as the physical process that generated the data. Therefore, it is preferable to use robust regression on order statistics (ROS) to impute replacement values for censored non-detects in well/constituent datasets with >50% non-detects (EPA 530/R-09-007). ROS uses a fitted model to construct a model-based imputation for each non-detect and it is capable of dealing with multiple detection limits.

# 3 Methodology

Hypothesis testing and summary statistics calculations were carried out in the R computer language framework. Schapiro-Wilkes, two-sample t-tests and Welch’s two-sample t-tests were implemented in R using the scripted function rquery.t.test (STHDA; *Statistical tools for high-throughput data analysis*, “T test analysis: is it always correct to compare means?”) modified to also include Wilcoxon tests. Summary

statistics calculations were implemented in R using the stats package. Datasets containing >50% non-detect values were fitted with ROS and censored values were replaced with modeled values. Datasets were then subjected to hypothesis testing. Excel was used to store data in the comma separated value (csv) files that were imported into R. The process for data importation, filtering, hypothesis testing and summary statistics calculations is outlined in Figure 3 and following section. It should be noted that there are many ways to achieve the desired objectives using the various utilities and formats within R. The following steps are just one of many possible procedures.

1. Import Table A-23 from ECF-200PO1-19-0007 (Appendix A), into R.

2. Extract relevant dangerous waste constituent (chloroform, chromium, copper, nickel, octachlorodibenzo-p-dioxin, sulfide, and vanadium) data for each WMA A-AX well in the dataset in which these constituents were detected. Additionally, extract chromium, copper, nickel, and vanadium from filtered aliquot data only. Save extracted results as individual dataframes for each well/constituent. These dataframes contain all data for chromium, copper, nickel, sulfide, and vanadium during the assessment period, including non-detect values. Statistical comparison was not possible for sulfide and octachlorodibenzo-p-dioxin because those constituents were detected in downgradient locations only. Therefore, those constituents, results are not listed in Table 1.

3. Average duplicate values and remove any non-detect values that are greater than the highest detect value.

   Duplicate values are defined as multiple samples taken for the same well, constituent, and date. If a duplicate sampling event contains both detect and non-detect values, return only the detect value, rather than an average.

4. Run ROS on well/constituent datasets with >50% non-detects. If a dataset has only one or zero detect values, exclude dataset from analysis. ROS is carried out by running the “ros(obs, censored, forwardT="log", reverseT="exp", na.action)” function from the “NADA” package in R. Function inputs are as follows:

   a. Obs – observed constituent data including non-detect values.

   b. Censored – logical values distinguishing censored non-detects (value = TRUE) and observed detections (value = FALSE).

   c. forwardT – pre-ROS data transformation function.

   d. reverseT – reverses transformation after running ROS.

   e. na.action – function for determining action on NA (empty) data. For example, “na.omit” omits all NA’s from the comparison.

   Replace the raw well/constituent data in Table 1 having >50% non-detects with the modeled well/constituent data generated by ROS (Table 2).

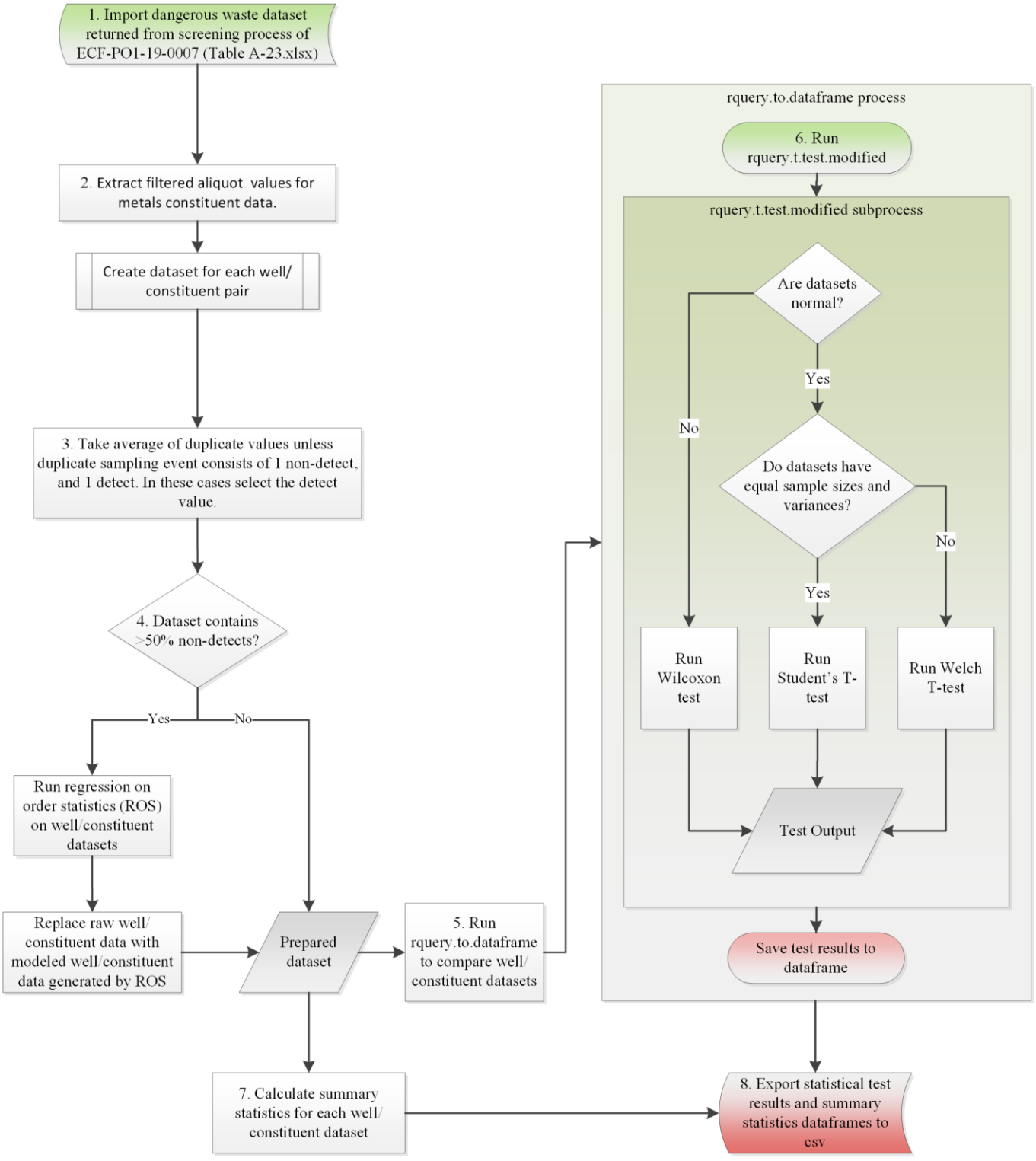


**Figure 3. Flow Chart Illustrating the Steps Taken in This ECF**

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E24-20 | Chloroform | 3/8/2016 | 0.15 | J |
| 299-E24-20 | Chloroform | 9/15/2016 | 0.17 | J |
| 299-E24-20 | Chloroform | 9/15/2016 | 0.21 | J |
| 299-E24-20 | Chloroform | 12/6/2016 | 0.15 | J |
| 299-E24-20 | Chloroform | 3/14/2017 | 0.14 | J |
| 299-E24-20 | Chloroform | 6/15/2017 | 0.14 | J |
| 299-E24-20 | Chloroform | 9/20/2017 | 0.19 | J |
| 299-E24-20 | Chloroform | 12/11/2017 | 0.19 | J |
| 299-E24-20 | Chloroform | 3/16/2018 | 0.18 | J |
| 299-E24-20 | Chloroform | 6/21/2018 | 0.24 | U |
| 299-E24-22 | Chloroform | 3/8/2016 | 0.3 | U |
| 299-E24-22 | Chloroform | 9/15/2016 | 0.31 | J |
| 299-E24-22 | Chloroform | 12/6/2016 | 0.36 | J |
| 299-E24-22 | Chloroform | 3/13/2017 | 0.3 | U |
| 299-E24-22 | Chloroform | 6/15/2017 | 0.3 | J |
| 299-E24-22 | Chloroform | 9/18/2017 | 0.3 | U |
| 299-E24-22 | Chloroform | 12/11/2017 | 0.3 | U |
| 299-E24-22 | Chloroform | 3/16/2018 | 0.49 | BJ |
| 299-E24-22 | Chloroform | 6/22/2018 | 0.3 | U |
| 299-E25-237 | Chloroform | 3/7/2016 | 0.49 | J |
| 299-E25-237 | Chloroform | 9/16/2016 | 0.39 | J |
| 299-E25-237 | Chloroform | 9/16/2016 | 0.49 | J |
| 299-E25-237 | Chloroform | 12/4/2016 | 0.39 | J |
| 299-E25-237 | Chloroform | 3/10/2017 | 0.37 | J |
| 299-E25-237 | Chloroform | 6/16/2017 | 0.37 | J |
| 299-E25-237 | Chloroform | 9/20/2017 | 0.41 | J |
| 299-E25-237 | Chloroform | 12/11/2017 | 0.4 | J |
| 299-E25-237 | Chloroform | 3/15/2018 | 0.32 | J |
| 299-E25-237 | Chloroform | 6/21/2018 | 0.4 | J |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E24-20 | Chromium | 3/8/2016 | 5 | B |
| 299-E24-20 | Chromium | 9/15/2016 | 6.3 | |
| 299-E24-20 | Chromium | 9/15/2016 | 6.7 | B |
| 299-E24-20 | Chromium | 12/6/2016 | 3.9 | B |
| 299-E24-20 | Chromium | 3/14/2017 | 5.3 | |
| 299-E24-20 | Chromium | 6/15/2017 | 6.2 | B |
| 299-E24-20 | Chromium | 9/20/2017 | 4.1 | B |
| 299-E24-20 | Chromium | 12/11/2017 | 5.5 | B |
| 299-E24-20 | Chromium | 3/16/2018 | 6.6 | |
| 299-E24-20 | Chromium | 6/21/2018 | 6.7 | |
| 299-E24-22 | Chromium | 3/8/2016 | 5.12 | CB |
| 299-E24-22 | Chromium | 9/15/2016 | 3.65 | B |
| 299-E24-22 | Chromium | 12/6/2016 | 4.03 | B |
| 299-E24-22 | Chromium | 3/13/2017 | 3.99 | B |
| 299-E24-22 | Chromium | 6/15/2017 | 4.05 | B |
| 299-E24-22 | Chromium | 9/18/2017 | 4.03 | B |
| 299-E24-22 | Chromium | 12/11/2017 | 4.51 | B |
| 299-E24-22 | Chromium | 3/16/2018 | 3.6 | B |
| 299-E24-22 | Chromium | 6/22/2018 | 4.02 | B |
| 299-E25-2 | Chromium | 3/8/2016 | 3.52 | CB |
| 299-E25-2 | Chromium | 4/4/2016 | 4.11 | CB |
| 299-E25-2 | Chromium | 9/15/2016 | 3 | U |
| 299-E25-2 | Chromium | 10/18/2016 | 3 | U |
| 299-E25-2 | Chromium | 11/1/2016 | 3 | U |
| 299-E25-2 | Chromium | 12/6/2016 | 3 | U |
| 299-E25-2 | Chromium | 1/25/2017 | 3 | U |
| 299-E25-2 | Chromium | 3/14/2017 | 3 | U |
| 299-E25-2 | Chromium | 4/19/2017 | 4 | UD |
| 299-E25-2 | Chromium | 6/16/2017 | 3 | U |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E25-2 | Chromium | 9/15/2017 | 3 | U |
| 299-E25-2 | Chromium | 10/9/2017 | 3 | U |
| 299-E25-2 | Chromium | 12/12/2017 | 4.3 | B |
| 299-E25-2 | Chromium | 3/15/2018 | 3 | U |
| 299-E25-2 | Chromium | 6/21/2018 | 3 | U |
| 299-E25-40 | Chromium | 3/7/2016 | 5 | B |
| 299-E25-40 | Chromium | 9/19/2016 | 4.51 | B |
| 299-E25-40 | Chromium | 12/7/2016 | 4.35 | B |
| 299-E25-40 | Chromium | 12/7/2016 | 3.35 | B |
| 299-E25-40 | Chromium | 3/10/2017 | 3 | U |
| 299-E25-40 | Chromium | 6/16/2017 | 3 | U |
| 299-E25-40 | Chromium | 9/15/2017 | 3.6 | |
| 299-E25-40 | Chromium | 9/15/2017 | 3.2 | |
| 299-E25-40 | Chromium | 12/15/2017 | 3.6 | |
| 299-E25-40 | Chromium | 3/16/2018 | 3.2 | B |
| 299-E25-40 | Chromium | 6/21/2018 | 2.5 | |
| 299-E25-41 | Chromium | 3/7/2016 | 2.5 | B |
| 299-E25-41 | Chromium | 3/7/2016 | 3.1 | B |
| 299-E25-41 | Chromium | 9/16/2016 | 3 | B |
| 299-E25-41 | Chromium | 12/7/2016 | 1.5 | B |
| 299-E25-41 | Chromium | 3/10/2017 | 2.7 | |
| 299-E25-41 | Chromium | 6/16/2017 | 3.6 | B |
| 299-E25-41 | Chromium | 9/15/2017 | 3 | U |
| 299-E25-41 | Chromium | 12/15/2017 | 3 | B |
| 299-E25-41 | Chromium | 3/16/2018 | 3 | |
| 299-E25-41 | Chromium | 6/21/2018 | 5.5 | BC |
| 299-E25-93 | Chromium | 3/7/2016 | 2.35 | B |
| 299-E25-93 | Chromium | 9/15/2016 | 23.3 | |
| 299-E25-93 | Chromium | 12/7/2016 | 3 | U |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E25-93 | Chromium | 3/14/2017 | 3 | U |
| 299-E25-93 | Chromium | 6/15/2017 | 3 | U |
| 299-E25-93 | Chromium | 9/15/2017 | 3 | U |
| 299-E25-93 | Chromium | 12/12/2017 | 4.5 | BD |
| 299-E25-93 | Chromium | 3/15/2018 | 3 | U |
| 299-E25-93 | Chromium | 6/21/2018 | 2.1 | |
| 299-E24-20 | Copper | 3/8/2016 | 1.1 | U |
| 299-E24-20 | Copper | 9/15/2016 | 0.75 | B |
| 299-E24-20 | Copper | 9/15/2016 | 1.1 | U |
| 299-E24-20 | Copper | 12/6/2016 | 1.1 | U |
| 299-E24-20 | Copper | 3/14/2017 | 0.65 | B |
| 299-E24-20 | Copper | 6/15/2017 | 6 | U |
| 299-E24-20 | Copper | 9/20/2017 | 1.6 | U |
| 299-E24-20 | Copper | 12/11/2017 | 11 | |
| 299-E24-20 | Copper | 3/16/2018 | 3.2 | |
| 299-E24-20 | Copper | 6/21/2018 | 0.56 | U |
| 299-E25-40 | Copper | 3/7/2016 | 1.42 | |
| 299-E25-40 | Copper | 9/19/2016 | 1.22 | |
| 299-E25-40 | Copper | 12/7/2016 | 0.596 | B |
| 299-E25-40 | Copper | 12/7/2016 | 0.516 | B |
| 299-E25-40 | Copper | 3/10/2017 | 1.15 | |
| 299-E25-40 | Copper | 6/16/2017 | 0.454 | B |
| 299-E25-40 | Copper | 9/15/2017 | 0.56 | U |
| 299-E25-40 | Copper | 9/15/2017 | 0.56 | U |
| 299-E25-40 | Copper | 12/15/2017 | 0.56 | U |
| 299-E25-40 | Copper | 3/16/2018 | 0.485 | B |
| 299-E25-40 | Copper | 6/21/2018 | 0.56 | U |
| 299-E25-94 | Copper | 3/8/2016 | 0.928 | B |
| 299-E25-94 | Copper | 3/8/2016 | 1.02 | |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E25-94 | Copper | 9/19/2016 | 0.56 | U |
| 299-E25-94 | Copper | 9/19/2016 | 0.535 | B |
| 299-E25-94 | Copper | 12/7/2016 | 1.27 | |
| 299-E25-94 | Copper | 3/14/2017 | 0.372 | B |
| 299-E25-94 | Copper | 6/16/2017 | 0.393 | B |
| 299-E25-94 | Copper | 9/18/2017 | 0.49 | BD |
| 299-E25-94 | Copper | 12/12/2017 | 0.56 | U |
| 299-E25-94 | Copper | 3/15/2018 | 1.9 | UD |
| 299-E25-94 | Copper | 6/21/2018 | 0.3 | U |
| 299-E24-20 | Nickel | 3/8/2016 | 4.8 | B |
| 299-E24-20 | Nickel | 9/15/2016 | 10 | B |
| 299-E24-20 | Nickel | 9/15/2016 | 3.1 | |
| 299-E24-20 | Nickel | 12/6/2016 | 4.5 | B |
| 299-E24-20 | Nickel | 3/14/2017 | 3.3 | |
| 299-E24-20 | Nickel | 6/15/2017 | 11 | U |
| 299-E24-20 | Nickel | 9/20/2017 | 2.8 | B |
| 299-E24-20 | Nickel | 12/11/2017 | 8.7 | B |
| 299-E24-20 | Nickel | 3/16/2018 | 2.8 | |
| 299-E24-20 | Nickel | 6/21/2018 | 3 | |
| 299-E25-2 | Nickel | 3/8/2016 | 3.6 | |
| 299-E25-2 | Nickel | 4/4/2016 | 3.6 | |
| 299-E25-2 | Nickel | 9/15/2016 | 2.2 | |
| 299-E25-2 | Nickel | 10/18/2016 | 2.2 | |
| 299-E25-2 | Nickel | 11/1/2016 | 2.6 | |
| 299-E25-2 | Nickel | 12/6/2016 | 2.25 | |
| 299-E25-2 | Nickel | 1/25/2017 | 2.98 | |
| 299-E25-2 | Nickel | 3/14/2017 | 1.89 | B |
| 299-E25-2 | Nickel | 4/19/2017 | 2.8 | BD |
| 299-E25-2 | Nickel | 6/16/2017 | 2.19 | |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E25-2 | Nickel | 9/15/2017 | 2.38 | |
| 299-E25-2 | Nickel | 10/9/2017 | 2.3 | |
| 299-E25-2 | Nickel | 12/12/2017 | 2.94 | |
| 299-E25-2 | Nickel | 3/15/2018 | 0.6 | U |
| 299-E25-2 | Nickel | 6/21/2018 | 0.6 | U |
| 299-E25-40 | Nickel | 3/7/2016 | 21.8 | |
| 299-E25-40 | Nickel | 9/19/2016 | 12.8 | |
| 299-E25-40 | Nickel | 12/7/2016 | 18.8 | |
| 299-E25-40 | Nickel | 12/7/2016 | 18.9 | |
| 299-E25-40 | Nickel | 3/10/2017 | 18.1 | |
| 299-E25-40 | Nickel | 6/16/2017 | 17.3 | |
| 299-E25-40 | Nickel | 9/15/2017 | 20.7 | |
| 299-E25-40 | Nickel | 9/15/2017 | 20.3 | |
| 299-E25-40 | Nickel | 12/15/2017 | 18.2 | |
| 299-E25-40 | Nickel | 3/16/2018 | 13.9 | |
| 299-E25-40 | Nickel | 6/21/2018 | 12 | |
| 299-E25-41 | Nickel | 3/7/2016 | 4.2 | U |
| 299-E25-41 | Nickel | 3/7/2016 | 4.2 | U |
| 299-E25-41 | Nickel | 9/16/2016 | 6.9 | B |
| 299-E25-41 | Nickel | 12/7/2016 | 4.2 | U |
| 299-E25-41 | Nickel | 3/10/2017 | 2.8 | |
| 299-E25-41 | Nickel | 6/16/2017 | 11 | U |
| 299-E25-41 | Nickel | 9/15/2017 | 11 | U |
| 299-E25-41 | Nickel | 12/15/2017 | 10 | B |
| 299-E25-41 | Nickel | 3/16/2018 | 2.9 | |
| 299-E25-41 | Nickel | 6/21/2018 | 3.9 | B |
| 299-E24-20 | Vanadium | 3/8/2016 | 23 | |
| 299-E24-20 | Vanadium | 9/15/2016 | 20.4 | |
| 299-E24-20 | Vanadium | 9/15/2016 | 23 | |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E24-20 | Vanadium | 12/6/2016 | 23 | |
| 299-E24-20 | Vanadium | 3/14/2017 | 25.9 | |
| 299-E24-20 | Vanadium | 6/15/2017 | 24 | |
| 299-E24-20 | Vanadium | 9/20/2017 | 25 | |
| 299-E24-20 | Vanadium | 12/11/2017 | 23 | |
| 299-E24-20 | Vanadium | 3/16/2018 | 24.1 | |
| 299-E24-20 | Vanadium | 6/21/2018 | 22.6 | |
| 299-E24-22 | Vanadium | 3/8/2016 | 20.1 | |
| 299-E24-22 | Vanadium | 9/15/2016 | 20.3 | |
| 299-E24-22 | Vanadium | 12/6/2016 | 21.1 | |
| 299-E24-22 | Vanadium | 3/13/2017 | 18.8 | |
| 299-E24-22 | Vanadium | 6/15/2017 | 18.5 | |
| 299-E24-22 | Vanadium | 9/18/2017 | 18.7 | |
| 299-E24-22 | Vanadium | 12/11/2017 | 18.7 | |
| 299-E24-22 | Vanadium | 3/16/2018 | 19.6 | |
| 299-E24-22 | Vanadium | 6/22/2018 | 18.4 | |
| 299-E25-2 | Vanadium | 3/8/2016 | 21.1 | |
| 299-E25-2 | Vanadium | 4/4/2016 | 18.8 | |
| 299-E25-2 | Vanadium | 9/15/2016 | 19.2 | |
| 299-E25-2 | Vanadium | 10/18/2016 | 20.7 | |
| 299-E25-2 | Vanadium | 11/1/2016 | 19.4 | |
| 299-E25-2 | Vanadium | 12/6/2016 | 19.4 | |
| 299-E25-2 | Vanadium | 1/25/2017 | 19.4 | |
| 299-E25-2 | Vanadium | 3/14/2017 | 20.2 | |
| 299-E25-2 | Vanadium | 4/19/2017 | 25 | U |
| 299-E25-2 | Vanadium | 6/16/2017 | 17.7 | |
| 299-E25-2 | Vanadium | 9/15/2017 | 15.1 | |
| 299-E25-2 | Vanadium | 10/9/2017 | 18.7 | |
| 299-E25-2 | Vanadium | 12/12/2017 | 19.3 | |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E25-2 | Vanadium | 3/15/2018 | 20.1 | |
| 299-E25-2 | Vanadium | 6/21/2018 | 19.2 | |
| 299-E25-237 | Vanadium | 3/7/2016 | 24.8 | B |
| 299-E25-237 | Vanadium | 9/16/2016 | 20.3 | |
| 299-E25-237 | Vanadium | 9/16/2016 | 22 | |
| 299-E25-237 | Vanadium | 12/4/2016 | 21 | |
| 299-E25-237 | Vanadium | 3/10/2017 | 24.1 | |
| 299-E25-237 | Vanadium | 6/16/2017 | 21 | |
| 299-E25-237 | Vanadium | 9/20/2017 | 22 | C |
| 299-E25-237 | Vanadium | 12/11/2017 | 22 | |
| 299-E25-237 | Vanadium | 3/15/2018 | 22.8 | |
| 299-E25-237 | Vanadium | 6/21/2018 | 21 | |
| 299-E25-40 | Vanadium | 3/7/2016 | 23.2 | |
| 299-E25-40 | Vanadium | 9/19/2016 | 22.3 | |
| 299-E25-40 | Vanadium | 12/7/2016 | 21 | |
| 299-E25-40 | Vanadium | 12/7/2016 | 21.6 | |
| 299-E25-40 | Vanadium | 3/10/2017 | 22.6 | |
| 299-E25-40 | Vanadium | 6/16/2017 | 23.9 | |
| 299-E25-40 | Vanadium | 9/15/2017 | 21.9 | |
| 299-E25-40 | Vanadium | 9/15/2017 | 20.9 | |
| 299-E25-40 | Vanadium | 12/15/2017 | 23.2 | |
| 299-E25-40 | Vanadium | 3/16/2018 | 21.1 | |
| 299-E25-40 | Vanadium | 6/21/2018 | 24.9 | |
| 299-E25-41 | Vanadium | 3/7/2016 | 23 | |
| 299-E25-41 | Vanadium | 3/7/2016 | 22 | |
| 299-E25-41 | Vanadium | 9/16/2016 | 22 | |
| 299-E25-41 | Vanadium | 12/7/2016 | 21 | |
| 299-E25-41 | Vanadium | 3/10/2017 | 24.5 | |
| 299-E25-41 | Vanadium | 6/16/2017 | 21 | |

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|
| 299-E25-41 | Vanadium | 9/15/2017 | 24 | |
| 299-E25-41 | Vanadium | 12/15/2017 | 22 | |
| 299-E25-41 | Vanadium | 3/16/2018 | 22.9 | |
| 299-E25-41 | Vanadium | 6/21/2018 | 23 | |
| 299-E25-93 | Vanadium | 3/7/2016 | 24.1 | |
| 299-E25-93 | Vanadium | 9/15/2016 | 22.6 | |
| 299-E25-93 | Vanadium | 12/7/2016 | 21.4 | |
| 299-E25-93 | Vanadium | 3/14/2017 | 21.4 | |
| 299-E25-93 | Vanadium | 6/15/2017 | 21.2 | |
| 299-E25-93 | Vanadium | 9/15/2017 | 21.5 | |
| 299-E25-93 | Vanadium | 12/12/2017 | 19 | B |
| 299-E25-93 | Vanadium | 3/15/2018 | 22.7 | |
| 299-E25-93 | Vanadium | 6/21/2018 | 23.7 | |
| 299-E25-94 | Vanadium | 3/8/2016 | 21.5 | |
| 299-E25-94 | Vanadium | 3/8/2016 | 21.2 | |
| 299-E25-94 | Vanadium | 9/19/2016 | 21.2 | |
| 299-E25-94 | Vanadium | 9/19/2016 | 21.2 | |
| 299-E25-94 | Vanadium | 12/7/2016 | 22.2 | |
| 299-E25-94 | Vanadium | 3/14/2017 | 22.2 | |
| 299-E25-94 | Vanadium | 6/16/2017 | 20 | |
| 299-E25-94 | Vanadium | 9/18/2017 | 25 | B |
| 299-E25-94 | Vanadium | 12/12/2017 | 19.3 | |
| 299-E25-94 | Vanadium | 3/15/2018 | 20.5 | BC |
| 299-E25-94 | Vanadium | 6/21/2018 | 20.1 | |

Notes: All metals values are from filtered aliquot samples.

Well/constituent pair data are excluded from this table if dataset contains one or fewer detect values, or only one well contained a constituent. Specific reasoning for excluding certain datasets is provided in section 4.2.

**Table 1. WMA A-AX Data for Statistical Comparison**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier |
|---|---|---|---|---|

Qualifiers:

B = INORGANICS and WETCHEM - The analyte was detected at a value less than the contract required detection limit (RDL), but greater than or equal to the IDL/MIDL (as appropriate). ORGANICS - The analyte was detected in both the sample and the associated QC blank, and the blank concentration was > than the PQL but <= 5% of the sample concentration.

C = INORGANICS/WETCHEM: The analyte was detected in both the sample and the associated QC blank, and the blank concentration was > than the PQL but <= 10% of the sample concentration. ORGANICS (PESTICIDE only) - The identification of a pesticide confirmed by GC/MS.

D = All - Analyte was reported at a secondary dilution factor, typically DF>1 (i.e., the primary preparation required dilution to either bring the analyte within the calibration range or to minimize interference). Required for organics/wetchem if the sample was diluted.

J = Estimated value; (1) constituent detected at a level less than the RDL or PQL and greater than or equal to the MDL, (2) estimated concentration for TICs.

N = Spike and/or spike duplicate sample recovery is outside control limits.

Q = Estimated maximum concentration. Used if one of the qualitative identification criteria is not met (e.g., Cl isotopic ratios outside theoretical range).

U = ALL - Analyzed for but not detected above limiting criteria. Limiting criteria may be any of the following: value reported < 0; value reported < counting error, value reported < total analytical error; value reported <= contract MDL/IDL/MDA/PQL.

| | | |
|---|---|---|
| DF | = | dilution factor |
| GC/MS | = | gas chromatograph/mass spectrometer |
| IDL | = | instrument detection limit |
| MDA | = | minimum detectable activity |
| MDL | = | method detection limit |
| MIDL | = | method instrument detection limit |
| PQL | = | practical quantitation limit |
| QC | = | quality control |
| RDL | = | required detection limit |
| TIC | = | tentatively identified compound |
| WMA | = | waste management area |

**Table 2. WMA A-AX Regression on Order Statistics**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier | Censored | Modeled Value (µg/L) | Modeled Value (µg/L, 2 sig. fig.) |
|---|---|---|---|---|---|---|---|
| 299-E24-20 | Copper | 3/8/2016 | 1.1 | U | TRUE | 0.2304197 | 0.23 |
| 299-E24-20 | Copper | 9/15/2016 | 0.75 | B* | FALSE | 0.75 | 0.75 |
| 299-E24-20 | Copper | 12/6/2016 | 1.1 | U | TRUE | 0.7195952 | 0.72 |
| 299-E24-20 | Copper | 3/14/2017 | 0.65 | B | FALSE | 0.65 | 0.65 |
| 299-E24-20 | Copper | 6/15/2017 | 6 | U | TRUE | 0.5512364 | 0.55 |
| 299-E24-20 | Copper | 9/20/2017 | 1.6 | U | TRUE | 0.4196912 | 0.42 |
| 299-E24-20 | Copper | 12/11/2017 | 11 | | FALSE | 11 | 11 |
| 299-E24-20 | Copper | 3/16/2018 | 3.2 | | FALSE | 3.2 | 3.2 |
| 299-E24-20 | Copper | 6/21/2018 | 0.56 | U | TRUE | 0.1035968 | 0.1 |
| 299-E24-22 | Chloroform | 3/8/2016 | 0.3 | U | TRUE | 0.118327 | 0.12 |
| 299-E24-22 | Chloroform | 9/15/2016 | 0.31 | J | FALSE | 0.31 | 0.31 |
| 299-E24-22 | Chloroform | 12/6/2016 | 0.36 | J | FALSE | 0.36 | 0.36 |
| 299-E24-22 | Chloroform | 3/13/2017 | 0.3 | U | TRUE | 0.1477164 | 0.15 |
| 299-E24-22 | Chloroform | 6/15/2017 | 0.3 | J | FALSE | 0.3 | 0.3 |
| 299-E24-22 | Chloroform | 9/18/2017 | 0.3 | U | TRUE | 0.1730591 | 0.17 |
| 299-E24-22 | Chloroform | 12/11/2017 | 0.3 | U | TRUE | 0.1978077 | 0.2 |
| 299-E24-22 | Chloroform | 3/16/2018 | 0.49 | BJ | FALSE | 0.49 | 0.49 |
| 299-E24-22 | Chloroform | 6/22/2018 | 0.3 | U | TRUE | 0.2236912 | 0.22 |
| 299-E25-2 | Chromium | 3/8/2016 | 3.52 | CB | FALSE | 3.52 | 3.5 |

**Table 2. WMA A-AX Regression on Order Statistics**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier | Censored | Modeled Value (µg/L) | Modeled Value (µg/L, 2 sig. fig.) |
|---|---|---|---|---|---|---|---|
| 299-E25-2 | Chromium | 4/4/2016 | 4.11 | CB | FALSE | 4.11 | 4.1 |
| 299-E25-2 | Chromium | 9/15/2016 | 3 | U | TRUE | 1.8357019 | 1.8 |
| 299-E25-2 | Chromium | 10/18/2016 | 3 | U | TRUE | 2.0400679 | 2 |
| 299-E25-2 | Chromium | 11/1/2016 | 3 | U | TRUE | 2.1940031 | 2.2 |
| 299-E25-2 | Chromium | 12/6/2016 | 3 | U | TRUE | 2.3275084 | 2.3 |
| 299-E25-2 | Chromium | 1/25/2017 | 3 | U | TRUE | 2.4514383 | 2.5 |
| 299-E25-2 | Chromium | 3/14/2017 | 3 | U | TRUE | 2.5715573 | 2.6 |
| 299-E25-2 | Chromium | 4/19/2017 | 4 | UD | TRUE | 2.6369268 | 2.6 |
| 299-E25-2 | Chromium | 6/16/2017 | 3 | U | TRUE | 2.6918516 | 2.7 |
| 299-E25-2 | Chromium | 9/15/2017 | 3 | U | TRUE | 2.815795 | 2.8 |
| 299-E25-2 | Chromium | 10/9/2017 | 3 | U | TRUE | 2.9471156 | 2.9 |
| 299-E25-2 | Chromium | 12/12/2017 | 4.3 | B | FALSE | 4.3 | 4.3 |
| 299-E25-2 | Chromium | 3/15/2018 | 3 | U | TRUE | 3.0905959 | 3.1 |
| 299-E25-2 | Chromium | 6/21/2018 | 3 | U | TRUE | 3.253396 | 3.3 |
| 299-E25-93 | Chromium | 3/7/2016 | 2.35 | B | FALSE | 2.35 | 2.4 |
| 299-E25-93 | Chromium | 9/15/2016 | 23.3 | | FALSE | 23.3 | 23 |
| 299-E25-93 | Chromium | 12/7/2016 | 3 | U | TRUE | 0.9489159 | 0.95 |
| 299-E25-93 | Chromium | 3/14/2017 | 3 | U | TRUE | 1.5437302 | 1.5 |
| 299-E25-93 | Chromium | 6/15/2017 | 3 | U | TRUE | 2.2271489 | 2.2 |
| 299-E25-93 | Chromium | 9/15/2017 | 3 | U | TRUE | 3.1024217 | 3.1 |

**Table 2. WMA A-AX Regression on Order Statistics**

| Well | Constituent | Sample Date | Value (µg/L) | Qualifier | Censored | Modeled Value (µg/L) | Modeled Value (µg/L, 2 sig. fig.) |
|---|---|---|---|---|---|---|---|
| 299-E25-93 | Chromium | 12/12/2017 | 4.5 | BD | FALSE | 4.5 | 4.5 |
| 299-E25-93 | Chromium | 3/15/2018 | 3 | U | TRUE | 4.344569 | 4.3 |
| 299-E25-93 | Chromium | 6/21/2018 | 2.1 | | FALSE | 2.1 | 2.1 |

Note: Censored = TRUE indicates that "Value" is a method detection limit given for a non-detect sample result.

*Lab qualifiers for each of the samples from averaged duplicates.

WMA = waste management area

5. Run the "rquery.t.test.modified" and "rquery.to.dataframe" scripts (Appendix B) to define the "rquery.t.test.modified" and "rquery.to.dataframe" functions, respectively. This step compiles the prepared dataset that will be used in statistical hypothesis testing (Step 6) and calculation of summary statistics (Step 7). These steps are not performed sequentially.

6. Run the function "rquery.to.dataframe" which will first run the function "rquery.t.test.modified" for each constituent dataframe using the concentration data of upgradient well locations (*x*) versus downgradient well locations (*y*), and then automatically add results to a dataframe. "rquery.t.test.modified" first runs the Shapiro-Wilke test for normality and a test for variance uniformity. If the Shapiro-Wilke test indicates *x* and/or *y* distributions are non-normal, the function runs the Wilcoxon test instead of a t-test, and a warning message is provided indicating so. Otherwise, the function will run the Student's t-test if the variance is uniform, and the Welch t-test if not. Using this function, the default for t-tests is unpaired analysis. Unpaired analysis is the appropriate setting for this application since it assumes the sample sites are distinct. Wilcoxon test warning messages indicating that exact p-values cannot be computed are ignored since exact p-values are not needed. Results of this step are presented in Table 3.

    a. For example, filtered copper in upgradient well 299-E24-20 was compared with filtered copper in downgradient well 299-E25-40, for which ROS was used to model values marked as non-detect (Step 4). Results were saved to the dataframe "rquery_results" as follows:

```
rquery_results <- rquery.to.dataframe(E2420.Cu.Rosmod$modeled,
cu.tst.E25.40$Value, rquery_results)

   Wilcoxon rank sum test with continuity correction

data:  x and y
W = 38, p-value = 0.8595
alternative hypothesis: true location shift is not equal to 0

Warning messages:
1: In rquery.t.test(upgradient, downgradient) :
  x is not normally distributed : Shapiro test p-value = 3.542e-
05.
 Wilcoxon non parameteric test is used instead.
2: In rquery.t.test(upgradient, downgradient) :
  y is not normally distributed : Shapiro test p-value =
0.006667.
 Wilcoxon non parameteric test is used instead.
3: In wilcox.test.default(x, y) : cannot compute exact p-value
with ties
```

7. Compute summary statistics mean, median, standard deviation, and variance using the stats package functions mean, median var, and sd for those statistics respectively. Compute these summary statistics for each well/constituent pair using combined raw and ROS concentration data used in hypothesis testing. Create dataframe containing the summary statistics. Results of this step are presented in Table 4.

8. Export statistical tests result and summary statistics dataframes to csv files.

# 4 Assumptions and Inputs

This section provides all the relevant assumptions and inputs necessary to perform the calculations, including a brief explanation of the basis for each and the methodology step it is supporting.

## 4.1 Assumptions

The first assumption made in this ECF regarding t-tests and Wilcoxon tests is that the scale of measurement applied to the data collected follows a continuous or ordinal scale. The second assumption made is that of a simple random sample; that is, the data were collected from a representative, randomly selected portion of the total population. The third and fourth assumptions are that the distribution is symmetrical and the data is stationary over the sampling period. The fifth assumption is that an adequately large sample size is used. A larger sample size means the distribution of results should approach a normal distribution. There is no minimum sample size for a t-test to be valid if the assumptions of the data being independent and identically distributed and having an unknown but estimated sample variance are met. However, EPA 530/R-09-007 indicates that formal goodness-of-fit tests are often of limited value for datasets with less than eight samples, although t-tests and Wilcoxon tests are a special case where analysis can still be valuable with as few as four samples. The minimum sample size of eight was generally satisfied in this calculation with nine sampling events. However, one well/constituent pair (299-E25-41/Nickel) used in this analysis had seven samples after an invalid value was removed. For the Wilcoxon test, the final assumption is homogeneity of variance. Homogeneous, or equal, variance exists when the standard deviations of samples are approximately equal.

## 4.2 Inputs

Inputs for the statistical tests include the groundwater concentrations for chromium, copper, nickel and vanadium in filtered aliquots for upgradient and downgradient wells in which those constituents were detected. Chloroform present at low concentrations as indicated by consistent consecutive “J” qualifiers was retained for further evaluation even though it was not considered dangerous waste attributable to WMA A-AX. Further evaluation of chloroform present at low-level concentrations was deemed necessary for estimating possible future increases in concentrations and to determine its suitability as a site-specific monitoring constituent. Table 1 contains the data used in the statistical comparison. Table 2 contains the modeled data generated by ROS used in the statistical comparison.

Statistical analysis and summary statistics were not performed on certain well/constituent datasets forwarded for further evaluation (from ECF-200PO1-19-0007) for the following reasons:

- Copper at well 299-E25-41 – downgradient monitoring location with only one filtered detect value. ROS requires at least two detect values.
- Sulfide at well 299-E25-2 – downgradient monitoring location with consecutive valid detections but there were no upgradient detections for comparison.
- Octachlorodibenzo-p-dioxin in well 299-E25-41 – downgradient monitoring location with two consecutive J-flagged values in 2018 of very low concentrations (on the order of magnitude of $10^{-6}$ µg/L). Similar low-level dioxin concentrations are frequently found in both field samples and quality control blanks. This phenomenon is common among multiple analytical laboratories and suggests that dioxin residues are present throughout the environment and often detected at very low levels because by sensitive analytical methods. No upgradient detections were available for comparison.

# 5 Software Applications

Microsoft® Excel® and R Programming Language software are approved and appropriate applications for this calculation. Excel was used to perform data sorting and R was used for statistical calculations and hypothesis testing.

## 5.1 Approved Software

The R programming language is approved under PRC-PRO-IRM-309, *Software Control Management* and is registered on the Hanford Information System Inventory (HISI) and identified as approved for use. It provides an environment that allows a user to choose specific tools to perform statistical calculations and graph results.

### 5.1.1 Description

#### *5.1.1.1 Excel*

- Microsoft Excel
- Software Version: 2016
- HISI Identification Number: 3911
- Workstation type and property number: Dell Laptop WF37103

#### *5.1.1.2 R*

- R Programming Language
- Software Version: 3.5.1
- HISI Identification Number: 3911
- Workstation type and property number: Dell Laptop WF37103

### 5.1.2 Software Installation and Checkout

Neither Excel nor R are controlled software and therefore do not require a software installation and checkout form.

### 5.1.3 Statement of Valid Software Application

The calculations performed within this ECF were well within the limits of the approved software.

# 6 Calculation

All calculations were carried out within the R programming language platform.

# 7 Results/Conclusions

Results of the statistical comparisons performed for this ECF are in Table 3. Results for summary statistics for well/constituent data evaluated in this ECF are listed in Table 4. Sample means compared between upgradient and downgradient locations provide an additional metric for determining whether groundwater contamination could be attributable to WMA A-AX when the null hypothesis is rejected. Using both sample mean comparison and hypothesis testing provides more certainty in evaluation of site

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impacts to groundwater than basing such an evaluation on a single metric. DOE/RL-2019-21 discusses how the statistical information derived in this calculation was used to evaluate analytical data in the determination of potential site releases that could have impacted groundwater.

**Table 3. Statistical Evaluation Results of Dangerous Waste Constituents Detected at WMA A-AX**

| Constituent | Upgradient Well | Downgradient Well | Comparison Test [a] | p-Value [b] | Null Hypothesis |
|---|---|---|---|---|---|
| Chromium (filtered) | 299-E24-20 | 299-E25-2 [c] | Two Sample t-test | 1.87E-07 | Reject |
| | 299-E24-20 | 299-E25-40 | Two Sample t-test | 3.75E-04 | Reject |
| | 299-E24-20 | 299-E25-41 | Wilcoxon | 1.62E-03 | Reject |
| | 299-E24-20 | 299-E25-93 [c] | Wilcoxon | 1.42E-02 | Reject |
| | 299-E24-22 | 299-E25-2 [c] | Wilcoxon | 1.57E-03 | Reject |
| | 299-E24-22 | 299-E25-40 | Wilcoxon | 5.16E-02 | Accept |
| | 299-E24-22 | 299-E25-41 | Wilcoxon | 6.73E-03 | Reject |
| | 299-E24-22 | 299-E25-93 [c] | Wilcoxon | 1.33E-01 | Accept |
| Copper (filtered) | 299-E24-20 [c] | 299-E25-40 | Wilcoxon | 8.60E-01 | Accept |
| | 299-E24-20[2] | 299-E25-94 | Wilcoxon | 6.06E-01 | Accept |
| Nickel (filtered) | 299-E24-20 | 299-E25-2 | Two Sample t-test | 2.13E-02 | Reject |
| | 299-E24-20 | 299-E25-40 | Two Sample t-test | 2.25E-07 | Reject |
| | 299-E24-20 | 299-E25-41 | Two Sample t-test | 7.30E-01 | Accept |
| Vanadium (filtered) | 299-E24-20 | 299-E25-2 | Wilcoxon | 7.95E-05 | Reject |
| | 299-E24-20 | 299-E25-237 | Wilcoxon | 4.58E-02 | Reject |
| | 299-E24-20 | 299-E25-40 | Two Sample t-test | 1.43E-01 | Accept |
| | 299-E24-20 | 299-E25-41 | Two Sample t-test | 9.53E-02 | Accept |
| | 299-E24-20 | 299-E25-93 | Two Sample t-test | 2.64E-02 | Reject |
| | 299-E24-20 | 299-E25-94 | Two Sample t-test | 5.65E-03 | Reject |
| | 299-E24-22 | 299-E25-2 | Wilcoxon | 8.00E-01 | Accept |
| | 299-E24-22 | 299-E25-237 | Wilcoxon | 1.05E-03 | Reject |
| | 299-E24-22 | 299-E25-40 | Two Sample t-test | 1.31E-05 | Reject |
| | 299-E24-22 | 299-E25-41 | Two Sample t-test | 1.26E-05 | Reject |
| | 299-E24-22 | 299-E25-93 | Two Sample t-test | 5.30E-04 | Reject |
| | 299-E24-22 | 299-E25-94 | Two Sample t-test | 8.21E-03 | Reject |
| Chloroform | 299-E24-20 | 299-E25-237 | Wilcoxon | 5.97E-04 | Reject |
| | 299-E24-22 [c] | 299-E25-237 | Two Sample t-test | 7.34E-03 | Reject |

**Table 3. Statistical Evaluation Results of Dangerous Waste Constituents Detected at WMA A-AX**

| Constituent | Upgradient Well | Downgradient Well | Comparison Test [a] | p-Value [b] | Null Hypothesis |
|---|---|---|---|---|---|

a. Wilcoxon test is used when one or both samples are not normally distributed.

b. p-Values were compared to a level of significance of 0.05.

c. Data subjected to regression on order statistics.

WMA = waste management area

**Table 4. Summary Statistics of Statistically Evaluated Data**

| Well | Constituent | Mean | Median | Variance | Standard Deviation |
|---|---|---|---|---|---|
| 299-E24-20 | Chloroform | 0.17 | 0.16 | 0 | 0.02 |
| 299-E24-22 | Chloroform | 0.26 | 0.22 | 0.01 | 0.12 |
| 299-E25-237 | Chloroform | 0.4 | 0.4 | 0 | 0.05 |
| 299-E24-20 | Chromium | 5.53 | 5.5 | 1.12 | 1.06 |
| 299-E24-22 | Chromium | 4.11 | 4.03 | 0.21 | 0.46 |
| 299-E25-2 | Chromium | 2.85 | 2.69 | 0.5 | 0.71 |
| 299-E25-40 | Chromium | 3.56 | 3.4 | 0.62 | 0.79 |
| 299-E25-41 | Chromium | 3.12 | 3 | 1.11 | 1.05 |
| 299-E25-93 | Chromium | 4.94 | 2.35 | 48.83 | 6.99 |
| 299-E24-20 | Copper | 1.96 | 0.65 | 12.35 | 3.51 |
| 299-E25-40 | Copper | 0.77 | 0.56 | 0.14 | 0.38 |
| 299-E25-94 | Copper | 0.61 | 0.51 | 0.11 | 0.34 |
| 299-E24-20 | Nickel | 4.56 | 3.9 | 4.48 | 2.12 |
| 299-E25-2 | Nickel | 2.34 | 2.3 | 0.75 | 0.87 |
| 299-E25-40 | Nickel | 17.05 | 18.1 | 11.71 | 3.42 |
| 299-E25-41 | Nickel | 4.99 | 4.2 | 6.72 | 2.59 |
| 299-E24-20 | Vanadium | 23.59 | 23 | 1.67 | 1.29 |
| 299-E24-22 | Vanadium | 19.36 | 18.8 | 0.92 | 0.96 |
| 299-E25-2 | Vanadium | 19.16 | 19.35 | 2.1 | 1.45 |
| 299-E25-237 | Vanadium | 22.21 | 22 | 2.03 | 1.42 |
| 299-E25-40 | Vanadium | 22.66 | 22.6 | 1.64 | 1.28 |
| 299-E25-41 | Vanadium | 22.54 | 22.5 | 1.46 | 1.21 |

**Table 4. Summary Statistics of Statistically Evaluated Data**

| Well | Constituent | Mean | Median | Variance | Standard Deviation |
|---|---|---|---|---|---|
| 299-E25-93 | Vanadium | 21.96 | 21.5 | 2.34 | 1.53 |
| 299-E25-94 | Vanadium | 21.32 | 21.2 | 2.89 | 1.7 |

Note: All values are in µg/L.

Chromium in filtered aliquots was detected above background levels in two upgradient wells (299-E24-20 and 299-E24-22) and four downgradient wells (299-E25-2 and 299-E25-40, 299-E25-41, and 299-E25-93). Chromium concentration sample populations are statistically significant in all four downgradient wells when compared to upgradient well 299-E24-20. Two downgradient wells (299-E25-2 and 299-E25-41) are statistically significant when compared to upgradient well 299-E24-22 (Table 3). Yet, sample means from all downgradient wells are lower than in both upgradient wells (Table 4). Therefore, chromium concentrations in the downgradient wells are likely the result of different (or additional) factors (e.g. casing corrosion) than those in the upgradient wells. Corrosion is a known issue in well 299-E25-41. Instances of well casing and screen corrosion at WMA A-AX are discussed in detail in DOE/RL-2019-21.

Copper in filtered aliquots was detected above background levels in upgradient well 299-E24-20 and two downgradient wells (299-E25-40 and 299-E25-94). Neither downgradient well is statistically significant when compared to the upgradient well. The sample means are also lower for both downgradient wells. Therefore, WMA A-AX is not likely responsible for the copper concentrations detected in them. Consequently, copper concentrations in the downgradient wells are likely the result of different (or additional) factors (e.g. casing corrosion) than those in the upgradient wells.

Nickel in filtered aliquots was detected above background levels in upgradient well 299-E24-20 and three downgradient wells (299-E25-2, 299-E25-40, and 299-E25-41). While the other two downgradient wells are not statistically significant when compared to the upgradient well, 299-E25-40 is. Well 299-E25-40 is also the only downgradient well with a higher sample mean than the upgradient well. Nickel is a major component of stainless steel and can be used as indicator of well casing and or screen corrosion. Corrosion is a known issue in well 299-E25-40. Instances of well casing and screen corrosion at WMA A-AX are discussed in detail in DOE/RL-2019-21. These results indicate it is possible, but unlikely, that WMA A-AX is partially responsible for nickel in the downgradient wells.

Sulfide was detected at a single downgradient location (299-E25-2) and at no upgradient locations. Sulfide is a product of sulfate reduction by anaerobic bacteria in low oxygen environments. Sulfate is widely distributed in the unconfined aquifer within the 200 East Area. Reducing conditions at specific locations can result in elevated sulfide levels. For example, wells with very little flow through the well screen can contain stagnant water with low dissolved oxygen, providing for conditions in which anaerobic bacteria can reduce sulfate to sulfide. These conditions are evaluated for sulfide at well 299-E25-2 in DOE/RL-2019-21.

Vanadium was detected above background levels in two upgradient wells (299-E24-20 and 299-E24-22) and six downgradient wells (299-E25-2, 299-E25-237, 299-E25-40, 299-E25-41, 299-E25-93, and 299-E25-94). Vanadium concentrations in three downgradient wells are statistically significant when compared to 299-E24-20, and all six are statistically significant when compared to 299-E24-22. The sample mean from 299-E24-20 is higher than all downgradient wells, while all downgradient wells except

299-E25-2 have higher sample means than 299-E24-22. These results indicate it is possible, but not probable, that WMA A-AX is partially responsible for vanadium in the downgradient wells.

Chloroform was detected at low-level concentrations in two upgradient wells (299-E24-20 and 299-E24-22) and in downgradient well 299-E25-237. Chloroform concentrations in 299-E25-237 are statistically significant with both upgradient wells. The chloroform sample mean is greater at the downgradient location 299-E25-237 than both upgradient locations. This suggests that WMA A-AX could be partially responsible for the low-level chloroform values measured at 299-E25-237. However, all instances of chloroform detections are associated with the "J" laboratory qualifier, indicating the analytical result is an estimated value above the method detection limit and below the required detection limit. Consistent, consecutive "J" qualifiers suggest that the organic constituent is detectable in groundwater at very low concentrations.

# 8 References

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# Appendix A

# WMA A-AX Assessment Data for Statistical Comparison

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# WMA A-AX Assessment Sampling Dataset

WMA A-AX assessment dangerous waste sampling data collected between March of 2016 and June of 2018 are listed in Table A-1 below and is available upon request.

| Table A-1. Comma Separated Value File |
| --- |
| Table A-23.xlsx |

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# Appendix B

# R Script for the rquery.t.test.modified and rquery.to.dataframe Functions

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# rquery.test.modified R Script Function

Reference to original script that was modified:
Reference: STHDA, 2018, *Statistical tools for high-throughput data analysis*, "T test analysis: is it always correct to compare means?" Available at: http://www.sthda.com/english/wiki/t-test-analysis-is-it-always-correct-to-compare-means

```
#++++++++++++++++++++++++
#rquery.t.test.modified
#modified version of the rquery.t.test, adding the wilcoxon test when shapiro.px < 0.05
#++++++++++++++++++++++++
# x :  a (non-empty) numeric vector of data values.
# y : an optional (non-empty) numeric vector of data values
# paired : if TRUE, paired t-test is performed
# for the inspection of normality
# ... : further arguments to be passed to the built-in t.test() R function
# 1. shapiro.test is used to check normality
# 2. F-test is performed to check equality of variances
# If the variances are different, then Welch t-test is used
# If either x or y is not normal, then Wilcoxon test is used.
rquery.t.test<-function(x, y = NULL, paired = FALSE, ...)
{
 # 1. Check for normal distribution
 shapiro.px<-signif(shapiro.test(x)$p.value,4)
 if(shapiro.px < 0.05)
   warning("x is not normally distributed :",
           " Shapiro test p-value = ", shapiro.px,
           ".\n Wilcoxon non parameteric test is used instead.")

 if(!is.null(y)){
   shapiro.py<-signif(shapiro.test(y)$p.value,4)
   if(shapiro.py < 0.05)
     warning("y is not normally distributed :",
             " Shapiro test p-value = ", shapiro.py,
             ".\n Wilcoxon non parameteric test is used instead.")

   # Run and return the wilcox test if either x or y are not normally distributed.
   if(shapiro.py < 0.05 || shapiro.px < 0.05)
     return(wilcox.test(x,y))

   # 2. Check for equality of variances
   var.equal=FALSE # by default
   if(!paired & var.test(x,y)$p.value>=0.05) var.equal=TRUE
 }
 # 3. Student's t-test
 res <- t.test(x, y, paired=paired, var.equal=var.equal, ...)
 return(res)
}
```

## rquery.to.dataframe R Script Function

```
#run rquery and append model results to a specified dataframe
rquery.to.dataframe<-function(upgradient, downgradient, destination_df)
{
  x <- rquery.t.test(upgradient, downgradient)
  print(x)
  results <- as.data.frame(tidy(x))
  results$Upgradient <- deparse(substitute(upgradient))
  results$downgradient <- deparse(substitute(downgradient))
  destination_df <- bind_rows(destination_df, results)
}
```