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Revision 1

Analysis of Spatial Variability of Specific Conductance in Groundwater at the 216-S-10 Pond & Ditch

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

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Plateau Remediation Company
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CH2M HILL Plateau Remediation Company

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Environmental Calculation Cover Page

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Terms

ANOVA	Analysis of variance
CM	Critical mean
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	Code of Federal Regulations
HEIS	Hanford Environmental Information System
HISI	Hanford Information Systems Inventory
RCRA	*Resource Conservation and Recovery Act of 1976*
WAC	Washington Administrative Code

1 Purpose

This document describes a statistical test performed to evaluate spatial variability in specific conductance in the 216-S-10 Pond & Ditch groundwater monitoring wells. These wells are sampled for detection monitoring under the *Resource Conservation and Recovery Act of 1976* (RCRA).

2 Background

From the 1940's until the 1980's, the Hanford Site produced plutonium for national defense. During that time many chemical constituents were used which potentially can migrate to groundwater from disposal sites. In the 1990's, the mission at Hanford changed to environmental cleanup, including remediation of known groundwater contamination under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) and groundwater monitoring under RCRA. Some facilities at Hanford that could potentially impact groundwater became subject to RCRA regulations, one of which was the 216-S-10 Pond & Ditch.

Under 40 CFR 265.92(b)(3), as referenced by WAC 173-303-400(3)(a), interim-status groundwater monitoring of the 216-S-10 Pond & Ditch requires measurement of pH, specific conductance, total organic carbon, and total organic halides as indicators of groundwater contamination from the facility. Downgradient measurements of these parameters are compared with upgradient measurements to determine potential facility impact to groundwater (i.e., an interwell test). 40 CFR 265.93(b) requires that this comparison be done with a *t*-test at a 0.01 significance level, but the results of this test can be affected by spatial variability in the parameters. Spatial variability is defined as a change in "...the distribution or pattern of concentration measurements...from well location to well location (most typically in the form of differing mean levels)" (EPA 530/R-09-007, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance*, page 13-1). The use of multiple background wells exhibiting spatially variable results decreases the power of the *t*-test because a large downgradient concentration would be needed to produce an exceedance. On the other hand, the use of a single background well in the presence of spatial variability can cause false positive results in the interwell comparison, i.e., concentration differences that occur due to spatial variability can be misinterpreted to indicate a release from the facility. Thus, when performing interwell comparisons using the *t*-test, the assumption is made that the parameter being tested exhibits no spatial variability (EPA 530/R-09-007, page 5-6).

The monitoring well network for the 216-S-10 Pond & Ditch (Figure 1) consists of a single upgradient well and five downgradient wells, four of which are used for interwell comparisons of the indicator parameters. The threshold value of the downgradient well sample results that would statistically exceed the mean of the background data at the 0.01 significance level is calculated from measurements in the upgradient well, 699-33-76, and is called the critical mean (CM). The CM represents an upper limit on the background data and depends on the variability of the background measurements - the greater the variability, the higher the critical mean. Specific conductance in the upgradient well, 699-33-76, is very stable which can lead to a CM with little difference from the mean value. Further, specific conductance varies between all the network monitoring wells, and this is thought to be caused by spatial variability. Thus, the assumption that the indicator parameters exhibit no spatial variability may not be valid for the 216-S-10 Pond & Ditch, and because the site has only a single upgradient well, the risk of a false positive result may be high. To evaluate the spatial variability assumption, a statistical test was performed to determine if specific conductance is spatially variable in the aquifer at the 216-S-10 Pond & Ditch.

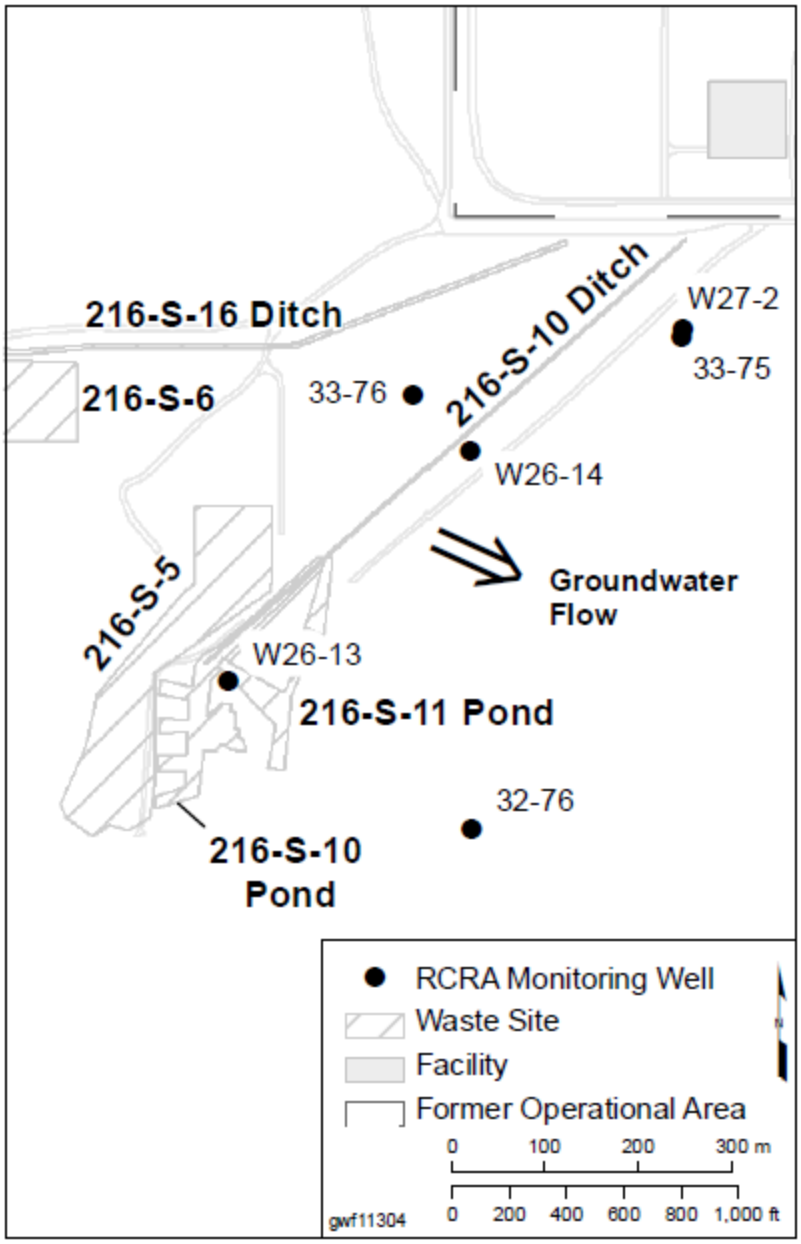

Figure 1. Well Location Map for the 216-S-10 Pond & Ditch.

3 Methodology

Spatial variability of specific conductance in the 216-S-10 Pond & Ditch groundwater monitoring wells was evaluated by a one-way analysis of variance (ANOVA), as described by EPA 530/R-09-007 (Chapters 13 and 17). This test compares measurements from two or more groups of data and evaluates whether all the measurements were obtained from the same population. For application at 216-S-10, if all the specific conductance measurements from the wells are from the same population, the variability of the measurements for individual wells about their means should be similar to the variability of the measurements about the mean from all the wells combined. Thus, the test statistic is the variability between the wells divided by the variability within the wells. The critical point is derived from the *F* probability distribution for a specified level of significance and the degrees of freedom for each data set

being compared. The *F* probability distribution is "…the theoretical distribution of values that would be expected by randomly sampling from a normal population and calculating, for all possible pairs of sample variances, the ratios" of those variances (*Statistics and Data Analysis in Geology*, Davis, 2002). The specific null and alternative hypotheses are:

- Null Hypothesis: There are no differences in mean specific conductance between the wells (i.e., there is no spatial variability in specific conductance).
- Alternative Hypothesis: The mean specific conductance from at least one well is significantly different from the others (i.e., specific conductance is spatially variable).

If the test statistic exceeds the critical value, the null hypothesis is rejected in favor of the alternative hypothesis.

The test was performed by constructing an ANOVA table, as shown in Table 1. The equations used to calculate the parameters in the table follow (from EPA 530/R-09-007).

Table 1. Standard ANOVA Table

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	*F*-Statistic
Between the Wells	SS_{wells}	*p-1*	MS_{wells}	*F*
Error (within wells)	SS_{error}	*N-p*	MS_{error}	
Total	SS_{total}	*N-1*		

$$SS_{wells} = \sum_{i=1}^{p} n_i (\bar{x}_i - \bar{x}_T)^2 \qquad \text{Equation 1}$$

$$SS_{total} = \sum_{i=1}^{p} \sum_{j=1}^{n_i} (x_{ij} - \bar{x}_T)^2 \qquad \text{Equation 2}$$

$$SS_{error} = SS_{total} - SS_{wells} \qquad \text{Equation 3}$$

$$MS_{wells} = \frac{SS_{wells}}{(p-1)} \qquad \text{Equation 4}$$

$$MS_{error} = \frac{SS_{error}}{(N-p)} \qquad \text{Equation 5}$$

$$F = \frac{MS_{wells}}{MS_{error}} \qquad \text{Equation 6}$$

where *p* is the number of wells, n_i is the number of measurements for the *i*-th well, $\bar{x}_i$ is the mean specific conductance for the *i*-th well, $\bar{x}_T$ is the mean specific conductance across all wells, x_{ij} is the *j*-th

specific conductance measurement for the *i*-th well, and *N* is the total number of specific conductance measurements across all wells.

The level of significance for this test was chosen to be 0.05, as suggested in EPA 530/R-09-007 (page 13-7).

4 Assumptions and Inputs

Ideally, the determination of spatial variability at a waste site would be made using measurements only from upgradient wells to make certain the analysis is not affected by "synthetic variability", i.e., groundwater impacts from the facility. However, because there is only a single upgradient well at 216-S-10, it was necessary to include some downgradient wells. Well 299-W27-2 was excluded because it is screened deeper in the aquifer and is not used for the interwell comparisons. Wells 299-W26-13 and 699-32-76 were also excluded because both have elevated levels of chromium and nitrate which could affect specific conductance. The nitrate and chromium may be from 216-S-10 or from other upgradient sources, and the nitrate may also originate from an offsite agricultural source. The remaining two downgradient wells, 299-W26-14 and 699-33-75, and the upgradient well, 699-33-76, all have a similar contaminant chemistry: low levels of nitrate and carbon tetrachloride, and no chromium. The carbon tetrachloride originates from the 200-ZP-1 Operable Unit and is believed to have migrated into the 216-S-10 vicinity by vapor phase transport through the vadose zone. This mechanism precludes the presence of co-contaminants that could affect specific conductance. Thus, it was assumed that specific conductance in wells 299-W26-14, 699-33-75, and 699-33-76 represents background conditions. All three of these wells were used in this analysis.

The sample results used for this analysis were the eight most recent quadruplicate measurements of specific conductance for each well, and were obtained from the Hanford Environmental Information System (HEIS) database. The data used are listed in Appendix A. The measurements collected on 5/20/2011 for well 699-33-75 were excluded because they were taken less than three weeks after the previous sampling event on 5/2/2011, and as such, they could be autocorrelated with the previous measurements (i.e., not temporally independent).

5 Software Applications

A Microsoft Excel 2007®[1] spreadsheet was used to perform the calculations described in Section 3, using functions available in that software.

5.1 Description

Software Title: Microsoft® Excel 2007

Software Version: 2007

Hanford Information System Inventory (HISI) Number: 1915

Workstation Type and property number: HLAN Standard Workstation #WC91734

5.2 Software Installation and Checkout

Calculations are presented and discussed in Section 6. The Microsoft® Excel 2007 spreadsheets used for the calculations are shown in Appendix B. Inclusion of the calculation spreadsheet files in their complete configuration is exempt from the validation and verification requirements of PRC-PRO-IRM-309, *Controlled Software Management*.

[1] Microsoft Excel is a registered product of the Microsoft Corporation.

5.3 Statement of Valid Software Application

Microsoft® Excel 2007 is approved software for use in performing calculations at Hanford and the calculations were performed within the limitations of the software, as approved, and consistent with the requirements of PRC-PRO-IRM-309.

6 Calculations

The spreadsheet used for the ANOVA calculations is shown in Appendix B. Two versions are shown: one with the formulas displayed to document the design of the spreadsheet (Figure B.1), and a second with the formula results (Figure B.2).

Referring to Figure B.1 in Appendix B, the input data is listed for each well in the block of cells from B10 to D17 (these are the average of the replicate measurements listed in Table A.1 of Appendix A). The mean specific conductance for each well is computed in row 20. Cell D22 contains the average of all the measurements for all three wells. The ANOVA table is contained in the block of cells from F9 to J12. The layout of this table in the spreadsheet is exactly as specified in Table 1 and Equations 1 through 6 in Section 3. The level of significance is specified in cell G16. The critical point is derived in cell G17 using the FINV function in Excel, which "returns the inverse of the *F* probability distribution" (*Function Reference Microsoft Excel*, Microsoft Corporation, 1992). The critical point is the lower bound of the rejection region of the probability distribution for the specified level of significance and degrees of freedom. Thus, if the *F* statistic is greater than the critical value, the null hypothesis is rejected.

7 Results and Discussion

The ANOVA table for the spatial variability analysis at the 216-S-10 Pond & Ditch is shown below in Table 2 (compare with the spreadsheet in Figure B.2 of Appendix B). The test statistic was calculated to be 244.70 and the critical value was 3.47. The test statistic exceeds the critical value, so the null hypothesis (i.e., no spatial variability) was rejected in favor of the alternative hypothesis (i.e., specific conductance is spatially variable).

Table 2. ANOVA Table for Specific Conductance at the 216-S-10 Pond & Ditch

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	*F*-Statistic
Between the Wells	10,990.04	2	5,495.02	244.70
Error (within wells)	471.58	21	22.46	
Total	11,461.61	23		

In fact, the test statistic far exceeds the critical value. By comparison, even if the level of significance had been chosen to be 0.01, the critical value would only have increased to 5.78. The reason for the large difference is evident from Figure 2, which shows the mean and range of the specific conductance results used in this analysis. There is no overlap in the range of values for the wells (i.e., the minimum and maximum values for each well are outside the range of the other wells). This visual analysis strongly suggests that the specific conductance values from each well are from different populations.

The result that specific conductance exhibits spatial variability means there is a high risk of a false positive result when applying the *t*-test for detection monitoring at the 216-S-10 Pond & Ditch. In other words, it is possible that specific conductance in a downgradient well can exceed the background value established using data from the upgradient well due solely to natural spatial variation in the parameter. Under this condition, EPA 530/R-09-007 recommends that intrawell comparisons be performed in which

separate background values be determined for each well in the monitoring network. However, regulations require that interwell comparisons be performed under interim status monitoring whereby concentrations in the downgradient wells be compared to background conditions established using the upgradient wells (40 CFR 265.92 and 265.93).

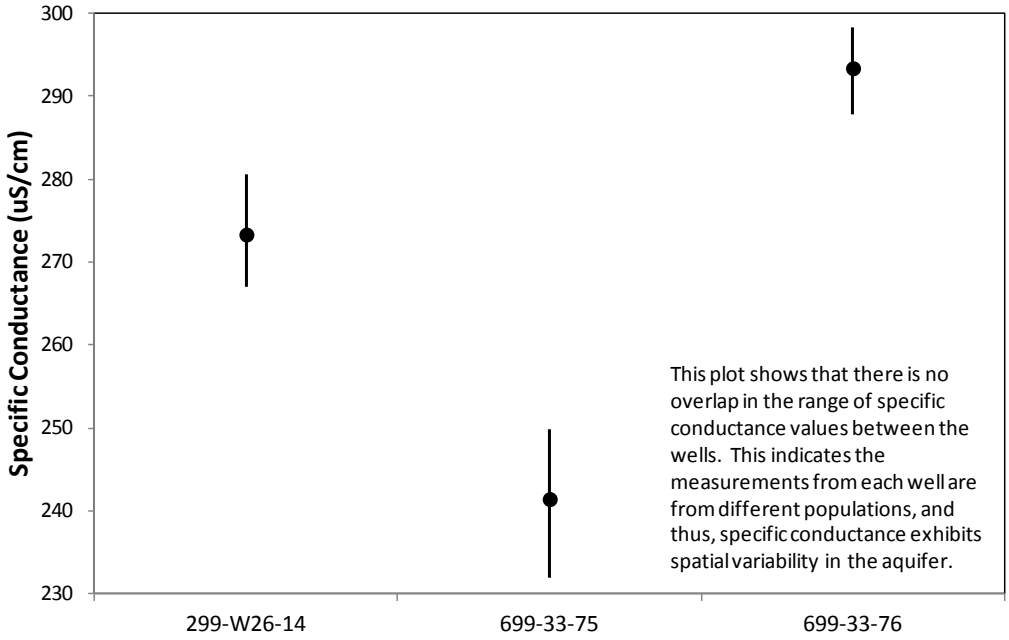

Figure 2. Mean (dots) and Range (bars) of Specific Conductance Values in the Wells.

As described in Section 2, the upper limit of the background is referred to as the critical mean (CM). Calculation of the CM is affected by the variability of the parameter and the number of sample results used in the calculation. High variability causes a high CM and vice versa. The relationship is an inverse one for sample size: a large number of samples causes a low CM whereas a low number of samples results in a higher CM. Because the temporal variability of specific conductance in the upgradient well is quite low (i.e., the mean specific conductance results for 699-33-76 ranges from a low of 288 and a high of 298), the calculated critical mean comes out relatively low when a sample size of eight to ten is used in the CM calculation, as recommended by EPA 530/R-09-007 (page 5-3). Thus, to compensate for spatial variability in specific conductance and to guard against false positive results at the 216-S-10 Pond & Ditch, it is recommended that the minimum sample size required by regulations (i.e., four) (40 CFR 265.92[c][1]) be used to compute the CM.

8 References

Davis, J. C., 2002, *Statistics and Data Analysis in Geology*, 3rd Edition, John Wiley & Sons, New York.

EPA, 2009, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance*, EPA 530/R-09-007, U.S. Environmental Protection Agency, Washington, D.C.

Microsoft Corporation, 1992, *Function Reference Microsoft Excel*, Document Number XL26298-1292.

PRC-PRO-IRM-309, Rev. 1, Change 0, 11/29/2010, "Controlled Software Management," CH2M HILL Plateau Remediation Company, Richland, Washington.

Appendix A
Specific Conductance Measurements

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Table A.1. Specific Conductance Measurements in Wells 299-W26-14, 699-33-76, and 699-33-75 (3 pages)

Well Name	Date/Time	Specific Conductance (µS/cm)	Average of Replicates (µS/cm)
299-W26-14	6/24/2008 10:41	268	
299-W26-14	6/24/2008 10:41	268	
299-W26-14	6/24/2008 10:41	268	
299-W26-14	6/24/2008 10:41	268	268
299-W26-14	12/17/2008 10:22	279	
299-W26-14	12/17/2008 10:22	278	
299-W26-14	12/17/2008 10:22	278	
299-W26-14	12/17/2008 10:22	280	278.75
299-W26-14	6/17/2009 9:27	271	
299-W26-14	6/17/2009 9:27	271	
299-W26-14	6/17/2009 9:27	271	
299-W26-14	6/17/2009 9:27	271	271
299-W26-14	12/2/2009 10:25	276	
299-W26-14	12/2/2009 10:25	276	
299-W26-14	12/2/2009 10:25	277	
299-W26-14	12/2/2009 10:25	277	276.5
299-W26-14	6/8/2010 10:49	267	
299-W26-14	6/8/2010 10:49	267	
299-W26-14	6/8/2010 10:49	267	
299-W26-14	6/8/2010 10:49	267	267
299-W26-14	12/21/2010 8:38	275	
299-W26-14	12/21/2010 8:38	275	
299-W26-14	12/21/2010 8:38	275	
299-W26-14	12/21/2010 8:38	275	275
299-W26-14	8/16/2011 9:21	270	
299-W26-14	8/16/2011 9:21	270	
299-W26-14	8/16/2011 9:21	270	
299-W26-14	8/16/2011 9:21	270	270
299-W26-14	5/2/2012 10:03	281	
299-W26-14	5/2/2012 10:03	281	
299-W26-14	5/2/2012 10:03	280	
299-W26-14	5/2/2012 10:03	280	280.5
699-33-76	6/2/2010 9:11	291	
699-33-76	6/2/2010 9:11	292	
699-33-76	6/2/2010 9:11	292	
699-33-76	6/2/2010 9:11	292	291.75
699-33-76	8/11/2010 11:49	296	
699-33-76	8/11/2010 11:49	295	
699-33-76	8/11/2010 11:49	292	
699-33-76	8/11/2010 11:49	293	294
699-33-76	1/12/2011 11:42	290	
699-33-76	1/12/2011 11:42	290	
699-33-76	1/12/2011 11:42	290	
699-33-76	1/12/2011 11:42	290	290

Table A.1. Specific Conductance Measurements in Wells 299-W26-14, 699-33-76, and 699-33-75 (3 pages)

Well Name	Date/Time	Specific Conductance (µS/cm)	Average of Replicates (µS/cm)
699-33-76	3/31/2011 11:39	293	
699-33-76	3/31/2011 11:39	293	
699-33-76	3/31/2011 11:39	293	
699-33-76	3/31/2011 11:39	294	293.25
699-33-76	5/17/2011 9:29	296	
699-33-76	5/17/2011 9:29	295	
699-33-76	5/17/2011 9:29	296	
699-33-76	5/17/2011 9:29	296	295.75
699-33-76	8/16/2011 10:20	288	
699-33-76	8/16/2011 10:20	287	
699-33-76	8/16/2011 10:20	288	
699-33-76	8/16/2011 10:20	288	287.75
699-33-76	12/2/2011 10:28	296	
699-33-76	12/2/2011 10:28	296	
699-33-76	12/2/2011 10:28	297	
699-33-76	12/2/2011 10:28	297	296.5
699-33-76	5/3/2012 12:35	298	
699-33-76	5/3/2012 12:35	298	
699-33-76	5/3/2012 12:35	297	
699-33-76	5/3/2012 12:35	300	298.25
699-33-75	8/4/2009 9:27	239	
699-33-75	8/4/2009 9:27	239	
699-33-75	8/4/2009 9:27	239	
699-33-75	8/4/2009 9:27	239	239
699-33-75	2/12/2010 9:48	243	
699-33-75	2/12/2010 9:48	242	
699-33-75	2/12/2010 9:48	243	
699-33-75	2/12/2010 9:48	243	242.75
699-33-75	6/2/2010 10:07	239	
699-33-75	6/2/2010 10:07	239	
699-33-75	6/2/2010 10:07	239	
699-33-75	6/2/2010 10:07	239	239
699-33-75	8/11/2010 10:16	242	
699-33-75	8/11/2010 10:16	242	
699-33-75	8/11/2010 10:16	241	
699-33-75	8/11/2010 10:16	242	241.75
699-33-75	5/2/2011 9:30	232	
699-33-75	5/2/2011 9:30	232	
699-33-75	5/2/2011 9:30	232	
699-33-75	5/2/2011 9:30	232	232

Table A.1. Specific Conductance Measurements in Wells 299-W26-14, 699-33-76, and 699-33-75 (3 pages)

Well Name	Date/Time	Specific Conductance (µS/cm)	Average of Replicates (µS/cm)
699-33-75	6/28/2011 11:24	240	
699-33-75	6/28/2011 11:24	240	
699-33-75	6/28/2011 11:24	240	
699-33-75	6/28/2011 11:24	240	240
699-33-75	12/2/2011 10:09	250	
699-33-75	12/2/2011 10:09	250	
699-33-75	12/2/2011 10:09	249	
699-33-75	12/2/2011 10:09	250	249.75
699-33-75	5/11/2012 13:09	247	
699-33-75	5/11/2012 13:09	247	
699-33-75	5/11/2012 13:09	247	
699-33-75	5/11/2012 13:09	248	247.25

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Appendix B
Spreadsheets Used in the ANOVA

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Figure B.1. ANOVA Spreadsheet with Formulas Displayed.

	A	B	C	D	E	F	G	H	I	J
1										
2	**Analysis of Variance of Spatial Variability in Specific Conductance at the 216-S-10 Pond & Ditch**									
3										
4		Null Hypothesis: There are no differences in mean specific conductance between the wells.								
5		Alternative Hypothesis: The mean specific conductance from at least one well is significantly different from the others.								
6										
7		**Input Data:**				**ANOVA Table:**				
8										
9		**299-W26-14**	**699-33-75**	**699-33-76**		**Source of Variation**	**Sums of Squares**	**Degrees of Freedom**	**Mean Squares**	**F-Statistic**
10		268	239	291.75		Between Wells	=8*((B20-D22)^2+(C20-D22)^2+(D20-D22)^2)	=3-1	=G10/H10	=I10/I11
11		278.75	242.75	294		Error (within wells)	=G12-G10	=24-3	=G11/H11	
12		271	239	290		Total	=SUM((B10:D17-D22)^2)	=24-1		
13		276.5	241.75	293.25						
14		267	232	295.75		**Statistical Test:**				
15		275	240	287.75						
16		270	249.75	296.5		Level of Significance:	0.05			
17		280.5	247.25	298.25		Critical Point:	=FINV(G16,H10,H11)			
18										
19		**Means:**				The F-Statistic exceeds the critical point, so the null hypothesis is rejected in favor of the alternative hypothesis.				
20		=AVERAGE(B10:B17)	=AVERAGE(C10:C17)	=AVERAGE(D10:D17)						
21										
22			Total Mean:	=AVERAGE(B10:D17)						

Figure B.2. ANOVA Spreadsheet with Results Displayed.

Analysis of Variance of Spatial Variability in Specific Conductance at the 216-S-10 Pond & Ditch

Null Hypothesis: There are no differences in mean specific conductance between the wells.

Alternative Hypothesis: The mean specific conductance from at least one well is significantly different from the others.

Input Data:

299-W26-14	699-33-75	699-33-76
268	239	291.75
278.75	242.75	294
271	239	290
276.5	241.75	293.25
267	232	295.75
275	240	287.75
270	249.75	296.5
280.5	247.25	298.25

Means:

273.34375	241.4375	293.40625
	Total Mean:	269.3958333

ANOVA Table:

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Statistic
Between Wells	10990.03646	2	5495.018229	244.7004572
Error (within wells)	471.578125	21	22.45610119	
Total	11461.61458	23		

Statistical Test:

Level of Significance:	0.05
Critical Point:	3.466800112

The F-Statistic exceeds the critical point, so the null hypothesis is rejected in favor of the alternative hypothesis.