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Revision 0

Hydraulic Gradients in 100-FR-3, 2010 and 2011

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
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Richland, Washington 99352

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Environmental Calculation Cover Page

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Contents

1 Purpose **4**

2 Methodology **4**

2.1 Trend-Surface Analysis 4

2.2 Statistical Test 5

2.3 Average Linear Velocity 7

3 Assumptions and Inputs **7**

4 Software Applications **7**

4.1 Description 8

4.2 Software Installation and Checkout 8

4.3 Statement of Valid Software Application 8

5 Calculations **8**

6 Results **9**

6.1 Northeastern 100-F 9

6.2 Southwestern 100-F 9

6.3 South of 100-F Area 9

7 References **10**

Appendix A- Hydraulic Gradient Calculations **22**

Figures

Figure 1. Water Table Wells in and near 100-F 19

Figure 2. 100-F Water Table, March 2011 20

Figure 3. Magnitude and Direction of Hydraulic Gradients in 100-F Region 21

Tables

Table 1. Hydraulic Gradient Calculation Spreadsheet with Data for September 2010, Southwestern 100-F (3 Sheets)..... 12
Table 2. Velocity Calculation Spreadsheet 16
Table 3. Hydraulic Gradient and Fit Statistics, 100-F 17
Table 4. Groundwater Velocity Estimates for 100-F 18
Table A.1. Hydraulic Gradient Calculations for February 2010, Northeastern 100-F (2 sheets) 24
Table A.2. Hydraulic Gradient Calculations for February 2010, Southwestern 100-F (2 sheets) 26
Table A.3. Hydraulic Gradient Calculations for March 2010, Region South of 100-F (2 sheets) 28
Table A.4. Hydraulic Gradient Calculations for July 2010, Northeastern100-F (2 sheets) 30
Table A.5. Hydraulic Gradient Calculations for July 2010, Southwestern100-F (2 sheets) 32
Table A.6. Hydraulic Gradient Calculations for September 2010, Northeastern100-F (2 sheets) 34
Table A.7. Hydraulic Gradient Calculations for September 2010, Southwestern100-F (2 sheets) 36
Table A.8. Hydraulic Gradient Calculations for March 2011, Northeastern100-F (2 sheets) 38
Table A.9. Hydraulic Gradient Calculations for March 2011, Southwestern100-F (2 sheets) 40
Table A.10. Hydraulic Gradient Calculations for March 2011, Region South of 100-F (2 sheets) 42
Table A.11. Hydraulic Gradient Calculations for December 2011, Northeastern 100-F (2 sheets) 44
Table A.12. Hydraulic Gradient Calculations for December 2011, Southwestern 100-F (2 sheets) 46

Terms

ANOVA	Analysis of variance
Df	Degrees of freedom
Diff	Difference
DOE	United States Department of Energy
m/d	Meters per day
NAVD88	North American Vertical Datum of 1988

1 Purpose

The purpose of these environmental calculations is to estimate hydraulic gradients and groundwater flow velocity in the 100-F Area using least squares-regression analysis of water-level data collected in 2010 and 2011. Results of these calculations are to be included in the Remedial Investigation/Feasibility Study report for 100-F.

2 Methodology

A Microsoft Excel 2007®[1] spreadsheet was used to calculate hydraulic gradients and groundwater velocity based on water-level data from 100-F wells.

Water-level data were analyzed by trend-surface analysis calculations in a Microsoft Excel 2007 spreadsheet created by J.P. McDonald. The method was described by Davis (2002, *Statistics and Data Analysis in Geology*). A first-order, linear trend surface (i.e., a plane) was fitted to the water-level elevation data using least squares regression. The slope of the fitted surface represented the hydraulic gradient magnitude, and the dip direction represented the hydraulic gradient direction. To determine if the fitted plane was valid for determining the hydraulic gradient, a statistical test was used to evaluate the goodness of fit of the plane to the water-level data. Sections 2.1 and 2.2, written by J.P. McDonald, describe the trend-surface analysis and statistical test. Section 2.3 describes calculation of average linear velocity.

2.1 Trend-Surface Analysis

The following linear regression equation was used for the trend-surface analysis (from Davis [2002]):

$$z = b_0 + b_1 x + b_2 y \qquad \text{Equation 1}$$

where z is the predicted water-level elevation (meters NAVD88) at a location x,y, in which x is the easting geographic coordinate (meters) and y is the northing geographic coordinate (meters), b_0 is the offset (meters), b_1 is the slope in the x-direction (meter/meter), and b_2 is the slope in the y-direction (meter/meter). Equation 1 can be rearranged as follows:

$$b_1 x + b_2 y - z + b_0 = 0 \qquad \text{Equation 2}$$

This equation has the same form as

$$ax + by + cz + d = 0 \qquad \text{Equation 3}$$

which is the familiar equation of a plane in standard form.

The least-squares regression was performed by solving the following matrix equation for the regression coefficients, b_0, b_1, and b_2 (from Davis [2002]):

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

$$\begin{bmatrix} k & \sum_{j=1}^{k} x_j & \sum_{j=1}^{k} y_j \\ \sum_{j=1}^{k} x_j & \sum_{j=1}^{k} x_j^2 & \sum_{j=1}^{k} x_j y_j \\ \sum_{j=1}^{k} y_j & \sum_{j=1}^{k} x_j y_j & \sum_{j=1}^{k} y_j^2 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{k} z_j \\ \sum_{j=1}^{k} x_j z_j \\ \sum_{j=1}^{k} y_j z_j \end{bmatrix} \qquad \text{Equation 4}$$

where k is the number of wells, x_j is the easting geographic coordinate of the jth well, y_j is the northing geographic coordinate of the jth well, and z_j is the measured water-level elevation in the jth well. Equation 4 was solved in a spreadsheet modeled after the spreadsheet of Devlin (2003, *A Spreadsheet Method of Estimating Best-Fit Hydraulic Gradients Using Head Data from Multiple Wells*).

The hydraulic gradient magnitude is represented by the slope of the fitted plane. It follows from mathematics that vector $<a,b,c>$ is a normal vector to the plane (i.e., a vector perpendicular to the plane) in Equation 3, and therefore, vector $<b_1,b_2,-1>$ is a normal vector to the plane represented in Equation 2. The slope of the fitted plane, which is the gradient magnitude, was calculated from the deviation of vector $<b_1,b_2,-1>$ from the vertical (i.e., its "tilt") using the Pythagorean theorem as follows:

$$i = \left(b_1^2 + b_2^2\right)^{1/2} \qquad \text{Equation 5}$$

Vector $<b_1,b_2,-1>$ begins at the origin of the coordinate system and points in the negative z direction (i.e., downward), because $c = -1$. Thus, the vector $<-b_1,-b_2,1>$ is also a normal vector to the fitted plane pointing in the positive z direction (i.e., upward). This vector can be projected onto the x,y plane by setting $c = 0$, and the direction of the resulting vector, $<-b_1,-b_2,0>$, is the direction of the hydraulic gradient. This direction was calculated from $-b_1$ and $-b_2$ using trigonometric functions.

2.2 Statistical Test

It is possible to use the equations in Section 2.1 to fit a plane to any set of x_j,y_j,z_j data, even random data, and calculate the slope and dip direction of the fitted plane. When applying these equations to water-level measurements, how can it be known that the results are due to the hydraulic gradient and not due to random error? In other words, how can it be known that the hydraulic gradient has been measured successfully? This question was answered by performing a statistical test.

In a statistical test, a null hypothesis and alternative hypothesis are established such that if the null hypothesis is false, then the alternative hypothesis will be true (Davis, 2002; Ott and Mendenhall, 1985, *Understanding Statistics*). The test is designed such that the null hypothesis will only be rejected if the probability of obtaining the observed result or a result more contradictory to the null hypothesis, assuming the null hypothesis is true, is below some threshold value. In statistical testing, there is always a chance that the decision to reject or not reject the null hypothesis will be incorrect. A Type I error occurs when the null hypothesis is rejected when it is true, and a Type II error occurs when the null hypothesis is not rejected when it is false. The acceptable probability of committing a Type I error is denoted by α (alpha), and the probability of committing a Type II error is denoted by β (beta). The threshold value for rejecting or not rejecting the null hypothesis is α, and the probability of obtaining the observed result or a result more contradictory to the null hypothesis, assuming the null hypothesis is true, is referred to as the level of significance (denoted as the p-value). Thus, if the p-value is less than or equal to α, the null hypothesis will be rejected and the alternative hypothesis will be accepted. However, if the p-value is greater than α, it does not mean that the null hypothesis is true. Instead, it means there is

insufficient justification to reject the null hypothesis. To emphasize, a statistical test does not choose between the null and alternative hypotheses. Rather, it tests whether or not there is sufficient justification to accept the alternative hypothesis.

The statistical test used for the 100-F analyses is known as an analysis of variance (ANOVA). In this test, the variance (i.e., the variability) of the set of deviations of each measurement from a horizontal plane centered on the mean of the measurements is compared to the variance of the set of deviations of each measurement from the fitted plane. If the deviations from the fitted plane are much smaller than the deviations from the horizontal plane, it can be concluded that there is a linear trend in the data not explainable by random error. Thus, the fitted plane would be deemed statistically significant.

For the ANOVA analysis at 100-F, the specific null hypothesis was both b_1 and b_2 in Equation 1 were equal to zero (i.e., the best fit plane is horizontal). The alternative hypothesis was that either b_1 was not equal to zero, b_2 was not equal to zero, or both b_1 and b_2 were not equal to zero (i.e., the best fit plane is distinguishable from a horizontal plane). To evaluate the null hypothesis, the ratio of the variance about the horizontal plane to the variance about the fitted plane was computed (this value is known as the test statistic), and then the probability of obtaining that ratio or a larger ratio (i.e., the *p*-value) was determined using the *f* probability distribution[2]. The acceptable probability of committing a Type I error (α) was chosen, *a priori*, to be 0.05 for this study. Thus, when the *p*-value for a given trend-surface analysis was less than or equal to 0.05, the null hypothesis (both coefficients are equal to zero) was rejected and the alternative hypothesis (one or both coefficients are nonzero) was accepted, and there was a 95% chance that this decision was correct. In other words, if the probability of obtaining the observed deviations about the fitted plane (or a set of smaller deviations) from a random sampling of deviations about a horizontal plane was less than or equal to 0.05, then there was high confidence that a spatial trend really exists in the water-level measurements and that the hydraulic gradient was measured successfully.

The goodness of fit coefficient (R^2) was another statistic used in this study to ascertain whether or not the water-level measurements fit a plane. This statistic is the ratio of the sum of squares due to the regression (SS_R) to the total sum of squares (SS_T), as follows (Davis 2002):

$$R^2 = \frac{SS_R}{SS_T} \qquad \text{Equation 6}$$

where the sum of squares due to the regression is given by:

$$SS_R = \sum_{j=1}^{k} (\hat{z}_j - Z)^2 \qquad \text{Equation 7}$$

and the total sum of squares is given by:

$$SS_T = \sum_{j=1}^{k} (z_j - Z)^2 \qquad \text{Equation 8}$$

in which z_j is the measured water-level elevation in the jth well, Z is the average water-level elevation in all k wells, and $\hat{z}_j$ is the predicted water-level elevation for the jth well from the trend-surface regression

[2] 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 (Davis, 2002).

equation. If the measurements fit a plane closely, SS_R and SS_T will be approximately equal and their ratio, R^2, will be approximately 1. If the measurements do not fit a plane very well, the best fit plane will be nearly horizontal. In this case, SS_R will be small compared to SS_T and their ratio will be near zero. Thus, the more closely an R^2 value is to unity, the better the measurements fit a plane.

2.3 Average Linear Velocity

The average linear velocity of groundwater can be calculated using a form of the Darcy equation (Freeze and Cherry, 1979):

$$\bar{v} = \frac{Ki}{n_e}$$

in which $\bar{v}$ is average linear velocity, K is hydraulic conductivity, i is hydraulic gradient, and n_e is effective porosity.

3 Assumptions and Inputs

Manually-measured water-level data were retrieved from the "Environmental Monitoring" module of the Hanford Site's Virtual Library for wells screened across the water table within and south of 100-F Area (Figure 1). Concurrent dates were chosen as much as possible for the following time periods, which cover a range of seasonal conditions: February, March, July, and September 2010 and March and December 2011. Appendix A includes the data used in these calculations.

Well coordinates (northing and easting) were retrieved from the Hanford Site's "Environmental Dashboard Application" (http://environet.rl.gov/EDA), rounded to the nearest hundredth of a meter and are listed in the Tables of Appendix A.

The calculation assumes that the water table is planar. This is of course a simplification, because water table contours form a varied "topography." The water table near the river in 100-F is much more variable and responsive to changes in river stage than it is inland. For this evaluation the 100-F Area was divided along a line that runs parallel to the river, approximately through wells 199-F7-2 and 199-F8-4, and the two regions were analyzed separately. A third region, located south of 100-F where a nitrate plume is present, was also evaluated (Figure 1).

As applied here, the Darcy equation assumes that flow is horizontal (vertical gradients are insignificant) and the aquifer is homogeneous.

Hydraulic conductivity and effective porosity values were chosen from those used for groundwater modeling in support of the Remedial Investigation/Feasibility Study. Recent slug tests in 100-F provided a range of results for the Hanford formation (ECF-100FR3-11-0146). The 10th and 90th percentiles were 10 m/d and 75 m/d, respectively, and the median was approximately 35 m/day. Effective porosity was assumed to be 18 percent, the value used in the computer model.

4 Software Applications

A Microsoft Excel 2007®[3] spreadsheet was used to perform calculations described in Section 2, using the default calculation formulae available in that software. The spreadsheet previously was validated by comparison of results with a commercial software (personal communication, e-mail from Dennis Weier,

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

Pacific Northwest National laboratory, to John McDonald, Fluor Hanford, Inc., "Spreadsheet verification," April 7, 2008).

4.1 Description

Software Title: Microsoft® Excel 2007

Software Version: 2007

Hanford Information System Number: 1915

Workstation Type and property number: HLAN Standard Workstation #WC96718

4.2 Software Installation and Checkout

Calculations are presented and discussed in Section 5. The Microsoft® Excel 2007 spreadsheet is attached in Appendix A. Inclusion of the calculation spreadsheet files in their complete configuration is exempt from the validation and verification requirements of PRC-PRO-IRM-309.

4.3 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.

5 Calculations

As an example of hydraulic gradient calculations, Table 1 shows the September 2010 spreadsheet for southwestern 100-F, with formulae visible to illustrate the calculations. On sheet 1 of Table 1, well names, easting, northing, observed hydraulic head, and measurement dates were input data with consistent units (meters) in the blue-shaded cells (B9 through F15). The spreadsheet calculation fits a plane through the data and computes what the head "should" be at each well based on that approximation.

Also on sheet 1 of Table 1, computed data with formulae for predicted hydraulic head and predicted difference from mean and residuals are shown in cells G9 through I28. The magnitude and direction of the gradient are displayed in cells L10 and L11. Statistical indicators goodness of fit (L15) and correlation coefficient (L16) should be very close to 1.0. The level of significance is set at 0.05. If the P value (L18) is less than the level of significance, there is a statistically significant trend (L19). Additional intermediate calculations are displayed in columns K and L such as number of observations (cell L23). Columns N through S, rows 13 through 17, display an ANOVA table.

On sheet 2 of Table 1, computed data formulae continue in cells G24 through I28. Intermediate computations continue in cells K24 through L36. Matrix equation computations are shown in cells K40 through O42. Inverse Matrix and coefficients of the Fitted Plane equations are shown in cells K46 through M48 and L54.

On sheet 3 of Table 1, normal vector to the fitted plane, gradient magnitude and gradient direction formulae are in columns K, L, and M.

Table 2 shows a spreadsheet, with formulae visible, to calculate groundwater velocity using the Darcy equation. A range of hydraulic conductivity (K) and effective porosity (n) are input and the spreadsheet calculates the rate of groundwater linear velocities for three regions: Southwest (inland 100-F), Northeast (near-river 100-F) and South of 100-F.

6 Results

Table 3 lists the calculated hydraulic gradients and fit statistics for each of the three regions at various time periods in 2010 and 2011. Table 4 lists a range of groundwater velocity estimates. Sections 6.1 through 6.3 provide additional discussion and Tables A.1 through A.12 in Appendix A provide the calculations.

Figure 2 is a water-table map for 100-F for March 2011, when river stage was relatively high. Groundwater flow is variable in northeastern 100-F, where the water table responds rapidly to changing river stage. The gradient is more consistent in the southwestern (inland) portion of 100-F. Groundwater flows toward the southeast (parallel to the river) in the region south of 100-F.

6.1 Northeastern 100-F

In northeastern 100-F (near the Columbia River), the slope of the hydraulic gradient varies widely, depending on river stage (Table 3). Excluding data from well 199-F8-4 improved the goodness of fit and reduced residuals for most of the data sets. This well has lower head than the other wells in 100-F.

During low river stage (February and September 2010), the water table sloped to the northeast, perpendicular to the river. The maximum gradient was 1.6×10^{-3} in September 2010. December 2011 was a time of fairly low, but variable river stage. The gradient sloped toward the east-northeast. Using the median value for hydraulic conductivity, velocity ranged from 0.17 to 0.31 m/d (Table 4) during these periods of low river stage.

During high and moderately high river stage (early July 2010 and March 2011, respectively), the gradient reversed and sloped gently to the south or south-southwest (Table 3). The July data set did not form a good plane: goodness of fit (0.24) and correlation coefficient (0.49) were far below 1.0 and the P Value (0.28) far above the 0.05 level of significance. March 2011 data were a fairly good fit if well 199-F8-4 was excluded. The gradient magnitude was 3.5×10^{-4} in March 2011. Using the median value for hydraulic conductivity, velocity was 0.07 m/d in March 2011 (Table 4).

6.2 Southwestern 100-F

Groundwater flow in the inland portion of 100-F was consistently to the east or east-northeast during the periods studied (Table 3). All of the data sets had a good fit and low P values, indicating the water table could be approximated by a plane. The magnitude of the gradient varied little (1.04×10^{-3} to 1.5×10^{-3}). Using the median value for hydraulic conductivity, velocity ranged from 0.20 to 0.29 m/d (Table 4).

6.3 South of 100-F Area

A large nitrate plume extends southward several kilometers from 100-F. The gradient in this region was calculated from water-level data from five wells in March 2010 and three wells in March 2011. During both periods the gradient sloped to the south-southeast at 1.2×10^{-3} and velocity was estimated at 0.24 m/d (Tables 3 and 4). In March 2010 the data achieved a good fit and low P value, but the two wells near the river had high residuals. Because only three wells had data in March 2011, fit statistics could not be calculated for that period.

Water levels are not measured as frequently in these wells as in 100-F, so calculations could not be performed for periods of high or low river stage.

7 References

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

Devlin, J. F., 2003, "A Spreadsheet Method of Estimating Best-Fit Hydraulic Gradients Using Head Data from Multiple Wells," in *Ground Water*, 41(3):316-320.

ECF-100FR3-11-0146, 2011, *Analysis of Slug Test Data at the 100-FR-3 Operable Unit*, CH2M HILL Plateau Remediation Company, Richland, Washington.

Freeze, R. Allan, and John A. Cherry, *Groundwater*, 1979. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Ott, L., and W. Mendenhall, 1985, *Understanding Statistics*, 4th Edition, Duxbury Press, Boston.

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

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Table 1. Hydraulic Gradient Calculation Spreadsheet with Data for September 2010, Southwestern 100-F (3 sheets)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1		**Trend Surface Analysis of Hydraulic Gradient**																	
2		**(Least Squares Regression of a Plane to Points in 3-D Space)**																	
3		**Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons**																	
4		**Prepared by JP McDonald**																	
5																			
6																			
7		**Input Data**					**Computed Data**												
8		**Well Name**	**Easting (x-coord)**	**Northing (y-coord)**	**Observed Hydraulic Head (z-coord)**	**Date**	**Predicted Hydraulic Head**	**Predicted Diff from Mean**	**Residuals (Observed - Predicted)**		**Hydraulic Gradient**								
9		199-F7-1	579687.17	147022.43	114.63	40447	=IF(ISBLANK(E9),,$L$52+$L$53*C9+$L$54*D9)	=IF(G9=0,0,G9-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E9),,G9-E9)										
10		199-F7-3	579884.71	147112.53	114.57	40447	=IF(ISBLANK(E10),,$L$52+$L$53*C10+$L$54*D10)	=IF(G10=0,0,G10-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E10),,G10-E10)		**Gradient Magnitude:**	=L64							
11		199-F8-3	580253.99	147253.37	114.25	40447	=IF(ISBLANK(E11),,$L$52+$L$53*C11+$L$54*D11)	=IF(G11=0,0,G11-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E11),,G11-E11)		**Gradient Direction (azimuth):**	=INDEX(M69:M77,MATCH("Yes",L69:L77,0))							
12		199-F8-4	580958.51	147123.53	113.21	40447	=IF(ISBLANK(E12),,$L$52+$L$53*C12+$L$54*D12)	=IF(G12=0,0,G12-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E12),,G12-E12)										
13		199-F8-7	580242.91	147116.74	114.3	40447	=IF(ISBLANK(E13),,$L$52+$L$53*C13+$L$54*D13)	=IF(G13=0,0,G13-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E13),,G13-E13)		**Statistics**			**ANOVA**					
14		199-F5-4	580583.19	147533.73	113.89	40447	=IF(ISBLANK(E14),,$L$52+$L$53*C14+$L$54*D14)	=IF(G14=0,0,G14-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E14),,G14-E14)					**Var Source**	Sum of Squares	Df	Mean Squares	F-Test	P-Value
15		199-F5-48	580517.58	147690.10	113.77	40447	=IF(ISBLANK(E15),,$L$52+$L$53*C15+$L$54*D15)	=IF(G15=0,0,G15-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E15),,G15-E15)		**Goodness of Fit (R^2):**	=L36/L35		**Regression**	=SUM(H9:H28*H9:H28)	2	=O15/P15	=Q15/Q16	=FDIST(R15,P15,P16)
16		8					=IF(ISBLANK(E16),,$L$52+$L$53*C16+$L$54*D16)	=IF(G16=0,0,G16-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E16),,G16-E16)		**Correlation Coefficient (R):**	=SQRT(L15)		**Deviation**	=SUM(I9:I28*I9:I28)	=L23-3	=O16/P16		
17		9					=IF(ISBLANK(E17),,$L$52+$L$53*C17+$L$54*D17)	=IF(G17=0,0,G17-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E17),,G17-E17)		**Level of Significance:**	0.05		**Total**	=O15+O16	=L23-1			
18		10					=IF(ISBLANK(E18),,$L$52+$L$53*C18+$L$54*D18)	=IF(G18=0,0,G18-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E18),,G18-E18)		**P-Value:**	=ROUND(S15,4)							
19		11					=IF(ISBLANK(E19),,$L$52+$L$53*C19+$L$54*D19)	=IF(G19=0,0,G19-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E19),,E19-G19)		**Statistically Significant Trend?:**	=IF(L23=3,"N/A - 3 pts",IF(L18<=L17,"Yes","No"))							
20		12					=IF(ISBLANK(E20),,$L$52+$L$53*C20+$L$54*D20)	=IF(G20=0,0,G20-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E20),,E20-G20)										
21		13					=IF(ISBLANK(E21),,$L$52+$L$53*C21+$L$54*D21)	=IF(G21=0,0,G21-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E21),,E21-G21)		**Intermediate Computations**								
22		14					=IF(ISBLANK(E22),,$L$52+$L$53*C22+$L$54*D22)	=IF(G22=0,0,G22-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E22),,E22-G22)										
23		15					=IF(ISBLANK(E23),,$L$52+$L$53*C23+$L$54*D23)	=IF(G23=0,0,G23-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E23),,E23-G23)		**# of Observations:**	=COUNT(C9:C28)							

Table 1. Hydraulic Gradient Calculation Spreadsheet with Data for September 2010, Southwestern 100-F (3 sheets)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
24		16					=IF(ISBLANK(E24),,$L$52+$L$53*C24+$L$54*D24)	=IF(G24=0,0,G24-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E24),,E24-G24)		**Sum of Easting:**	=SUM(C9:C28)							
25		17					=IF(ISBLANK(E25),,$L$52+$L$53*C25+$L$54*D25)	=IF(G25=0,0,G25-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E25),,E25-G25)		**Sum of Northing:**	=SUM(D9:D28)							
26		18					=IF(ISBLANK(E26),,$L$52+$L$53*C26+$L$54*D26)	=IF(G26=0,0,G26-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E26),,E26-G26)		**Sum of Easting*Northing:**	=SUM(C9:C28*D9:D28)							
27		19					=IF(ISBLANK(E27),,$L$52+$L$53*C27+$L$54*D27)	=IF(G27=0,0,G27-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E27),,E27-G27)		**Sum of Easting^2:**	=SUM(C9:C28^2)							
28		20					=IF(ISBLANK(E28),,$L$52+$L$53*C28+$L$54*D28)	=IF(G28=0,0,G28-SUM($G$9:$G$28)/$L$23)	=IF(ISBLANK(E28),,E28-G28)		**Sum of Northing^2:**	=SUM(D9:D28^2)							
29											**Sum of Observed Heads:**	=SUM(E9:E28)							
30											**Sum of Easting*Observed Heads:**	=SUM(C9:C28*E9:E28)							
31											**Sum of Northing*Observed Heads:**	=SUM(D9:D28*E9:E28)							
32											**Sum of Observed Heads^2:**	=SUM(E9:E28^2)							
33											**Sum of Predicted Heads:**	=SUM(G9:G28)							
34											**Sum of Predicted Heads^2:**	=SUM(G9:G28^2)							
35											**SSt:**	=L32-(L29^2)/L23							
36											**SSr:**	=L34-(L33^2)/L23							
37																			
38											**Matrix Equation (Equation 5.86 in Davis, 2002)**								
39																			
40											=L23	=L24	=L25	b0	=L29				
41											=L24	=L27	=L26	b1	=L30				
42											=L25	=L26	=L28	b2	=L31				
43																			
44											**Inverse Matrix**								
45																			
46											=MINVERSE(K40:M42)	=MINVERSE(K40:M42)	=MINVERSE(K40:M42)						
47											=MINVERSE(K40:M42)	=MINVERSE(K40:M42)	=MINVERSE(K40:M42)						
48											=MINVERSE(K40:M42)	=MINVERSE(K40:M42)	=MINVERSE(K40:M42)						
49																			
50											**Coefficients of the Fitted Plane (z = b0 + b1x + b2y)**								
51																			
52											b0=	=MMULT(K46:M48,O40:O42)							
53											b1=	=MMULT(K46:M48,O40:O42)							
54											b2=	=MMULT(K46:M48,O40:O42)							
55																			

Table 1. Hydraulic Gradient Calculation Spreadsheet with Data for September 2010, Southwestern 100-F (3 sheets)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
56											**Normal Vector to the Fitted Plane (<a,b,c> where a = -b1, b = -b2, c = 1)**								
57																			
58											a:	=$L$53*(-1)							
59											b:	=$L$54*(-1)							
60											c:	1							
61																			
62											**Gradient Magnitude**								
63																			
64												=SQRT(L58^2+L59^2)							
65																			
66											**Gradient Direction**								
67																			
68													Azimuth:						
69											**Horizontal Plane?:**	=IF(AND($L$58=0,$L$59=0),"Yes","No")	n/a						
70											**Due North?:**	=IF(AND($L$58=0,$L$59>0),"Yes","No")	=IF(L70="Yes",0,"n/a")						
71											**Due East?:**	=IF(AND($L$58>0,$L$59=0),"Yes","No")	=IF(L71="Yes",90,"n/a")						
72											**Due South?:**	=IF(AND($L$58=0,$L$59<0),"Yes","No")	=IF(L72="Yes",180,"n/a")						
73											**Due West?:**	=IF(AND($L$58<0,$L$59=0),"Yes","No")	=IF(L73="Yes",270,"n/a")						
74											**First Quadrant?:**	=IF(AND($L$58>0,$L$59>0),"Yes","No")	=IF(L74="Yes",ATAN($L$58/$L$59)*180/PI(),"n/a")						
75											**Second Quadrant?:**	=IF(AND($L$58>0,$L$59<0),"Yes","No")	=IF(L75="Yes",90+ATAN(ABS($L$59)/$L$58)*180/PI(),"n/a")						
76											**Third Quadrant?:**	=IF(AND($L$58<0,$L$59<0),"Yes","No")	=IF(L76="Yes",180+ATAN($L$58/$L$59)*180/PI(),"n/a")						
77											**Fourth Quadrant?:**	=IF(AND($L$58<0,$L$59>0),"Yes","No")	=IF(L77="Yes",270+ATAN($L$59/ABS($L$58))*180/PI(),"n/a")						

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Table 2. Velocity Calculation Spreadsheet

	A	B	C	D	E	F	G	H	I	J
1	Date	Gradient	Gradient Azimuth (E of N)	K low (m/d)	K high (m/d)	K median (m/d)	n	v low (m/d)	v high (m/d)	v median (m/d)
2	Southwest (inland 100-F)									
3	Feb-10	0.00151	77	10	75	35	0.18	=(D3*B3)/G3	=(E3*B3)/G3	=(F3*B3)/G3
4	Jul-10	0.00125	83.4	10	75	35	0.18	=(D4*B4)/G4	=(E4*B4)/G4	=(F4*B4)/G4
5	Sep-10	0.00116	95.2	10	75	35	0.18	=(D5*B5)/G5	=(E5*B5)/G5	=(F5*B5)/G5
6	Mar-11	0.0012	90.1	10	75	35	0.18	=(D6*B6)/G6	=(E6*B6)/G6	=(F6*B6)/G6
7	Dec-11	0.00104	97.9	10	75	35	0.18	=(D7*B7)/G7	=(E7*B7)/G7	=(F7*B7)/G7
8	Northeast (near-river 100-F)									
9	Feb-10	0.000974	52.9	10	75	35	0.18	=(D9*B9)/G9	=(E9*B9)/G9	=(F9*B9)/G9
10	Jul-10	0.000853	202.4	10	75	35	0.18	=(D10*B10)/G10	=(E10*B10)/G10	=(F10*B10)/G10
11	Sep-10	0.00157	42.7	10	75	35	0.18	=(D11*B11)/G11	=(E11*B11)/G11	=(F11*B11)/G11
12	Mar-11	0.000354	169.7	10	75	35	0.18	=(D12*B12)/G12	=(E12*B12)/G12	=(F12*B12)/G12
13	Dec-11	0.000865	73.6	10	75	35	0.18	=(D13*B13)/G13	=(E13*B13)/G13	=(F13*B13)/G13
14	South of 100-F									
15	Mar-10	0.00121	157.4	10	75	35	0.18	=(D15*B15)/G15	=(E15*B15)/G15	=(F15*B15)/G15
16	Mar-11	0.00122	158.5	10	75	35	0.18	=(D16*B16)/G16	=(E16*B16)/G16	=(F16*B16)/G16

Table 3. Hydraulic Gradient and Fit Statistics, 100-F

Region	Date	# Wells	Gradient	Azimuth (E of N)	R2	R	P Value	Comment
North-eastern 100-F (near river)	Feb. 2010	8	9.74×10^{-4}	52.9	0.94	0.97	0.0009	
	July 2010	13	3.88×10^{-4}	215.9	0.24	0.49	0.2848	Reversed gradient. Poor fit; large residuals. Water table not planar.
	Sept. 2010	8	1.57×10^{-3}	42.7	0.99	1.00	0.000	
	Mar. 2011	9	3.54×10^{-4}	169.7	0.78	0.89	0.010	Reversed gradient
	Dec. 2011	9	8.65×10^{-4}	73.6	0.85	0.92	0.0037	
South-western 100-F (inland)	Feb. 2010	7	1.51×10^{-3}	77.0	0.93	0.97	0.0045	
	July 2010	7	1.25×10^{-3}	83.4	0.96	0.98	0.0019	
	Sept. 2010	7	1.16×10^{-3}	95.2	0.94	0.97	0.0037	
	Mar. 2011	7	1.20×10^{-3}	90.1	0.93	0.96	0.0054	
	Dec. 2011	7	1.04×10^{-3}	97.9	0.88	0.94	0.0155	
South of 100-F	Mar. 2010	5	1.21×10^{-3}	157.4	0.95	0.98	0.0467	
	Mar. 2011	3	1.22×10^{-3}	158.5	NC[a]	NC[a]	NC[a]	

NC = Not calculated

R = Correlation coefficient

R2 = Goodness of fit

Yellow highlight indicates case where P value is greater than 0.05 (trend not statistically significant at 0.05 level)

[a] These parameters are not meaningful for case with three data points (plane is perfect fit)

Table 4. Groundwater Velocity Estimates for 100-F

Date	Gradient	Azimuth (E of N)	v low[a] (m/d)	v high[b] (m/d)	v median[c] (m/d)
Northeastern 100-F (Near River)					
Feb-10	9.74×10^{-4}	53	0.054	0.406	0.189
Jul-10	NC	NC	NC	NC	NC
Sep-10	1.57×10^{-3}	43	0.087	0.654	0.305
Mar-11	3.54×10^{-4}	170	0.020	0.148	0.069
Dec-11	8.65×10^{-4}	74	0.048	0.360	0.168
Southwestern 100-F (Inland)					
Feb-10	1.51×10^{-3}	77	0.084	0.629	0.294
Jul-10	1.25×10^{-3}	83	0.069	0.521	0.243
Sep-10	1.16×10^{-3}	95	0.064	0.483	0.226
Mar-11	1.20×10^{-3}	90	0.067	0.500	0.233
Dec-11	1.04×10^{-3}	98	0.058	0.433	0.202
South of 100-F					
Mar-10	1.21×10^{-3}	157	0.067	0.504	0.235
Mar-11	1.22×10^{-3}	159	0.068	0.508	0.237

Notes

a. 10th percentile from 100-F aquifer tests (10 m/d)

b. 90th percentile from 100-F aquifer tests (75 m/d)

c. Median from 100-F aquifer tests (35 m/d)

Blue shading indicates periods with reversed gradient.

Effective porosity of 0.18 used for all calculations

NC = Not calculated. Water table in northeastern region was not planar in July 2010.

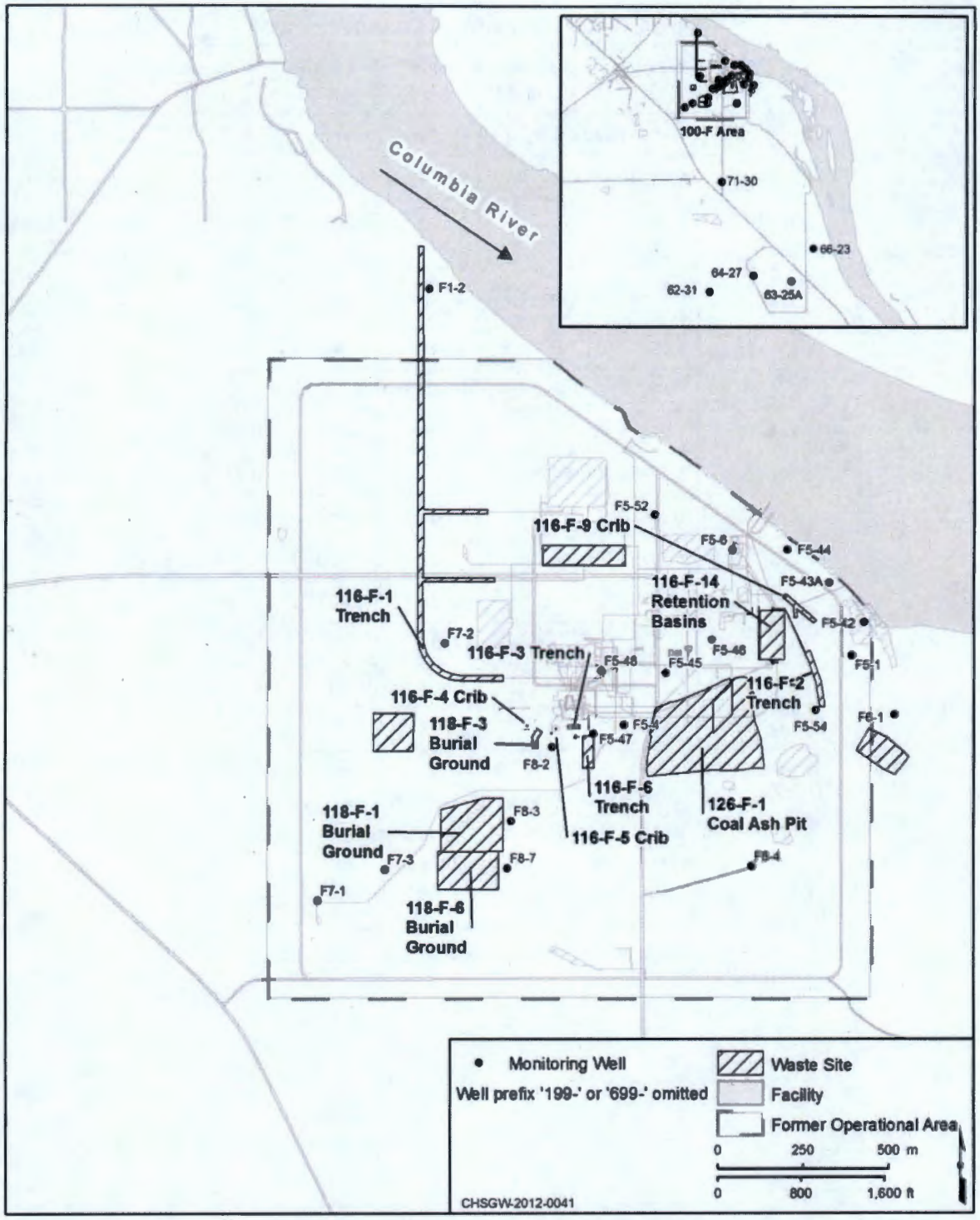

Figure 1. Water Table Wells in and near 100-F

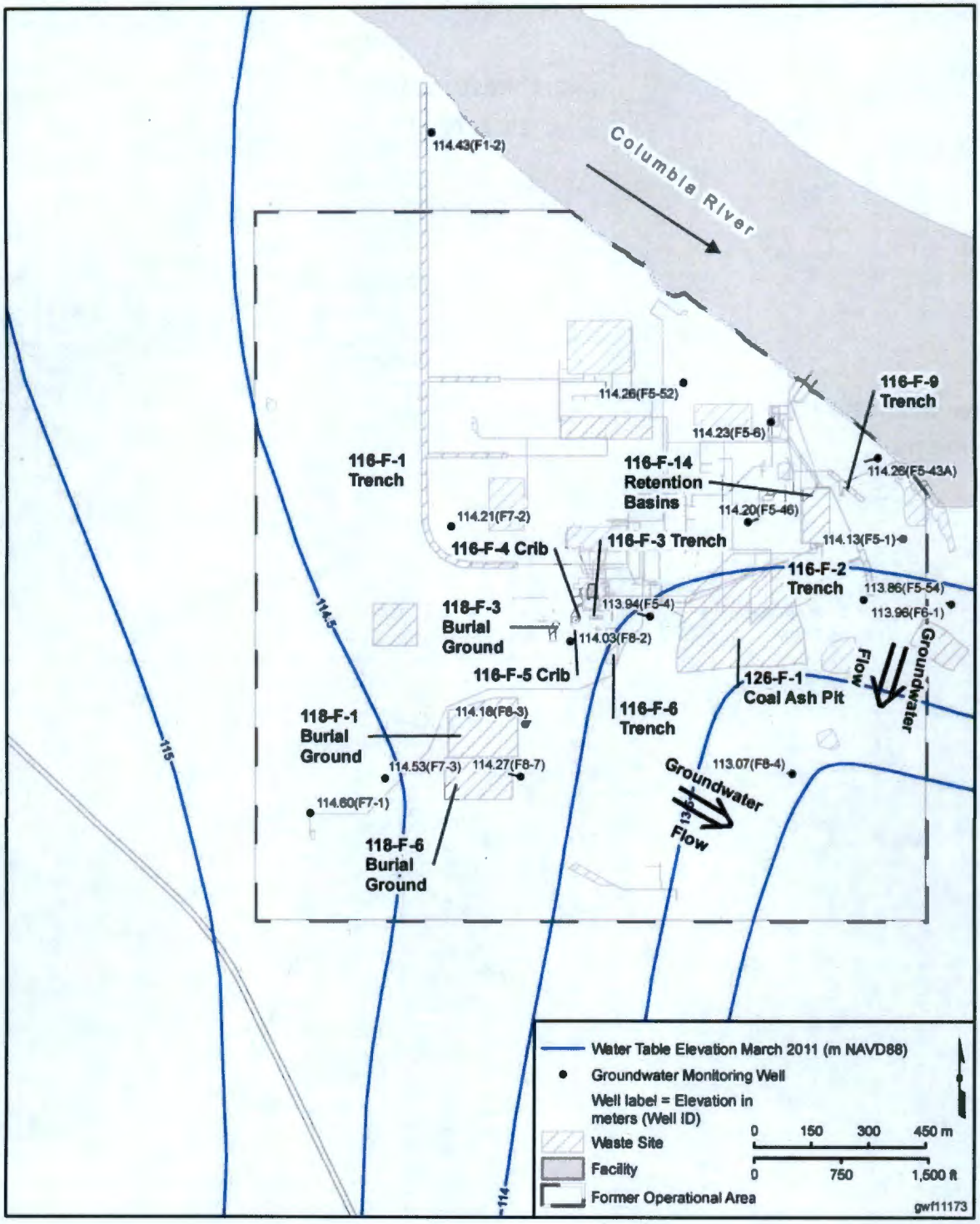

Figure 2. 100-F Water Table, March 2011

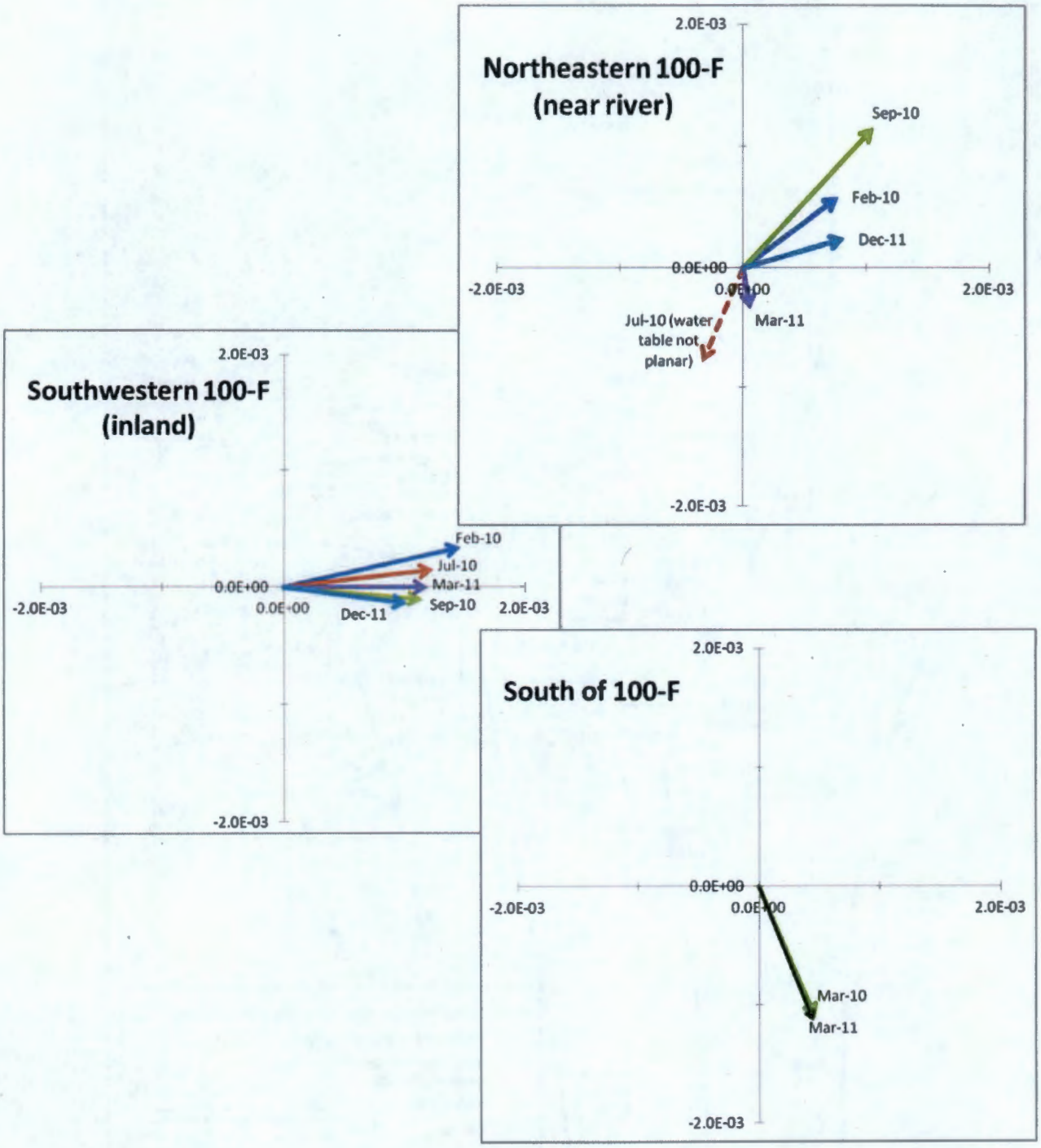

Figure 3. Magnitude and Direction of Hydraulic Gradients in 100-F Region

Appendix A

Hydraulic Gradient Calculations

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Table A.1. Hydraulic Gradient Calculations for February 2010, Northeastern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F1-2	580011.04	148805.30	113.33	2/26/2010	113.379	0.060	0.049
199-F5-1	581250.12	147736.87	113.13	2/26/2010	113.045	-0.274	-0.085
199-F5-4	580583.19	147533.73	113.61	2/26/2010	113.683	0.364	0.073
199-F5-6	580901.65	148041.99	113.15	2/26/2010	113.136	-0.183	-0.014
199-F5-43A	581183.87	147948.07	113.07	2/26/2010	112.972	-0.346	-0.098
199-F5-46	580841.34	147781.51	113.23	2/26/2010	113.336	0.018	0.106
199-F6-1	581375.87	147564.51	112.97	2/26/2010	113.049	-0.270	0.079
199-F7-2	580060.04	147770.40	114.06	2/26/2010	113.950	0.631	-0.110
					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	9.74E-04
Gradient Direction (azimuth):	52.9

Statistics

Goodness of Fit (R^2):	0.94
Correlation Coefficient (R):	0.97
Level of Significance:	0.05
P-Value:	0.0009
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	0.835593341	2	0.417796671	38.47528872	0.000919486
Deviation	0.054294157	5	0.010858831		
Total	0.889887498	7			

Intermediate Computations

# of Observations:	8
Sum of Easting:	4646207.125
Sum of Northing:	1183182.375
Sum of Easting*Northing:	6.87163E+11
Sum of Easting^2:	2.69841E+12
Sum of Northing^2:	1.74991E+11
Sum of Observed Heads:	906.55
Sum of Easting*Observed Heads:	526501361
Sum of Northing*Observed Heads:	134076677.6
Sum of Observed Heads^2:	102730.0027
Sum of Predicted Heads:	906.5500004
Sum of Predicted Heads^2:	102729.9485
SSt:	0.8898875
SSr:	0.835593341

Matrix Equation (Equation 5.86 in Davis, 2002)

8	4646207.125	1183182.375	b0	906.55
4646207.125	2.69841E+12	6.87163E+11	b1	526501361
1183182.375	6.87163E+11	1.74991E+11	b2	134076677.6

Inverse Matrix

355822.8594	-0.494354868	-0.464600197
-0.494354868	7.25747E-07	4.92628E-07
-0.464600197	4.92628E-07	1.20687E-06

Table A.1. Hydraulic Gradient Calculations for February 2010, Northeastern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	651.4567409	
b1=	-0.000776731	
b2=	-0.000588454	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	0.000776731	
b:	0.000588454	
c:	1	
Gradient Magnitude		
	0.000974469	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	Yes	52.85232294
Second Quadrant?:	No	n/a
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.2. Hydraulic Gradient Calculations for February 2010, Southwestern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F7-1	579687.17	147022.43	114.76	2/26/2010	114.968	0.853	0.208
199-F7-2	580060.04	147770.40	114.06	2/26/2010	114.163	0.047	0.103
199-F7-3	579884.71	147112.53	114.7	2/26/2010	114.646	0.530	-0.054
199-F8-2	580373.89	147468.47	113.89	2/26/2010	113.803	-0.312	-0.087
199-F8-3	580253.99	147253.37	114.19	2/26/2010	114.054	-0.062	-0.136
199-F8-7	580242.91	147116.74	114.33	2/26/2010	114.117	0.001	-0.213
199-F8-4	580958.51	147123.53	112.88	2/26/2010	113.059	-1.057	0.179
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.51E-03
Gradient Direction (azimuth):	77.0

Statistics

Goodness of Fit (R^2):	0.93
Correlation Coefficient (R):	0.97
Level of Significance:	0.05
P-Value:	0.0045
Statistically Significant Trend?:	Yes

Intermediate Computations

# of Observations:	7
Sum of Easting:	4061461.219
Sum of Northing:	1030867.472
Sum of Easting*Northing:	5.98118E+11
Sum of Easting^2:	2.3565E+12
Sum of Northing^2:	1.51813E+11
Sum of Observed Heads:	798.81
Sum of Easting*Observed Heads:	463475077.9
Sum of Northing*Observed Heads:	117638000.6
Sum of Observed Heads^2:	91159.1627
Sum of Predicted Heads:	798.8099999
Sum of Predicted Heads^2:	91159.00207
SSt:	2.388971429
SSr:	2.228360435

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	2.228360435	2	1.114180218	27.74854169	0.004519898
Deviation	0.160610994	4	0.040152749		
Total	2.388971429	6			

Matrix Equation (Equation 5.86 in Davis, 2002)

7	4061461.219	1030867.472	b0	798.81
4061461.219	2.3565E+12	5.98118E+11	b1	463475077.9
1030867.472	5.98118E+11	1.51813E+11	b2	117638000.6

Inverse Matrix

382116.3342	-0.577712304	-0.318622159
-0.577712304	1.00952E-06	-5.4452E-08
-0.318622159	-5.4452E-08	2.3781E-06

Table A.2. Hydraulic Gradient Calculations for February 2010, Southwestern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	1019.941504	
b1=	-0.001474523	
b2=	-0.000341521	
Normal Vector to the Fitted Plane (<a,b,c> where a = -b1, b = -b2, c = 1)		
a:	0.001474523	
b:	0.000341521	
c:	1	
Gradient Magnitude		
	0.001513557	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	Yes	76.95941966
Second Quadrant?:	No	n/a
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.3. Hydraulic Gradient Calculations for March 2010, Region South of 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
699-71-30	580603.35	145226.91	113.86	3/6/2010	113.754	2.430	-0.106
699-64-27	581375.457	142946.078	110.75	3/6/2010	110.843	-0.481	0.093
699-66-23	582864.757	143617.192	110.56	3/6/2010	110.902	-0.422	0.342
699-63-25A	582315.476	142798.003	110.71	3/6/2010	110.241	-1.083	-0.469
699-62-31	580302.597	142532.469	110.74	3/6/2010	110.880	-0.444	0.140
6					0.000	0.000	0.000
7					0.000	0.000	0.000
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.21E-03
Gradient Direction (azimuth):	157.4

Statistics

Goodness of Fit (R^2):	0.95
Correlation Coefficient (R):	0.98
Level of Significance:	0.05
P-Value:	0.0467
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	7.686053903	2	3.843026952	20.41632426	0.046693354
Deviation	0.376466097	2	0.188233048		
Total	8.06252	4			

Intermediate Computations

# of Observations:	5
Sum of Easting:	2907461.635
Sum of Northing:	717120.65
Sum of Easting*Northing:	4.16999E+11
Sum of Easting^2:	1.69067E+12
Sum of Northing^2:	1.02857E+11
Sum of Observed Heads:	556.62
Sum of Easting*Observed Heads:	323667212.5
Sum of Northing*Observed Heads:	79838343.16
Sum of Observed Heads^2:	61973.2274
Sum of Predicted Heads:	556.62
Sum of Predicted Heads^2:	61972.85094
SSt:	8.06252
SSr:	7.686053903

Matrix Equation (Equation 5.86 in Davis, 2002)

5	2907461.635	717120.65	b0	556.62
2907461.635	1.69067E+12	4.16999E+11	b1	323667212.5
717120.65	4.16999E+11	1.02857E+11	b2	79838343.16

Inverse Matrix

82559.68652	-0.129457127	-0.050766634
-0.129457127	2.14351E-07	3.3562E-08
-0.050766634	3.3562E-08	2.17889E-07

Table A.3. Hydraulic Gradient Calculations for March 2010, Region South of 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	221.2249559	
b1=	-0.000464945	
b2=	0.001118787	
Normal Vector to the Fitted Plane (<a,b,c> where a = -b1, b = -b2, c = 1)		
a:	0.000464945	
b:	-0.001118787	
c:	1	
Gradient Magnitude		
	0.001211552	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	Yes	157.4332235
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.4. Hydraulic Gradient Calculations for July 2010, Northeastern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F1-2	580011.04	148805.30	114.64	7/8/2010	114.507	0.111	-0.133
199-F5-1	581250.12	147736.87	114.44	7/13/2010	114.453	0.057	0.013
199-F5-4	580583.19	147533.73	113.95	7/8/2010	114.238	-0.158	0.288
199-F5-6	580901.65	148041.99	114.23	7/13/2010	114.470	0.074	0.240
199-F5-42	581285.48	147834.82	114.48	7/8/2010	114.492	0.096	0.012
199-F5-43A	581183.87	147948.07	114.39	7/8/2010	114.504	0.108	0.114
199-F5-44	581060.85	148043.20	114.3	7/8/2010	114.506	0.110	0.206
199-F5-45	580706.88	147683.92	114.53	7/8/2010	114.313	-0.083	-0.217
199-F5-46	580841.34	147781.51	114.72	7/8/2010	114.374	-0.022	-0.346
199-F5-48	580517.58	147690.10	114.23	7/8/2010	114.272	-0.124	0.042
199-F6-1	581375.87	147564.51	114.68	7/8/2010	114.427	0.032	0.253
199-F7-2	580060.04	147770.40	114.16	7/8/2010	114.193	-0.203	-0.033
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	3.88E-04
Gradient Direction (azimuth):	215.9

Statistics

Goodness of Fit (R^2):	0.24
Correlation Coefficient (R):	0.49
Level of Significance:	0.05
P-Value:	0.2848
Statistically Significant Trend?:	No

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	0.143964661	2	0.071982331	1.448896997	0.284768724
Deviation	0.447127005	9	0.049680778		
Total	0.591091667	11			

Intermediate Computations

# of Observations:	12
Sum of Easting:	6969777.909
Sum of Northing:	1774434.413
Sum of Easting*Northing:	1.03062E+12
Sum of Easting^2:	4.04815E+12
Sum of Northing^2:	2.62386E+11
Sum of Observed Heads:	1372.75
Sum of Easting*Observed Heads:	797313858.6
Sum of Northing*Observed Heads:	202988140.1
Sum of Observed Heads^2:	157037.4713
Sum of Predicted Heads:	1372.75
Sum of Predicted Heads^2:	157037.0242
SSt:	0.591091667
SSr:	0.143964661

Matrix Equation (Equation 5.86 in Davis, 2002)

12	6969777.909	1774434.413	b0	1372.75
6969777.909	4.04815E+12	1.03062E+12	b1	797313858.6
1774434.413	1.03062E+12	2.62386E+11	b2	202988140.1

Inverse Matrix

245450.1094	-0.344331569	-0.307413869
-0.344331569	5.20097E-07	2.85734E-07
-0.307413869	2.85734E-07	9.56621E-07

Table A.4. Hydraulic Gradient Calculations for July 2010, Northeastern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)

b0=	-63.93875416
b1=	0.000227086
b2=	0.00031406

Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)

a:	-0.000227086
b:	-0.00031406
c:	1

Gradient Magnitude

0.000387558

Gradient Direction

		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	No	n/a
Third Quadrant?:	Yes	215.869345
Fourth Quadrant?:	No	n/a

Table A.5. Hydraulic Gradient Calculations for July 2010, Southwestern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F7-1	579687.17	147022.43	114.71	7/8/2010	114.811	0.684	0.101
199-F7-2	580060.04	147770.40	114.16	7/8/2010	114.240	0.113	0.080
199-F7-3	579884.71	147112.53	114.54	7/8/2010	114.553	0.426	0.013
199-F8-2	580373.89	147468.47	113.99	7/13/2010	113.893	-0.235	-0.097
199-F8-3	580253.99	147253.37	114.14	7/13/2010	114.073	-0.054	-0.067
199-F8-4	580958.51	147123.53	113.09	7/8/2010	113.214	-0.913	0.124
199-F8-7	580242.91	147116.74	114.26	7/13/2010	114.106	-0.021	-0.154
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.25E-03
Gradient Direction (azimuth):	83.4

Statistics

Goodness of Fit (R^2):	0.96
Correlation Coefficient (R):	0.98
Level of Significance:	0.05
P-Value:	0.0019
Statistically Significant Trend?:	Yes

Intermediate Computations

# of Observations:	7
Sum of Easting:	4061461.219
Sum of Northing:	1030867.472
Sum of Easting*Northing:	5.98118E+11
Sum of Easting^2:	2.3565E+12
Sum of Northing^2:	1.51813E+11
Sum of Observed Heads:	798.89
Sum of Easting*Observed Heads:	463521726.9
Sum of Northing*Observed Heads:	117649870.5
Sum of Observed Heads^2:	91176.6567
Sum of Predicted Heads:	798.8899997
Sum of Predicted Heads^2:	91176.58663
SSt:	1.623542857
SSr:	1.553542655

Matrix Equation (Equation 5.86 in Davis, 2002)

7	4061461.219	1030867.472	b0	798.89
4061461.219	2.3565E+12	5.98118E+11	b1	463521726.9
1030867.472	5.98118E+11	1.51813E+11	b2	117649870.5

Inverse Matrix

382116.3342	-0.577712304	-0.318622159
-0.577712304	1.00952E-06	-5.4452E-08
-0.318622159	-5.4452E-08	2.3781E-06

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	1.553542655	2	0.776771327	44.3868039	0.001858964
Deviation	0.070000204	4	0.017500051		
Total	1.623542858	6			

Table A.5. Hydraulic Gradient Calculations for July 2010, Southwestern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	857.5081828	
b1=	-0.001244766	
b2=	-0.000143665	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	0.001244766	
b:	0.000143665	
c:	1	
Gradient Magnitude		
	0.001253029	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	Yes	83.41630729
Second Quadrant?:	No	n/a
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.6. Hydraulic Gradient Calculations for September 2010, Northeastern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F1-2	580011.04	148805.30	113	9/26/2010	112.999	-0.196	-0.001
199-F5-1	581250.12	147736.87	112.93	9/26/2010	112.914	-0.281	-0.016
199-F5-4	580583.19	147533.73	113.89	9/26/2010	113.860	0.665	-0.030
199-F5-42	581285.48	147834.82	112.83	9/26/2010	112.763	-0.432	-0.067
199-F5-43A	581183.87	147948.07	112.7	9/26/2010	112.741	-0.454	0.041
199-F5-45	580706.88	147683.92	113.49	9/26/2010	113.554	0.359	0.064
199-F5-48	580517.58	147690.10	113.77	9/26/2010	113.749	0.554	-0.021
199-F6-1	581375.87	147564.51	112.95	9/26/2010	112.979	-0.216	0.029
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.57E-03
Gradient Direction (azimuth):	42.7

Statistics

Goodness of Fit (R^2):	0.99
Correlation Coefficient (R):	1.00
Level of Significance:	0.05
P-Value:	0.0000
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	1.434483676	2	0.717241838	282.0162325	7.2374E-06
Deviation	0.012716322	5	0.002543264		
Total	1.447199998	7			

Intermediate Computations

# of Observations:	8
Sum of Easting:	4646914.03
Sum of Northing:	1182797.316
Sum of Easting*Northing:	6.87044E+11
Sum of Easting^2:	2.69923E+12
Sum of Northing^2:	1.74877E+11
Sum of Observed Heads:	905.56
Sum of Easting*Observed Heads:	526006619.3
Sum of Northing*Observed Heads:	133886252.1
Sum of Observed Heads^2:	102506.3114
Sum of Predicted Heads:	905.5600002
Sum of Predicted Heads^2:	102506.2987
SSt:	1.4472
SSr:	1.434483676

Matrix Equation (Equation 5.86 in Davis, 2002)

8	4646914.03	1182797.316	b0	905.56
4646914.03	2.69923E+12	6.87044E+11	b1	526006619.3
1182797.316	6.87044E+11	1.74877E+11	b2	133886252.1

Inverse Matrix

449925.3405	-0.631253986	-0.563087783
-0.631253986	9.24035E-07	6.39264E-07
-0.563087783	6.39264E-07	1.29701E-06

Table A.6. Hydraulic Gradient Calculations for September 2010, Northeastern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	903.1896873	
b1=	-0.001065737	
b2=	-0.001156215	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	0.001065737	
b:	0.001156215	
c:	1	
Gradient Magnitude		
	0.00157246	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	Yes	42.66820782
Second Quadrant?:	No	n/a
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.7. Hydraulic Gradient Calculations for September 2010, Southwestern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F7-1	579687.17	147022.43	114.63	9/26/2010	114.775	0.687	0.145
199-F7-3	579884.71	147112.53	114.57	9/26/2010	114.557	0.468	-0.013
199-F8-3	580253.99	147253.37	114.25	9/26/2010	114.145	0.057	-0.105
199-F8-4	580958.51	147123.53	113.21	9/26/2010	113.318	-0.770	0.108
199-F8-7	580242.91	147116.74	114.3	9/26/2010	114.144	0.055	-0.156
199-F5-4	580583.19	147533.73	113.89	9/26/2010	113.795	-0.294	-0.095
199-F5-48	580517.58	147690.10	113.77	9/26/2010	113.887	-0.202	0.117
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.16E-03
Gradient Direction (azimuth):	95.2

Statistics

Goodness of Fit (R^2):	0.94
Correlation Coefficient (R):	0.97
Level of Significance:	0.05
P-Value:	0.0037
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	1.417312373	2	0.708656186	31.09049904	0.003653031
Deviation	0.091173343	4	0.022793336		
Total	1.508485716	6			

Intermediate Computations

# of Observations:	7
Sum of Easting:	4062128.06
Sum of Northing:	1030852.432
Sum of Easting*Northing:	5.98208E+11
Sum of Easting^2:	2.35727E+12
Sum of Northing^2:	1.51808E+11
Sum of Observed Heads:	798.62
Sum of Easting*Observed Heads:	463441132
Sum of Northing*Observed Heads:	117608178.9
Sum of Observed Heads^2:	91114.9234
Sum of Predicted Heads:	798.62
Sum of Predicted Heads^2:	91114.83223
SSt:	1.508485714
SSr:	1.417312373

Matrix Equation (Equation 5.86 in Davis, 2002)

7	4062128.06	1030852.432	b0	798.62
4062128.06	2.35727E+12	5.98208E+11	b1	463441132
1030852.432	5.98208E+11	1.51808E+11	b2	117608178.9

Inverse Matrix

302332.0873	-0.527011899	0.023733961
-0.527011899	1.13443E-06	-8.91621E-07
0.023733961	-8.91621E-07	3.35231E-06

Table A.7. Hydraulic Gradient Calculations for September 2010, Southwestern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)

b0=	768.4859308
b1=	-0.001154415
b2=	0.000105349

Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)

a:	0.001154415
b:	-0.000105349
c:	1

Gradient Magnitude

0.001159212

Gradient Direction

		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	Yes	95.21421872
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.8. Hydraulic Gradient Calculations for March 2011, Northeastern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F1-2	580011.04	148805.30	114.43	3/6/2011	114.503	0.368	0.073
199-F5-1	581250.12	147736.87	114.13	3/6/2011	114.052	-0.082	-0.078
199-F5-4	580583.19	147533.73	113.94	3/6/2011	114.024	-0.111	0.084
199-F5-6	580901.65	148041.99	114.23	3/6/2011	114.181	0.046	-0.049
199-F5-46	580841.34	147781.51	114.19	3/6/2011	114.094	-0.041	-0.096
199-F5-52	580672.81	148143.82	114.26	3/6/2011	114.231	0.096	-0.029
199-F5-54	581145.51	147576.44	113.86	3/6/2011	114.003	-0.131	0.143
199-F6-1	581375.87	147564.51	113.96	3/6/2011	113.984	-0.150	0.024
199-F7-2	580060.04	147770.40	114.21	3/6/2011	114.139	0.005	-0.071
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	3.54E-04
Gradient Direction (azimuth):	169.7

Statistics

Goodness of Fit (R^2):	0.78
Correlation Coefficient (R):	0.89
Level of Significance:	0.05
P-Value:	0.01
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	0.207637745	2	0.103818872	10.93127919	0.009985982
Deviation	0.056984478	6	0.009497413		
Total	0.264622222	8			

Intermediate Computations

# of Observations:	9
Sum of Easting:	5226841.573
Sum of Northing:	1330954.565
Sum of Easting*Northing:	7.72964E+11
Sum of Easting^2:	3.03554E+12
Sum of Northing^2:	1.96828E+11
Sum of Observed Heads:	1027.21
Sum of Easting*Observed Heads:	596562211
Sum of Northing*Observed Heads:	151908274.5
Sum of Observed Heads^2:	117240.3073
Sum of Predicted Heads:	1027.210001
Sum of Predicted Heads^2:	117240.2505
SSt:	0.264622222
SSr:	0.207637745

Matrix Equation (Equation 5.86 in Davis, 2002)

9	5226841.573	1330954.565	b0	1027.21
5226841.573	3.03554E+12	7.72964E+11	b1	596562211
1330954.565	7.72964E+11	1.96828E+11	b2	151908274.5

Inverse Matrix

410539.9447	-0.572577143	-0.527507479
-0.572577143	8.32536E-07	6.02319E-07
-0.527507479	6.02319E-07	1.20165E-06

Table A.8. Hydraulic Gradient Calculations for March 2011, Northeastern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	99.2705514	
b1=	-6.31414E-05	
b2=	0.000348476	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	6.31414E-05	
b:	-0.000348476	
c:	1	
Gradient Magnitude		
	0.00035415	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	Yes	169.7298195
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.9. Hydraulic Gradient Calculations for March 2011, Southwestern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F7-1	579687.17	147022.43	114.6	3/6/2011	114.753	0.626	0.153
199-F7-2	580060.04	147770.40	114.21	3/6/2011	114.307	0.180	0.097
199-F7-3	579884.71	147112.53	114.53	3/6/2011	114.516	0.389	-0.014
199-F8-2	580373.89	147468.47	114.03	3/6/2011	113.929	-0.198	-0.101
199-F8-3	580253.99	147253.37	114.18	3/6/2011	114.073	-0.054	-0.107
199-F8-4	580958.51	147123.53	113.07	3/6/2011	113.226	-0.901	0.156
199-F8-7	580242.91	147116.74	114.27	3/6/2011	114.086	-0.041	-0.184
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.20E-03
Gradient Direction (azimuth):	90.1

Statistics

Goodness of Fit (R^2):	0.93
Correlation Coefficient (R):	0.96
Level of Significance:	0.05
P-Value:	0.0054
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	1.429919229	2	0.714959615	25.30301403	0.005365853
Deviation	0.113023629	4	0.028255907		
Total	1.542942858	6			

Intermediate Computations

# of Observations:	7
Sum of Easting:	4061461.219
Sum of Northing:	1030867.472
Sum of Easting*Northing:	5.98118E+11
Sum of Easting^2:	2.3565E+12
Sum of Northing^2:	1.51813E+11
Sum of Observed Heads:	798.89
Sum of Easting*Observed Heads:	463521773.9
Sum of Northing*Observed Heads:	117649933
Sum of Observed Heads^2:	91176.5761
Sum of Predicted Heads:	798.8899999
Sum of Predicted Heads^2:	91176.46306
SSt:	1.542942857
SSr:	1.429919229

Matrix Equation (Equation 5.86 in Davis, 2002)

7	4061461.219	1030867.472	b0	798.89
4061461.219	2.3565E+12	5.98118E+11	b1	463521773.9
1030867.472	5.98118E+11	1.51813E+11	b2	117649933

Inverse Matrix

382116.3342	-0.577712304	-0.318622159
-0.577712304	1.00952E-06	-5.4452E-08
-0.318622159	-5.4452E-08	2.3781E-06

Table A.9. Hydraulic Gradient Calculations for March 2011, Southwestern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)

b0=	810.4769808
b1=	-0.001200782
b2=	2.40476E-06

Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)

a:	0.001200782
b:	-2.40476E-06
c:	1

Gradient Magnitude

0.001200784

Gradient Direction

		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	Yes	90.11474397
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.10. Hydraulic Gradient Calculations for March 2011, Region South of 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
699-71-30	580603.35	145226.91	113.82	3/6/2011	113.820	1.957	0.000
699-64-27	581375.457	142946.078	110.88	3/6/2011	110.880	-0.983	0.000
699-62-31	580302.597	142532.469	110.89	3/6/2011	110.890	-0.973	0.000
4					0.000	0.000	0.000
5					0.000	0.000	0.000
6					0.000	0.000	0.000
7					0.000	0.000	0.000
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.22E-03
Gradient Direction (azimuth):	158.5

Statistics

Goodness of Fit (R^2):	1.00
Correlation Coefficient (R):	1.00
Level of Significance:	0.05
P-Value:	#DIV/0!
Statistically Significant Trend?:	N/A - 3 pts

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	5.742866667	2	2.871433333	#DIV/0!	#DIV/0!
Deviation	6.98224E-16	0	#DIV/0!		
Total	5.742866667	2			

Intermediate Computations

# of Observations:	3
Sum of Easting:	1742281.402
Sum of Northing:	430705.455
Sum of Easting*Northing:	2.50137E+11
Sum of Easting^2:	1.01185E+12
Sum of Northing^2:	61839940742
Sum of Observed Heads:	335.59
Sum of Easting*Observed Heads:	194896938.7
Sum of Northing*Observed Heads:	48185013.28
Sum of Observed Heads^2:	37545.9589
Sum of Predicted Heads:	335.59
Sum of Predicted Heads^2:	37545.95891
SSt:	5.742866667
SSr:	5.742866667

Matrix Equation (Equation 5.86 in Davis, 2002)

3	1742281.402	430705.455	b0	335.59
1742281.402	1.01185E+12	2.50137E+11	b1	194896938.7
430705.455	2.50137E+11	61839940742	b2	48185013.28

Inverse Matrix

572786.3801	-0.968236057	-0.072946522
-0.968236057	1.65081E-06	6.6244E-08
-0.072946522	6.6244E-08	2.40127E-07

Table A.10. Hydraulic Gradient Calculations for March 2011, Region South of 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	208.6404353	
b1=	-0.000447815	
b2=	0.00113741	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	0.000447815	
b:	-0.00113741	
c:	1	
Gradient Magnitude		
	0.001222391	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	Yes	158.5097039
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.11. Hydraulic Gradient Calculations for December 2011, Northeastern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F5-1	581250.12	147736.87	113.55	12/7/2011	113.470	-0.379	-0.080
199-F5-6	580901.65	148041.99	113.65	12/7/2011	113.684	-0.164	0.034
199-F5-44	581060.85	148043.20	113.80	12/7/2011	113.552	-0.297	-0.248
199-F5-46	580841.34	147781.51	113.66	12/7/2011	113.798	-0.051	0.138
199-F5-47	580495.51	147508.45	114.28	12/7/2011	114.152	0.303	-0.128
199-F5-48	580517.58	147690.10	114.00	12/7/2011	114.089	0.240	0.089
199-F5-52	580672.81	148143.82	113.71	12/6/2011	113.850	0.001	0.140
199-F5-54	581145.51	147576.44	113.47	12/15/2011	113.596	-0.253	0.126
199-F7-2	580060.04	147770.40	114.52	12/6/2011	114.449	0.601	-0.071
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	8.65E-04
Gradient Direction (azimuth):	73.6

Statistics

Goodness of Fit (R^2):	0.85
Correlation Coefficient (R):	0.92
Level of Significance:	0.05
P-Value:	0.0037
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	0.836039782	2	0.418019891	16.40912022	0.003692719
Deviation	0.152849105	6	0.025474851		
Total	0.988888888	8			

Intermediate Computations

# of Observations:	9
Sum of Easting:	5226945.407
Sum of Northing:	1330292.77
Sum of Easting*Northing:	7.72596E+11
Sum of Easting^2:	3.03566E+12
Sum of Northing^2:	1.96631E+11
Sum of Observed Heads:	1024.64
Sum of Easting*Observed Heads:	595080967.8
Sum of Northing*Observed Heads:	151452190.9
Sum of Observed Heads^2:	116655.1144
Sum of Predicted Heads:	1024.64
Sum of Predicted Heads^2:	116654.9616
SSt:	0.988888889
SSr:	0.836039782

Matrix Equation (Equation 5.86 in Davis, 2002)

9	5226945.407	1330292.77	b0	1024.64
5226945.407	3.03566E+12	7.72596E+11	b1	595080967.8
1330292.77	7.72596E+11	1.96631E+11	b2	151452190.9

Inverse Matrix

327454.7161	-0.49333732	-0.27696475
-0.49333732	8.97979E-07	-1.90674E-07
-0.27696475	-1.90674E-07	2.62298E-06

Table A.11. Hydraulic Gradient Calculations for December 2011, Northeastern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	632.1188551	
b1=	-0.0008302	
b2=	-0.00024432	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	0.0008302	
b:	0.00024432	
c:	1	
Gradient Magnitude		
	0.000865405	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	Yes	73.60132523
Second Quadrant?:	No	n/a
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a

Table A.12. Hydraulic Gradient Calculations for December 2011, Southwestern 100-F (2 sheets)

Trend Surface Analysis of Hydraulic Gradient
(Least Squares Regression of a Plane to Points in 3-D Space)
Reference: Davis, J. C. 2002. Statistics and Data Analysis in Geology, John Wiley & Sons
Prepared by JP McDonald

Input Data					Computed Data		
Well Name	Easting (x-coord)	Northing (y-coord)	Observed Hydraulic Head (z-coord)	Date	Predicted Hydraulic Head	Predicted Diff from Mean	Residuals (Observed - Predicted)
199-F5-47	580495.51	147508.45	114.28	12/7/2011	114.164	-0.243	-0.116
199-F7-1	579687.17	147022.43	114.77	12/7/2011	114.925	0.518	0.155
199-F7-2	580060.04	147770.40	114.52	12/6/2011	114.648	0.241	0.128
199-F7-3	579884.71	147112.53	114.74	12/6/2011	114.735	0.328	-0.005
199-F8-3	580253.99	147253.37	114.56	12/6/2011	114.376	-0.031	-0.184
199-F8-4	580958.51	147123.53	113.44	12/7/2011	113.634	-0.773	0.194
199-F8-7	580242.91	147116.74	114.54	12/6/2011	114.368	-0.039	-0.172
8					0.000	0.000	0.000
9					0.000	0.000	0.000
10					0.000	0.000	0.000
11					0.000	0.000	0.000
12					0.000	0.000	0.000
13					0.000	0.000	0.000
14					0.000	0.000	0.000
15					0.000	0.000	0.000
16					0.000	0.000	0.000
17					0.000	0.000	0.000
18					0.000	0.000	0.000
19					0.000	0.000	0.000
20					0.000	0.000	0.000

Hydraulic Gradient

Gradient Magnitude:	1.04E-03
Gradient Direction (azimuth):	97.9

Statistics

Goodness of Fit (R^2):	0.88
Correlation Coefficient (R):	0.94
Level of Significance:	0.05
P-Value:	0.0155
Statistically Significant Trend?:	Yes

ANOVA

Var Source	Sum of Squares	Df	Mean Squares	F-Test	P-Value
Regression	1.092547235	2	0.546273617	14.07961401	0.015470657
Deviation	0.155195623	4	0.038798906		
Total	1.247742858	6			

Intermediate Computations

# of Observations:	7
Sum of Easting:	4061582.841
Sum of Northing:	1030907.453
Sum of Easting*Northing:	5.98159E+11
Sum of Easting^2:	2.35664E+12
Sum of Northing^2:	1.51825E+11
Sum of Observed Heads:	800.85
Sum of Easting*Observed Heads:	464673024.3
Sum of Northing*Observed Heads:	117943178.9
Sum of Observed Heads^2:	91624.2081
Sum of Predicted Heads:	800.8499998
Sum of Predicted Heads^2:	91624.05286
SSt:	1.247742857
SSr:	1.092547235

Matrix Equation (Equation 5.86 in Davis, 2002)

7	4061582.841	1030907.453	b0	800.85
4061582.841	2.35664E+12	5.98159E+11	b1	464673024.3
1030907.453	5.98159E+11	1.51825E+11	b2	117943178.9

Inverse Matrix

352683.6498	-0.540752024	-0.264306369
-0.540752024	9.64347E-07	-1.27568E-07
-0.264306369	-1.27568E-07	2.29727E-06

Table A.12. Hydraulic Gradient Calculations for December 2011, Southwestern 100-F (2 sheets)

Coefficients of the Fitted Plane (z = b0 + b1x + b2y)		
b0=	689.0837798	
b1=	-0.00102644	
b2=	0.00014185	
Normal Vector to the Fitted Plane (<a,b,c> w here a = -b1, b = -b2, c = 1)		
a:	0.00102644	
b:	-0.00014185	
c:	1	
Gradient Magnitude		
	0.001036195	
Gradient Direction		
		Azimuth:
Horizontal Plane?:	No	n/a
Due North?:	No	n/a
Due East?:	No	n/a
Due South?:	No	n/a
Due West?:	No	n/a
First Quadrant?:	No	n/a
Second Quadrant?:	Yes	97.86823526
Third Quadrant?:	No	n/a
Fourth Quadrant?:	No	n/a