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Revision 0

HYDRAULIC GRADIENT AND VELOCITY CALCULATIONS FOR RCRA SITES IN 2017

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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Richland, Washington 99352

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APPROVED
By Julia Raymer at 2:00 pm, Feb 15, 2018

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Terms

AWLN	automated water-level network
LLWMA	low-level waste management area
NRDWL	Nonradioactive Dangerous Waste Landfill
P&T	pump and treat
PUREX	Plutonium-Uranium Extraction Plant
RCRA	*Resource Conservation and Recovery Act of 1976*
WMA	waste management area

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1 Purpose

The purpose of this environmental calculation is to estimate hydraulic gradients and groundwater flow velocities at Hanford Site *Resource Conservation and Recovery Act of 1976*, (RCRA) facilities in 2017.

2 Methodology

Gradients were determined via three methods:

1. Conventional method: trend-surface analysis of measured data
2. Low-gradient method: trend-surface analysis of a digital grid for the region of 200 East Area where the gradient is too low for conventional analysis
3. Map estimates: estimated magnitude and direction from March 2017 water-table map for regions where the water table is not planar

Methods of trend-surface analysis, digital gridding, and statistical testing were described in ECF-Hanford-16-0013, *Hydraulic Gradients and Velocity Calculations for RCRA Sites in 2015,* and will not be repeated here. Methods of correcting water-level data for barometric effects and borehole deviation from vertical are described in SGW-54165, *Evaluation of the Unconfined Aquifer Hydraulic Gradient Beneath the 200 East Area, Hanford Site.*

2.1 Conventional Method

Water-level data were analyzed by trend-surface analysis calculations in a Microsoft Excel 2013®[1] spreadsheet using a method 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 planes were valid for determining the hydraulic gradient, statistical tests were used to evaluate the goodness of fit of the planes to the water-level data.

2.2 Low-Gradient Method

The water table in the 200 East Area is very flat (i.e., a low hydraulic gradient magnitude), and water-level measurements typically exhibit a variability that is larger than the local change in the water table elevation (i.e., a low signal to noise ratio). Thus, it is difficult to use water-level measurements in the local vicinity of a 200 East Area RCRA site to determine the gradient. Groundwater flow directions in the 200 East Area were determined by preparing a digital grid of the water table across most of the 200 East Area based on average water-level measurements[2]. The grid nodes from the local area around a RCRA site were then extracted from the larger grid and a trend surface was fitted to the grid node values to determine the gradient.

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

[2] Method described in SGW-58828, *Water Table Maps for the Hanford Site 200 East Area, 2013 and 2014*

2.3 Map Estimates

In several locations where the water table is perturbed by groundwater extraction and injection, a planar surface cannot be fitted to the data. The direction of groundwater flow was estimated from the March 2017 water table map, as documented in ECF-Hanford-17-0120, *Preparation of the March 2017 Hanford Site Water Table and Potentiometric Surface Maps*. The magnitude of the gradient was estimated from the spacing of the contours, or from measured water levels, if well locations allowed.

3 Assumptions and Inputs

For the conventional calculations, water-level data were retrieved from the "Environmental Monitoring" module of the Hanford Site's Virtual Library for wells screened across the water table near RCRA waste management area (WMAs). Calculations were performed for March 2017 and, in many cases, for additional time periods. For 183-H Basins, automated water-level network (AWLN) data were used in lieu of manual measurements for June 2017.

Well coordinates (northing and easting) were retrieved from the Hanford Site "Environmental Dashboard Application" (https://ehs.hanford.gov/eda/), rounded to the nearest hundredth of a meter. The data are provided in the electronic spreadsheet files that accompany this calculation.

For the 200 East Area sites analyzed by the low-gradient method, the digital grid was based on annual average water-level elevations for October 2016 through September 2017 (to be documented in an upcoming environmental calculation). This time period is used to represent 2017 conditions because the last quarter of 2017 data were not ready for analysis at the time of this calculation. Gradients based on this digital grid are referred to herein as 2017 gradients.

The hydraulic gradient calculation assumes that the water table is planar. This is of course a simplification, because water table contours form a varied "topography." Thus, the hydraulic gradient calculation provides an average result.

As applied here, the Darcy equation assumes that flow is horizontal (vertical gradients are insignificant) and the aquifer is homogeneous. Table 1 lists hydraulic parameters and their sources.

4 Software Applications

A Microsoft Excel 2013® spreadsheet was used to perform calculations described in Section 2, using the default calculation formulae available in that software. The hydraulic gradient spreadsheet previously was validated by comparison of results with a commercial software (personal communication, e-mail from Dennis Weier, Pacific Northwest National laboratory, to John McDonald, Fluor Hanford, Inc., "Spreadsheet verification," April 7, 2008).

5 Calculations

Table 1 of ECF-Hanford-16-0013 illustrates the Excel spreadsheet and its formulae. The same formulae were used for the 2017 calculations, and they are included in the electronic spreadsheet that accompany this calculation.

6 Results

Table 1 and the following paragraphs summarize results of the hydraulic gradient and velocity calculations.

Table 1. Results of Gradient and Velocity Calculations

WMA	Method	Date (2017)	v min (m/d)	v max (m/d)	Gradient (m/m)	Direction (degrees east of north)	Goodness of Fit (R^2)	Correlation Coefficient (R):	P-Value	Hydrologic Properties (references)	Comments
1301-N	Conven -tional	March	0.014	0.26	7.0E-04	350	0.96	0.98	0.036	K = 6.1 to 37 m/d (PNL-8335); n_e = 0.10 to 0.30	
		Sept.	0.048	0.87	2.4E-03	325	0.97	0.99	0.027		
1324-N/NA	Conven -tional	March	0.015	0.28	7.5E-04	36	0.97	0.99	0.029	K = 6.1 to 37 m/d (PNL-8335); n_e = 0.10 to 0.30	Influenced by 100-K injection wells.
		Sept.	0.016	0.29	7.8E-04	305	0.98	0.99	0.017		
1325-N	Conven -tional	March	0.013	0.24	6.6E-04	357	0.98	0.99	0.000	K = 6.1 to 37 m/d (PNL-8335); n_e = 0.10 to 0.30	
		October	0.036	0.65	1.8E-03	13	0.89	0.94	0.012		
183-H	Conven -tional	March	0.097	2.7	1.9E-03	236	0.83	0.91	0.072	K = 15 to 140 m/d (PNL-6728); n_e = 0.10 to 0.30	Influenced by P&T extraction and injection wells
		June AWLN	0.18	5.1	3.6E-03	225	0.91	0.95	0.029		
		October	0.15	4.1	2.9E-03	64	0.87	0.93	0.016		
216-A-29	Low gradient	FY 2017	0.34	0.34	4.0E-06	258	0.98	0.99	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
216-A-36B	Low gradient	FY 2017	0.0001	0.0001	3.4E-06	110	0.97	0.98	0.000	K = 3.26; n_e = 0.1 (assumed)	
216-A-37-1	Low gradient	FY 2017	0.38	0.38	4.4E-06	247	0.99	0.99	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
216-B-3 Ringold	3-point plane	March	0.068	0.068	1.4E-03	227	N/A	N/A	N/A	K = 5 m/d; n_e = 0.1 (CP-57037)	Data from 3 wells screened in confined Ringold

Table 1. Results of Gradient and Velocity Calculations

WMA	Method	Date (2017)	v min (m/d)	v max (m/d)	Gradient (m/m)	Direction (degrees east of north)	Goodness of Fit (R^2)	Correlation Coefficient (R):	P-Value	Hydrologic Properties (references)	Comments
216-B-3 Hanford	Low gradient	FY 2017	0.34	0.34	4.0E-06	258	0.98	0.99	0.000	K = 17,000; n_e = 0.2 (CP-57037)	Gradient assumes same as 216-A-29 Ditch
216-B-63	Low gradient	FY 2017	0.73	0.73	8.5E-06	125	1.00	1.00	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
216-S-10	Conven -tional	March	0.14	0.14	2.8E-03	101	0.99	1.00	0.008	K = 5 m/d; n_e = 0.1 (CP-47631)	
300 APT	Conven -tional	Feb.	17	17	3.2E-04	178	0.98	0.99	0.000	K = 9,000 m/d; n_e = 0.17 (PNL-17708)	
IDF	Low gradient	FY 2017	0.0001	1.1	6.6E-06	98	0.99	0.99	0.000	K = 3.26 to 17,000; n_e = 0.01 to 0.2 (CP-57037)	Aquifer includes both Ringold and Hanford
LERF	Conven -tional	CY 2017	0.12	0.12	3.0E-04	182	0.97	0.99	0.11	K = 39.5 m/d (DOE/RL-2013-46); n_e =0.1 (assumed)	Average results from monthly gradient calculations, excluding January, April, and August.
LLWMA-1	Low gradient	FY 2017	0.65	0.65	7.6E-06	138	0.99	1.00	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
LLWMA-2 East	Low gradient	FY 2017	0.064	0.29	8.5E-06	125	1.00	1.00	0.000	K = 1,500 m/d east (PNL-6820) and 17,000 m/d west	

Table 1. Results of Gradient and Velocity Calculations

WMA	Method	Date (2017)	v min (m/d)	v max (m/d)	Gradient (m/m)	Direction (degrees east of north)	Goodness of Fit (R^2)	Correlation Coefficient (R):	P-Value	Hydrologic Properties (references)	Comments
										(CP-57037); n_e = 0.2 (CP-57037)	
LLWMA-2 West	Low gradient	FY 2017	0.73	0.73	8.5E-06	125	1.00	1.00	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
LLWMA-3 North	Map estimate	March	0.21	0.21	4.2E-03	East	N/A	N/A	N/A	K = 5 m/d; n_e = 0.1 (CP-47631)	Gradient estimated from water table contours
LLWMA-3 South	Map estimate	March	0.036	0.036	7.3E-04	East	N/A	N/A	N/A		Gradient magnitude calculated between wells 299-W9-2 and 299-W10-29
LLWMA-4	Map estimate	March	0.57	0.57	1.2E-02	East	N/A	N/A	N/A	K = 5 m/d; n_e = 0.1 (CP-47631)	Gradient estimated from water table contours
NRDWL	Conven -tional	March	0.014	0.014	2.5E-05	110	0.84	0.91	0.000	K = 109 m/d; n_e = 0.2 (CP-57037)	
WMA A-AX	Low gradient	FY 2017	0.12	0.12	1.4E-06	207	0.83	0.91	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
WMA B-BX-BY	Low gradient	FY 2017	0.59	0.66	7.0E-06	127	1.00	1.00	0.000	K = 17,000 to 18,800 m/d; n_e = 0.2 (CP-57037, DOE/RL-2015-75)	

Table 1. Results of Gradient and Velocity Calculations

WMA	Method	Date (2017)	v min (m/d)	v max (m/d)	Gradient (m/m)	Direction (degrees east of north)	Goodness of Fit (R^2)	Correlation Coefficient (R):	P-Value	Hydrologic Properties (references)	Comments
WMA C	Low gradient	FY 2017	0.41	0.41	4.9E-06	142	0.95	0.98	0.000	K = 17,000; n_e = 0.2 (CP-57037)	
WMA S-SX	Conven -tional	March	0.15	0.15	3.0E-03	91	0.89	0.94	0.000	K = 5 m/d; n_e = 0.1 (CP-47631)	
WMA T	Conven -tional	March	0.34	0.34	6.7E-03	110	0.97	0.98	0.000	K = 5 m/d; n_e = 0.1 (CP-47631)	P&T extraction well east of WMA.
WMA TX-TY (north)	Map estimate	March	0.19	0.34	6.8E-03	South-east	N/A	N/A	N/A	K = 5 m/d; n_e = 0.1 (CP-47631)	Directions and gradient estimated from water table contours.
WMA TX-TY (south)		March	0.20	0.35	7.1E-03	East-northeast					
WMA U	Conven -tional	March	0.35	0.35	7.1E-03	82	0.98	0.99	0.000	K = 5 m/d; n_e = 0.1 (CP-47631)	

Sources:

CP-47631, *Model Package Report: Central Plateau Groundwater Model Version 8.3.4.*

CP-57037, *Model Package Report: Plateau to River Groundwater Transport Model Version 7.1.*

DOE/RL-2013-46, *Groundwater Monitoring Plan for the Liquid Effluent Retention Facility.*

DOE/RL-2015-75, *Aquifer Treatability Test Report for the 200-BP-5 Groundwater Operable Unit.*

PNL-6728, *Geohydrologic Characterization of the Area Surrounding the 183-H Solar Evaporation Basins.*

PNL-6820, *Hydrogeology of 200 Area Low-Level Burial Grounds—An Interim Report.*

PNL-8335, *Application of Three Aquifer Test Methods for Estimating Hydraulic Properties within 100-N Area.*

PNNL-17708, *Three-Dimensional Groundwater Models of the 300 Area at the Hanford Site, Washington State.*

Table 1. Results of Gradient and Velocity Calculations

WMA	Method	Date (2017)	v min (m/d)	v max (m/d)	Gradient (m/m)	Direction (degrees east of north)	Goodness of Fit (R^2)	Correlation Coefficient (R):	P-Value	Hydrologic Properties (references)	Comments

Notes: FY 2017 - average of monthly results for fiscal year 2017 (October 2016 through September 2017).

Conventional method - trend-surface analysis of measured water levels.

Low gradient method - estimated using a digital grid.

Map estimate - from March 2017 water table map (ECF-Hanford-17-0120).

AWLN = automated water-level network

IDF = integrated disposal facility

K = horizontal hydraulic conductivity

LERF = Liquid Effluent Retention Facility

LLWMA = low-level waste management area

N/A = not applicable

n_e = effective porosity

P&T = pump and treat

v = average linear velocity

WMA = waste management area

6.1 1301-N Liquid Waste Disposal Facility

This facility is located near the Columbia River in 100-N Area. In March 2017 the gradient dipped to the north (azimuth 350°) at 7.0×10^{-4} m/m. Statistical tests indicated a good fit. Estimated groundwater flow rates ranged from 0.014 to 0.26 m/d.

In September 2017, when the river stage was low, the gradient dipped to the northwest (azimuth 325 °) at 2.4×10^{-3} m/m. Statistical tests indicated a good fit. Estimated groundwater flow rates ranged from 0.048 to 0.87 m/d.

6.2 1324-N Surface Impoundment and 1324-NA Percolation Pond

The 1324-N Surface Impoundment and 1324-NA Percolation Pond (1324-N/NA Facilities) are located in southern 100-N Area. The KX pump and treat (P&T) system includes injection wells located 200 to 300 meters west and south of 1324-N/NA. No water-level data are available between these injection wells and the 1324-N/NA monitoring network, and it is likely that the water table beneath 1324-N/NA is not truly planar. Thus the gradient estimated by trend surface analysis has more uncertainty here than at other locations.

The gradient estimates used data from the four shallow wells in the 1324-N/NA monitoring network plus well 199-N-57, located north of the site.

The gradient in March 2017 was 7.5×10^{-4} m/m dipping toward the northeast (azimuth 36°). Statistical parameters show a good fit and acceptably low P value. Estimated groundwater flow rates ranged from 0.015 to 0.28 m/d.

Based on September 2017 water-level data, the gradient was 7.8×10^{-4} m/m, and dipping toward the northwest (azimuth 305°). Statistical parameters show a good fit and acceptably low P value. Estimated groundwater flow rates ranged from 0.016 to 0.29 m/d.

6.3 1325-N Liquid Waste Disposal Facility

This facility is located in the 100-N Area and is farther from the river than the 1301-N facility. The data set includes the five wells in the RCRA network plus three nearby wells. The gradient in March 2017 was 6.6×10^{-4} m/m dipping to the north (azimuth 357°). Statistical tests indicated a good fit. Estimated groundwater flow rates ranged from 0.013 to 0.24 m/d.

The September 2017 data set yielded a gradient dipping to the northeast, which was atypical and probably not realistic. October 2017 data indicated a gradient of 1.8×10^{-3} m/m, dipping to the north-northeast (13°). Statistical tests indicated a good fit. Estimated groundwater flow rates ranged from 0.036 to 0.65 m/d.

6.4 183-H Basins

This unit is located in 100-H Area. The natural direction of groundwater flow is toward the east (toward the Columbia River), but the HX P&T system affects groundwater flow in this region with extraction wells located north and east of 183-H, and injection wells located to the west.

In March 2017 (moderate river stage), however, the gradient dipped to the southwest (236°) with a magnitude 1.9×10^{-3} m/m. Statistical tests indicated a reasonable fit, but the P value was greater than the 0.05 level of significance. Estimated groundwater flow rates ranged from 0.097 to 2.7 m/d.

In June (high river stage), data from the automated water-level network were used in lieu of manual measurements. The gradient dipped to the southwest (225° azimuth) at 3.6×10^{-3} m/m. Statistical tests indicated a good fit. Estimated flow rates ranged from 0.18 to 5.1 m/d.

In October 2017 (low river stage), the gradient was 2.9×10^{-3} m/m to the east-northeast (64°). Statistical tests indicated a good fit. Estimated flow rates ranged from 0.15 to 4.1 m/d.

6.5 216-A-29 Ditch

This unit is located east of the 200 East Area. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid and performing a trend surface analysis, as described in Sections 2 and 3. The calculated gradient magnitude was 4.0×10^{-6} m/m, sloping to the west-southwest (258°). The estimated groundwater flow rate was 0.34 m/d.

6.6 216-A-36B Crib

This crib is located in the southeast part of the 200 East Area south of the Plutonium-Uranium Extraction (PUREX) Plant. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient was 3.4×10^{-6} m/m, dipping to the east-southeast (110°). The estimated groundwater flow rate was 0.0001 m/d.

6.7 216-A-37-1 Crib

This crib is located east of the southern part of the 200 East Area. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient magnitude was 4.4×10^{-6} m/m, with a direction of west-southwest (247°). The estimated groundwater flow rate was to 0.38 m/d.

6.8 216-B-3 Pond

This pond is located east of the 200 East Area. The uppermost aquifer in part of this area is the unconfined Hanford formation. Where Ringold Formation mud units are above the regional water table, the uppermost aquifer is a semiconfined unit in the Ringold Formation.

The hydraulic gradient in the Ringold confined aquifer was determined using March 2017 water-level measurements from three wells. The gradient was 1.4×10^{-3} m/m, dipping to the southwest (227°). The estimated groundwater flow rate is 0.068 m/d.

In the unconfined aquifer, the gradient is assumed to be the same as for the 216-A-29 Ditch (Section 6.5), and the estimated flow rate is 0.34 m/d.

6.9 216-B-63 Trench

This facility is located in the northern part of the 200 East Area and is adjacent to low-level waste management area (LLWMA)-2. The hydraulic gradient was determined jointly for this site and the adjacent LLWMA-2 by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The average gradient was 8.5×10^{-6} m/m dipping to the southeast (125°). The groundwater flow rate was estimated to be 0.73 m/d.

6.10 216-S-10 Pond and Ditch

This unit is located in southern 200 West Area. The March 2017 hydraulic gradient was 2.8×10^{-3} m/m dipping to the east (101°). Statistical indicators showed a good fit. Groundwater flow rate was 0.14 m/d.

6.11 300 Area Process Trenches

This unit is located near the Columbia River in the 300 Area. Water levels were measured on February 27, 2017 and the gradient dipped to the south (178° azimuth), with a magnitude of 3.2×10^{-4} m/m. Statistical indicators showed a good fit. Groundwater flow velocity was estimated at 17 m/d.

A planar surface could not be fitted to data from June 2017 (high river stage).

6.12 Integrated Disposal Facility

This facility is located in the southeast part of the 200 East Area. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient magnitude was 6.6×10^{-6} m/m, with a direction of east (98°). The estimated groundwater flow rate was between 0.0001 and 1.1 m/d.

6.13 Liquid Effluent Retention Facility

This facility is located just outside the northeast corner of the 200 East Area. Due to the low gradient magnitude in this area, all wells used have been resurveyed for casing elevation and have had gyroscope surveys performed to control for deviation error.

Hydraulic gradients were calculated from monthly data sets from January to November 2017, and the azimuths and magnitudes were averaged for the year. April and August data did not result in good fits and were excluded from the annual average. The January results also were excluded because the gradient was nearly an order of magnitude higher than the other results. The average hydraulic gradient was 3.0×10^{-4} m/m toward the south (182 degrees) and the estimated groundwater flow rate is 0.12 m/d.

6.14 Low-Level Waste Management Area (LLWMA) 1

This unit is located in the northwest corner of the 200 East Area. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient was 7.6×10^{-6} m/m dipping to the southeast (138°). The groundwater flow rate was estimated to be 0.65 m/d.

6.15 LLMWA 2

This unit is located in the northern part of the 200 East Area and is adjacent to the 216-B-63 Trench. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient was 8.5 × 10-6 m/m dipping to the southeast (125°). The hydraulic conductivity in the eastern part of the LLWMA is lower than in the western part. Estimates of groundwater flow rates ranged from 0.064 in the east to 0.73 m/d in the west.

6.16 LLWMA 3

This unit is located in the northern 200 West Area. Two injection wells for the 200 West P&T system are located within the boundaries of LLMWA-3 and the water table cannot be approximated by a single plane. The March 2017 water table map[3] indicates groundwater flows generally to the east. The gradient magnitude was estimated to be 4.2×10^{-3} m/m in the northern part of LLWMA-3, based on the water-table contours. In the southern part of LLWMA-3 near trenches 31 and 34, the gradient between wells

[3] The March 2017 water table map was constructed using manual water-level measurements and a computer simulation of groundwater injection and extraction, as described in ECF-Hanford-17-0120.

299-W9-2 and 299-W10-29 was 7.3×10^{-4} m/m. The groundwater velocity was estimated to range from 0.036 in the south to 0.21 m/d in the north.

6.17 LLWMA 4

This unit is located in southwestern 200 West Area where the natural direction of groundwater flow is to the east. Injection wells for the 200 West P&T system are located west of LLWMA-4, creating a groundwater mound. There are no monitoring wells between the injection wells and the downgradient wells, so water-level data alone cannot be used to estimate the hydraulic gradient. Based on the March 2017 water-table map[3], groundwater flows primarily to the east. The gradient was estimated to be 1.2×10^{-2} m/m and the flow rate was 0.57 m/d.

6.18 Nonradioactive Dangerous Waste Landfill

This landfill is located southeast of the 200 East Area. Due to the low gradient magnitude in this area, all wells used have been resurveyed for casing elevation and have had gyroscope surveys performed to control for deviation error. The calculated average gradient for March 2017 was 2.5×10^{-5} m/m, dipping to the east-southeast (110°). Statistical tests indicated a good fit. The estimated groundwater flow rate was 0.014 m/d.

6.19 Waste Management Area (WMA) A-AX

These tank farms are located in the eastern part of the 200 East Area south of WMA C. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient was 1.4×10^{-6} m/m, dipping to the south-southwest (207°). The groundwater flow rate was estimated to be 0.12 m/d.

6.20 WMA B-BX-BY

These tank farms are located in the northwestern part of the 200 East Area east of LLWMA-1. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient was 7.0×10^{-6} m/m, dipping to the southeast (127°). The groundwater flow rate was estimated at between 0.59 and 0.66 m/d.

6.21 WMA C

This tank farm is located in the eastern part of the 200 East Area north of WMA A-AX. The hydraulic gradient was determined by extracting head values from the 200 East Area water table digital grid as described in Sections 2 and 3. The calculated gradient was 4.9×10^{-6} m/m dipping to the southeast (142°). The groundwater flow rate was estimated to be 0.41 m/d.

6.22 WMA S-SX

These tank farms are located in the southern 200 West Area. Two P&T extraction wells operate immediately east of the WMA, but they appear to have only a minor effect on the water table. In March 2017 the gradient magnitude was 3.0×10^{-3} m/m, dipping toward the east (91°). To improve the fit, the wells with the largest residuals were removed from the data set. Groundwater flow velocity was estimated to be 0.15 m/d.

6.23 WMA T

This tank farm is located in northern 200 West Area. An extraction well for the 200 West P&T is located east of the site, affecting the water table locally. Using March 2017 data, the gradient was 6.7×10^{-3} m/m dipping toward the east-southeast (110°). Statistical indicators showed a good fit. The estimated groundwater velocity was 0.34 m/d.

6.24 WMA TX-TY

These tank farms are located in central 200 West Area. 200 West P&T system extraction wells are located on the east and west sides of the WMA. Consequently, a plane could not be fit to the data. Instead, flow directions and gradient magnitude were estimated from the water table contours[3]. In the northern part of the WMA the flow direction in March 2017 was to the southeast with a gradient of 6.8×10^{-3} m/m. In the southern part of the WMA the flow direction was to the east-northeast with a gradient of 7.1×10^{-3} m/m. Estimated flow rates ranged from 0.19 to 0.35 m/d.

6.25 WMA U

The tank farm is located in southern 200 West Area. The March 2017 gradient magnitude was 7.1×10^{-3} m/m dipping to the east (82°). Statistical tests indicate a good fit. Groundwater velocity was estimated at 0.35 m/d.

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