Review for the 2016 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model

February, 2018

Acronyms

BC	Bayou Creek
LBC	Little Bayou Creek
DOE	U.S. Department of Energy
KRCEE	Kentucky Research Consortium for Energy and Environment
PGDP	Paducah Gaseous Diffusion Plant
RGA	Regional Gravel Aquifer
UCRS	Upper Continental Recharge System

Contents

Introduction

In 2011, the Kentucky Research Consortium for Energy and Environment (KRCEE) conducted a review for the 2008 Sitewide Groundwater Model for the Paducah Gaseous Diffusion Plant (PGDP) (KRCEE, 2011). The 2008 model was subsequently updated twice: once in 2012 and then in 2016. This report summarizes an independent review for the 2016 update. Material available to the reviewer for the 2016 update consisted mainly of two parts. One was the 2016 update report (DOE, 2017) and the other was the model files of the calibrated version of the 2016 update. The model files included input and output files, as well as a graphic interface file (Groundwater Vistas .GV). The 2008 model report (DOE, 2010) was also used to compare with the 2016 update.

The 2008 model simulated groundwater flow in the regional gravel aquifer (RGA) as steady state flow. The model domain excluded the Upper Continental Recharge System (UCRS) and the McNairy Formation. The UCRS overlies the RGA whereas the McNairy Formation underlies the RGA. The model was calibrated to water level data measured in February 1995 and the Ohio River Flux. Model parameters selected for calibration were horizontal hydraulic conductivity and recharges. Horizontal hydraulic conductivity values were allowed to vary from cell to cell. Recharges were configured using a traditional zonation pattern with one value for each zone. PEST coupled with pilot points was used to estimate these parameters automatically.

KRCEE's review of the 2008 model (KRCEE, 2011) found that the model achieved good match to site observations with majority of parameters within reasonable ranges. The review also suggested the calibrated anthropogenic recharges within the industrial area of the PGDP site needed improvements and pointed out that the exclusion of the UCRS and the McNairy formation limited the model's capacity in simulating contaminant migration between the UCRS and the RGA and between the RGA and the McNairy.

Details about the 2012 update were not available for review, but the 2016 update report summarized the 2012 model as an incremental update to the 2008 model. Changes made in the 2012 model included revisions to the bottom and top RGA elevations and calibration to seven steady-state periods and a one-day transient stress period. The overall conceptual groundwater model remained the same as the 2008 model. As a result, although the 2016 update was described on the basis of the 2012 model configuration, it was actually an update from the 2008 model.

This review focuses on the changes the 2016 update made to the 2008 model and evaluates if these changes improved the model in achieving the intended model objective. The objective of the 2016 update was to develop a tool for evaluating potential remedies, developing cleanup criteria, and determining additional data needs (DOE, 2017). Another objective of this review is to provide suggestions to support future groundwater modeling efforts for the PGDP site.

Review of Model Configuration

The 2016 update kept the design of the 2008 model. The key components in the 2008 model included:

1. A steady state flow model with the model domain encompassing the RGA.
2. The RGA was divided into three layers of equal thickness.
3. A uniform cell size of 50 ft. by 50 ft.
4. Surface water divides were used to define model boundaries along the east and west sides.
5. The Ohio River and the Porters Creek Clay defined the northern and southern boundaries of the model domain.
6. The Terrace Gravel, located south of PGDP, was excluded from the model because of very limited hydrologic data.
7. Precipitation was considered the main recharge to the RGA and anthropogenic recharge was considered within the industrial area of the PGDP site.
8. Lower reaches of Bayou Creek (BC), Little Bayou Creek (LBC), and the Ohio River were represented with drain cells.
9. Horizontal hydraulic conductivity was allowed to vary from cell to cell and a constant ratio of 10:1 assumed for the horizontal and the vertical hydraulic conductivity.
10. Model calibration was performed using PEST with pilot points to estimate parameters automatically.
11. Angle targets derived from contaminant plume trajectories were used in assisting the calibration.

Several changes were made to the 2016 update to incorporate new data from the site. The changes included:

1. Groundwater inflow from the Terrace Gravel was added as recharge and the inflow rate was estimated using baseflow volume and drainage area.
2. The southern model boundary was revised to reflect the areal extent of the RGA.
3. Anthropogenic recharge zonation was modified and refined to reflect lithology of the UCRS and plant use within the industrial rea of the PGDP site.
4. RGA elevation and thickness were revised to reflect updated knowledge of RGA lithology.
5. Lower reaches of Bayou Creek (BC), Little Bayou Creek (LBC), and the Ohio River were converted from drain boundaries to river boundaries.

These changes reflected a more recent understanding of the groundwater system in the RGA. It is a natural step for any groundwater model to incorporate as much field information as possible to improve the representation of groundwater system. Meanwhile, these changes often require the model to be re-calibrated.

Review of Model Calibration

The 2016 update adopted the same calibration method used for the 2008 model. Model parameters were estimated automatically using PEST coupled with pilot points. While the 2008 model calibrated the model using water level measurements from one period, the 2016 update calibrated model parameters using water level measurements from two periods.

The 2016 update had two steady state stress periods, one for before the pump-and-treat operation was initiated (SP1) and the other for post plant shutdown conditions with pump-and-treat still in operation (SP2). The first stress period was calibrated to water levels measured in February 1995 and the second stress period to water levels measured in September 2014. The February 1995 water level measurements were previously used for calibrating the 2008 model. Inclusion of the 1995 data allowed the model to add trajectory targets under non-pumping conditions. The trajectory targets were derived from observed plume geometry and allowed the calibrated flow direction to match the observed plume flow paths.

Recharge values for each stress period and horizontal hydraulic conductivity were estimated using PEST with pilot points. Parameter constraints (upper and lower bounds) were revised to reflect the analysis of recent data. The calibration or parameter estimation problem is inherently non- unique because the number of parameters are much greater than number of targets. This is similar to a problem where you have more unknowns than the number of independent equations. In such case, there will be infinite number of solutions, meaning there are many combinations of hydraulic conductivity and recharge values that can match calibration targets. Therefore, it is critical to examine the calibrated parameters to make sure these parameters represent our knowledge of the site.

Predicted water levels from the 2016 update reasonably matched water level targets. However, the mass balance results of the model revealed inconsistencies between the two stress periods. For a steady state flow model, the total flows into (inflow) and out of (outflow) the entire model are always equal. Consequently, either total inflow or total outflow can be used to compare total flows between the two stress periods. The total inflow of SP1 was 2,480 gallons per minute (gpm) while the total inflow of SP2 was 2,920 gpm. The total inflow of SP2 was 18% higher than the total inflow of SP1, which contradicted with the field observation that SP1 was in a relatively higher water level stage than SP2. Comparison of 54 monitoring wells that had water level measurements in both periods showed most of them had water levels higher in SP1 than in SP2 (Table A1). Only two monitoring wells had water levels lower in SP1 than in SP2. These monitoring data suggested the groundwater system in SP1 was at a higher stage than in SP2. Consequently, the total inflow in SP1 should have been higher than total inflow in SP2.

A major difference in model configuration between the two stress periods was that SP2 included two pump-and-treat sites with a combined pumping rate of 411 gpm. Groundwater pumping at the sites can lower water levels in some monitoring wells. However, comparison of the water level differences between the two periods versus distance to nearest pumping wells showed the water level differences had little correlation to pumping (Figure A1). The correlation coefficient between water level differences and distances to nearest pumping well was -0.1, suggesting pumping was not the main reason for the lower water levels in SP2 than in SP1. Particularly, four monitoring wells (MW137, MW147, MW199, and MW201), which were located more than 1.5 miles (ranging from 8,910 – 12,475 ft.) north of the pumping sites, had water levels more than 0.7 ft. higher (0.76-1.46 ft.) in SP1 than in SP2 (Table A1). The pumping at the two pump-and-treat sites should have little impacts to water levels in these wells given their distances to the pumping sites.

The higher total flow in SP2 was mainly from increased ambient recharge, which was 3.63 inches/year for SP1 and 4.29 inches/year for SP2, an increase inflow of 354 gpm to the model. This increase accounted for 80% of the increase in total flow. The increase of ambient recharge appeared to be needed to counter-balance the water level decreases caused by the pumping. The total pumping rate from all pumping wells in SP2 was 411 gpm. Assuming no changes in all recharges from SP1 to SP2, the water levels in the monitoring wells would decrease by an average of 4.5 ft (Table A2). However, the average decrease of the observed water levels from SP1 to SP2 was about 0.8 ft (Table A1). Significant increase in recharge was required to offset the impacts of pumping. A hypothetical non-pumping scenario was simulated for SP2 where all pumping wells were turned off; the simulated water levels in these monitoring wells increased an average of 5.4 ft (Table A3), indicating the pumping had slightly larger impact on water levels in SP2 than in SP1. Also notice that water level data used in SP1 were collected in February 1995 while water level data used in SP2 were collected in September 2014. The higher annual precipitation in 2014 (46.8 inches) than that in 1995 (38.6 inches) should not be used to justify the increased ambient recharge since water levels in February were not affected by low precipitation later in the year.

The 2016 update report attributed the inconsistency in ambient recharge to the non-steady-state conditions in SP1. But the specific role that non-steady-state groundwater conditions played in decreasing recharge from precipitation was not explained. The increased recharge in SP2 also indicated that pumping groundwater would enhance precipitation recharge; however, little physical evidence exists to support that indication, especially when the pumping aquifer did not directly receive recharge from precipitation. The UCRS is the shallow geologic unit receiving recharge from precipitation directly.

A possible explanation of the inconsistency is that the calibrated model significantly over predicts drawdowns resulting from pumping of the pump-and-treat sites. The transient calibration (section 6.10, DOE 2017) in the 2016 update report showed that drawdown was underestimated during the early stage of pumping and was overestimated for the later stage. As a steady state model, the 2016 update predicted final drawdown for a pumping test as if the pumping was allowed to last for a long time to reach steady state. The drawdown predictions from the 2016 update resembled drawdown at the later stage of a pumping test.

Another possible explanation may be a result of incorrect model conceptualization about the two periods. Under natural conditions (i.e., without the pump-and-treat), SP2 might be in a higher flow condition than SP1. In such case, higher ambient recharge should be expected and higher stages in all river cells should also be expected. The 2016 update used the same river stage values for both periods, essentially treating both periods as similar conditions. This treatment of the river stages may also have contributed to the inconsistency.

A comparison of the two PGDP groundwater models that preceded the 2016 update reveals that the mass balance results were quite different. The 1997 model had a total inflow of 14,650 gpm (Table 3.4, DOE, 2010) and the 2008 model had a total inflow of 5,384 gpm (Table 7.4, DOE, 2010).   The 2016 update has a total inflow of 2,480 gpm for SP1. The 1997 model included the UCRS and the McNairy, so higher total flow was expected. The 2008 model was calibrated to the same targets as the SP1 of the 2016 update. The difference in mass balance between the 2008 model and SP1 of 2016 update showed that matching water level and trajectory targets alone don't guarantee a robust model. A robust model should also produce a water balance concurring with the site conceptual model. However, a good estimate of overall mass balance of the site is apparently lacking, which is evident from the rather large range of estimated total groundwater discharge of 1,161 to 15,434 gpm (DOE, 2017). The 2008 model predicted 4,739 gpm discharge to the Ohio River whereas the SP1 of the 2016 update predicted discharge of 1,912 gpm.

The 2016 update used different minimum and maximum values for hydraulic conductivity inside and outside the plant area during calibration. This choice appeared to be arbitrary. There is no reason to believe that the boundary of the site was selected based on variation of the RGA hydraulic conductivity. In addition, the estimated hydraulic conductivity values from the pumping tests do not necessary represent hydraulic conductivity at the location of the pumping well. Rather, these values are estimated based on assumption of aquifer homogeneity for the area surrounding the pumping well and observation well(s).

Review of Model Validation

The 2016 update was applied to simulate six periods corresponding to field monitoring events. For each period, the Ohio River stage was adjusted and model predicted particle traces and hydraulic gradient were evaluated. The idea was to see if the model maintained similar flow paths and match measured hydraulic gradients under different site conditions.

In all six simulations, the only change made to the model was the Ohio River stage. All recharge values and stages of BC and LBC remained the same except for the April 2011 simulation where Ohio River stage (327.2 ft.) was used for BC and LBC reaches with stages lower than the Ohio River stage. Intuitively, the recharge and stream stage values should vary according to site conditions for all simulations. Ideally, these values should be made available from field data, so the model can be evaluated against other field measurements, such as water levels. Without field data, there was no easy way to adjust these values. However, without adjusting recharge values and stages of BC and LBC, the six model runs cannot be considered to represent different site conditions. Rather, they can be viewed as sensitivity analysis to evaluate responses of plume trajectory to changes in the Ohio River stage.

The evaluation of hydraulic gradient was only done to one pair of monitoring wells. Even with this one pair, the model calculated gradients were not consistent with the measured gradients. Although the model calculated gradients were in the same order of magnitude with the observed values, the impacts of changes in the Ohio River stage on the gradient were not reflected correctly. Figure A2a showed that hydraulic gradient generally increased with increasing Ohio River stage when the stage was in the range of 290 – 300 ft. But the model calculated gradient decreased with increasing Ohio River stage (Figure A2b). Also, the magnitude of hydraulic gradient response to Ohio River stage was much less than observed. For the six periods included in the figure, the range of observed hydraulic gradient was 0.00021 whereas the range of simulated hydraulic gradient was only 0.00004.

Review of Transient Calibration

A transient calibration was conducted using data from a 10-day pumping test. The steady state model of SP1 was re-calibrated to obtain the initial condition prior to the pumping test. Only ambient recharge was adjusted for this re-calibration. During the transient calibration, homogeneous specific storage was manually adjusted to match the drawdown observations. In both steady state and transient calibrations, the Ohio River stage was adjusted based on field measurements.

Water level residuals for the initial condition calibration were generally small, but showed obvious bias. Figure 6.45 of the 2016 update report is included in the appendix as Figure A3 for easy access. There is an obvious linear trend in Figure 6.45 in that the residuals were associated with observed water levels, a sign of bias. The model underestimated water levels above 325 ft and overestimated water levels below 325 ft. This bias appeared to be due to the highly varying water levels on site. Figures 6.45 and 6.46 of the 2016 update report showed that the water levels near the pumping test site varied spatially with a high degree of irregularity.

The calibration to the drawdown data also showed some bias, as pointed out in the 2016 update report. The model underestimated early drawdown and overestimated later drawdown. This type of bias can be caused by an underestimation of hydraulic conductivity. As a steady state model, the 2016 update would yield results resembling drawdown at later pumping state when the pumping wells were included in the model. Overestimating drawdown at a later stage indicates that the model can potentially over-predict drawdown caused by the pump-and-treat systems, at least the one with EW232 and EW233. This over-prediction of drawdown can adversely affect capture zone analysis, likely leading to an exaggeration of the size of the capture zone.

Review Summary

The 2016 update incorporated recent site data to the 2008 model and recalibrated the model to water levels measured in two periods. Although the incorporation of additional field data could potentially improve the model to better represent the groundwater system of the site, the results from the 2016 update showed inconsistency in the model calibration and biases in the model verification.

The stress period 1 (SP1, February 2005) was conceptualized at a higher water level condition than the stress period 2 (SP2, September 2014), but the calibrated total inflow in the SP2 was 18% higher than the total inflow in the SP1. The increased total inflow in SP2 was mainly from calibrated ambient recharge, which was increased to offset the water level decreases caused by the pumping from the two pump-and-treat sites in SP2.

Stress Period 1 (SP1) was calibrated to the same water level targets used in the 2008 model. Both models achieved reasonable match to the targets, but with different total flows. The total inflow of 2008 model (5,384 gpm) was more than twice of the total inflow of the SP1 in the 2016 update (2,480 gpm). Thus, the predicted site-wide groundwater flow from the 2008 model was expected to be much faster than the predicted flow from the 2016 update. When used for solute transport modeling, these two models would yield very different travel times even though the migration paths might be similar. This discrepancy in the total flow results demonstrates the need for a better understanding of the water budget across the entire groundwater basin.

Evaluation of the 2016 update was conducted by running the calibrated model with different Ohio River stages. These model runs failed to capture the actual responses of hydraulic gradients to changes of the Ohio River stages. Changing stages of the Ohio River alone did not represent different field conditions. A more plausible field condition would be that ambient recharge and stages of LBC and BC also vary with changing Ohio River stages.

The supplemental transient calibration to a pumping test showed systematic biases in matching field water levels prior to the pumping test and the drawdown data during the pumping test.

In conclusion, although it incorporated additional field data into the groundwater model, the 2016 update showed inconsistencies in model calibration and biases in predicting the aquifer's responses to changes in the Ohio River stages and to a pumping test.

A solute transport model is needed for the purpose of assisting remediation for a site like PGDP. Without a transport model built on flow fields produced from a flow model, evaluating any flow model on whether the flow model can serve the purpose of helping site remediation is futile.

Suggestions

The 2016 update was intended to represent steady-state conditions that only occur during drier months of the year. The Ohio River stage data (Figures 3.16 through 3.25, DOE 2017) clearly demonstrated that the groundwater system is in a transient state for much of the year. Even with the Olmsted Locks and Dam in operation, the groundwater system is still expected to remain transient for most of the year as the groundwater status is also highly influenced by the naturally varying precipitation throughout the year. Further tuning of the steady-state model will provide little improvements in representing the actual groundwater system across the groundwater basin. Consequently, future modeling efforts should focus on capturing the transient behavior of the groundwater system. When recalibrated with consistency, the existing steady state model can be used to provide initial conditions, calibrated hydraulic conductivity, and other non-temporally varying parameters for transient modeling.

References

DOE (U.S. Department of Energy), 2017, 2016 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model, A Product of the Paducah Gaseous Diffusion Plant Site Groundwater Modeling Working Group, DOE/LX/07-2415&D1

DOE (U.S. Department of Energy), 2010, 2008 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model, A Product of the Paducah Gaseous Diffusion Plant Site Groundwater Modeling Working Group, PRS-ENR-0028.

KRCEE (Kentucky Research Consortium for Energy and Environment), 2011, Paducah Gaseous Diffusion Plant Groundwater Modeling Support Activities Phase 1 Summary Report, UK/KRCEE Doc#: P30.1 2011.

Appendix

Table A1: Comparison of observed water levels for the two periods

Well Name	SP1(Feb,1995)	SP2(Sept 2014)	Difference (ft) (SP1-SP2)	Distance to nearest pumping Well (ft)
MW106	325.41	324.57	0.84	1716
MW123	323.85	323.24	0.61	5053
MW125	323.83	323.26	0.57	5067
MW126	325.29	323.43	1.86	75
MW132	323.48	322.88	0.6	5734
MW137	321.09	320.33	0.76	8910
MW139	323.58	322.85	0.73	5736
MW144	325.74	324.97	0.77	2017
MW145	325.68	325.01	0.67	2014
MW147	320.09	318.63	1.46	12475
MW150	324.69	323.79	0.9	3305
MW156	326.62	325.76	0.86	3310
MW163	326.35	325.53	0.82	3895
MW165	326.3	325.33	0.97	2695
MW168	326.37	325.12	1.25	2237
MW169	325.22	324.81	0.41	1294
MW173	326.28	324.73	1.55	538
MW175	326.71	325.88	0.83	2891
MW178	326.65	325.54	1.11	2884
MW185	326.18	324.29	1.89	173
MW188	326.7	325.86	0.84	3145
MW193	325.1	324.33	0.77	2428
MW194	325.39	324.94	0.45	3542
MW197	325.06	324.02	1.04	1820
MW199	323.77	322.59	1.18	9618
MW200	324.52	323.99	0.53	3514
MW201	322	320.89	1.11	9141
MW205	325.15	325.08	0.07	2053
MW222	324.59	324.41	0.18	4162
MW224	325.74	324.47	1.27	4218
MW225	324.81	324.58	0.23	3903
MW226	326.94	325.66	1.28	2318
MW325	325.64	325.86	-0.22	3178
MW326	326.76	325.91	0.85	3524
MW327	326.62	325.86	0.76	3654
MW328	326.07	325.84	0.23	3098

MW329	326.12	325.8	0.32	2571
MW330	326.87	325.86	1.01	3283
MW63	325.88	324.37	1.51	541
MW66	324.97	324.28	0.69	176
MW67	326.82	325.17	1.65	1856
MW71	325.24	325.89	-0.65	3468
MW79	326.43	325	1.43	1948
MW84	326.34	325.29	1.05	1885
MW86	325.85	325.25	0.6	1884
MW87	326.32	325.1	1.22	1880
MW89	325.75	325.07	0.68	1879
MW92	325.78	325.13	0.65	1889
MW93	326.32	325.55	0.77	2110
MW98	322.97	322.55	0.42	6815
MW99	323.14	322.57	0.57	6062
PZ109	326.56	325.91	0.65	4739
PZ110	326.54	325.9	0.64	4727
W108	326.82	325.92	0.9	4715

Table A2 Model predict water levels for SP2 assuming no changes in recharge values from SP1

Well Name	Observed Head in SP2	Predicted in Current Model	Predicted no recharge increases	Difference
MW106	324.57	324.74	320.27	4.47
MW123	323.24	323.37	319.29	4.07
MW125	323.26	323.36	319.29	4.07
MW126	323.43	323.97	319.53	4.44
MW132	322.88	323.06	318.93	4.13
MW137	320.33	320.47	316.92	3.55
MW139	322.85	323.06	318.93	4.13
MW144	324.97	324.92	320.34	4.58
MW145	325.01	324.91	320.34	4.58
MW147	318.63	317.86	315.08	2.77
MW150	323.79	323.86	319.51	4.34
MW156	325.76	325.73	320.99	4.74
MW163	325.53	325.45	320.78	4.67
MW165	325.33	325.31	320.66	4.65
MW168	325.12	325.39	320.70	4.69
MW169	324.81	325.10	320.47	4.63
MW173	324.73	324.74	320.18	4.56
MW175	325.88	325.63	320.90	4.74
MW178	325.54	325.57	320.86	4.71

MW185	324.29	324.49	319.96	4.53
MW188	325.86	325.34	320.67	4.67
MW193	324.33	324.09	319.70	4.39
MW194	324.94	324.93	320.48	4.46
MW197	324.02	324.41	320.03	4.38
MW199	322.59	323.21	319.31	3.90
MW200	323.99	323.98	319.74	4.24
MW201	320.89	321.43	317.78	3.66
MW205	325.08	325.36	320.68	4.67
MW222	324.41	324.20	319.83	4.37
MW224	324.47	324.20	319.83	4.37
MW225	324.58	324.26	319.88	4.38
MW226	325.66	325.38	320.65	4.73
MW325	325.86	325.48	320.76	4.72
MW326	325.91	325.59	320.85	4.74
MW327	325.86	325.44	320.75	4.69
MW328	325.84	325.23	320.60	4.63
MW329	325.80	325.14	320.52	4.61
MW330	325.86	325.41	320.72	4.70
MW63	324.37	324.65	320.14	4.50
MW66	324.28	324.53	320.02	4.52
MW67	325.17	325.06	320.44	4.62
MW71	325.89	325.76	321.00	4.76
MW79	325.00	325.27	320.59	4.67
MW84	325.29	325.11	320.47	4.64
MW86	325.25	325.12	320.48	4.64
MW87	325.10	325.16	320.51	4.65
MW89	325.07	325.17	320.51	4.65
MW92	325.13	325.21	320.55	4.66
MW93	325.55	325.22	320.55	4.67
MW98	322.55	322.15	318.31	3.84
MW99	322.57	322.46	318.42	4.05
PZ109	325.91	325.80	321.05	4.75
PZ110	325.90	325.81	321.05	4.76
W108	325.92	325.80	321.05	4.75

Table A3 Model predict water levels for SP2 assuming no pumping

Well Name	Observed Head in SP2	Predicted in Current Model	predicted no pump in SP2	difference
MW106	324.57	324.74	330.26	5.52
MW123	323.24	323.37	327.98	4.61
MW125	323.26	323.36	327.97	4.61
MW126	323.43	323.97	329.73	5.75
MW132	322.88	323.06	327.82	4.77
MW137	320.33	320.47	324.32	3.85
MW139	322.85	323.06	327.82	4.77
MW144	324.97	324.92	330.49	5.57
MW145	325.01	324.91	330.49	5.57
MW147	318.63	317.86	320.71	2.85
MW150	323.79	323.86	329.01	5.15
MW156	325.76	325.73	331.38	5.65
MW163	325.53	325.45	331.06	5.61
MW165	325.33	325.31	330.90	5.59
MW168	325.12	325.39	331.11	5.72
MW169	324.81	325.10	330.88	5.78
MW173	324.73	324.74	330.63	5.89
MW175	325.88	325.63	331.31	5.68
MW178	325.54	325.57	331.25	5.68
MW185	324.29	324.49	330.46	5.97
MW188	325.86	325.34	331.04	5.71
MW193	324.33	324.09	329.40	5.31
MW194	324.94	324.93	330.31	5.38
MW197	324.02	324.41	329.73	5.31
MW199	322.59	323.21	327.36	4.15
MW200	323.99	323.98	328.89	4.91
MW201	320.89	321.43	325.39	3.96
MW205	325.08	325.36	331.07	5.71
MW222	324.41	324.20	329.37	5.16
MW224	324.47	324.20	329.36	5.16
MW225	324.58	324.26	329.45	5.19
MW226	325.66	325.38	331.11	5.73
MW325	325.86	325.48	331.19	5.71
MW326	325.91	325.59	331.29	5.69
MW327	325.86	325.44	331.14	5.70
MW328	325.84	325.23	330.93	5.70
MW329	325.8	325.14	330.84	5.70
MW330	325.86	325.41	331.12	5.71

MW63	324.37	324.65	330.37	5.73
MW66	324.28	324.53	330.42	5.89
MW67	325.17	325.06	330.82	5.76
MW71	325.89	325.76	331.42	5.66
MW79	325	325.27	331.01	5.75
MW84	325.29	325.11	330.87	5.75
MW86	325.25	325.12	330.87	5.75
MW87	325.1	325.16	330.91	5.75
MW89	325.07	325.17	330.92	5.75
MW92	325.13	325.21	330.96	5.75
MW93	325.55	325.22	330.96	5.74
MW98	322.55	322.15	326.39	4.24
MW99	322.57	322.46	327.10	4.63
PZ109	325.91	325.80	331.44	5.64
PZ110	325.9	325.81	331.45	5.64
W108	325.92	325.80	331.44	5.64

Figure A1: Water level differences between two periods vs distances to nearest pumping well. The difference in each well was defined as water level in SP1 minus water level in SP2

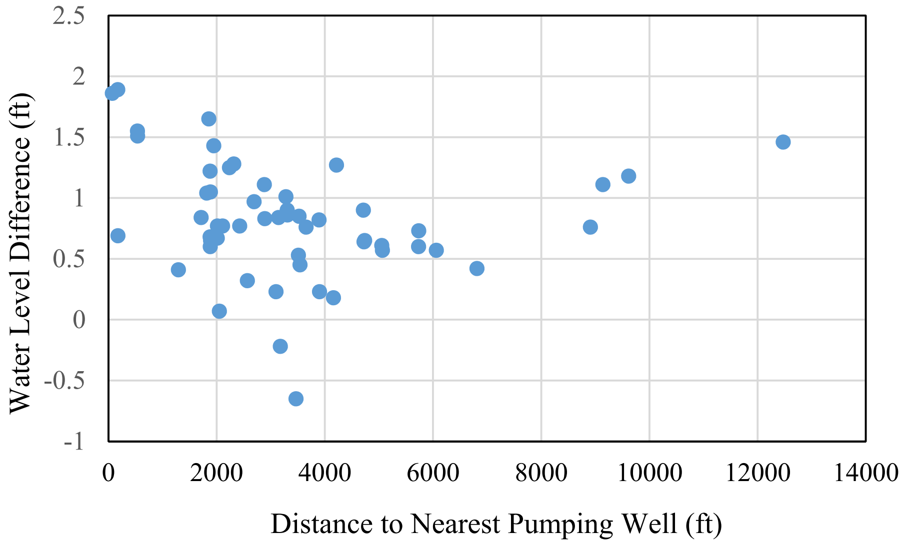


Figure A2: Comparison between a) observed hydraulic gradient and b) model calculated gradient. The data used in this figure were from Table 6.8 in the 2016 update report

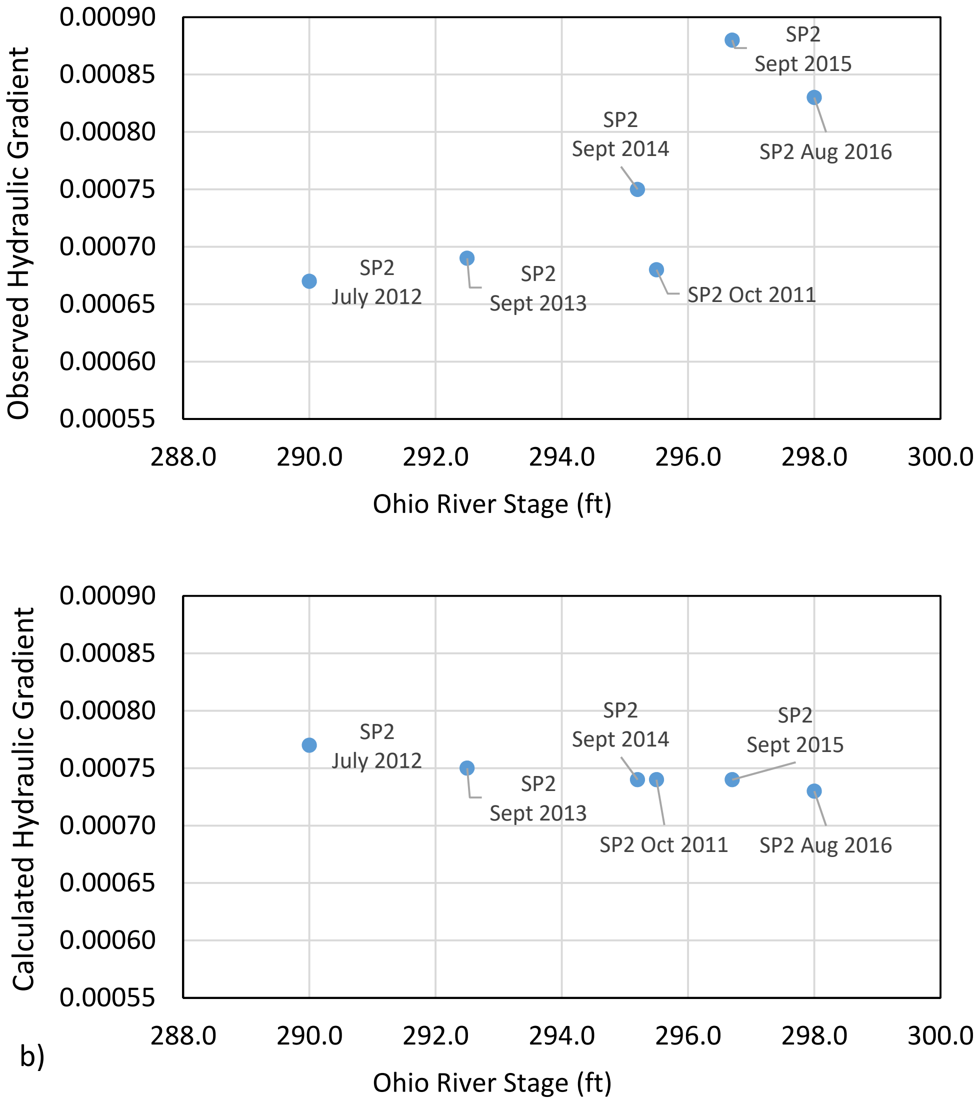
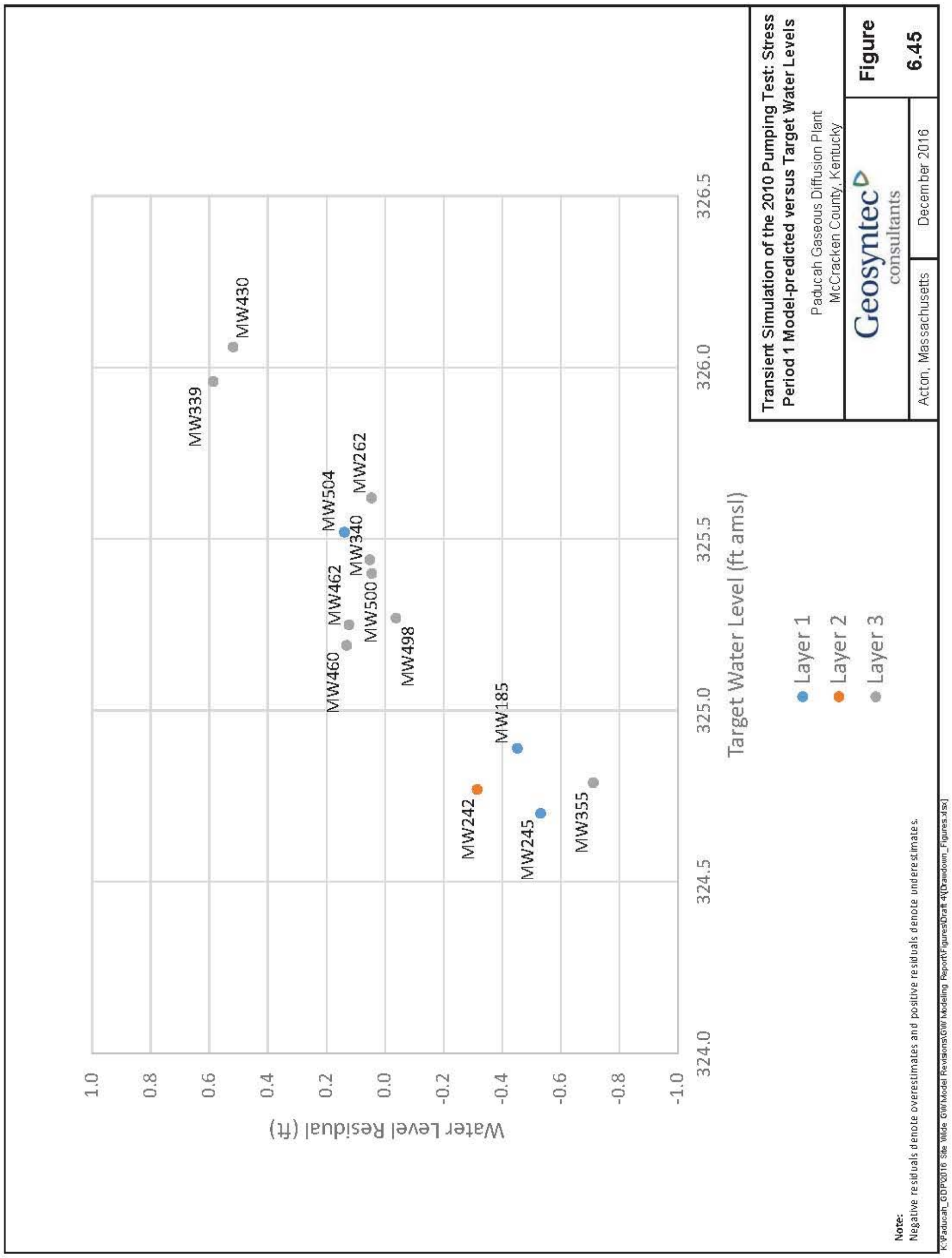


Figure A3: Figure 6.45 in the 2016 update report



Transient Simulation of the 2010 Pumping Test: Stress Period 1 Model-predicted versus Target Water Levels

Paducah Gaseous Diffusion Plant
McCracken County, Kentucky

Acton, Massachusetts

December 2016

Note:
Negative residuals denote overestimates and positive residuals denote underestimates.

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Figure 6.45. Transient Simulation of the 2010 Pumping Test: Stress Period 1 Model-predicted versus Target Water Levels

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