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Department of Energy
Carlsbad Field Office
P. O. Box 3090
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Mr. John Kieling, Acting Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 E. Rodeo Park Dr. Bldg. 1
Santa Fe, New Mexico 87505-6303

Subject: Transmittal of the Waste Isolation Pilot Plant Calendar Year 2005-2008 Culebra Potentiometric Surface Map Package

Dear Mr. Kieling:

On August 5, 2011 the New Mexico Environmental Department (NMED) approved the Groundwater Work Plan (Work Plan) submitted as a condition to the Final Stipulated Order (Order) dated December 1, 2009. An additional condition of the Order, upon approval of the Work Plan, is submittal of a series of revised Culebra Potentiometric Surface Maps (Culebra Potentiometric Surface Map Package) within timeframes specified by the Order. Enclosed is the second submittal due to the NMED within 180 days from the approval of the 2009 Map Package on November 2, 2011. The submittal is the Calendar Year 2005-2008 Culebra Potentiometric Surface Map Package.

We certify under penalty of law that this document and all attachments were prepared under our direction or supervision according to a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on our inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of our knowledge and belief, true, accurate and complete. We are aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

Please feel free to contact Mr. Daniel J. Ferguson at (575) 234-7018 if you have any questions regarding this transmittal.

Sincerely,

Jose R. Franco, Manager
Carlsbad Field Office

M. F. Sharif, General Manager
Washington TRU Solutions LLC

Enclosure

cc: w/enclosure
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Calendar Year 2005-2008 Culebra Map Package

Introduction

The Stipulated Final Order dated December 1, 2009, requires the Permittees to submit a Culebra Potentiometric Surface Map Package consistent with Groundwater Permit Modification Work Plan (work plan) for Calendar Year 2005-2008 groundwater level data. The work plan was approved on August 5, 2011, beginning the process of map package generation. Upon receiving the Notice of Approval from the New Mexico Environment Department (NMED) regarding the map package for Calendar Year 2009 on November 2, 2011, the Permittees are required to submit the 2005-2008 map package to the NMED within 180 days of this date.

The process for development of the potentiometric surface map entails analyzing the water level elevation data for each year during the reporting period to determine the best month to map for that year. Month selection is based on the least perturbation to the natural groundwater system due to well testing/pumping, oil field activities, or other unnatural events causing disturbance in groundwater elevations. Once the best month for mapping each year has been determined, the Waste Isolation Pilot Plant (WIPP) Permittees request Sandia National Laboratories (SNL) to model the freshwater heads measured in the wells for this month. SNL and the WIPP Permittees collaborate on the best month and SNL develops and provides the map to the Permittees for inclusion into the annual reports with the accompanying statistical graphs associated with the fit of the numerical finite-difference model to the data.

Mapping Methodology

For 2005-2008, the same methods were used by SNL to develop a new map for each year. Each year's results are contained in an individual section below but the general mapping techniques are described here.

Modeled freshwater head contours for the entire model domain are shown in the second figure of each section. These contours were generated using the results of the Culebra MODFLOW 2K (Harbaugh et al.,2000) model run utilizing ensemble average distributed aquifer parameters from the SNL Culebra Performance Assessment (PA) flow model, calibrated as part of the Performance Assessment Baseline Calculation (PABC) for the 2009 Compliance Recertification Application (DOE, 2009). The PA model was calibrated both to steady-state water levels (May 2007), and to transient multi-well responses observed during large-scale pumping tests. In the averaged version of the PA model used here, the boundary conditions were adjusted to improve the match between the model and the observed Culebra freshwater heads presented for each year. The portion of the flow domain of interest to the site is extracted on the first figure in each section. The freshwater head values were estimated using appropriate densities, either computed from the previous year or using whatever reliable data were available. The 100 model realizations, specifically the 100 transmissivity fields derived for the PABC embody the hydrologic and geologic understanding of the Culebra behavior in the vicinity surrounding the WIPP site (Kuhlman, 2010). This contouring exercise uses a single ensemble average field composed from these 100 realizations used for the PABC. This average model captures the mean flow behavior of the system, and allows straightforward contouring of results.

The Culebra flow model is a single-layer groundwater flow model. The boundary conditions of the flow model are of two types. First are the geologic- or hydrologic-type boundary conditions, which include the no-flow specified head along the eastern boundary, and the no-flow boundary along the axis of Nash Draw. The second type of boundary condition is the non-hydrologic specified head. The northern and southern boundaries are of this type, along with the southern portion of the west boundary. The second type of boundary condition was determined using the parameter estimation code PEST (Doherty, 2002) as part of this modeling effort. PEST is used to systematically adjust the boundary conditions to maximize the fit between modeled and observed heads at wells. The illustrated particle on the maps (heavy blue line) shows the model-predicted path a water particle would take through the Culebra from the coordinates corresponding to the WIPP facility Waste Shaft to the land withdrawal boundary (LWB).

The data used to construct the 2005-2008 maps was brought together by SNL from the Annual Site Environmental Report (ASER) for each year. Data were then plotted out for each well to determine the best month for mapping. Data for years prior to 2007 were adjusted to use more accurate modern reference point elevations to compute the freshwater head, which allowed for more consistency across the years.

Results for 2005

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for June 2005 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. June 2005 was determined to have a large number of Culebra water levels available, few Culebra water levels were affected by pumping events, and most Culebra water levels agree with a quasi-steady state trend. Table 1 shows the freshwater head data set. The following figures and discussion of mapping were modified from Kuhlman (2012).

Table 1.
Water Level Elevations for the June 2005 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (meters, AMSL)	Density (g/cm^3)
C-2737	6/21/05	920.04	1.019
ERDA-9	6/20/05	924.18	1.067
H-02b2	6/20/05	927.24	1.000
H-03b2	6/21/05	918.53	1.042
H-04b	6/20/05	916.53	1.015
H-05b	6/16/05	938.30	1.095
H-06b	6/13/05	935.43	1.040

Well	Measurement Date	Adjusted Freshwater Head (meters, AMSL)	Density (g/cm^3)
H-07b1	6/13/05	914.63	1.002
H-09c	6/20/05	913.53	1.001
H-10c	6/20/05	921.94	1.001
H-11b4	6/20/05	917.13	1.070
H-12	6/20/05	916.28	1.097
H-15	6/20/05	920.82	1.082
H-17	6/20/05	916.29	1.133
H-19b0	6/20/05	918.79	1.068
I-461	6/13/05	928.57	1.005
P-17	6/20/05	915.44	1.053
SNL-01	6/16/05	939.24	1.033
SNL-02	6/13/05	937.02	1.012
SNL-03	6/16/05	937.85	1.023
SNL-05	6/13/05	937.01	1.010
SNL-09	6/13/05	931.48	1.024
SNL-12	6/20/05	915.52	1.005
SNL-13	6/21/05	917.55	1.027
WIPP-11	6/13/05	938.87	1.038
WIPP-13	6/13/05	938.33	1.053
WIPP-19	6/20/05	932.01	1.044
WIPP-25	6/13/05	935.73	1.011
WIPP-30	8/17/05*	938.35	1.000
WQSP-1	6/20/05	936.94	1.048
WQSP-2	6/20/05	939.45	1.048
WQSP-3	6/20/05	935.46	1.146
WQSP-4	6/20/05	918.90	1.075
WQSP-5	6/20/05	918.04	1.025
WQSP-6	6/20/05	921.54	1.014
* WIPP-30 used an August water level, because there was no water level reported in June 2005 at that well.			

The model-generated freshwater head contours are given in Figures 1 and 2. There is a roughly east-west trending band of steeper gradients, corresponding to lower Culebra transmissivity. The uncontoured region in the eastern part of the figures corresponds to the portion of the Culebra that is located stratigraphically between halite in other members of the Rustler Formation (Tamarisk Member above and Los Medaños Member below). This region east of the "halite margin" has a high freshwater head but extremely low transmissivity, essentially serving as a no-flow boundary in this area.

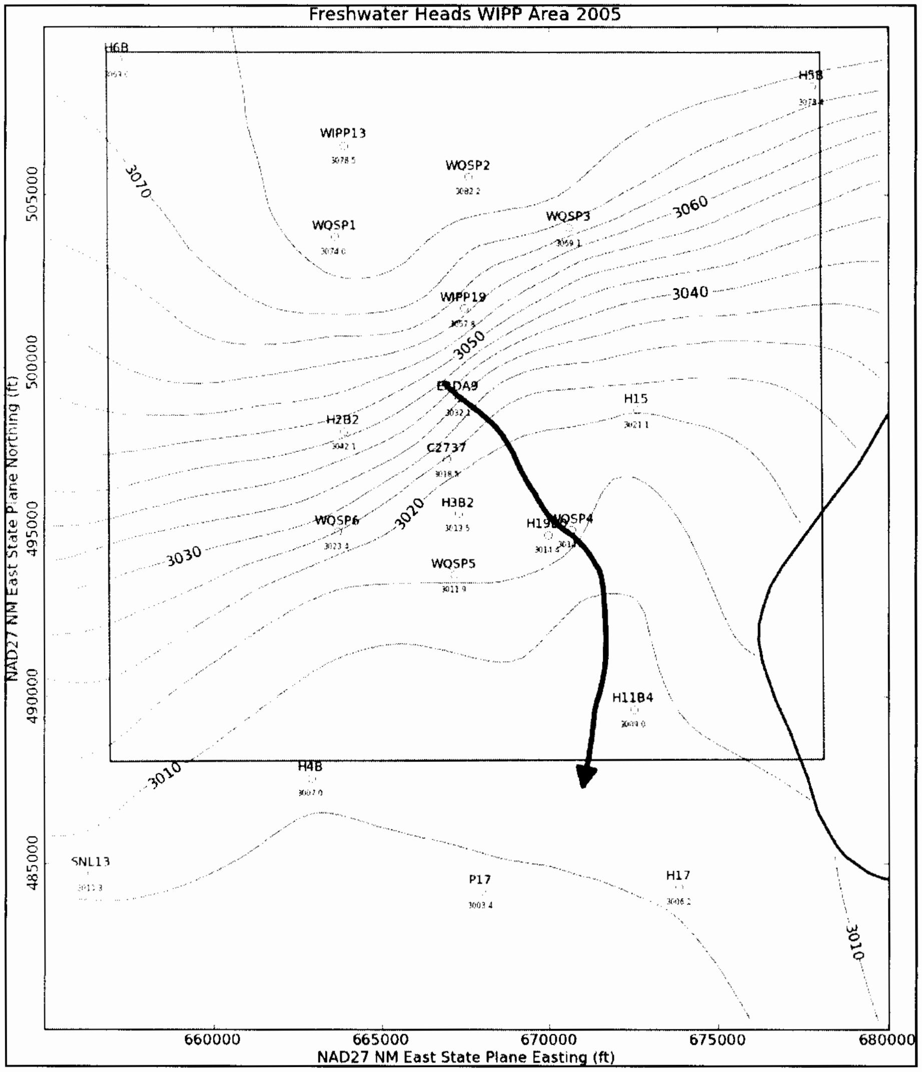

Figure 1. Model-generated June 2005 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

The blue arrow in Figure 1 shows the model-calculated path a water particle would take through the Culebra from the coordinates corresponding to the WIPP facility Waste Shaft to the land withdrawal boundary (a path length of 4,083 m). Assuming a 4-m thickness for the transmissive portion of the Culebra and a constant porosity of 16%, the travel time to the WIPP LWB is 6,170 years (model output is adjusted from an original 7.75-m Culebra thickness). This is an average velocity of 0.66 m/yr.

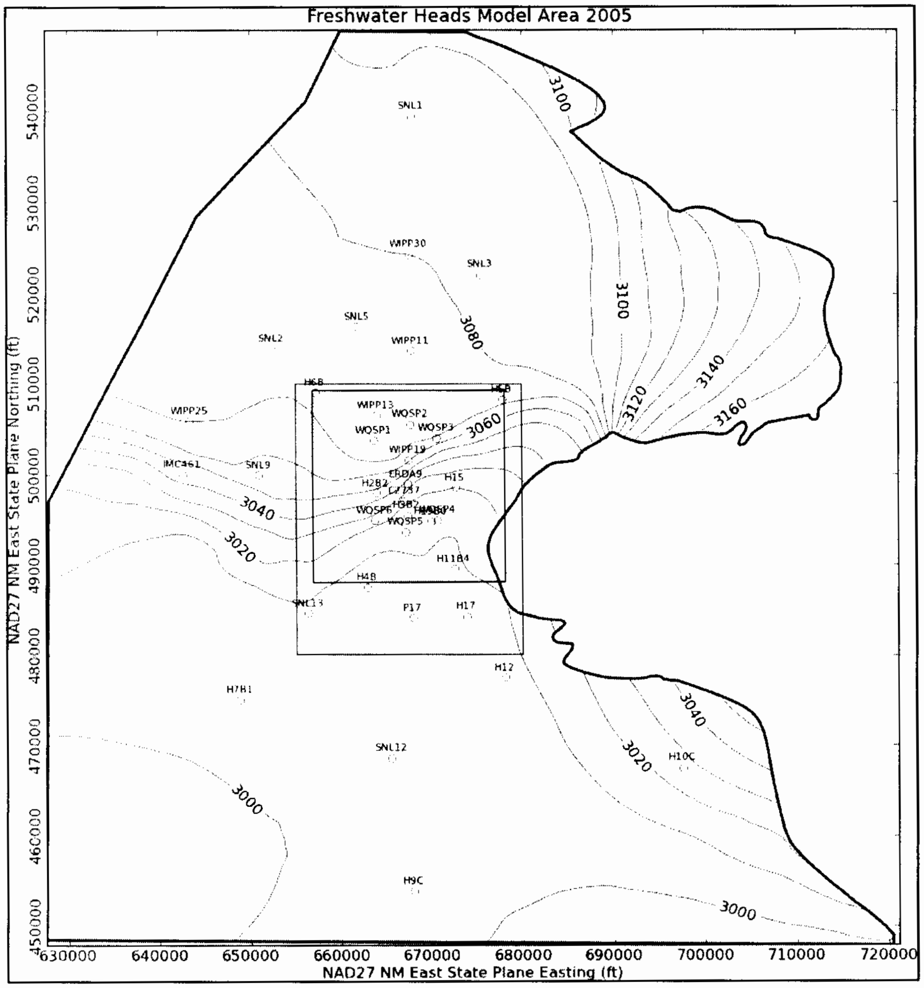

Figure 2. Model-generated June 2005 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 1, black square is WIPP LWB.

The scatter plot in Figure 3 shows measured and modeled freshwater heads at the observation locations used in the PEST calibration. The observations are divided into three groups, based on proximity to the WIPP site. Wells within the LWB are represented by red crosses, wells outside, but within 3 km of the LWB, are represented with green "×"s, and other wells within the MODFLOW model domain, but distant from the WIPP site, are given by a blue star. These groupings were utilized in the PEST calibration; higher weights (2.5) were given to wells inside the LWB, and lower weights (0.4) were given to wells distant to the WIPP site, while wells in the middle received an intermediate weight (1.0). IMC-461 was given a high weight, treating it as if it was inside the WIPP LWB, to compensate the lack of SNL-16 in the 2005 network. The area at the north end of the constant head boundary, and the southern end of the no-flow boundary is strongly influenced by the assigned boundary conditions – in 2006 and later SNL-16 is located in this area. Additional observations representing the average heads north of the LWB and south of the LWB were used to help prevent over-smoothing of the estimated results across the LWB. This allowed PEST to improve the fit of the model to observed heads inside the area contoured in Figure 1, sometimes at the expense of fitting wells closer to the boundary conditions (i.e., wells not shown in Figure 1).

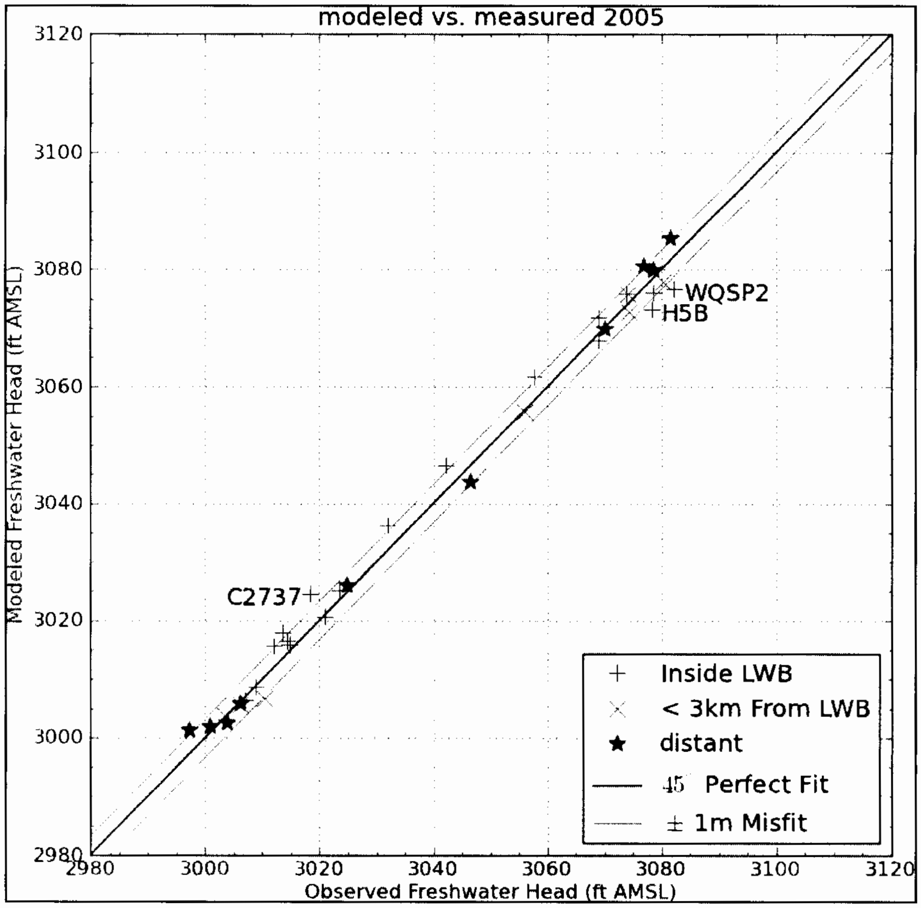

Figure 3. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and June 2005 observed freshwater heads

The central black diagonal line in Figure 3 represents a perfect model fit (1:1 or 45-degree slope); the two green lines on either side of this represent a 1-m misfit above or below the perfect fit. Wells more than 1.5 m from the 1:1 line are individually labeled.

The squared correlation coefficient (R^2) for the measured vs. modeled data is listed in Table 2. Figures 4 and 5 show the distribution of errors resulting from the PEST-adjusted model fit to observed data. The wells within and near the WIPP LWB have an R^2 of approximately 99%. The distribution in Figure 4 does not have a strong bias.

Table 2. 2005 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.989
wells <3km from WIPP LWB	0.990
all wells	0.982

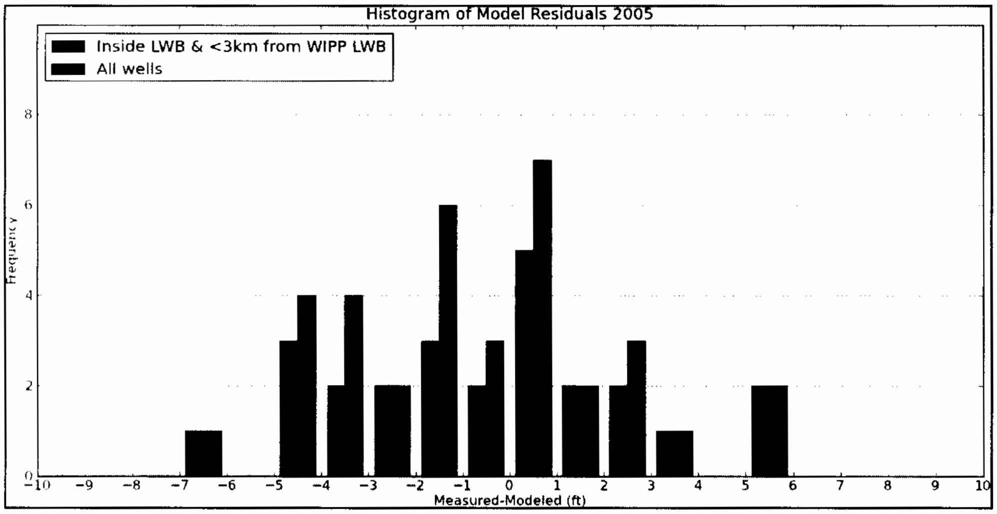

Figure 4. Histogram of Measured-Modeled errors for 2005

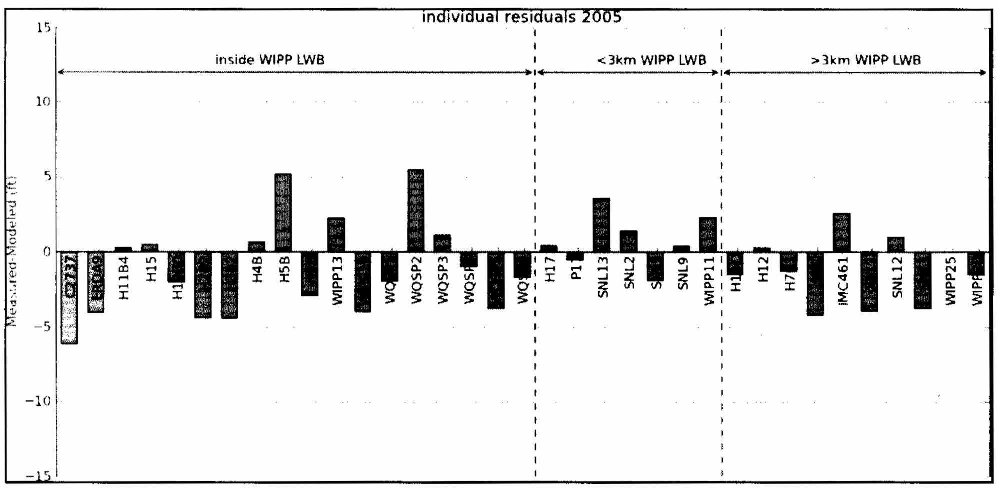

Figure 5. Measured-Modeled errors at each well location for 2005

The model fit to the June 2005 observations is very good. The ensemble-average model captures the average Culebra behavior, while the PEST calibration improved the model fit to the specific June 2005 observations.

Results for 2006

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for November 2006 were used to calibrate a groundwater flow model, which was used by

SNL to compute a potentiometric surface using SNL procedure SP 9-9. November 2006 was determined to have a large number of Culebra water levels available, few Culebra water levels were affected by pumping events, and most Culebra water levels agree with a quasi-steady state trend. Table 3 shows the freshwater head data set. The following figures and discussion of mapping were modified from Kuhlman (2012).

Table 3.
Water Level Elevations for the November 2006 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (meters, AMSL)	Density (g/cm^3)
C-2737	11/9/06	920.48	1.019
ERDA-9	11/9/06	924.78	1.067
H-02b2	11/9/06	928.24	1.000
H-03b2	11/9/06	918.31	1.042
H-04b	11/8/06	916.42	1.015
H-05b	11/6/06	938.96	1.095
H-06b	11/6/06	936.75	1.040
H-07b1	11/8/06	914.60	1.002
H-09c	11/8/06	912.58	1.001
H-10c	8/14/06*	921.93	1.001
H-11b4	11/9/06	917.07	1.070
H-12	11/9/06	916.62	1.097
H-17	11/9/06	916.29	1.133
H-19b0	11/8/06	918.80	1.068
I-461	11/6/06	929.34	1.005
SNL-01	11/6/06	941.47	1.033
SNL-02	11/6/06	938.35	1.012
SNL-03	11/6/06	939.47	1.023
SNL-05	11/6/06	938.61	1.010
SNL-08	11/6/06	930.52	1.052
SNL-09	11/6/06	932.50	1.024
SNL-12	11/6/06	915.22	1.005
SNL-13	11/6/06	918.00	1.027
SNL-16	11/8/06	918.43	1.010
SNL-17	11/6/06	916.75	1.006
SNL-18	11/6/06	939.86	1.028
SNL-19	11/6/06	937.92	1.003
WIPP-11	8/14/06*	939.87	1.038
WIPP-13	11/8/06	939.86	1.053
WIPP-19	11/8/06	933.51	1.044

Well	Measurement Date	Adjusted Freshwater Head (meters, AMSL)	Density (g/cm^3)
WIPP-30	11/6/06	939.29	1.000
WQSP-1	11/8/06	938.58	1.048
WQSP-2	11/8/06	941.14	1.048
WQSP-3	11/8/06	936.98	1.146
WQSP-4	11/8/06	918.97	1.075
WQSP-5	11/8/06	918.12	1.025
WQSP-6	11/8/06	921.95	1.014
*WIPP-11 and H-10c used an August 2006 water level because anomalously high water levels were reported October-December, 2006.			

The model-generated freshwater head contours are given in Figures 6 and 7. There is a roughly east-west trending band of steeper gradients, corresponding to lower Culebra transmissivity. The uncontoured region in the eastern part of the figures corresponds to the portion of the Culebra that is located stratigraphically between halite in other members of the Rustler Formation (Tamarisk Member above and Los Medaños Member below). This region east of the "halite margin" has high freshwater head but extremely low transmissivity, essentially serving as a no-flow boundary in this area.

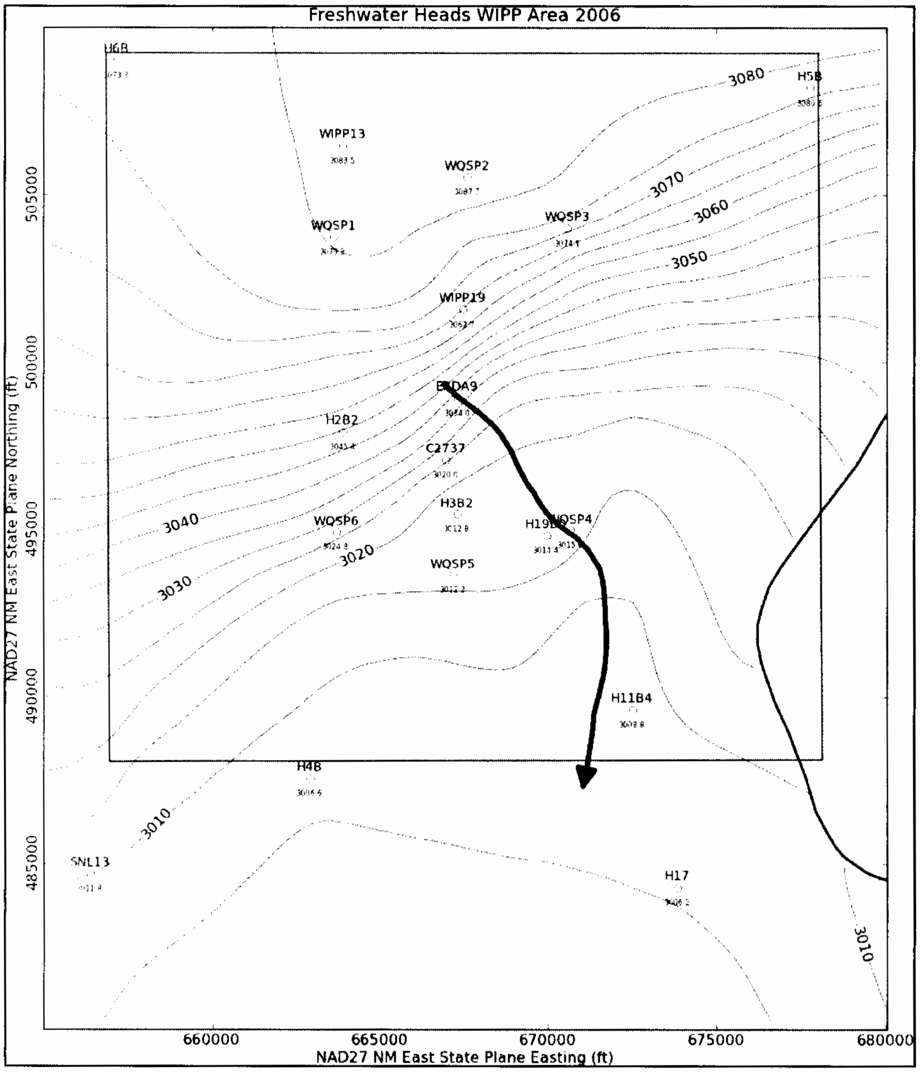

Figure 6. Model-generated November 2006 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

The blue arrow in Figure 6 shows the model-calculated path a water particle would take through the Culebra from the coordinates corresponding to the WIPP facility Waste Shaft to the land withdrawal boundary (a path length of 4,097 m). Assuming a 4-m thickness for the transmissive portion of the Culebra and a constant porosity of 16%, the travel time to the WIPP LWB is 5,642 years (model output is adjusted from an original 7.75-m Culebra thickness). This is an average velocity of 0.73 m/yr.

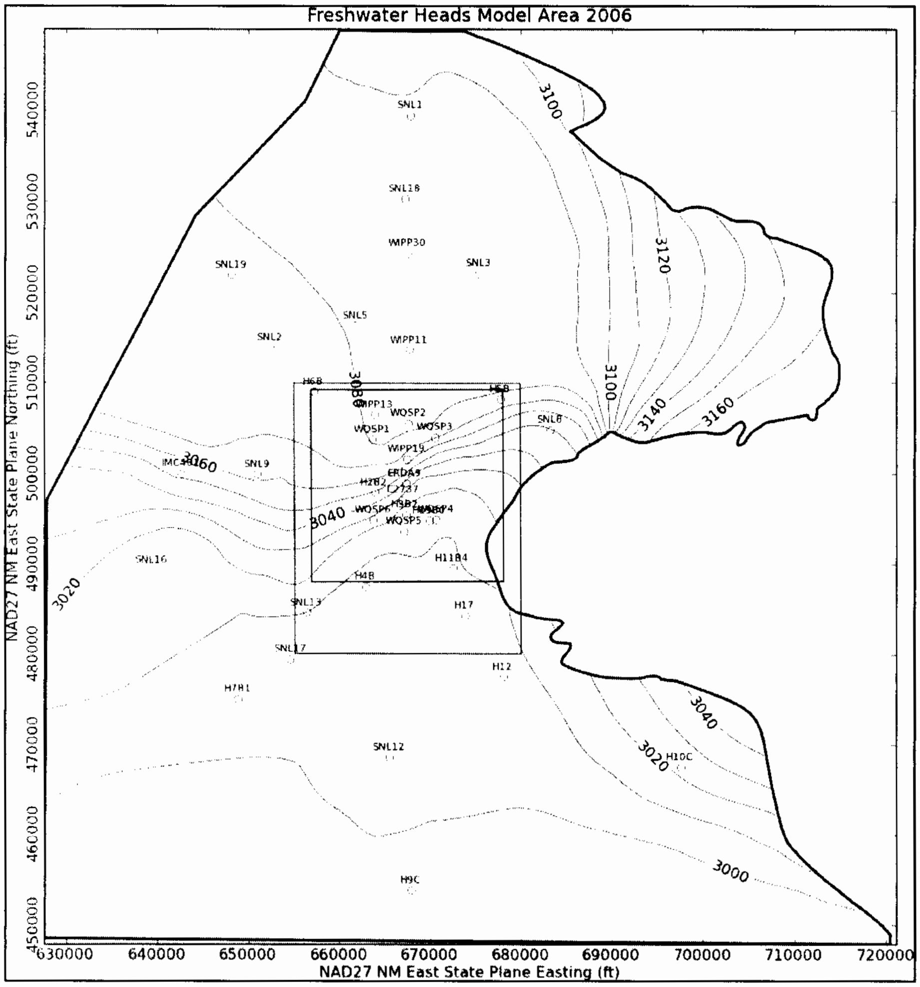

Figure 7. Model-generated November 2006 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 6, black square is WIPP LWB.

The scatter plot in Figure 8 shows measured and modeled freshwater heads at the observation locations used in the PEST calibration. The observations are divided into three groups, based on proximity to the WIPP site. Wells within the LWB are represented by red crosses, wells outside but within 3 km of the LWB are represented with green "x"s, and other wells within the MODFLOW model domain but distant from the WIPP site are given by a blue star. These groupings were utilized in the PEST calibration; higher weights (2.5) were given to wells inside the LWB, and lower weights (0.4) were given to wells distant to the WIPP site, while wells in the middle received an intermediate weight (1.0). Additional observations representing the average heads north of the LWB and south of the LWB were used to help prevent over-smoothing of the estimated results across the LWB. This allowed PEST to improve the fit of the model to observed heads inside the area contoured in Figure 6, at the expense of fitting wells closer to the boundary conditions (i.e., wells not shown in Figure 6).

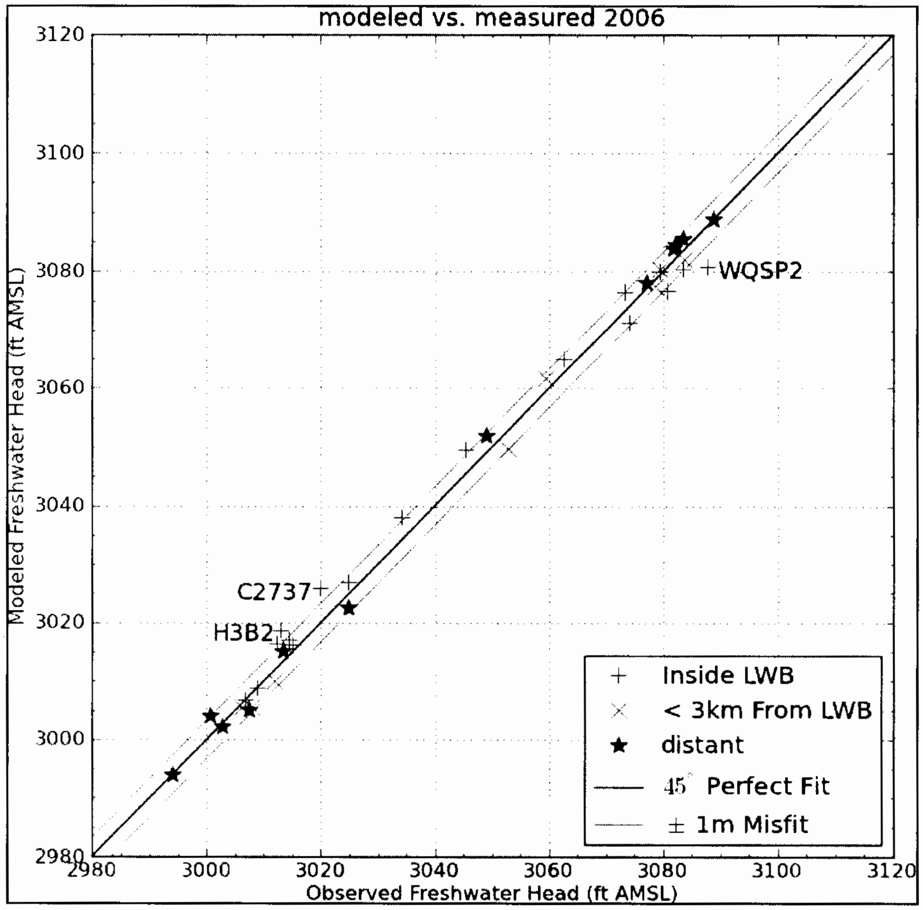

Figure 8. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and November 2006 observed freshwater heads

The central black diagonal line in Figure 8 represents a perfect model fit (1:1 or 45-degree slope); the two green lines on either side of this represent a 1-m misfit above or below the perfect fit. Wells more than 1.5 m from the 1:1 line are labeled.

The squared correlation coefficient (R^2) for the measured vs. modeled data is listed in Table 4. Figures 9 and 10 show the distribution of errors resulting from the PEST-adjusted model fit to observed data. The wells within and near the WIPP LWB have an R^2 of greater than 99%. The distribution in Figure 9 is roughly symmetric about 0, indicating there is not a strong bias.

Table 4. 2006 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.991
wells <3km from WIPP LWB	0.991
all wells	0.993

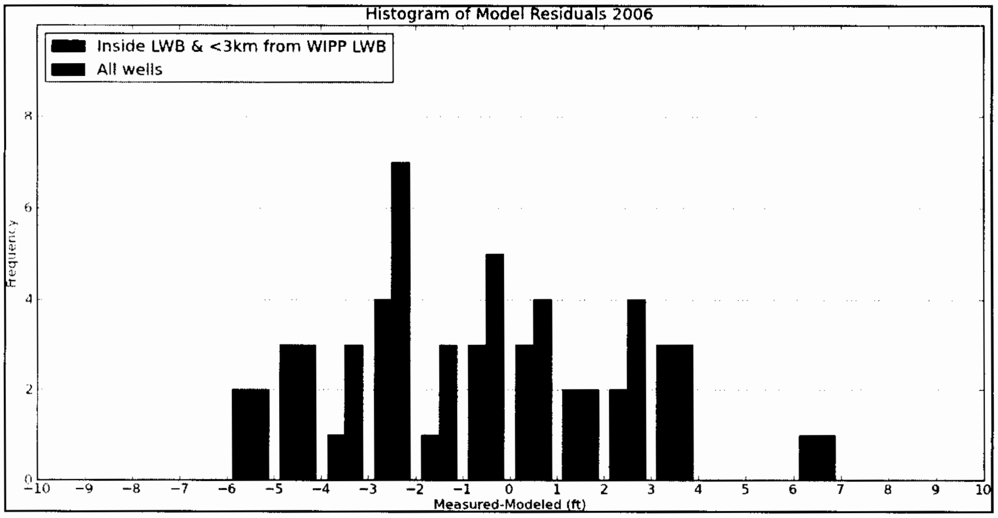

Figure 9. Histogram of Measured-Modeled errors for 2006

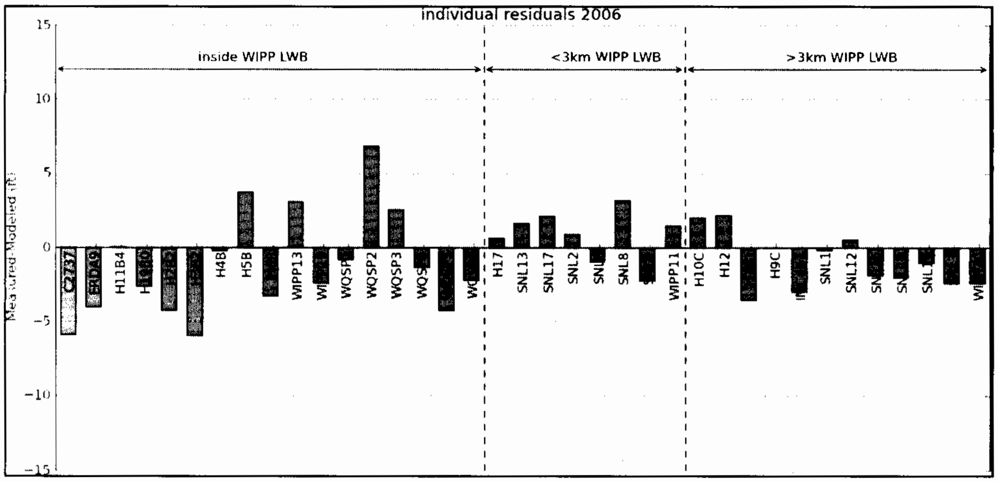

Figure 10. Measured-Modeled errors at each well for 2006

The model fit to the November 2006 observations is very good. The ensemble-average model captures the average Culebra behavior, while the PEST calibration improved the model fit to the specific November 2006 observations.

Results for 2007

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for May 2007 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. May 2007 was determined to have a large number of Culebra water levels available, few Culebra water levels were affected by pumping events, and most Culebra water levels agree with a quasi-steady trend. Table 5 shows the freshwater head data set. The following figures and discussion of mapping were modified from Kuhlman (2012).

Table 5.
Water Level Elevations for the May 2007 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (meters, AMSL)	Density (g/cm^3)
C-2737	5/9/07	920.71	1.010
ERDA-9	5/9/07	924.68	1.067
H-02b2	5/9/07	928.34	1.000
H-03b2	5/9/07	918.65	1.042
H-04b	5/9/07	916.35	1.015
H-05b	5/10/07	939.15	1.095
H-06b	5/7/07	936.45	1.040
H-07b1	5/7/07	914.58	1.002
H-09c	5/8/07	912.78	1.001
H-10c	5/8/07	922.07	1.001
H-11b4	5/7/07	917.05	1.070
H-12	5/8/07	916.54	1.097
H-15	5/9/07	920.08	1.053
H-17	5/7/07	916.29	1.133
H-19b0	5/9/07	918.83	1.068
I-461	5/7/07	928.94	1.005
SNL-01	5/8/07	941.85	1.033
SNL-02	5/7/07	937.66	1.012
SNL-03	5/8/07	939.77	1.023
SNL-05	5/7/07	938.59	1.010
SNL-08	5/7/07	930.01	1.052
SNL-09	5/7/07	932.03	1.024
SNL-10	5/7/07	931.57	1.011
SNL-12	5/7/07	915.24	1.005
SNL-13	5/7/07	918.20	1.027
SNL-14	11/14/07*	916.37	1.048
SNL-16	9/17/07*	918.17	1.010
SNL-17	5/7/07	916.78	1.006
SNL-18	5/8/07	939.90	1.028
SNL-19	5/7/07	937.58	1.003
WIPP-11	5/9/07	940.65	1.038
WIPP-13	5/9/07	939.84	1.053
WIPP-19	5/9/07	933.70	1.044
WIPP-30	5/8/07	939.06	1.000
WQSP-1	5/9/07	938.61	1.048

Well	Measurement Date	Adjusted Freshwater Head (meters, AMSL)	Density (g/cm^3)
WQSP-2	5/9/07	941.20	1.048
WQSP-3	5/9/07	936.81	1.146
WQSP-4	5/9/07	918.96	1.075
WQSP-5	5/9/07	918.18	1.025
WQSP-6	5/9/07	921.88	1.014

*SNL-14 used a November 2007 water level because no water levels were measured January-October 2007 due to pumping and sampling activities.
*SNL-16 used a September 2007 water level, because there was no May 2007 water recorded and previous to September, the well had anomalously high water levels.

The model-generated freshwater head contours are given in Figures 11 and 12. There is a roughly east-west trending band of steeper gradients, corresponding to lower Culebra transmissivity. The uncontoured region in the eastern part of the figures corresponds to the portion of the Culebra that is located stratigraphically between halite in other members of the Rustler Formation (Tamarisk Member above and Los Medaños Member below). This region east of the "halite margin" has high freshwater head but extremely low transmissivity, essentially serving as a no-flow boundary in this area.

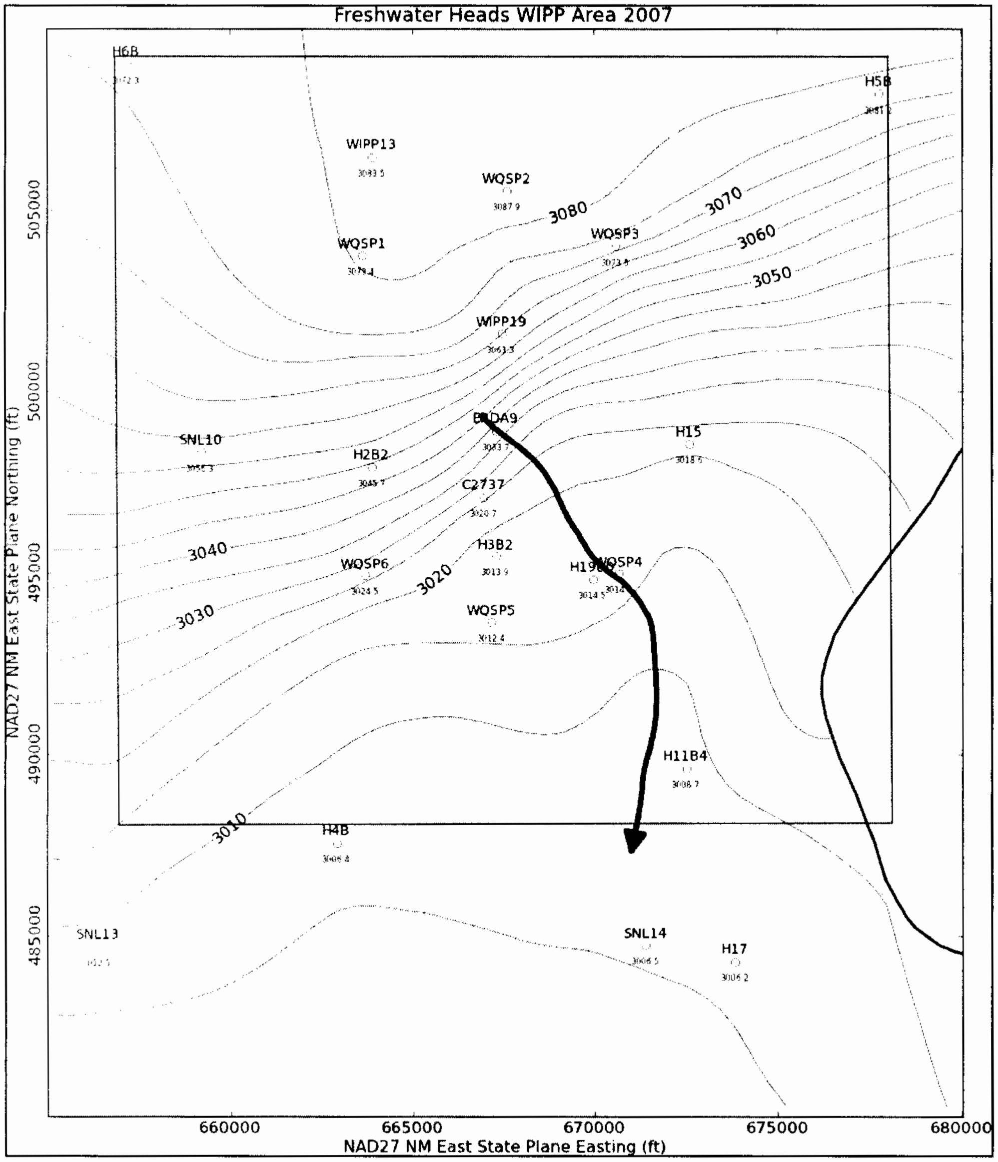

Figure 11. Model-generated May 2007 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

The blue arrow line in Figure 11 shows the model-calculated path a water particle would take through the Culebra from the coordinates corresponding to the WIPP facility Waste shaft to the land withdrawal boundary (a path length of 4,085 m). Assuming a 4-m thickness for the transmissive portion of the Culebra and a constant porosity of 16%, the travel time to the WIPP LWB is 5,845 years (model output is adjusted from an original 7.75-m Culebra thickness). This is an average velocity of 0.70 m/yr.

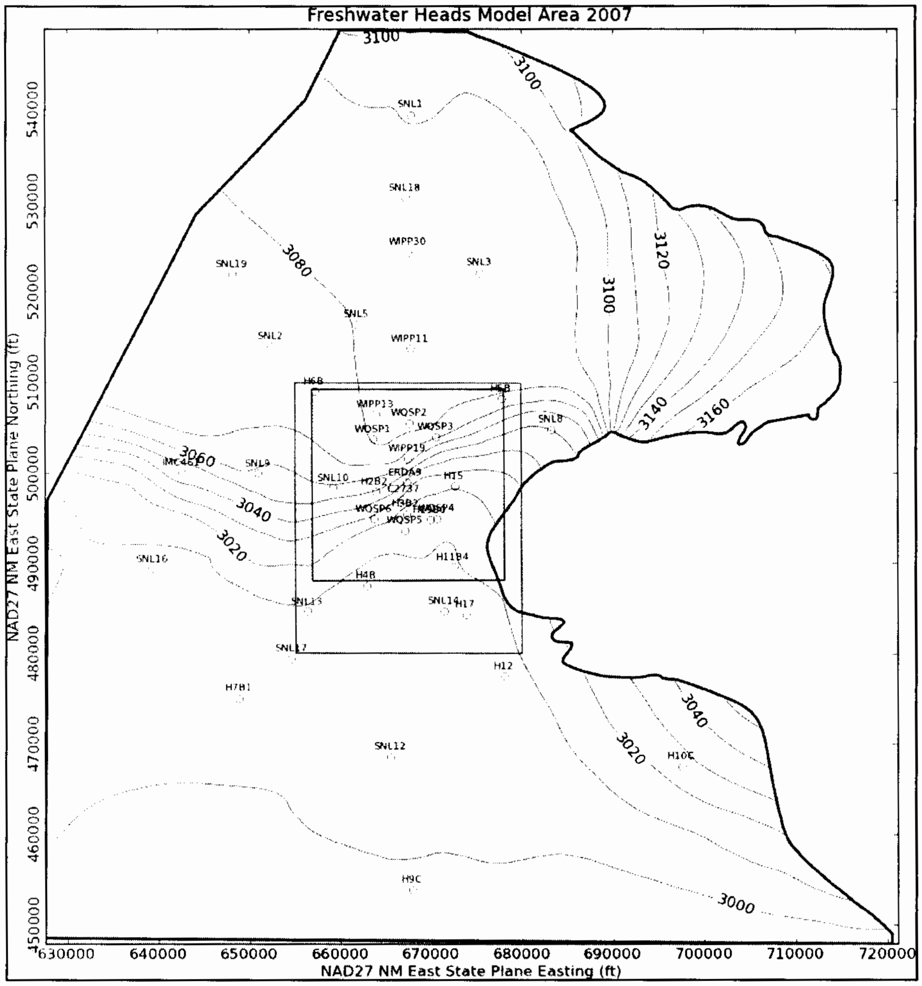

Figure 12. Model-generated May 2007 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 11; the black square is the WIPP LWB.

The scatter plot in Figure 13 shows measured and modeled freshwater heads at the observation locations used in the PEST calibration. The observations are divided into three groups, based on proximity to the WIPP site. Wells within the LWB are represented by red crosses, wells outside but within 3 km of the LWB are represented with green "×"s, and other wells within the MODFLOW model domain but distant from the WIPP site are given by a blue star. These groupings were utilized in the PEST calibration; higher weights (2.5) were given to wells inside the LWB, and lower weights (0.4) were given to wells distant to the WIPP site, while wells in the middle received an intermediate weight (1.0). Additional observations representing the average heads north of the LWB and south of the LWB were used to help prevent over-smoothing of the estimated results across the LWB. This allowed PEST to improve the fit of the model to observed heads inside the area contoured in Figure 11, at the expense of fitting wells closer to the boundary conditions (i.e., wells not shown in Figure 11).

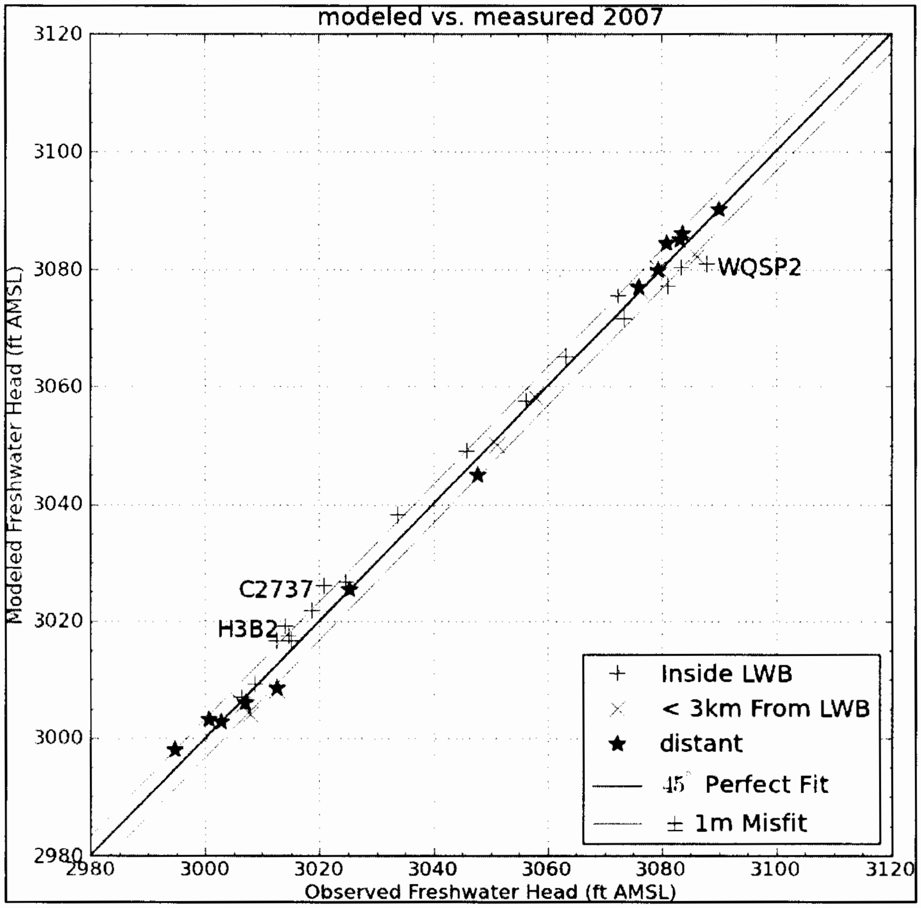

Figure 13. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and May 2007 observed freshwater heads

The black central diagonal line in Figure 13 represents a perfect model fit (1:1 or 45-degree slope); the two green lines on either side of this represent a 1-m misfit above or below the perfect fit. Wells more than 1.5 m from the 1:1 line are labeled.

The squared correlation coefficient (R^2) for the measured vs. modeled data is listed in Table 6. Figures 14 and 15 show the distribution of errors resulting from the PEST-adjusted fit to observed data. The wells within and near the WIPP LWB have an R^2 of greater than 99%. The distribution in Figure 14 is roughly symmetric about 0, indicating there is not a strong bias.

Table 6. 2007 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.992
wells <3km from WIPP LWB	0.990
all wells	0.992

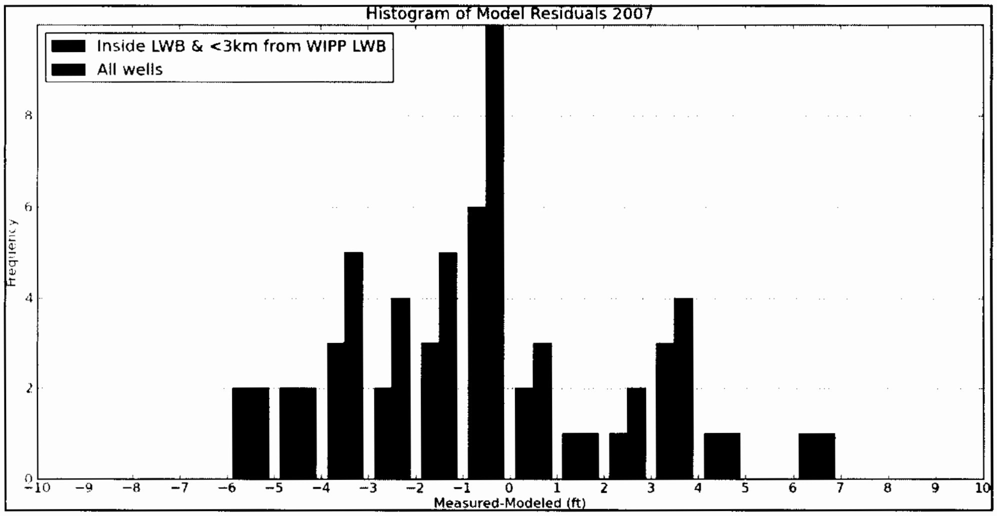

Figure 14. Histogram of Measured-Modeled errors for 2007

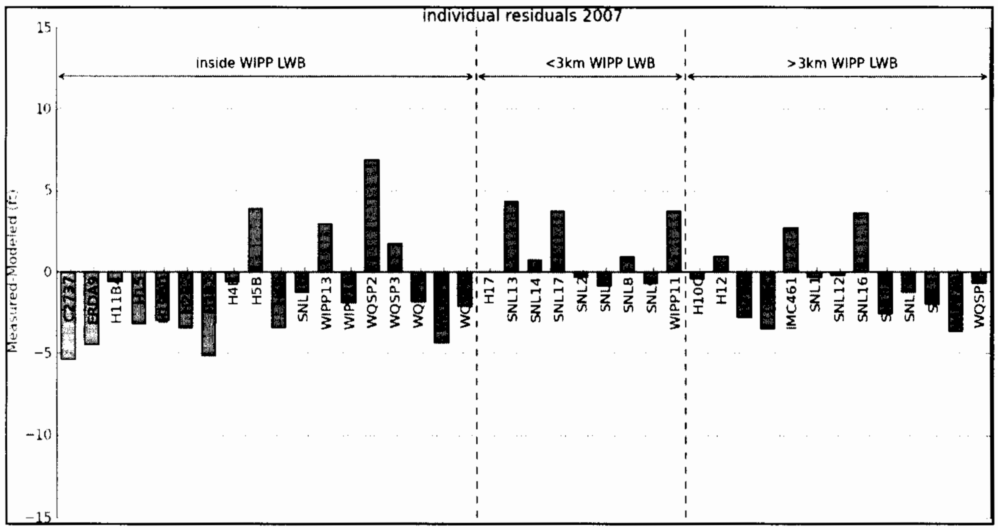

Figure 15. Measured-Modeled errors at each well for 2007

The model fit to the May 2007 observations is excellent, because these heads were the ones used to calibrate the PA MODFLOW model. The ensemble-average model captures the average Culebra behavior, while the PEST calibration improved the ensemble model fit to the May 2007 observations.

Results for 2008

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for September 2008 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. September 2008 was determined to have a large number of Culebra water levels available, few Culebra water levels were affected by pumping events, and most Culebra water levels agree with a quasi-steady state trend. Table 7 shows the freshwater head data set. The following discussion was adapted from the 2008 ASER.

Table 7.
Water Level Elevations for the September 2008 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Density (g/cm^3)
AEC-7	09/22/08	3,064.06	1.078
C-2737 (PIP)	09/24/08	3,023.61	1.029
ERDA-9	09/24/08	3,033.97	1.067
H-02b2	09/24/08	3,050.51	1.014
H-03b2	09/24/08	3,015.20	1.042
H-04b	09/24/08	3,006.82	1.015
H-05b	09/22/08	3,081.33	1.095
H-07b1	09/23/08	2,999.24	1.002
H-09c (PIP)	09/23/08	2,997.25	1.001
H-10c	09/23/08	3,024.16	1.001
H-11b4	09/22/08	3,009.92	1.070
H-12	09/23/08	3,007.71	1.097
H-16	09/25/08	3,050.45	1.039
H-17	09/22/08	3,007.52	1.133
H-19b0	09/24/08	3,015.69	1.068
I-461	09/23/08	3,046.33	1.005
SNL-01	09/23/08	3,085.69	1.033
SNL-02	09/23/08	3,074.57	1.012
SNL-03	09/23/08	3,081.17	1.023
SNL-05	09/23/08	3,077.77	1.010
SNL-09	09/22/08	3,057.49	1.024
SNL-10	09/22/08	3,056.14	1.011
SNL-12	09/23/08	3,003.45	1.005
SNL-13	09/22/08	3,012.72	1.027
SNL-14	09/22/08	3,006.17	1.048
SNL-16	09/22/08	3,010.72	1.010
SNL-17	09/23/08	3,007.36	1.006
SNL-18	09/23/08	3,082.59	1.028
SNL-19	09/23/08	3,073.61	1.003
WIPP-11	09/22/08	3,084.85	1.038
WIPP-13	09/22/08	3,081.86	1.053
WIPP-19	09/24/08	3,063.27	1.044

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Density (g/cm^3)
WIPP-25 (PIP)	09/23/08	3,069.43	1.011
WQSP-1	09/24/08	3,078.05	1.048
WQSP-2	09/24/08	3,086.54	1.048
WQSP-3	09/24/08	3,076.08	1.146
WQSP-4	09/24/08	3,016.16	1.075
WQSP-5	09/24/08	3,013.67	1.025
WQSP-6	09/24/08	3,022.96	1.014
The freshwater head values for September 2008 were estimated using densities computed from 2007 data except for wells ERDA-9, H-5b, and H-10c. Freshwater head calculations for these three wells use density values, obtained in the 2008 density survey, based on improved data collected from downhole Troll sensors.			

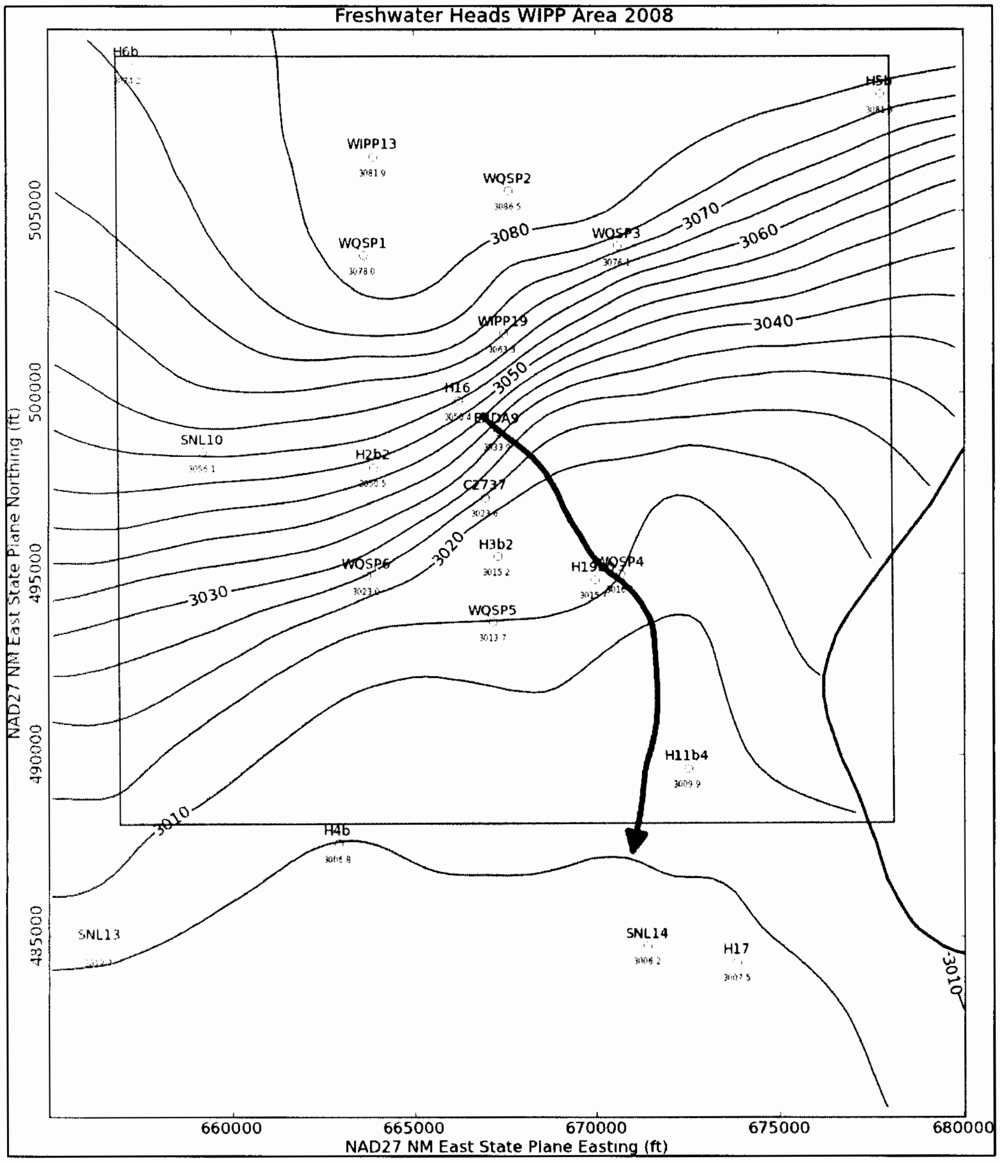

Figure 16. Model-generated September 2008 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

The blue arrow line in Figure 16 shows the model-calculated path a water particle would take through the Culebra from the coordinates corresponding to the WIPP facility Waste Shaft to the land withdrawal boundary (a path length of 4,085 m). The illustrated particle takes 5,715 years to travel from the waste handling shaft to the WIPP LWB assuming porous-medium flow with a porosity of 16 percent. The path has a length of 4,079 m, indicating a mean travel velocity of 0.71 m/year.

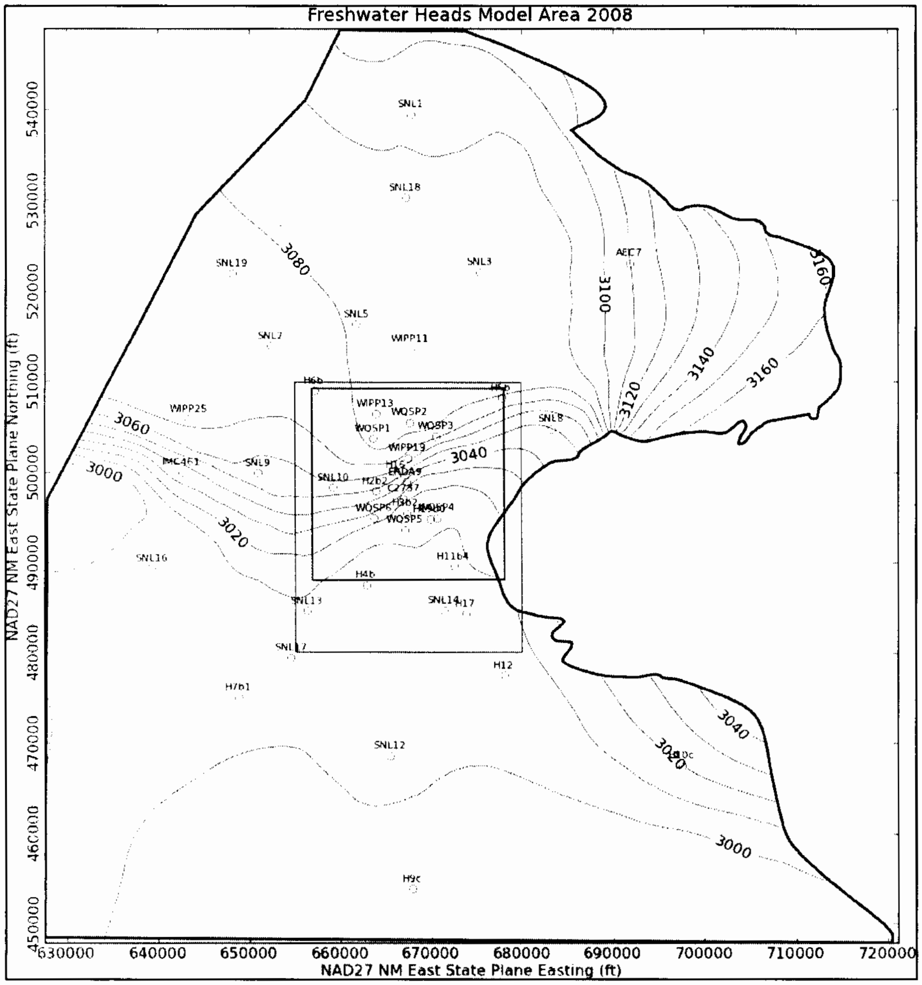

Figure 17. Model-generated September 2008 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 16; the black square is the WIPP LWB.

The scatter plot in Figure 18 shows measured and modeled freshwater heads at the observation locations used in the PEST calibration. The observations are divided into three groups, based on proximity to the WIPP site. Wells within the LWB are represented by red crosses, wells outside but within 3 km of the LWB are represented with green "×"s, and other wells within the MODFLOW model domain but distant from the WIPP site are given by a blue star. These groupings were utilized in the PEST calibration; higher weights (2.5) were given to wells inside the LWB, and lower weights (0.4) were given to wells distant to the WIPP site, while wells in the middle received an intermediate weight (1.0). Additional observations representing the average heads north of the LWB and south of the LWB were used to help prevent over-smoothing of the estimated results across the LWB. This allowed PEST to improve the fit of the model to observed heads inside the area contoured in Figure 16, at the expense of fitting wells closer to the boundary conditions (i.e., wells not shown in Figure 16).

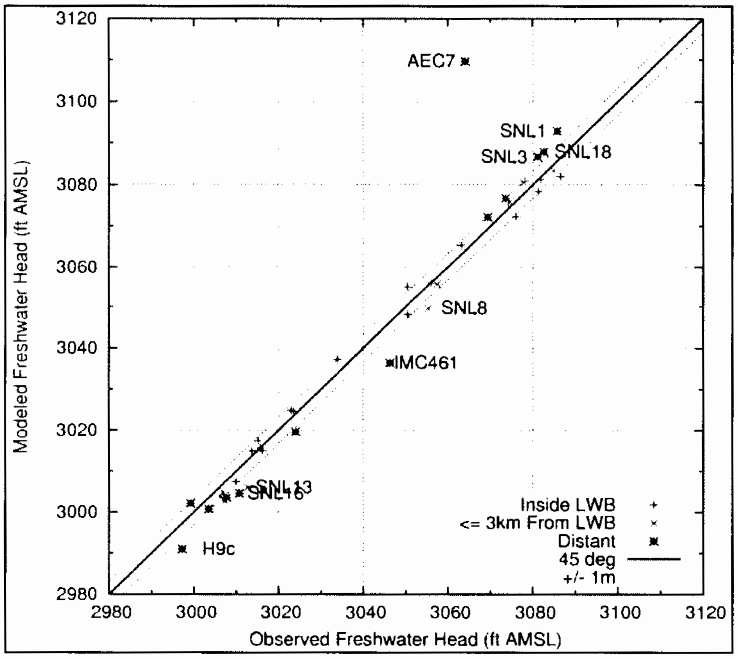

Figure 18. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and September 2008 observed freshwater heads

The black central diagonal line in Figure 18 represents a perfect model fit (1:1 or 45-degree slope); the two green lines on either side of this represent a 1-m misfit above or below the perfect fit. Wells more than 1.5 m from the 1:1 line are labeled.

The squared correlation coefficient (R^2) for the measured vs. modeled data is listed in Table 8. Figures 19 and 20 show the distribution of errors resulting from the PEST-adjusted fit to observed data. The wells within and near the WIPP LWB have an R^2 of greater than 99%. The distribution in Figure 19 is roughly symmetric about 0, indicating there is not a strong bias.

Table 8. 2008 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.992
wells <3km from WIPP LWB	0.991
all wells	0.948

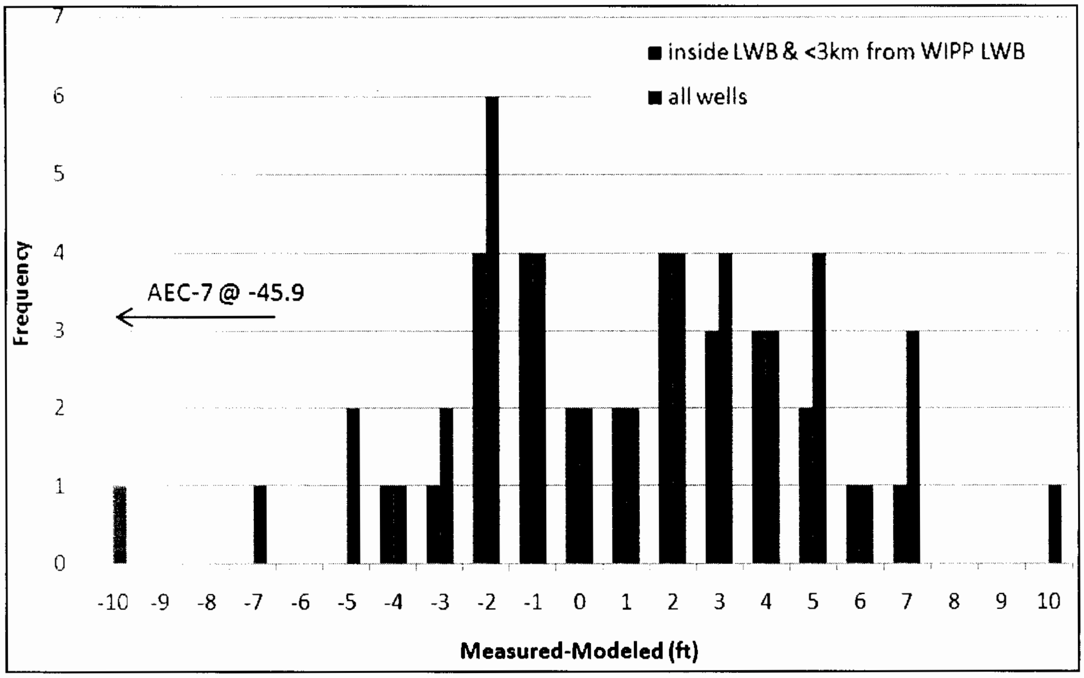

Figure 19. Histogram of Measured-Modeled errors for 2008

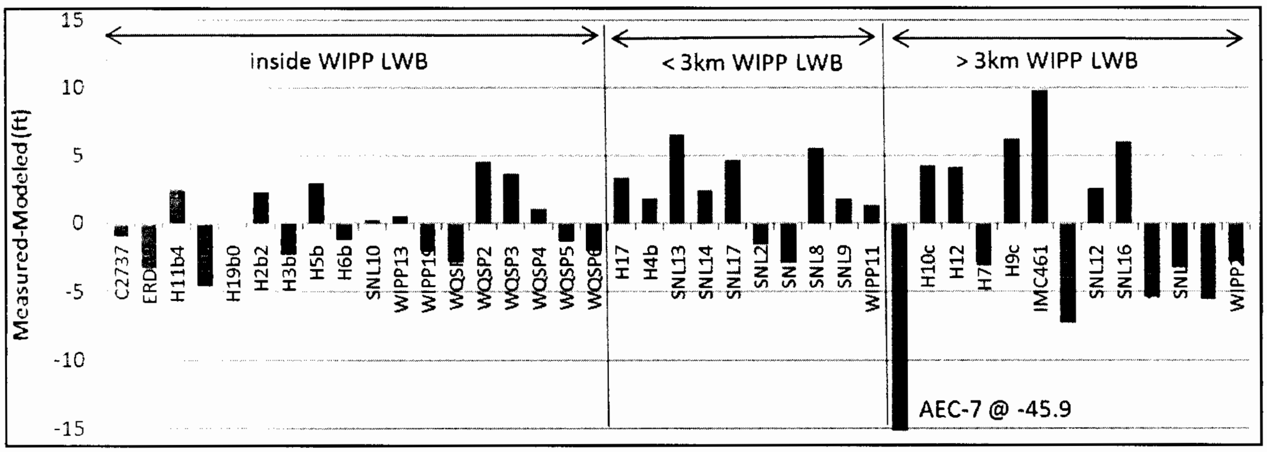

Figure 20. Measured-Modeled errors at each well for 2008

Well AEC-7 has a large misfit for two reasons. First, this well historically has consistently had an anomalously low freshwater head elevation lower than wells around it in all directions. Second, it did not have a May 2007 observation (due to well reconfiguration activities) and therefore was not included as a calibration target in the PABC MODFLOW model calibration. Aside from AEC-7, the model fit to the September 2008 observations is very good. The average model captures the average Culebra behavior, while the PEST calibration improved the model fit to the specific September 2008 observations.

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