Department of Energy
Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

JUN 2 8 2012

Mr. John Kieling, Acting Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 E. Rodeo Park Drive East, Bldg. 1
Santa Fe, New Mexico 87505-6303

Subject: Transmittal of the Waste Isolation Pilot Plant Calendar Year 2000-2004 Culebra Potentiometric Surface Map Package

Dear Mr. Kieling:

On August 5, 2011, the New Mexico Environment 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 Culebra potentiometric surface maps (Culebra Potentiometric Surface Map Package) within timeframes specified by the Order. Enclosed is the last submittal due to the NMED within 270 days from the approval of the 2009 Map Package on November 2, 2011. The submittal is the Calendar Year 2000-2004 Culebra Potentiometric Surface Map Package due by July 30, 2012.

Since this is the last requirement of the Final Stipulated Order, the Permittees request that this Order be closed following the NMED acceptance of this submittal.

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,

//Original signatures on file//

Jose R. Franco, Manager
Carlsbad Field Office

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

Enclosure

CBFO:OESH:DJF:ANC:12-0754:UFC 5486.00

cc: w/enclosure
R. Maestas, NMED *ED
CBFO M&RC

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J. Davis, NMED ED
T. Kliphuis, NMED ED
*ED denotes electronic distribution

CBFO:OESH:DJF:ANC:12-0754:UFC 5486.00

Calendar Year 2000-2004 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 2000-2004 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 2000-2004 map package by July 30, 2012

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 2000-2004, 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 (CRA) (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 WIPP site is given on the first figure of each section. The freshwater head values were estimated using appropriate specific gravities from 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 2000-2004 maps were assembled by SNL from the Annual Site Environmental Report (ASER) for each year. Water level data from 2000 was not reported in the ASER so it was collected from WIPP data records. The head data were plotted ateach well to determine the best month for modeling and mapping, choosingthe least-perturbed month. The selected month freshwater heads were then used in the model for calibration target heads. Culebra specific gravities were estimated from historic Troll data for 2003 and 2004; there was no Troll data available prior to 2003.

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. Prior to 2006, top of casing elevations were surveyed by different organizations and there was no traceable pedigree. In 2006 all monitoring wells were surveyed at the same time, using the same surveyor, to common benchmarks using modern GPS survey technologies. For the map package, the top of casing elevations were changed to normalize top of casing elevations from year to year. The water level data did not change only the reference elevations, which did not affect the modeling output. The specific gravity values (and freshwater heads computed from specific gravity, depth to water, and Culebra midpoint elevations) used in the following tables are from the SNL analysis (Kuhlman, 2012).

The set of wells used for calibration targets in this report is different from the wells used in the 2005-2007 report due to changes in the Culebra groundwater monitoring network through time. AEC-7 was re-perforated at the Culebra in 2004 and did not have representative water levels until it was again re-perforated in 2008. Only one of the SNL-series wells (SNL-12) existed and had representative water levels during the 2000-2004 timeframe. Wells H-14, H-15, H-18, and WIPP-18 were converted from Culebra to

Magenta using bridge plugs in 2001 (with a permanent plugback in 2003). Wells DOE-1, WIPP-12, WIPP-21, WIPP-25, WIPP-26 and P-15 were plugged and abandoned without replacement wells. Wells C-2737, I-461 (equivalent to IMC-461), and SNL-12 were drilled during the 2000-2004 timeframe and therefore do not have water levels for each year. On the H-07, H-09, and H-10 well pads there were redundant Culebra monitoring wells, and the primary Culebra monitoring well was changed during the 2000-2004 timeframe. H-07b1 was a redundant well (quarterly measurements) during this timeframe. H-09c was a redundant Culebra well on the H-09 pad, but became the primary Culebra well when H-09a and H-09b were plugged in 2002. H-10c was converted to a Culebra monitoring well by perforating the casing, to replace H-10b, which was plugged and abandoned at the same time in early 2002. At both the H-07 and H-09 well pads the same Culebra monitoring well was used through time, despite the shift in primary Culebra observation well at each pad. This was done to maintain as much consistency as possible (although earlier water level observations are only quarterly).

Results for 2000

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for December 2000 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. ERDA-9 used a September water level because of anomalously low water levels near the end of 2000. H-09c used a June water level because before 2002 only quarterly water levels were measured in this well (H-09b was the primary Culebra well on this pad until it was plugged in February 2002 during pressure-grouting activities in H-09a). H-14 used a September water level because later water levels were somewhat low. P-15 used a January water level because December was an anomalously low water level. WIPP-30 used a June water level because of low water levels following well-maintenance activities in October. WQSP-2, WQSP-3, WQSP-5, and WQSP-6 used water levels earlier in the year to avoid periods with residual drawdown from sampling events. 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 December 2000 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
AEC-7	12/7/2000	3060.76	1.089
DOE-1	12/5/2000	3005.09	1.088
ERDA-9	9/11/2000	3029.36	1.067
H-02b2	12/6/2000	3038.45	1.006
H-03b2	12/6/2000	3010.07	1.042
H-04b	12/6/2000	3003.08	1.015
H-05b	12/7/2000	3074.05	1.104
H-06b	12/7/2000	3063.94	1.040

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
H-07b1	12/5/2000	2997.51	1.002
H-09c	6/6/2000	2990.58	1.001
H-10b	12/5/2000	3026.25	1.047
H-11b4	12/5/2000	3005.12	1.070
H-12	12/5/2000	3005.18	1.095
H-14	9/11/2000	3011.91	1.010
H-15	12/6/2000	3015.32	1.154
H-17	12/5/2000	2999.84	1.133
H-18	12/7/2000	3075.23	1.045
H-19b0	12/6/2000	3010.50	1.068
P-15	1/19/2000	3015.22	1.015
P-17	12/5/2000	2998.75	1.070
WIPP-12	12/6/2000	3070.21	1.100
WIPP-13	12/7/2000	3077.00	1.053
WIPP-18	12/6/2000	3070.83	1.100
WIPP-19	12/6/2000	3060.99	1.059
WIPP-21	12/6/2000	3039.24	1.071
WIPP-22	12/6/2000	3059.94	1.087
WIPP-25	12/7/2000	3060.63	1.011
WIPP-26	12/4/2000	3022.34	1.009
WIPP-30	6/5/2000	3072.77	1.018
WQSP-1	12/7/2000	3069.72	1.048
WQSP-2	9/12/2000	3080.31	1.048
WQSP-3	9/11/2000	3069.85	1.146
WQSP-4	12/5/2000	3011.29	1.075
WQSP-5	10/11/2000	3008.83	1.025
WQSP-6	11/9/2000	3019.59	1.014
Note: non-December water levels are discussed in preceding text.			

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.

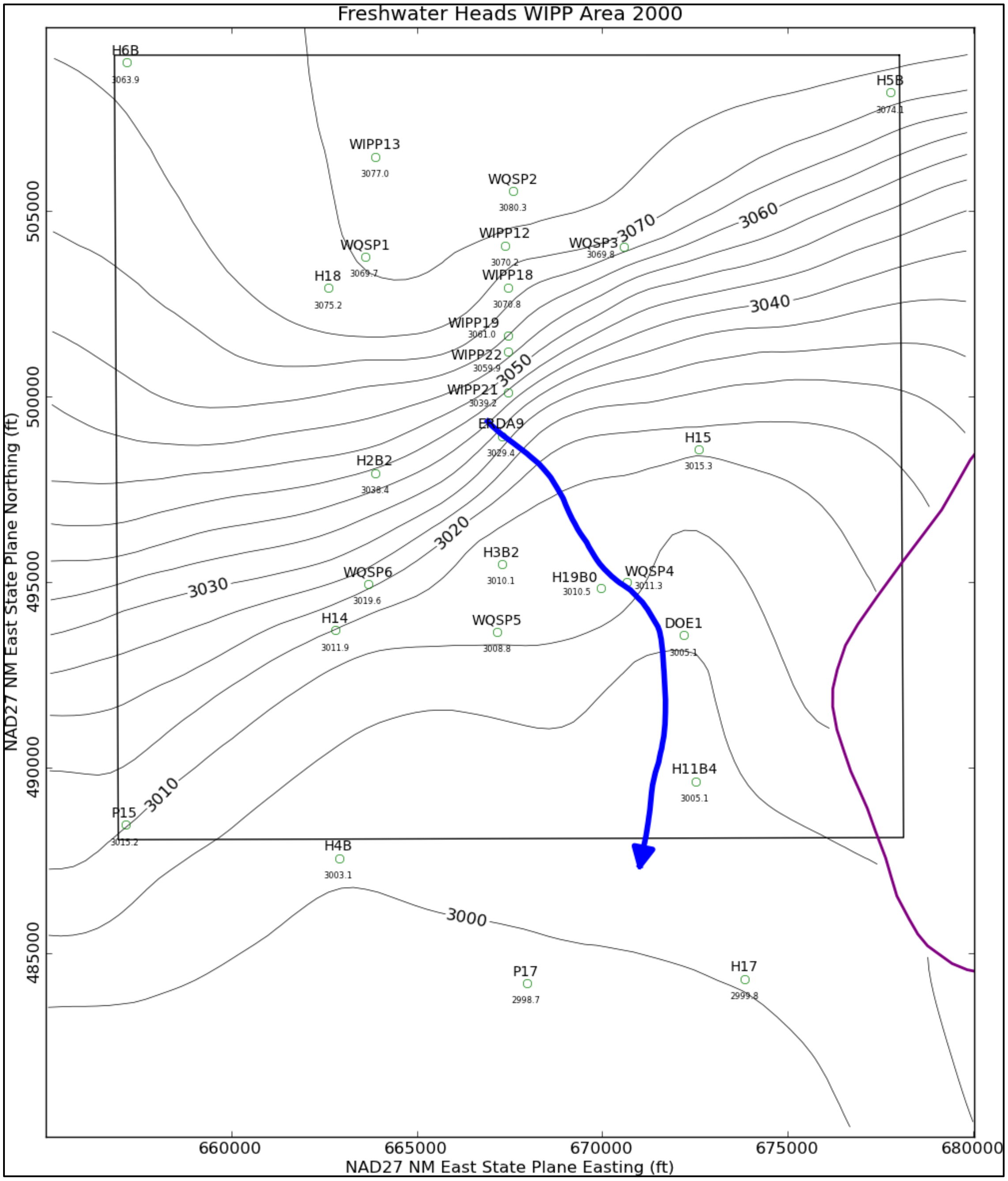

Figure 1. Model-generated December 2000 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

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 13,405 ft). Assuming a 4-m (13.1 ft) thickness for the transmissive portion of the Culebra and a constant porosity of 16%, the travel time to the WIPP LWB is 5,752 years (model output is adjusted from an original 7.75 m (25.4 ft) Culebra thickness). This is an average velocity of 2.33 ft/yr.

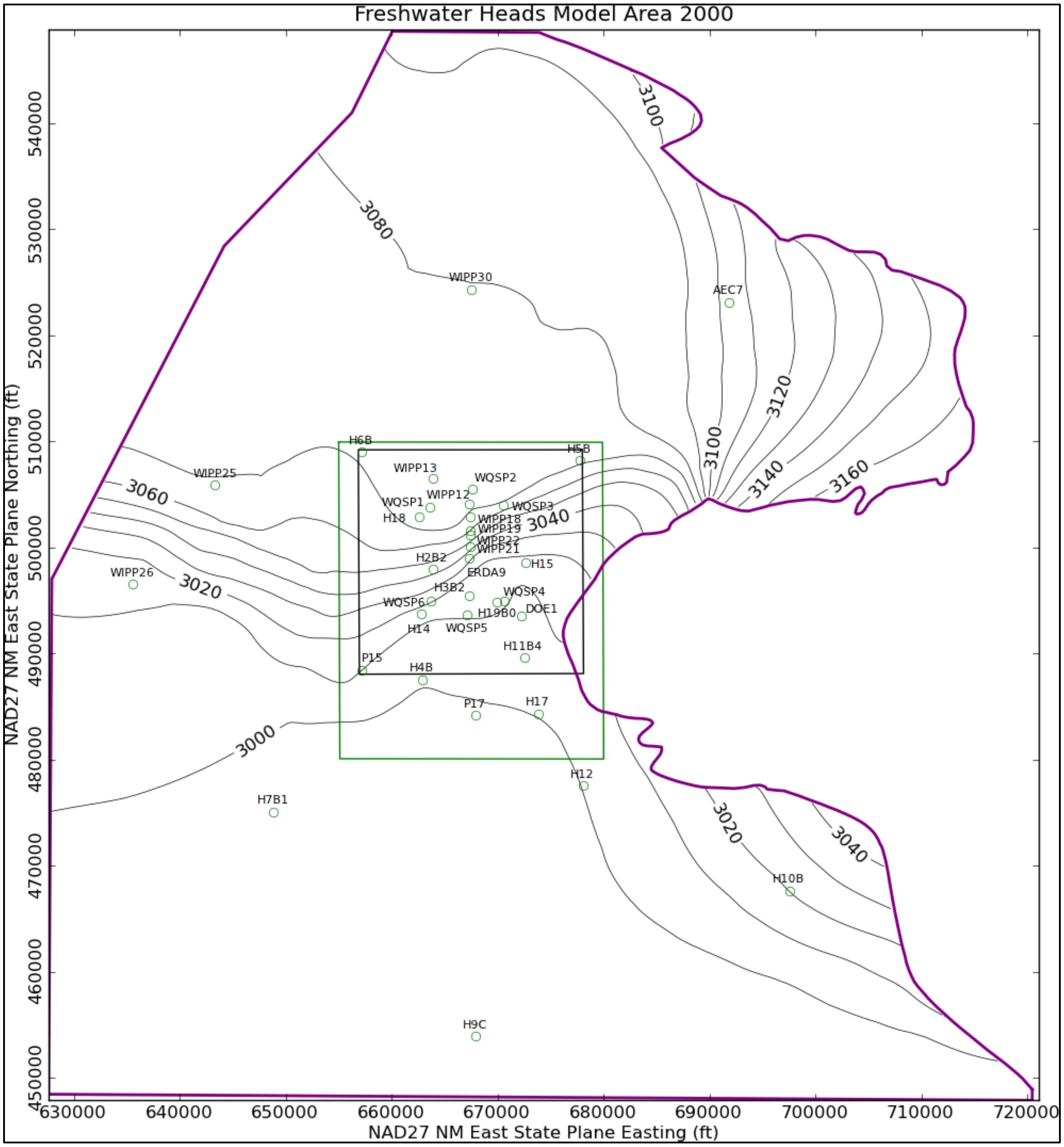

Figure 2. Model-generated December 2000 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 1, black square is WIPP LWB.

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 (1.86 miles) 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).

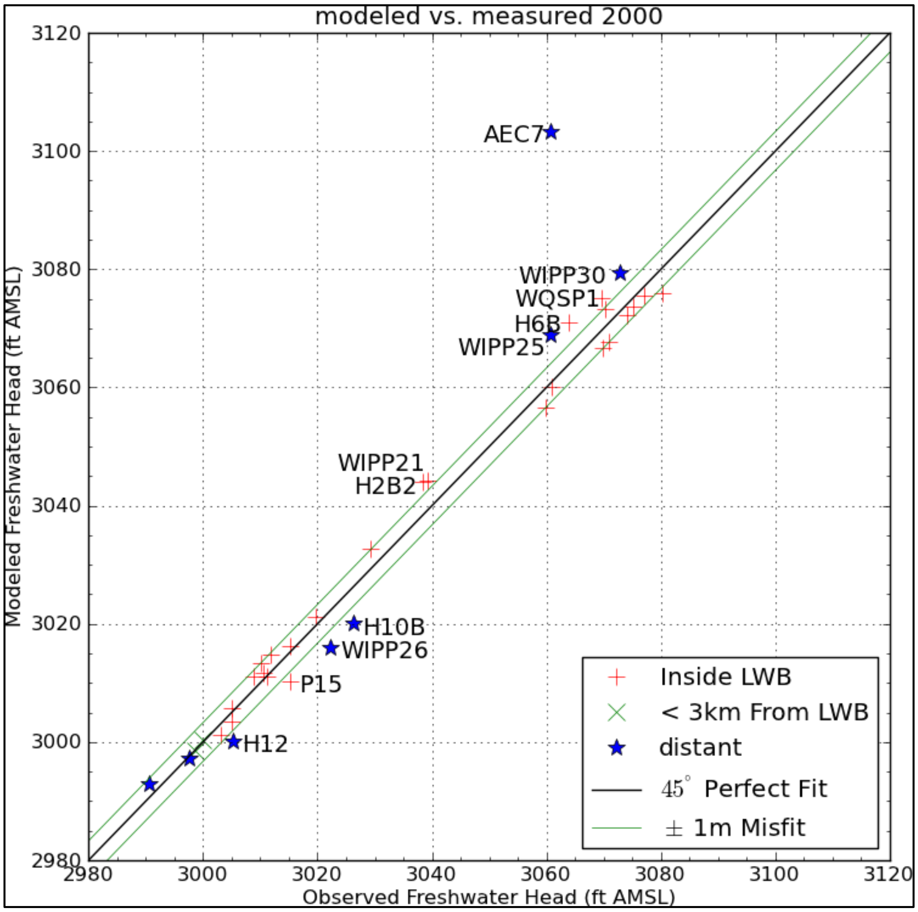

Figure 3. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and December 2000 observed freshwater heads

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 (3.28 ft) misfit above or below the perfect fit. Wells more than 1.5 m (4.92 ft) from the 1:1 line are individually labeled. AEC-7 has a large misfit for two reasons. First, this well has historically had an anomalously low freshwater head elevation, lower than wells around it in all directions. Secondly, it did not have a May 2007 observation and therefore was not included as a calibration target in the PA MODFLOW model calibration. This model was calibrated as part of the 2009 CRA, which provides the basis for current map generation.

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. 2000 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.989
wells <3km (1.86 miles) from WIPP LWB	0.989
all wells	0.940

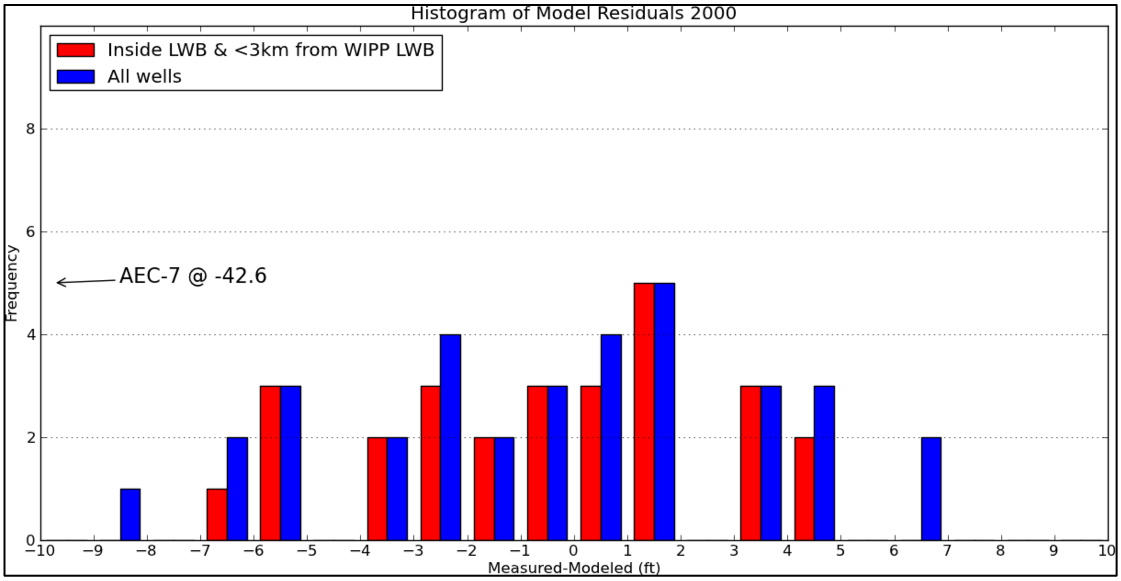

Figure 4. Histogram of Measured-Modeled errors for 2000

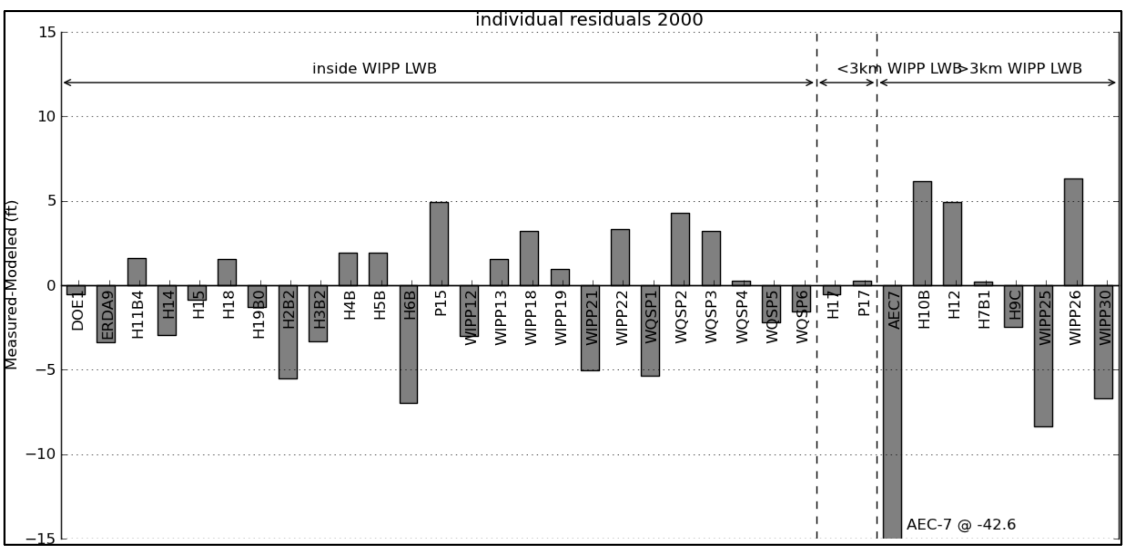

Figure 5. Measured-Modeled errors at each well location for 2000.

The model fit to the December observations is good. The ensemble-average model captures the bulk Culebra behavior, while the PEST calibration improved the model fit to the specific December 2000 observations. The results are good considering several wells (H-14, H-15, H-18, P-15, and WIPP-18) were used in the average model calibration that did not exist as Culebra monitoring wells after 2000, and therefore were not included in the steady-state T-Field calibration exercise for CRA-2009 PABC.

Results for 2001

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for December 2001 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. December 2001 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. An alternate month was used for WSQP-2, WQSP-3, WQSP-5, and WQSP-6 to avoid periods of drawdown following sampling events. 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 December 2001 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
AEC-7	12/4/2001	3060.83	1.089
DOE-1	12/5/2001	3006.92	1.088
ERDA-9	12/5/2001	3029.82	1.067
H-02b2	12/5/2001	3039.44	1.006
H-03b2	12/5/2001	3011.29	1.042
H-04b	12/5/2001	3003.90	1.015
H-05b	12/4/2001	3074.34	1.104
H-06b	12/5/2001	3064.76	1.040
H-07b1	12/3/2001	2997.44	1.002
H-09c	12/4/2001	2992.39	1.001
H-10b	12/4/2001	3026.44	1.047
H-11b4	12/3/2001	3006.23	1.070
H-12	12/4/2001	3005.94	1.095
H-17	12/4/2001	3001.41	1.133
H-19b0	12/5/2001	3011.78	1.068
P-17	12/3/2001	3011.78	1.068
WIPP-12	12/5/2001	3070.93	1.100
WIPP-13	12/5/2001	3076.48	1.053
WIPP-19	12/5/2001	3061.91	1.059
WIPP-21	12/5/2001	3040.26	1.071
WIPP-22	12/5/2001	3061.02	1.087
WIPP-25	12/4/2001	3063.65	1.011
WIPP-26	12/5/2001	3022.01	1.009

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
WIPP-30	12/3/2001	3074.15	1.018
WQSP-1	12/5/2001	3070.37	1.048
WQSP-2	9/6/2001	3080.25	1.048
WQSP-3	9/6/2001	3068.96	1.146
WQSP-4	12/5/2001	3012.30	1.075
WQSP-5	10/9/2001	3009.94	1.025
WQSP-6	10/10/2001	3020.24	1.014
Note: non-December water levels are discussed in preceding text.			

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.

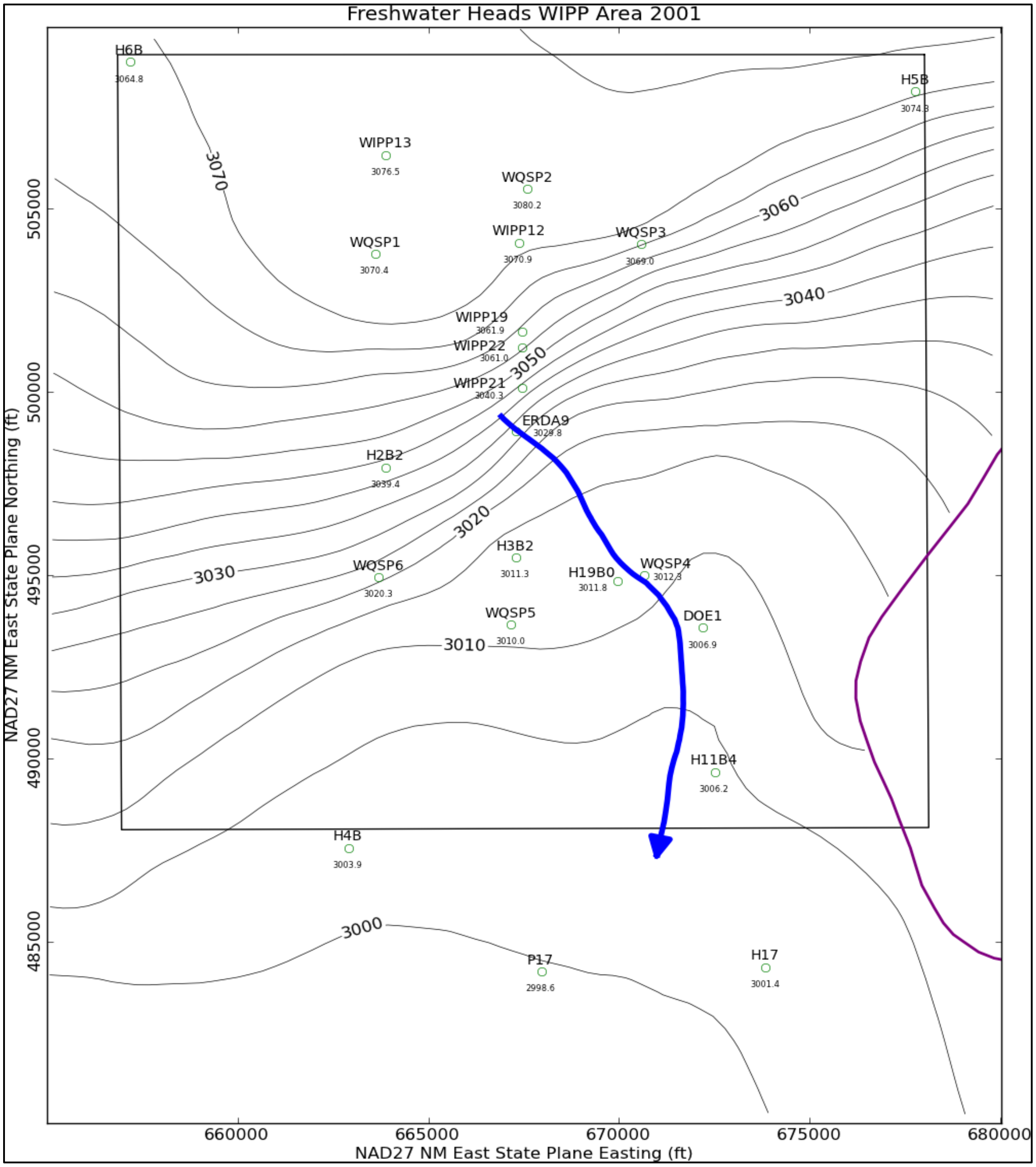

Figure 6. Model-generated December 2001 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

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 13,386 ft). Assuming a 4-m (13.1 ft) thickness for the transmissive portion of the Culebra and a constant porosity of 16%, the travel time to the WIPP LWB is 6,082 years (model output is adjusted from an original 7.75-m (25.4 ft) Culebra thickness). This is an average velocity of 2.20 ft/yr.

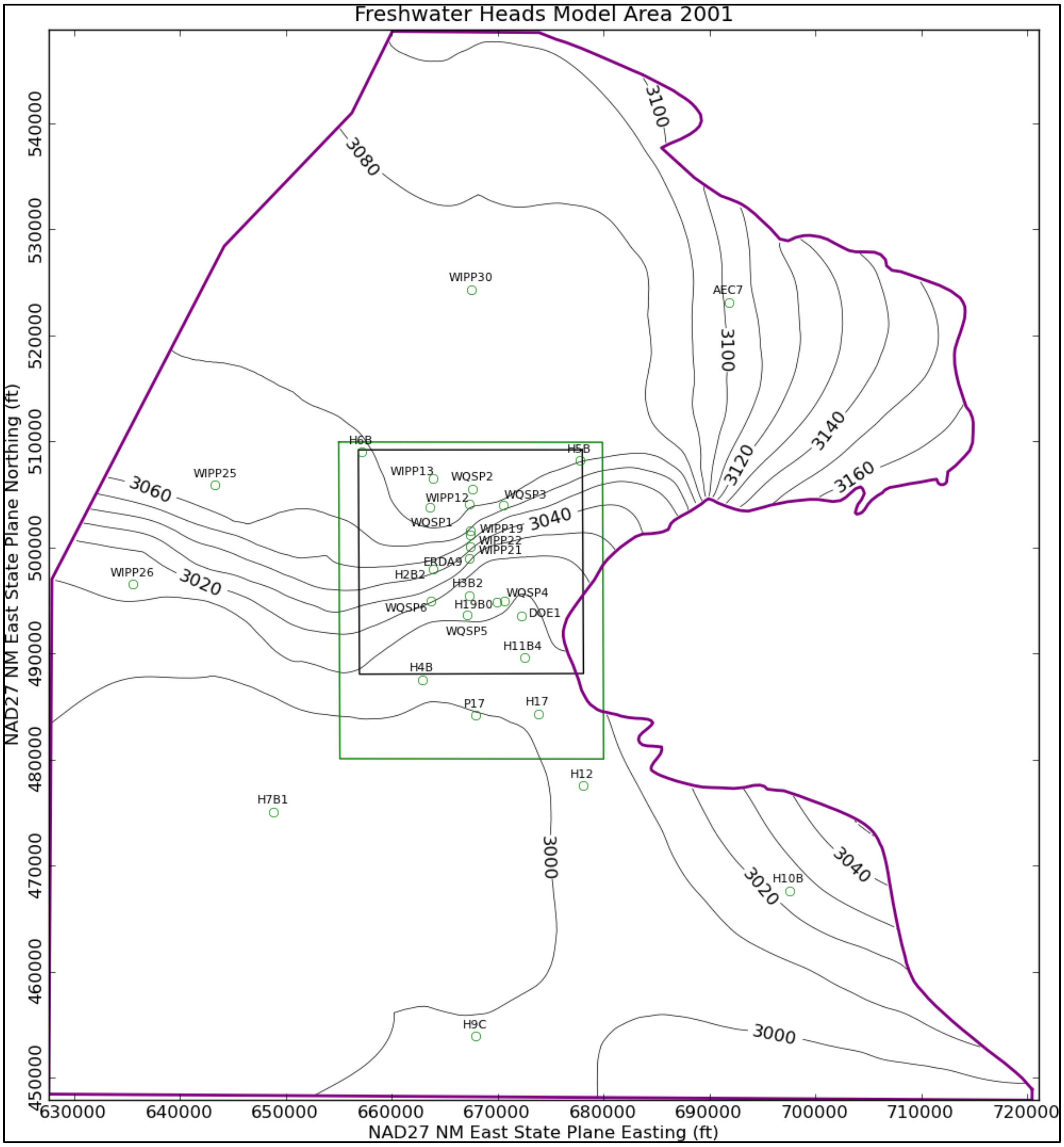

Figure 7. Model-generated December 2001 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 6, black square is WIPP LWB.

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 (1.86 miles) 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). AEC-7 was given a low weight (0.01), to prevent its large residual from dominating the optimization. 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).

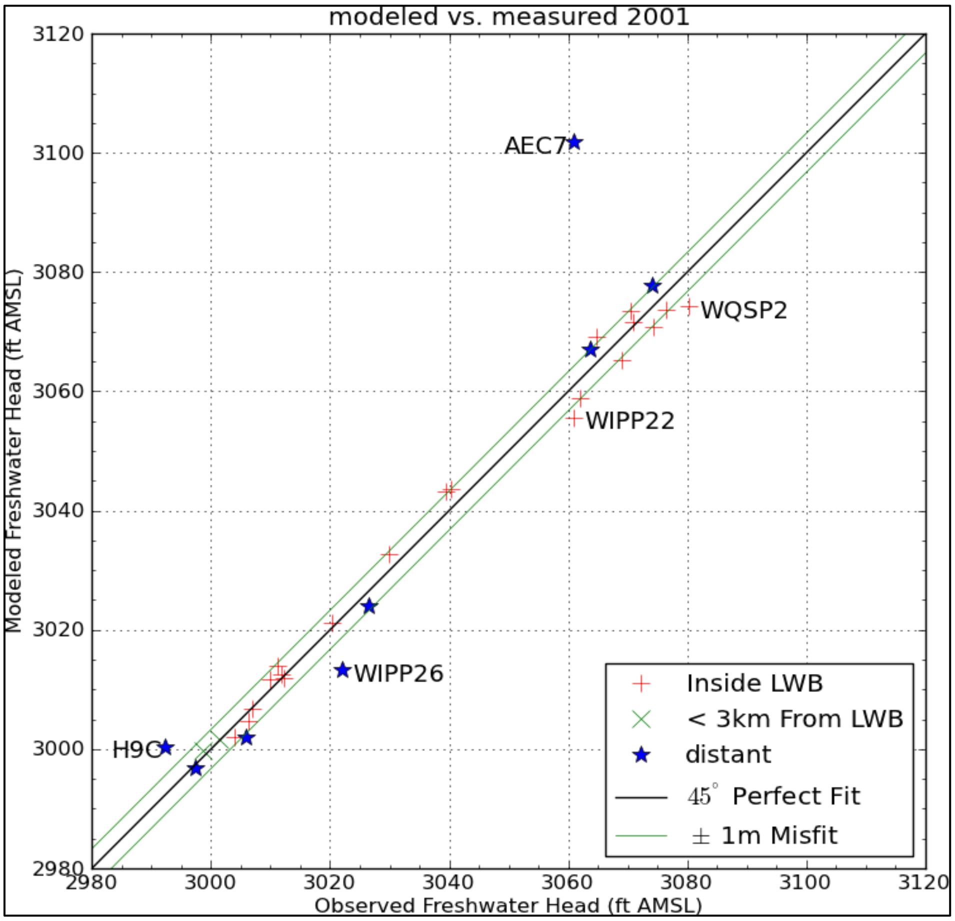

Figure 8. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and December 2001 observed freshwater heads

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. AEC-7 has a large misfit for two reasons. First, this well has historically had an anomalously low freshwater head elevation, lower than wells around it in all directions. Secondly, it did not have a May 2007 observation and therefore was not included as a calibration target in the PA MODFLOW model calibration. This model was calibrated as part of the 2009 CRA, which provides the basis for current map generation.

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. 2001 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.989
wells <3km (1.86 miles)from WIPP LWB	0.991
all wells	0.932

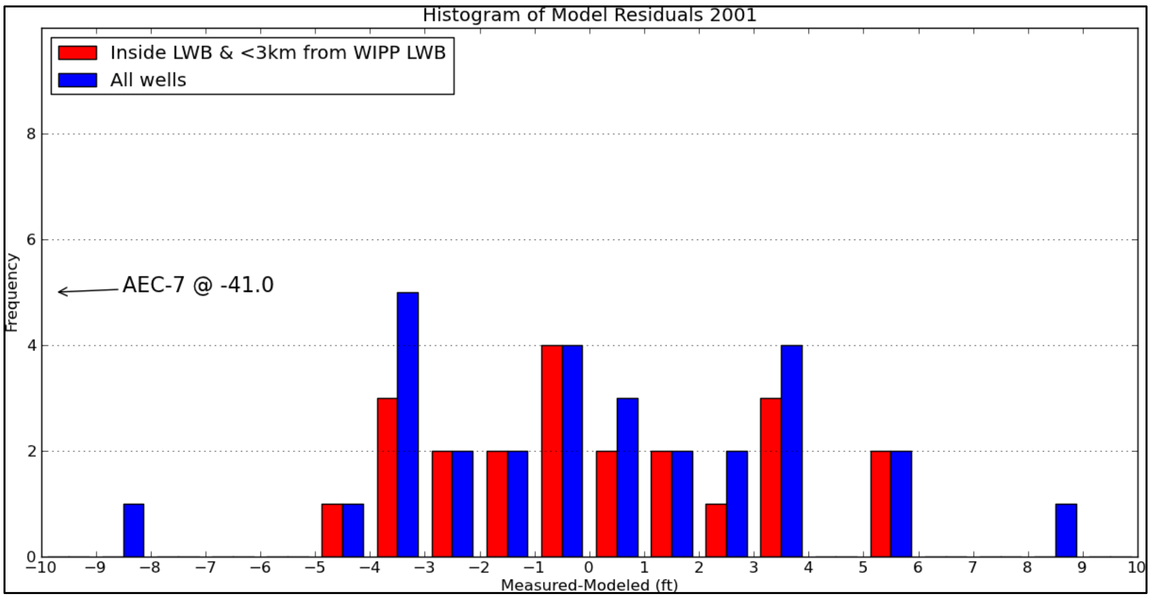

Figure 9. Histogram of Measured-Modeled errors for 2001

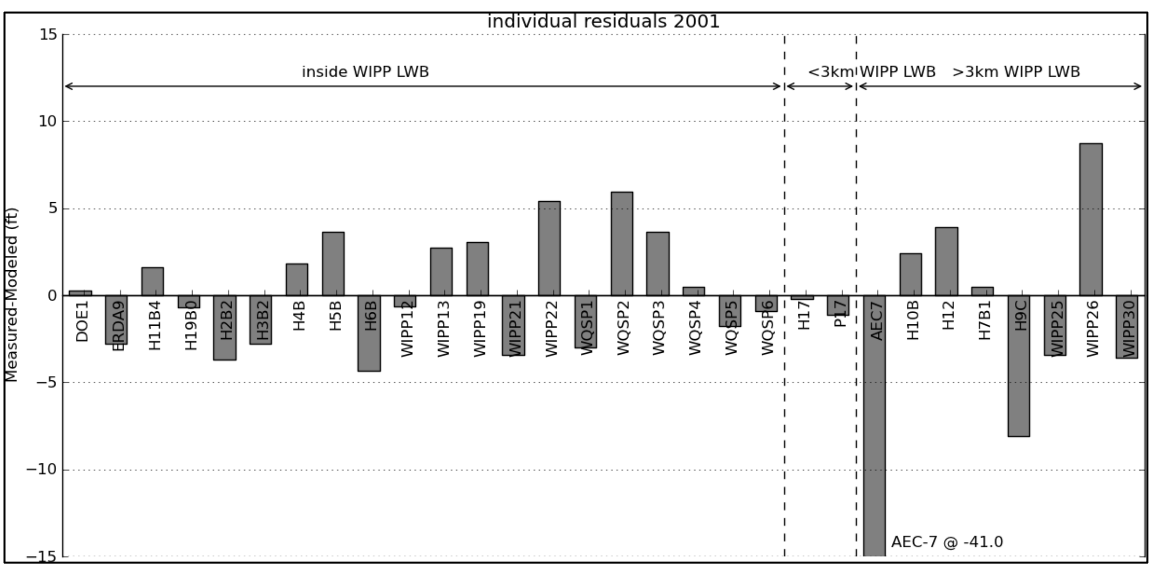

Figure 10. Measured-Modeled errors at each well for 2001

Aside from AEC-7 and to a lesser extent two more distant wells (H-09C far south of WIPP and WIPP-26 in Nash Draw), the model fit to the December 2001 observations is good. The averaged MODFLOW model captures the bulk Culebra flow behavior, while the PEST calibration improved the model fit to the specific December 2001 observations.

Results for 2002

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for December 2002 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. December 2002 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. September 2002 water levels were used for WQSP-2 and WQSP-3 due to drawdown from sampling activities in October 2002. 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 December 2002 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
AEC-7	12/3/2002	3060.66	1.089
C-2737	12/4/2002	3018.37	1.000
DOE-1	12/4/2002	3008.40	1.088
ERDA-9	12/2/2002	3031.14	1.067
H-02b2	12/4/2002	3040.75	1.006
H-03b2	12/2/2002	3012.43	1.042
H-04b	12/2/2002	3004.49	1.015
H-05b	12/3/2002	3074.70	1.104
H-06b	12/2/2002	3066.57	1.040
H-07b1	12/3/2002	2997.47	1.002
H-10c	12/3/2002	3026.21	1.001
H-11b4	12/4/2002	3005.74	1.070
H-12	12/3/2002	3007.15	1.095
H-17	12/4/2002	3002.76	1.133
H-19b0	12/4/2002	3013.09	1.068
P-17	12/4/2002	2999.74	1.070
WIPP-12	12/2/2002	3072.18	1.100
WIPP-13	12/2/2002	3077.46	1.053
WIPP-19	12/2/2002	3063.39	1.059
WIPP-21	12/2/2002	3041.57	1.071
WIPP-22	12/2/2002	3062.50	1.087

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
WIPP-25	12/3/2002	3065.58	1.011
WIPP-26	12/3/2002	3023.62	1.009
WIPP-30	12/3/2002	3076.94	1.018
WQSP-1	12/2/2002	3072.15	1.048
WQSP-2	9/9/2002	3081.33	1.048
WQSP-3	9/9/2002	3070.34	1.146
WQSP-4	12/2/2002	3013.65	1.075
WQSP-5	12/2/2002	3010.89	1.025
WQSP-6	12/2/2002	3020.47	1.014
Note: non-December water levels are discussed in preceding text.			

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.

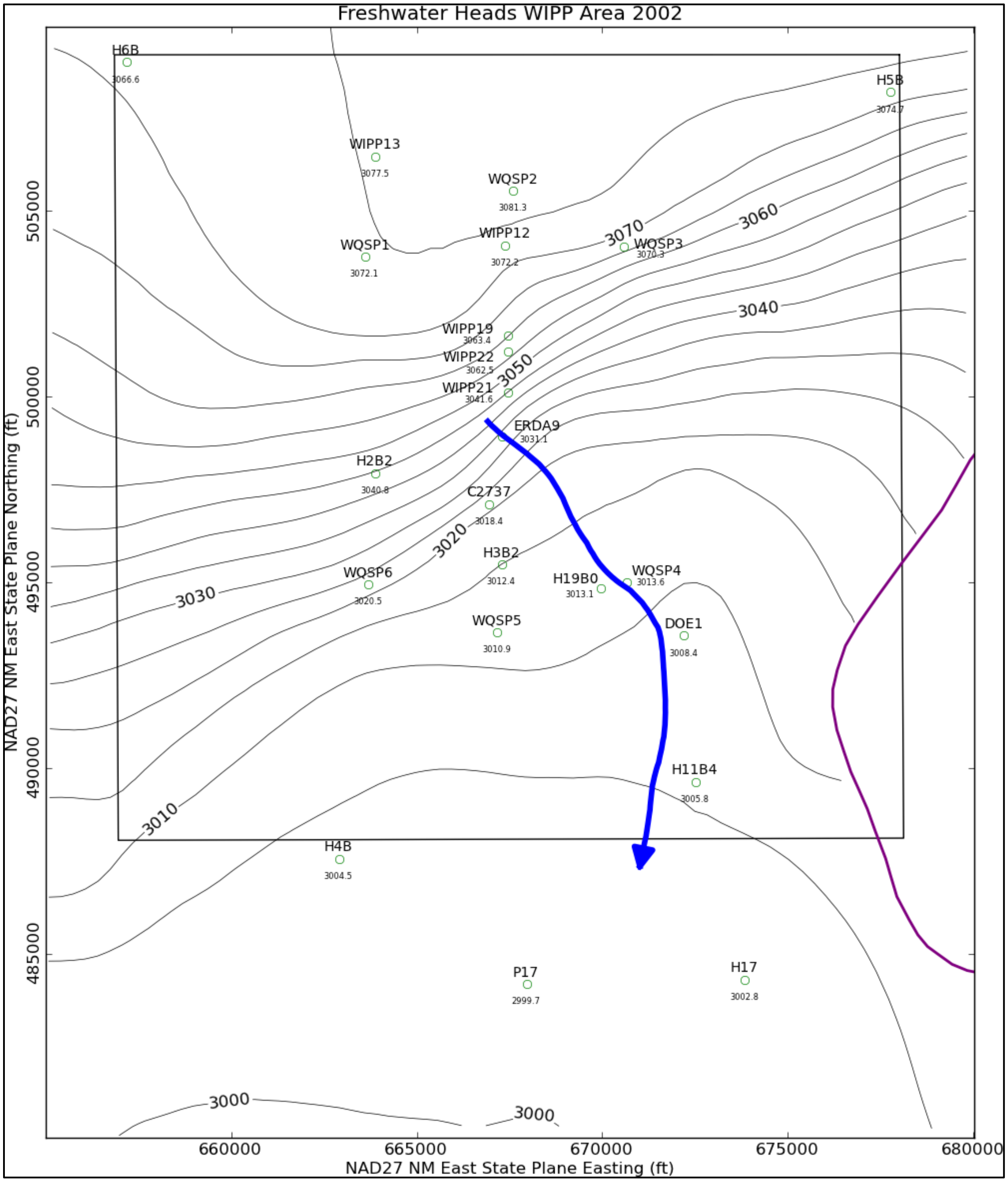

Figure 11. Model-generated December 2002 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

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 13,406 ft). Assuming a 4-m (13.1 ft) thickness for the transmissive portion of the Culebra and a constant porosity of 16%, the travel time to the WIPP LWB is 5,942 years (model output is adjusted from an original 7.75-m (25.4 ft) Culebra thickness). This is an average velocity of 2.26 ft/yr.

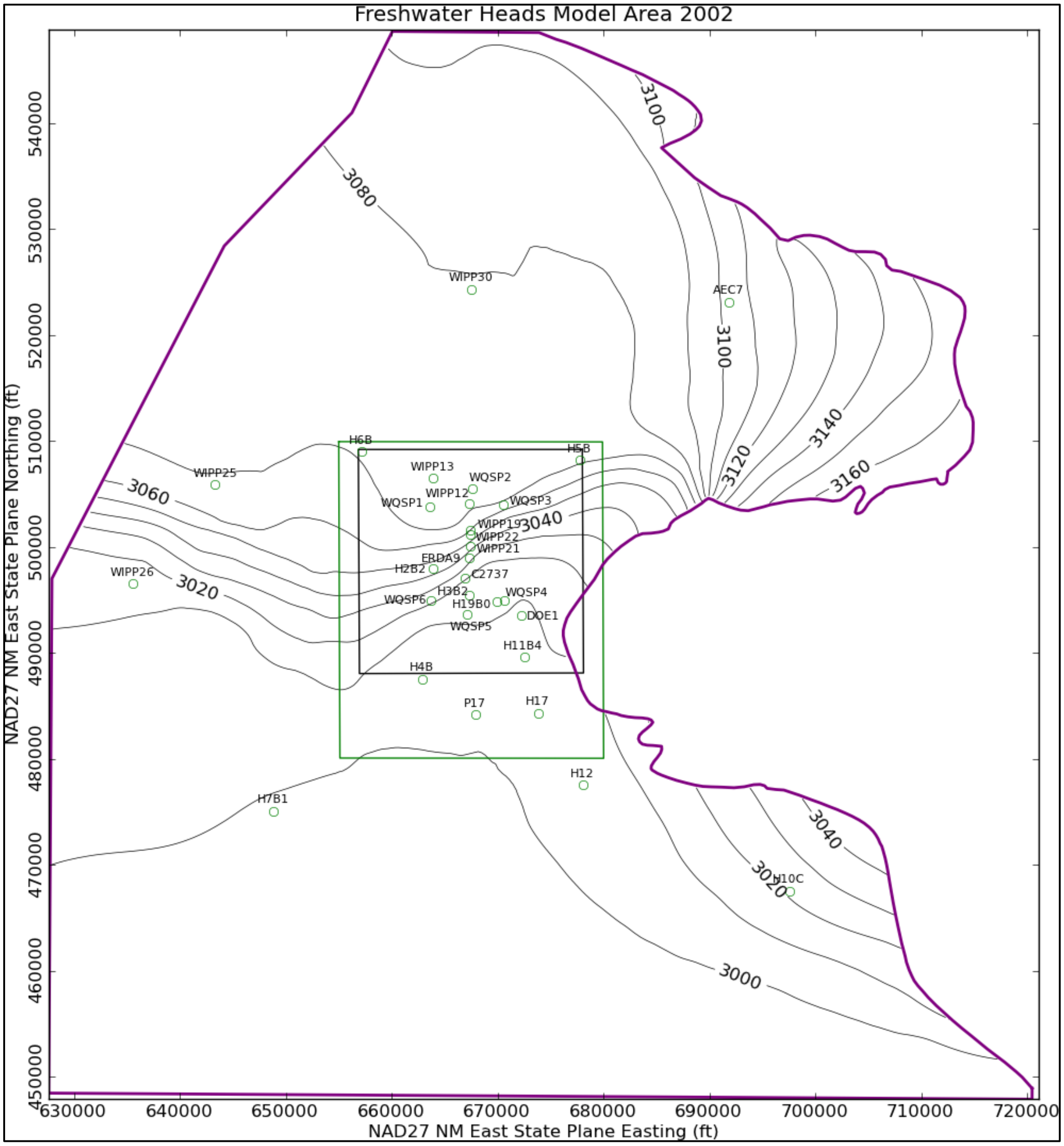

Figure 12. Model-generated December 2002 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 11; the black square is the WIPP LWB.

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 (1.86 miles) 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). AEC-7 was given a low weight (0.01), to

prevent its large residual from dominating the optimization. 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).

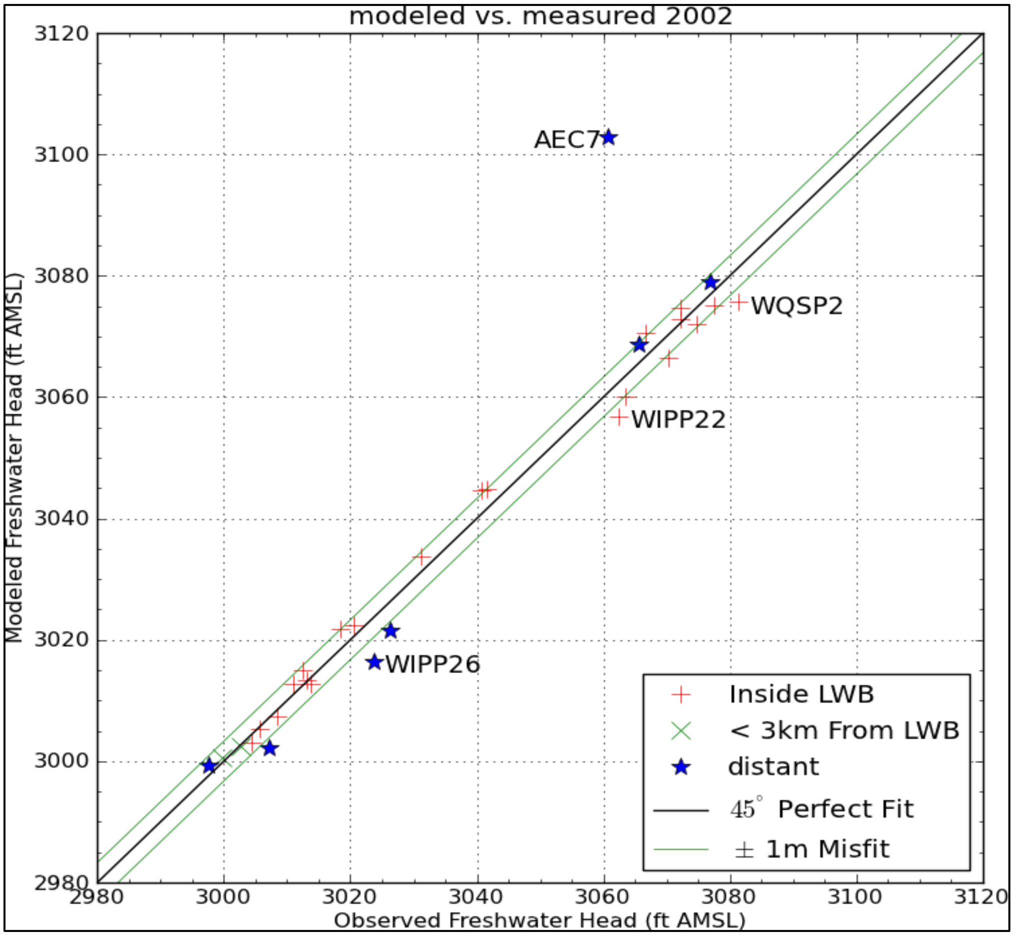

Figure 13. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and December 2002 observed freshwater heads

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 (3.28 ft) misfit above or below the perfect fit. Wells more than 1.5 m (4.92 ft) from the 1:1 line are labeled. AEC-7 has a large misfit for two reasons. First, this well has historically had an anomalously low freshwater head elevation, lower than wells around it in all directions. Secondly, it did not have a May 2007 observation and therefore was not included as a calibration target in the PA MODFLOW model calibration. This model was calibrated as part of the 2009 CRA, which provides the basis for current map generation.

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 approximately 99%. The distribution in Figure 14 is roughly symmetric about 0, indicating there is not a strong bias.

Table 6. 2002 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.989
wells <3km (1.86 miles) from WIPP LWB	0.990
all wells	0.929

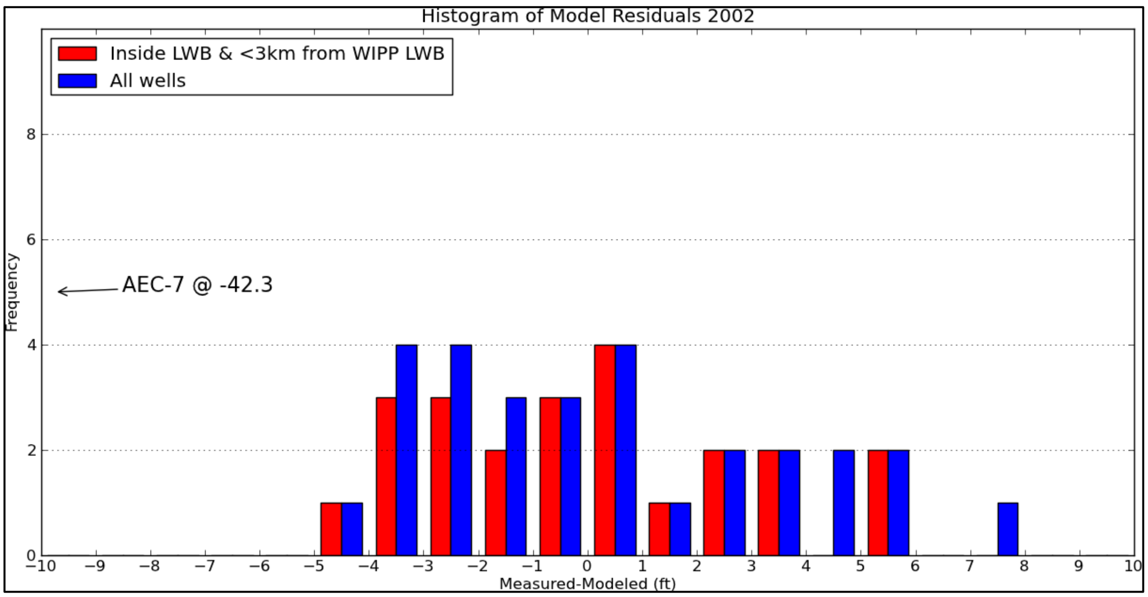

Figure 14. Histogram of Measured-Modeled errors for 2002

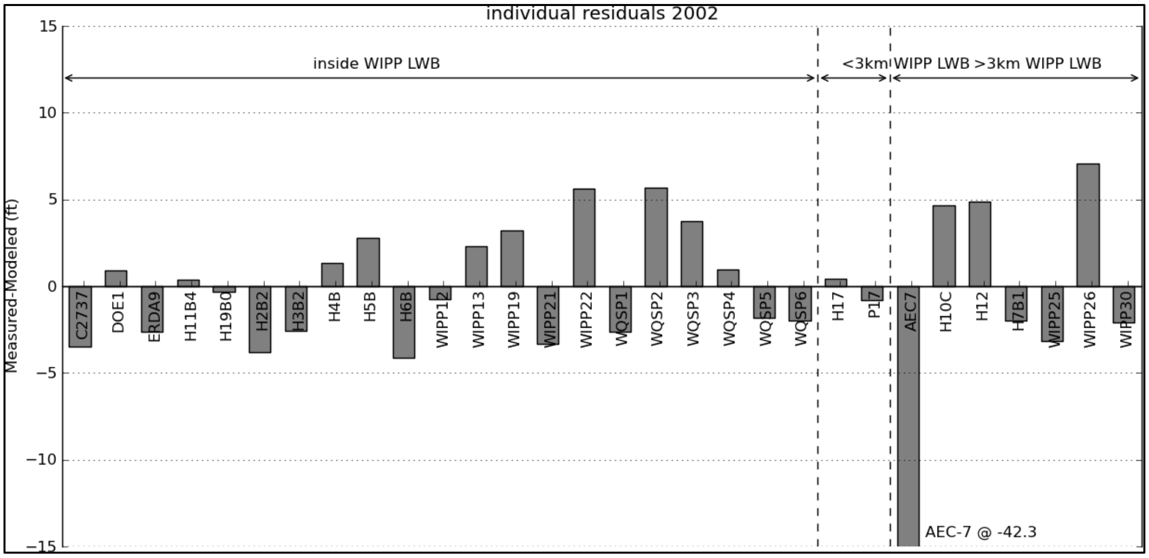

Figure 15. Measured-Modeled errors at each well for 2002

Aside from AEC-7, and to a lesser extent WIPP-26 (which is in Nash Draw), the model fit to the December 2002 observations is good. The averaged MODFLOW model captures the bulk Culebra flow behavior, while the PEST calibration improved model fit to the December 2002 observations.

Results for 2003

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads for September 2003 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 2003 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. C-2737 used a March water level because the well was configured for testing in the Magenta the remainder of 2003. Table 7 shows the freshwater head data set. The following figures and discussion of mapping were modified from Kuhlman (2012).

Table 7.
Water Level Elevations for the September 2003 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
AEC-7	9/10/2003	3062.53	1.089
C-2737	3/12/2003	3018.73	1.000
DOE-1	9/10/2003	3008.69	1.088
ERDA-9	9/10/2003	3031.30	1.067
H-02b2	9/9/2003	3041.21	1.006
H-03b2	9/10/2003	3012.50	1.042

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
H-04b	9/9/2003	3003.31	1.015
H-05b	9/10/2003	3075.49	1.104
H-06b	9/8/2003	3065.88	1.040
H-07b1	9/8/2003	2997.44	1.002
H-09c	9/8/2003	2991.27	1.001
H-10c	9/9/2003	3025.56	1.001
H-11b4	9/10/2003	3005.02	1.070
H-12	9/9/2003	3007.78	1.095
H-17	9/10/2003	3001.94	1.133
H-19b0	9/10/2003	3013.02	1.068
P-17	9/10/2003	2999.05	1.070
WIPP-12	9/9/2003	3072.08	1.100
WIPP-13	9/8/2003	3076.87	1.053
WIPP-19	9/9/2003	3063.42	1.059
WIPP-21	9/9/2003	3041.50	1.071
WIPP-22	9/9/2003	3062.53	1.087
WIPP-25	9/8/2003	3064.17	1.011
WIPP-26	9/8/2003	3022.77	1.009
WIPP-30	9/9/2003	3077.36	1.018
WQSP-1	9/9/2003	3071.88	1.048
WQSP-2	9/9/2003	3081.04	1.048
WQSP-3	9/9/2003	3070.51	1.146
WQSP-4	9/9/2003	3013.42	1.075
WQSP-5	9/9/2003	3011.15	1.025
WQSP-6	9/9/2003	3021.88	1.014
Note: non-September water levels are discussed in preceding text.			

The model-generated freshwater head contours are given in Figures 16 and 17. 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.

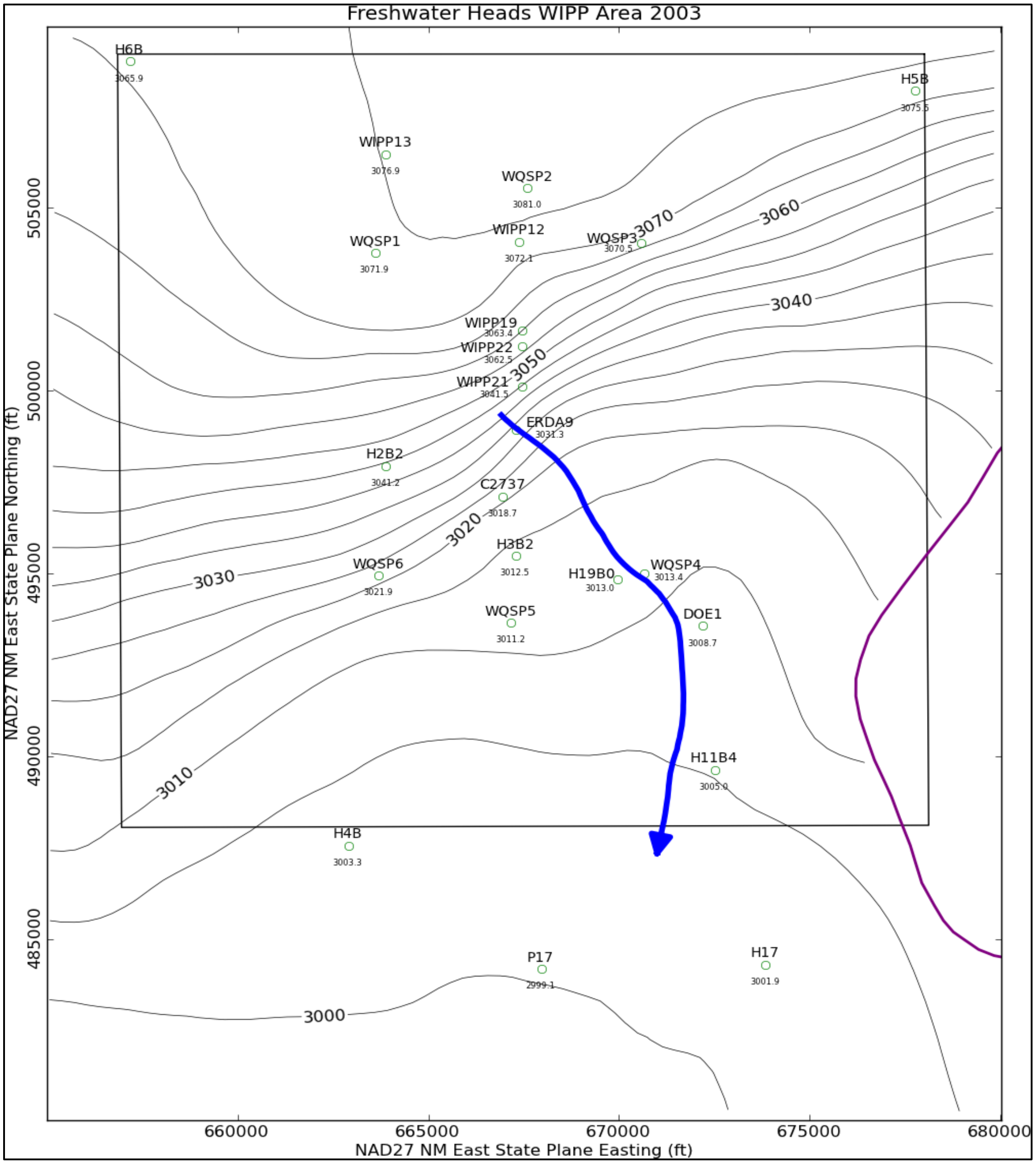

Figure 16. Model-generated September 2003 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

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 13,392 ft). The illustrated particle takes 5,984 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 mean travel velocity of 2.23 ft/year.

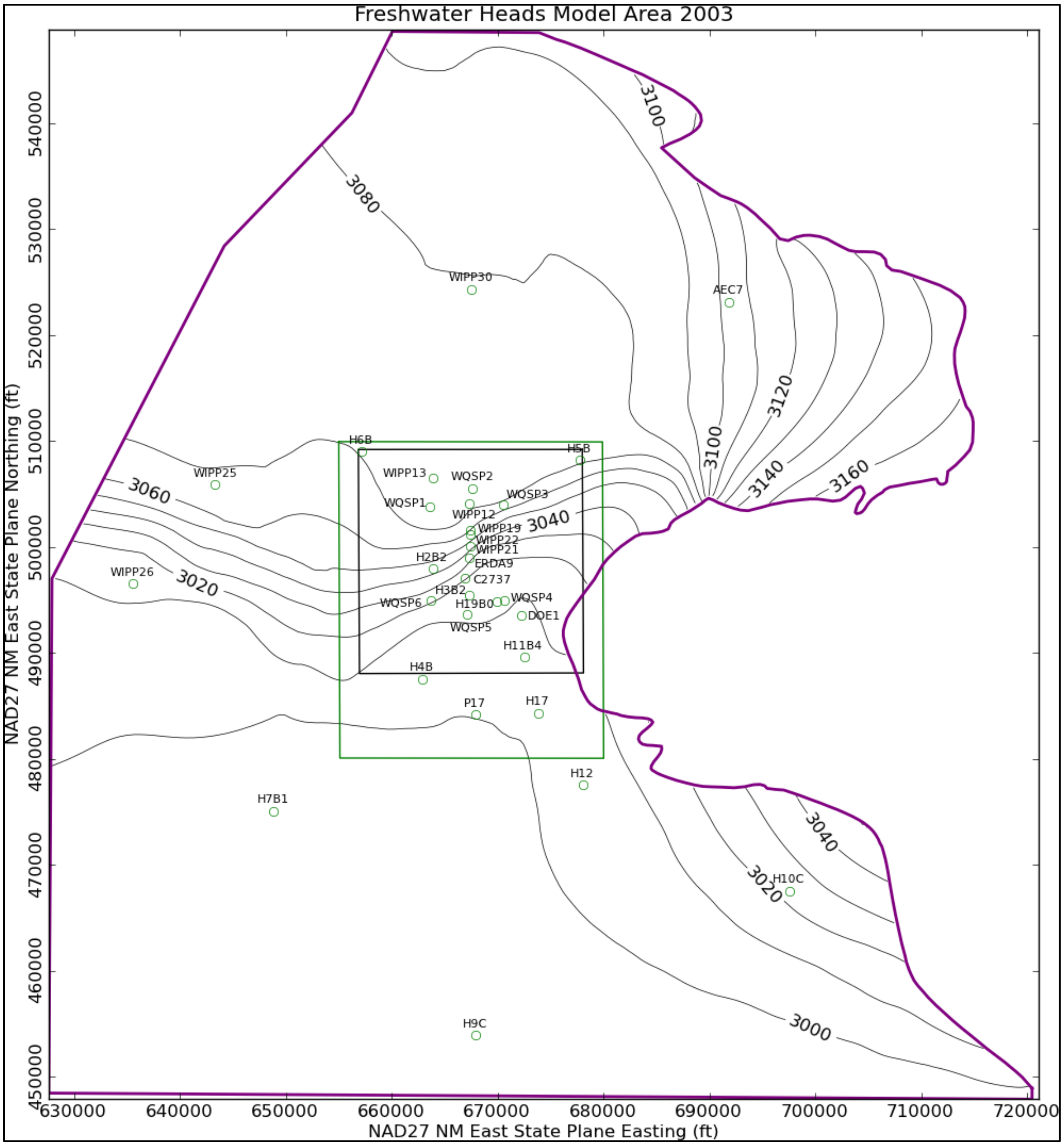

Figure 17. Model-generated September 2003 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 16; the black square is the WIPP LWB.

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 (1.86 miles) 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). AEC-7 was given a low weight (0.01), to

prevent its large residual from dominating the optimization. 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).

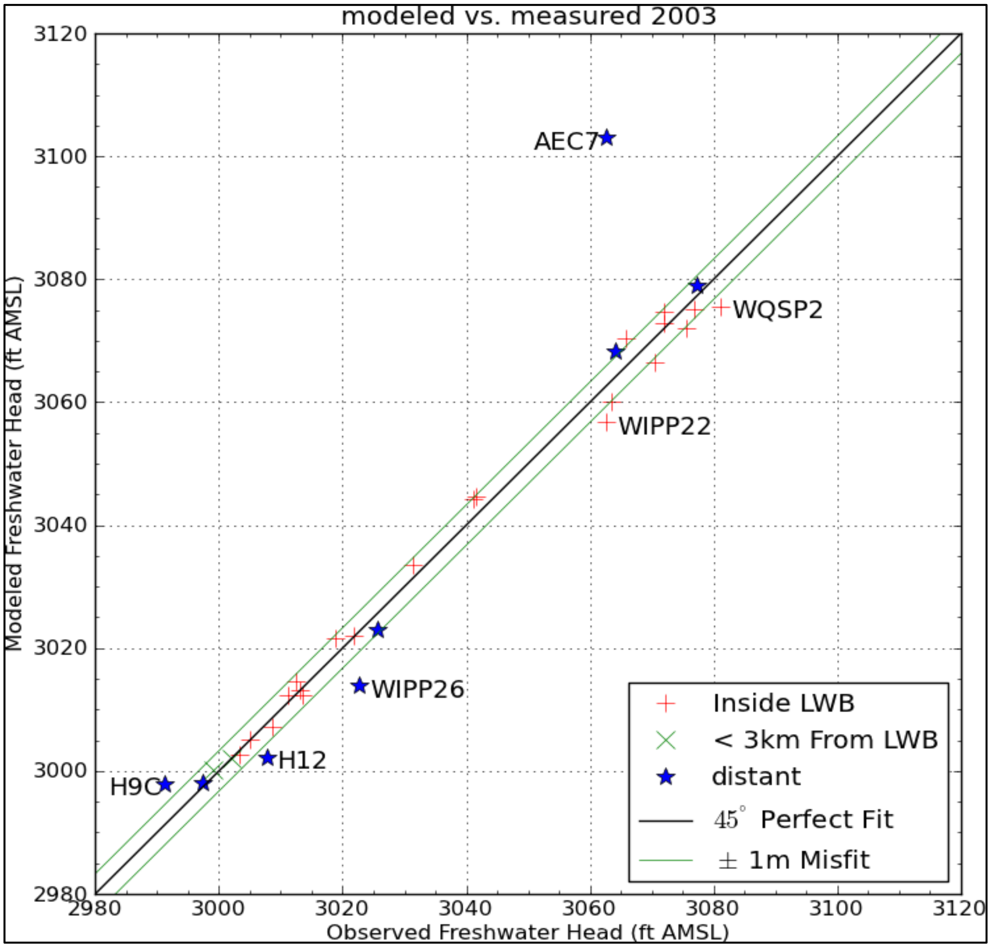

Figure 18. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and September 2003 observed freshwater heads.

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 (3.28 ft) misfit above or below the perfect fit. Wells more than 1.5 m (4.92 ft) from the 1:1 line are labeled. AEC-7 has a large misfit for two reasons. First, this well has historically had an anomalously low freshwater head elevation, lower than wells around it in all directions. Secondly, it did not have a May 2007 observation and therefore was not included as a calibration target in the PA MODFLOW model calibration. This model was calibrated as part of the 2009 CRA, which provides the basis for current map generation.

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 approximately 99%. The distribution in Figure 19 is roughly symmetric about 0, indicating there is not a strong bias.

Table 8. 2003 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.990
wells <3km (1.86 miles) from WIPP LWB	0.991
all wells	0.936

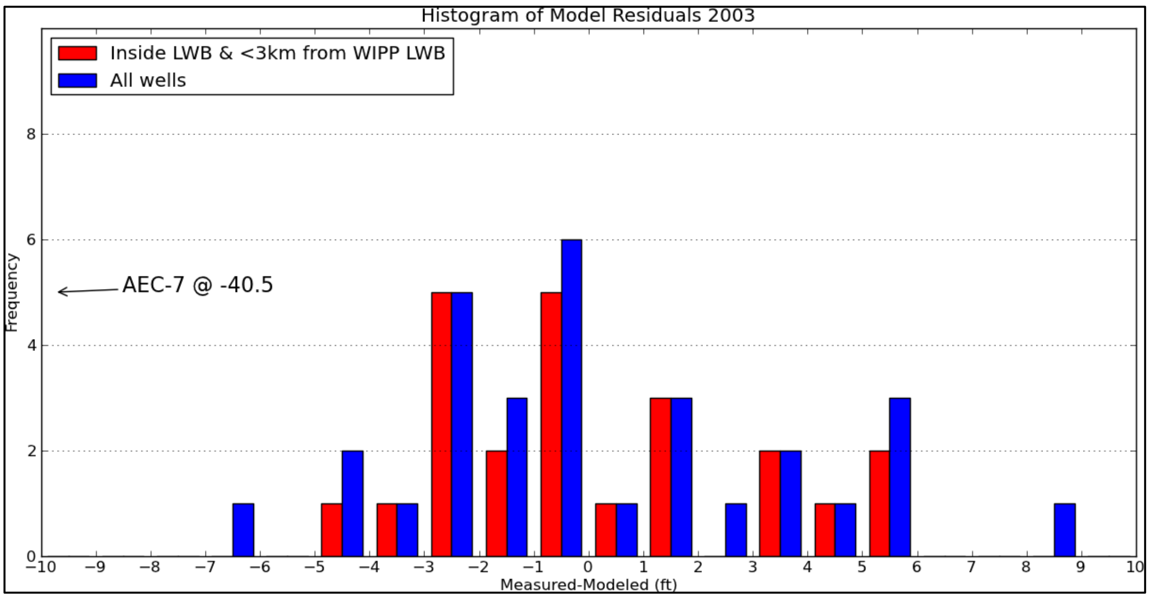

Figure 19. Histogram of Measured-Modeled errors for 2003

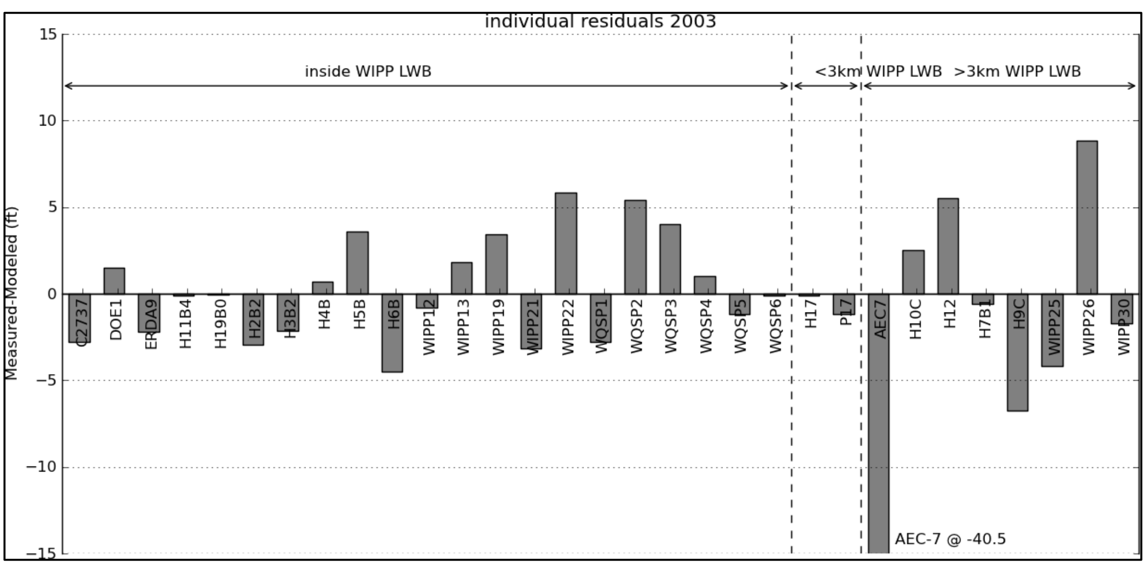

Figure 20. Measured-Modeled errors at each well for 2003

Aside from AEC-7, and to a lesser extent WIPP-26 (in Nash Draw), the model fit to the September 2003 observations is good. The averaged MODFLOW model captures the bulk Culebra flow behavior, while the PEST calibration improved model fit to the September 2003 observations.

Results for 2004

For the Culebra wells in the vicinity of the WIPP site, equivalent freshwater heads from August 2004 were used to calibrate a groundwater flow model, which was used by SNL to compute a potentiometric surface using SNL procedure SP 9-9. August was the best month in 2004 because water levels were impacted in many wells due to a series of large precipitation events in September 2004. Wells in Nash Draw (e.g., WIPP-25 and WIPP-26) rose significantly due to this event. AEC-7 used a March water level because the well was re-perforated in April 2004, which resulted in abnormal water levels until 2008. H-07b1 used a September water level because prior to 2005 the water level in this well was only measured quarterly (H-07b2 was the primary well on the H-07 well pad until it was plugged and abandoned in May 2005). I-461 and SNL-12 used December water levels because they were both drilled new in late 2003, requiring several months to stabilize after drilling and well development activities. WQSP-2 used a July water level because of an anomalous water level, which might be due to sampling activities. Table 9 shows the freshwater head data set. The following figures and discussion of mapping were modified from Kuhlman (2012).

Table 9.
Water Level Elevations for the August 2004 Potentiometric Surface Map Calibration, Culebra Hydraulic Unit

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
AEC-7	3/9/2004	3061.55	1.089
C-2737	8/11/2004	3016.57	1.019
ERDA-9	8/11/2004	3030.84	1.067
H-02b2	8/11/2004	3040.09	1.006
H-03b2	8/11/2004	3011.88	1.042
H-04b	8/11/2004	3004.33	1.015
H-05b	8/10/2004	3075.13	1.104
H-06b	8/10/2004	3064.17	1.040
H-07b1	9/13/2004	2997.87	1.002
H-09c	8/10/2004	2995.11	1.001
H-10c	8/10/2004	3025.39	1.001
H-11b4	8/11/2004	3006.33	1.070
H-17	8/11/2004	3003.41	1.133
H-19b0	8/11/2004	3012.60	1.068
I-461	12/6/2004	3044.98	1.005
P-17	8/11/2004	3000.20	1.070
SNL-12	12/7/2004	3002.76	1.005

Well	Measurement Date	Adjusted Freshwater Head (feet, AMSL)	Specific Gravity
WIPP-12	8/11/2004	3070.08	1.100
WIPP-13	8/10/2004	3074.80	1.053
WIPP-19	8/11/2004	3061.84	1.059
WIPP-21	8/11/2004	3040.88	1.071
WIPP-22	8/11/2004	3061.32	1.087
WIPP-25	8/9/2004	3062.34	1.011
WIPP-26	8/9/2004	3022.41	1.009
WIPP-30	8/10/2004	3075.75	1.018
WQSP-1	8/11/2004	3069.91	1.048
WQSP-2	7/8/2004	3078.81	1.048
WQSP-3	8/11/2004	3068.73	1.146
WQSP-4	8/11/2004	3012.93	1.075
WQSP-5	8/11/2004	3010.37	1.025
WQSP-6	8/11/2004	3021.92	1.014
Note: non-August water levels are discussed in preceding text.			

The model-generated freshwater head contours are given in Figures 21 and 22. 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.

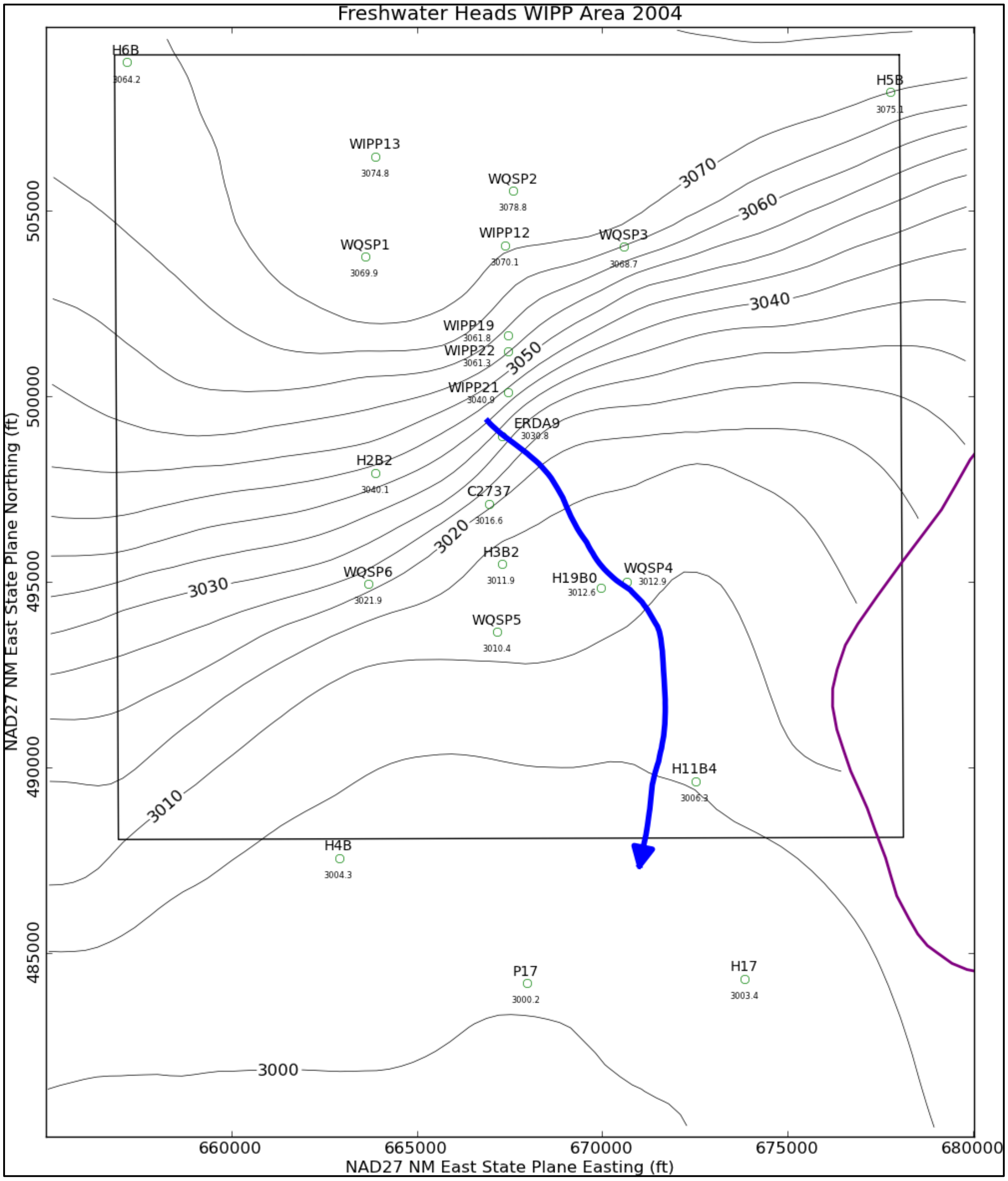

Figure 21. Model-generated August 2004 freshwater head contours with observed head listed at each well (5-foot contour interval) with blue water particle track from waste handling shaft to WIPP LWB

The blue arrow line in Figure 21 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 13,402 ft). The illustrated particle takes 6,105 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 mean travel velocity of 2.20 ft/year.

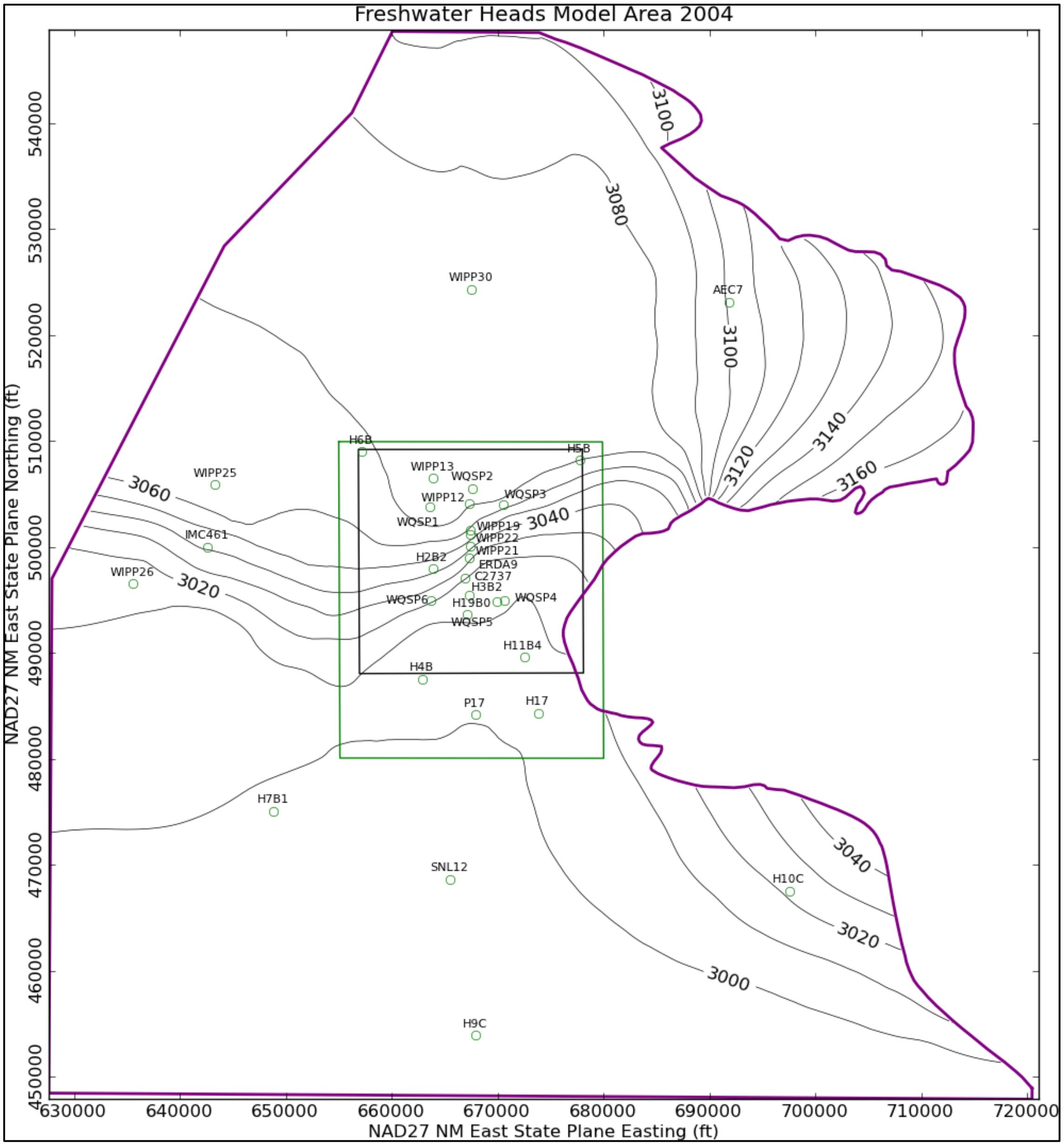

Figure 22. Model-generated August 2004 freshwater heads for entire model domain (10-foot contour interval). Green rectangle indicates region contoured in Figure 21; the black square is the WIPP LWB. IMC-461 is equivalent to I-461.

The scatter plot in Figure 23 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 (1.86 miles) 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). AEC-7 was given a low weight (0.01), to

prevent its large residual from dominating the optimization. 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 21, at the expense of fitting wells closer to the boundary conditions (i.e., wells not shown in Figure 21).

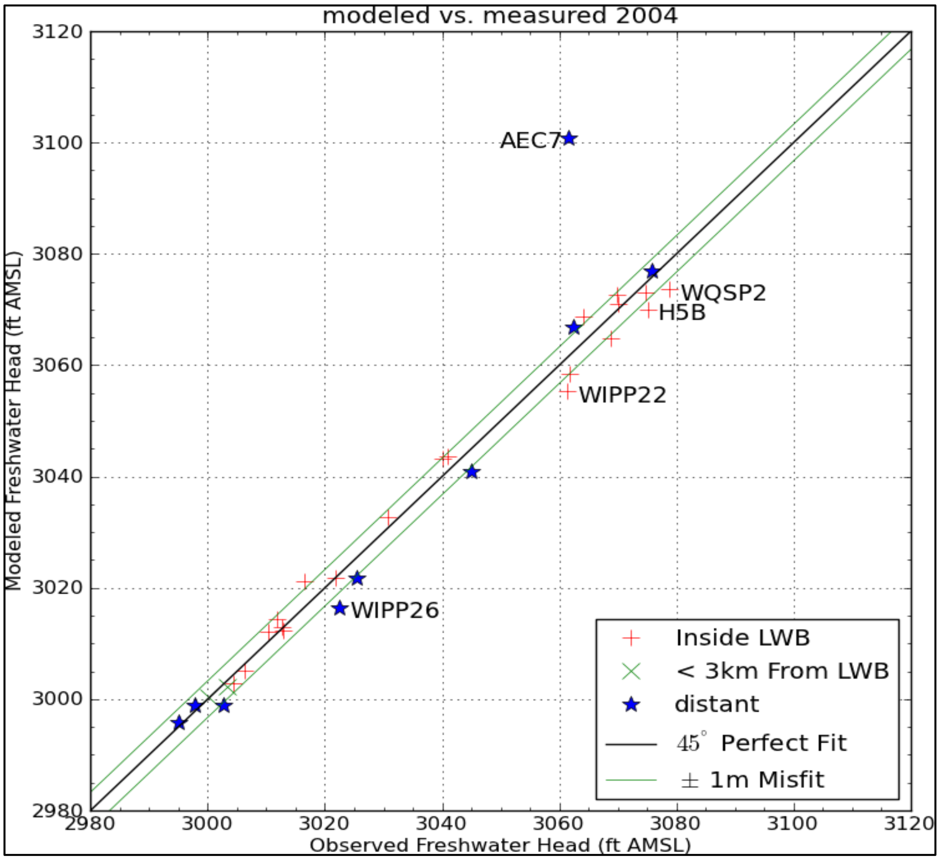

Figure 23. Measured vs. modeled scatter plot for PEST-calibrated model-generated heads and August 2004 observed freshwater heads.

The black central diagonal line in Figure 23 represents a perfect model fit (1:1 or 45-degree slope); the two green lines on either side of this represent a 1-m (3.28 ft) misfit above or below the perfect fit. Wells more than 1.5 m (4.92 ft) from the 1:1 line are labeled. AEC-7 has a large misfit for two reasons. First, this well has historically had an anomalously low freshwater head elevation, lower than wells around it in all directions. Secondly, it did not have a May 2007 observation and therefore was not included as a calibration target in the PA MODFLOW model calibration. This model was calibrated as part of the 2009 CRA, which provides the basis for current map generation.

The squared correlation coefficient (R^2) for the measured vs. modeled data is listed in Table 10. Figures 24 and 25 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 approximately 99%. The distribution in Figure 24 is roughly symmetric about 0, indicating there is not a strong bias.

Table 10. 2004 Measured vs. Modeled correlation coefficients

dataset	measured vs. modeled R^2
wells inside WIPP LWB	0.987
wells <3km (1.86 miles) from WIPP LWB	0.989
all wells	0.935

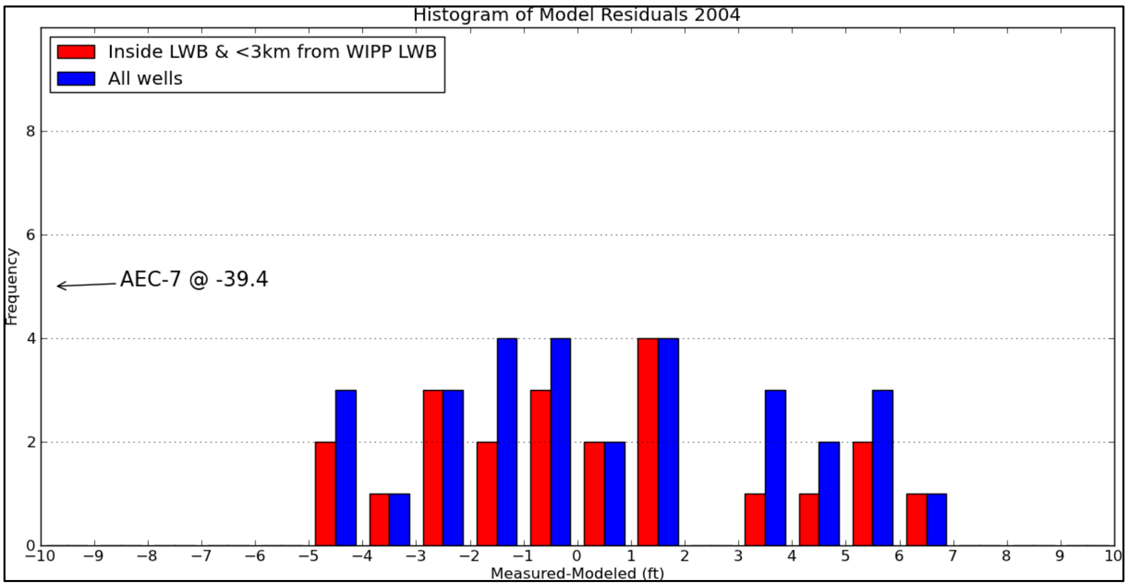

Figure 24. Histogram of Measured-Modeled errors for 2004

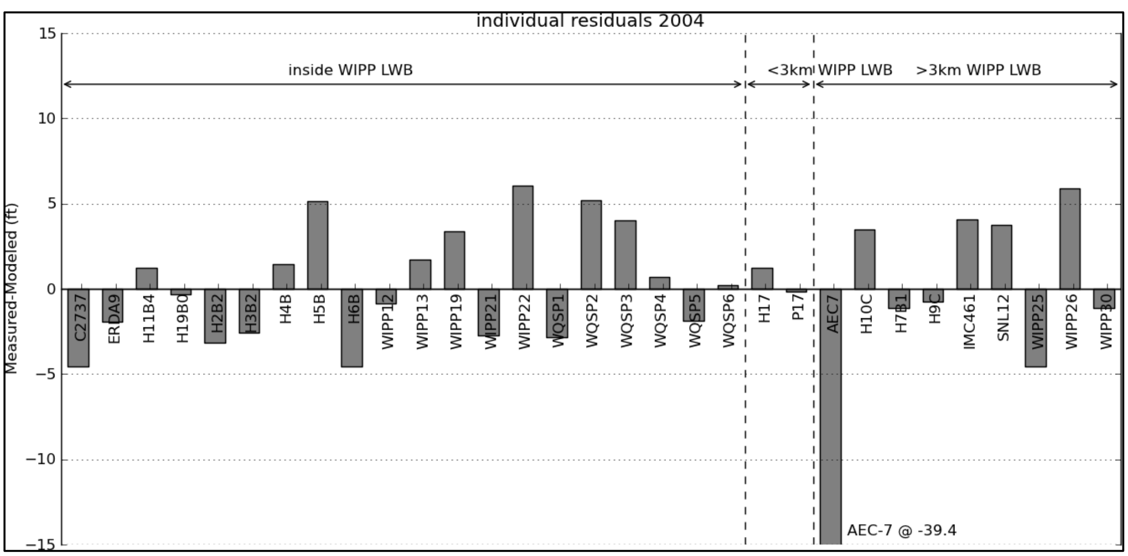

Figure 25. Measured-Modeled errors at each well for 2004. IMC-461 is equivalent to I-461.

Aside from AEC-7, the model fit to the August 2004 observations is good. The averaged MODFLOW model captures the bulk Culebra flow behavior, while the PEST calibration improved model fit to the August 2004 observations.

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