Analysis Report for AP-070

Analysis of Culebra Hydraulic Tests Performed Between June 2006 and September 2007

AP-070: Analysis Plan for Non-Salado Hydraulic-Test Interpretations

Task Number 1.4.2.3

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1. Introduction

This report discusses the analyses of hydraulic tests performed in the Culebra Dolomite Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP) site between June 2006 and September 2007. These analyses were performed between July 2006 and October 2007 in accordance with the Sandia National Laboratories (SNL) Analysis Plan for Non-Salado Hydraulic-Test Interpretations, AP-070, Revision 1 (Beauheim, 2004). The computer code used for analysis was nSIGHTS (n-dimensional Statistical Inverse Graphical Hydraulic Test Simulator), versions 2.40 and 2.41. A detailed description of the approach followed in these analyses can be found in Beauheim et al. (1993, Appendix B) and Roberts et al. (1999, Chapter 6). The data analyzed for this report were collected at the following wells: SNL-8, SNL-10, SNL-13, SNL-15, SNL-16, SNL-17A, SNL-18, and SNL-19. Both barometric and earth-tide effects were removed from the data sets prior to analysis, when necessary.

2. nSIGHTS Overview

The nSIGHTS code consists of two independent applications: nPre.exe and nPost.exe. The pre-processor and simulator, nPre, is used to process the field data prior to analysis, set up the mathematical model, and then run the model in inverse mode to estimate the hydraulic parameters of interest, e.g., transmissivity (*T*), flow dimension (*n*), etc. It also generates the data used to quantify the uncertainty associated with those hydraulic-parameter estimates. The post-processor, nPost, post-processes the results stored in the nPre output files, allowing graphical and statistical analysis of the simulation results.

All field data used in each analysis are entered or read into nPre and stored in a configuration file with an ***nPre*** extension. The field data include well radius, tubing-string radius, formation thickness, fluid density, and the transient pressure and flow-rate data. All input field data, including the reference ERMS numbers and field notebooks for each well, are listed in Appendix A.

The conceptual model chosen based on the characteristics of the test response determines the fitting parameters that will be estimated for each analysis. The model fitting parameters for each analysis are specified in the ***nPre*** configuration files named for each of the wells. Five hundred (500) sets of optimized fitting parameters were generated for each analysis in this report as part of the fitting-parameter uncertainty calculation. These 500 optimized parameter sets are stored in the nPre output file with an ***nOpt*** extension. The corresponding transient pressure simulations are stored in an nPre output file with an ***nXYsim*** extension. Both the ***nOpt*** and ***nXYsim*** files are read by nPost and all of the post-processing results are stored in a configuration file with an ***nPost*** extension.

The nSIGHTS input and output files for each tested well are stored in a directory structure like that shown in Figure 1.

Figure 1. Directory structure for Culebra nSIGHTS analyses.

The nPre configuration file is stored in the folder named for the tested well (Figure 1). Transient pressure and flow-rate files are stored in the Data folder (Figure 2) and all nPre output files as well as the nPost configuration file are stored in the Post folder (Figure 3).

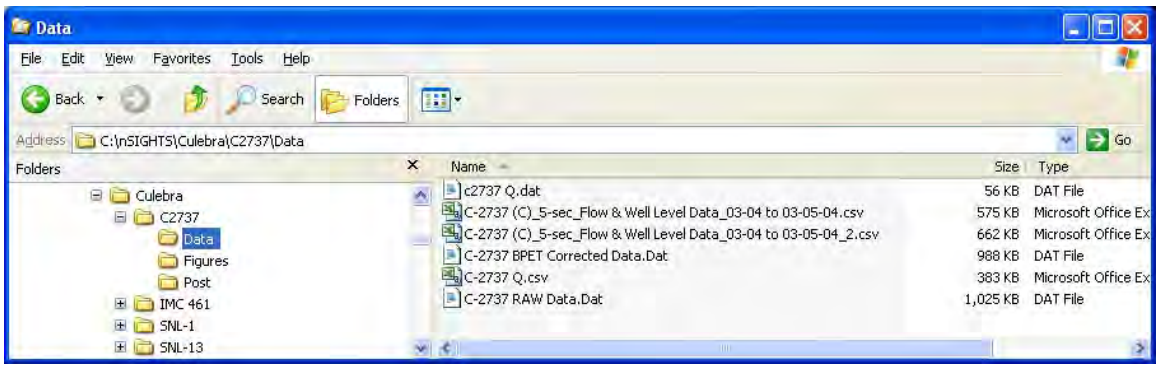

Figure 2. *Data* folder containing the pressure and flow-rate files for nPre input.

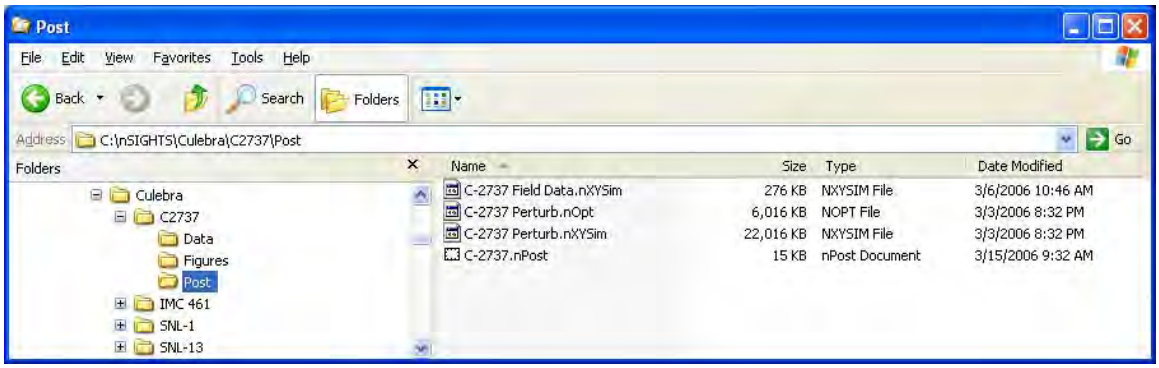

Figure 3. *Post* folder containing simulation output and post-processed data.

3. Test and Analysis Procedures

Slug tests were performed in wells SNL-8 and SNL-15. The SNL-8 slug test was performed using a single-packer test tool with a downhole shut-in valve. The Culebra was isolated with the packer, and the shut-in valve in the tubing string on which the packer was suspended was closed. While the Culebra pressure equilibrated beneath the packer, water was removed from the tubing above the shut-in valve so that the tubing would be underpressured relative to the Culebra when the shut-in valve was opened. The slug test was performed by opening the shut-in valve and monitoring the equilibration between the Culebra and tubing. The SNL-15 slug test was performed by simply pumping a volume of water from the well over a 26-minute period and monitoring the recovery of the water level.

The testing in SNL-13 utilized an unattended purging system designed to maintain a relatively constant pressure in the well. Pumping ceased periodically due to equipment safeguards built into the system, resulting in a series of constant-pressure periods followed by pressure-buildup periods. The testing sequence at the remaining wells discussed in this report consisted of a series of pumping events at more or less constant rates. At wells SNL-16 and SNL-17A, a pump was installed and operated just long enough to establish the rate the pump could sustain over the intended duration of the test, allowing the operator to set all control valves and the pump motor speed appropriate to that rate. The wells were then allowed to recover before beginning the constant-rate test. There was no pre-test pumping at SNL-10, SNL-18, and SNL-19 – rates were adjusted during the early portions of the tests in SNL-10 and SNL-18, while no adjustments were needed in SNL-19.

All the nSIGHTS test simulations incorporated pre-test pressure records of various durations as "history" periods where the associated pressures were simply specified in the simulations. This included the pre-test pumping events in SNL-16 and SNL-17A and the early-time variable-rate periods in SNL-10 and SNL-18.

Test analysis involved finding the values of the fitting parameters that produced the best simulated matches to the pressure data collected during the slug or constant-rate test and subsequent recovery period. In addition to the formation properties of interest (principally transmissivity (T) and flow dimension (n)), tubing string radius was also included as a fitting parameter in the pumping-test analyses so that nSIGHTS could exactly match the amount of wellbore storage observed during the test. The main objective of these analyses was to estimate T in the vicinity of each well for subsequent use in T-field generation and WIPP performance assessment calculations. Correlation between estimated T values and the other fitting parameters reported in Appendix B would be of interest if these correlations resulted in large uncertainty in the estimated T values. The uncertainty in the estimated T values shown in Table 1, however, is seen to be relatively small, so any correlation between T and other fitting parameters is not of interest.

The uncertainty quantification method applied to the analyses in this report is a process referred to as *perturbation analysis*. In this process, preliminary analyses are performed in which a reasonable fit is obtained to the specified constraints defined in the nPre configuration file. The resulting values of the fitting parameters are the *baseline solution* set – a single value for each

fitting parameter that provides a satisfactory fit to the data (*satisfactory* being a judgment call on the part of the analyst). Perturbation analysis begins by assigning a plus/minus range corresponding to the parameter space one wishes to investigate to each of the baseline fitting-parameter values. These plus/minus fitting-parameter ranges for each analysis are listed in Appendix B. Starting at the baseline value, the fitting parameters are randomly perturbed to fall somewhere within their assigned ranges and are then optimized from these random starting points. The objective of perturbation analysis is to adequately sample the parameter space and locate all of the minima within the parameter space. By definition, the parameter-space minimum that provides the best quantitative fit to the data, measured in terms of the smallest sum of squared errors (SSE), is the *global minimum* (assumed true solution), and the other minima are referred to as *local minima*. Local minima are effectively localized depressions in the parameter-space topography that trap the inverse regression algorithm during its attempt to find the global minimum – the smallest SSE.

Five hundred (500) perturbation/optimization runs were performed for each of the analyses discussed in this report, with the exception of the SNL-13 analysis. Given the relative complexity of the SNL-13 pumping period, 2500 perturbations were performed for that analysis to ensure adequate sampling of the possibly more complex parameter space. From these perturbation results, only those solutions that provided a satisfactory fit (as determined by the analyst) to the data are presented in this report – effectively those solutions that fall within the global minimum. In some cases, the original baseline solution may not fall within the global minimum defined through perturbation analysis. The final number of satisfactory perturbation results for each test is reported in the Section 4 figure captions.

4. Analysis Results

Discussions of the individual test analyses are given below. A summary of the transmissivity estimates obtained from perturbation analysis of each test is shown in Table 1. The full range of *T* values from which the statistics in Table 1 are derived is presented as a scatter plot in each section below and a full listing is contained within the nPost configuration file for each analysis.

Table 1. Transmissivity Estimates.

Well	Geometric Mean (m^2/s)	Log Geometric Mean (m^2/s)	Log Minimum (m^2/s)	Log Maximum (m^2/s)	Variance
SNL-8	2.42E-07	-6.62	-6.62	-6.61	4.39E-08
SNL-10	3.26E-07	-6.49	-6.51	-6.47	5.09E-06
SNL-13	3.83E-07	-6.42	-6.45	-6.38	3.62E-05
SNL-16	1.30E-03	-2.89	-2.93	-2.87	6.11E-06
SNL-17A	3.35E-04	-3.48	-3.75	-3.35	1.44E-03
SNL-18	1.36E-04	-3.87	-3.93	-3.83	3.96E-04
SNL-19	4.26E-04	-3.37	-3.38	-3.35	6.02E-06
SNL-15	1.38E-13	-12.86	-13.11	-12.34	3.07E-02

4.1 SNL-8

A slug test tool string was installed into SNL-8 on December 12, 2006. On December 14, 2006, the shut-in valve of the tool was opened to initiate the slug test and the test proceeded normally until it was terminated on December 15, 2006

Figure 4 shows the pressure record from SNL-8 used in this analysis. The pressures measured prior to the maximum slug-injection pressure on December 14, 2006, were included in the nSIGHTS simulation as a pressure history. The pressures shown in Figure 4 were separated into two nSIGHTS sequences for this analysis. The details of each sequence, i.e., start/end time, etc., are specified in the SNL-8.nPre file and are listed in Appendix B.1.

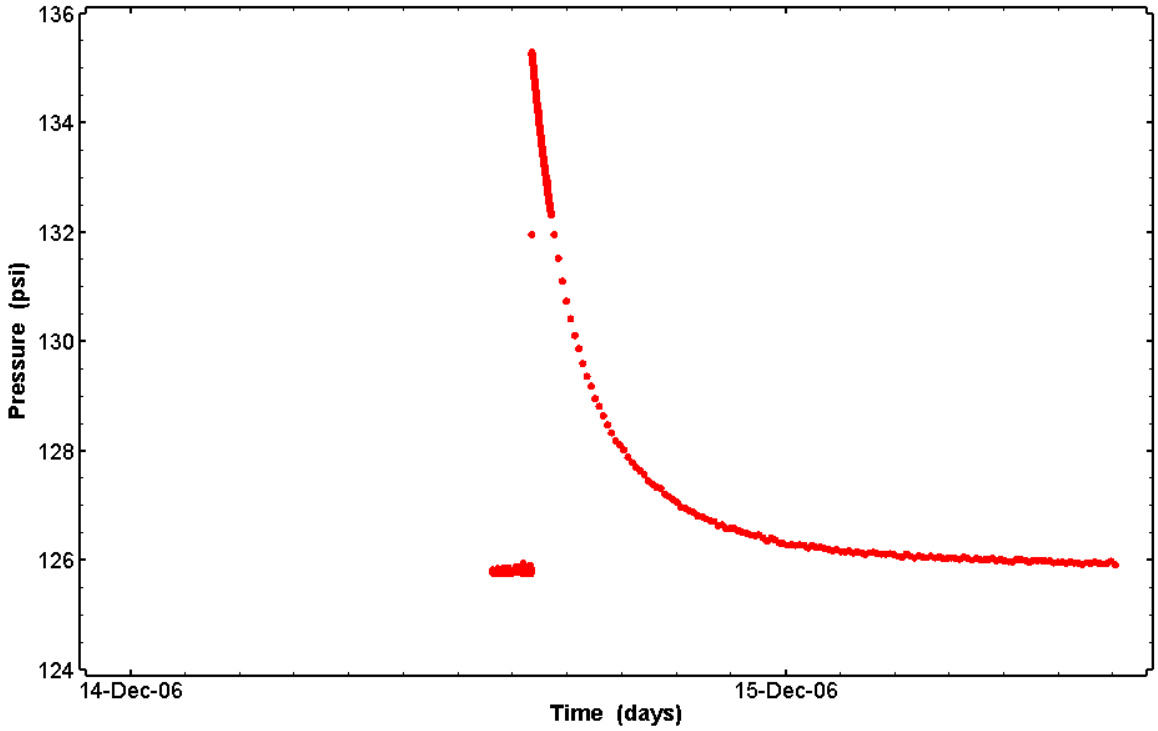

Figure 4. Pressure data from SNL-8.

The specified SNL-8 conceptual model was an infinite-acting, homogeneous, radial system with wellbore storage. Given the lack of definitive diagnostic characteristics in the Ramey B plot (Ramey et al., 1975) shown in Figure 5, the SNL-8 response was matched with the simplest flow model that would produce a satisfactory match. The conceptual model initially included a wellbore skin, but it did not improve the fit, so the skin was not included in the final model. The range of transmissivity (*T*) values estimated from the SNL-8 analysis is shown in Figure 6. The SNL-8 geometric mean *T* value was 2.42E-07 m^2/s. The Cartesian (linear), semilog Ramey A, and log-log Ramey B simulations corresponding to the 495 *T* values in Figure 6 are shown in Figures 7, 8, and 9, respectively.

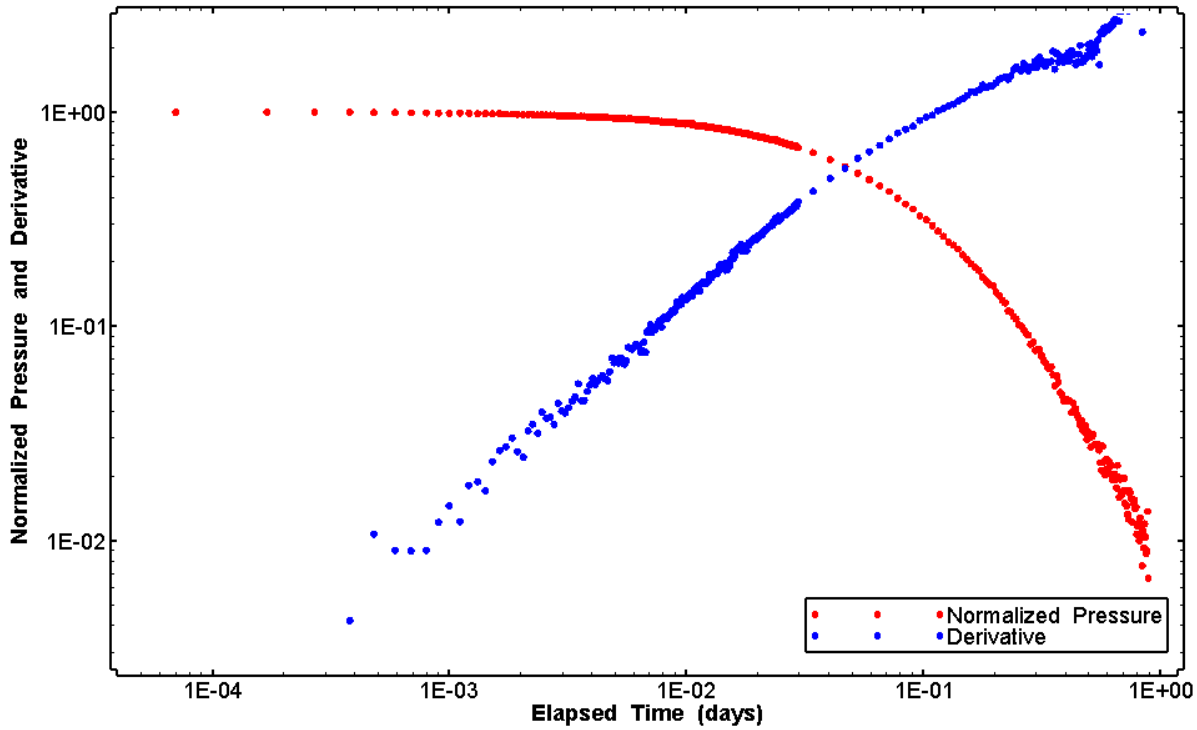

Figure 5. Ramey B plot of the SNL-8 slug test.

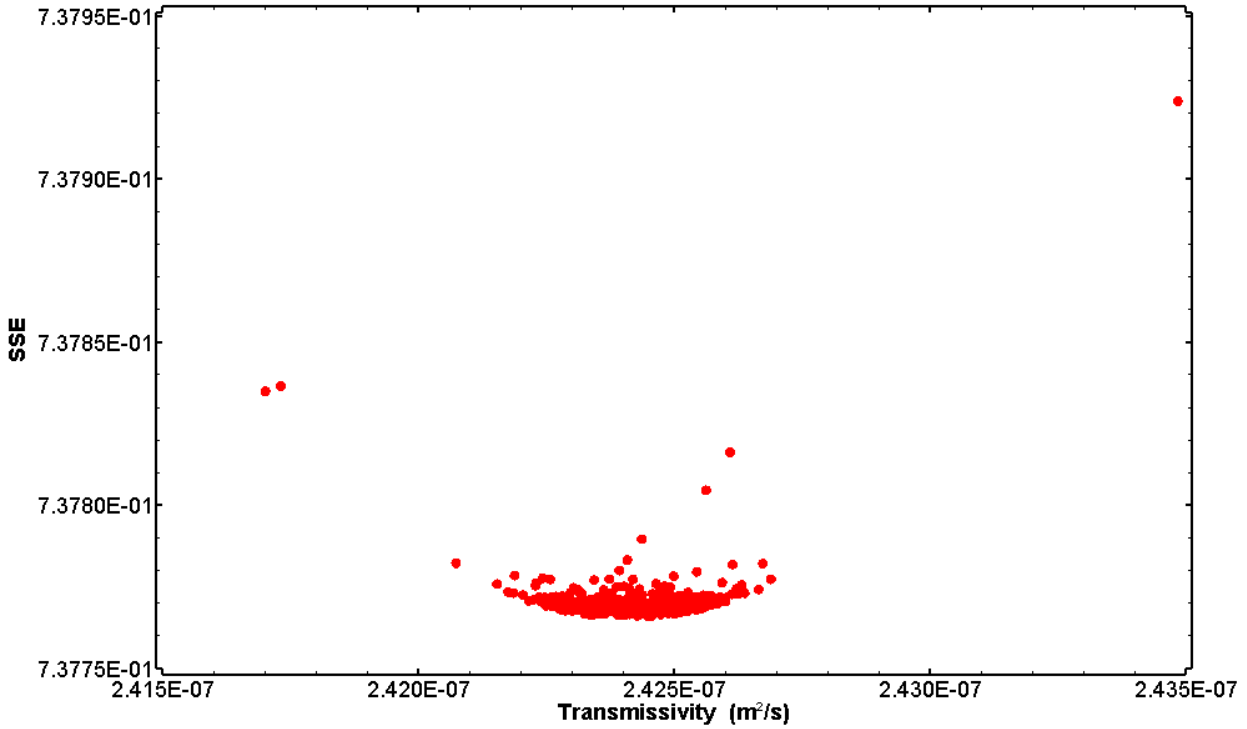

Figure 6. XY-scatter plot showing 495 estimates of transmissivity derived from the SNL-8 perturbation analysis.

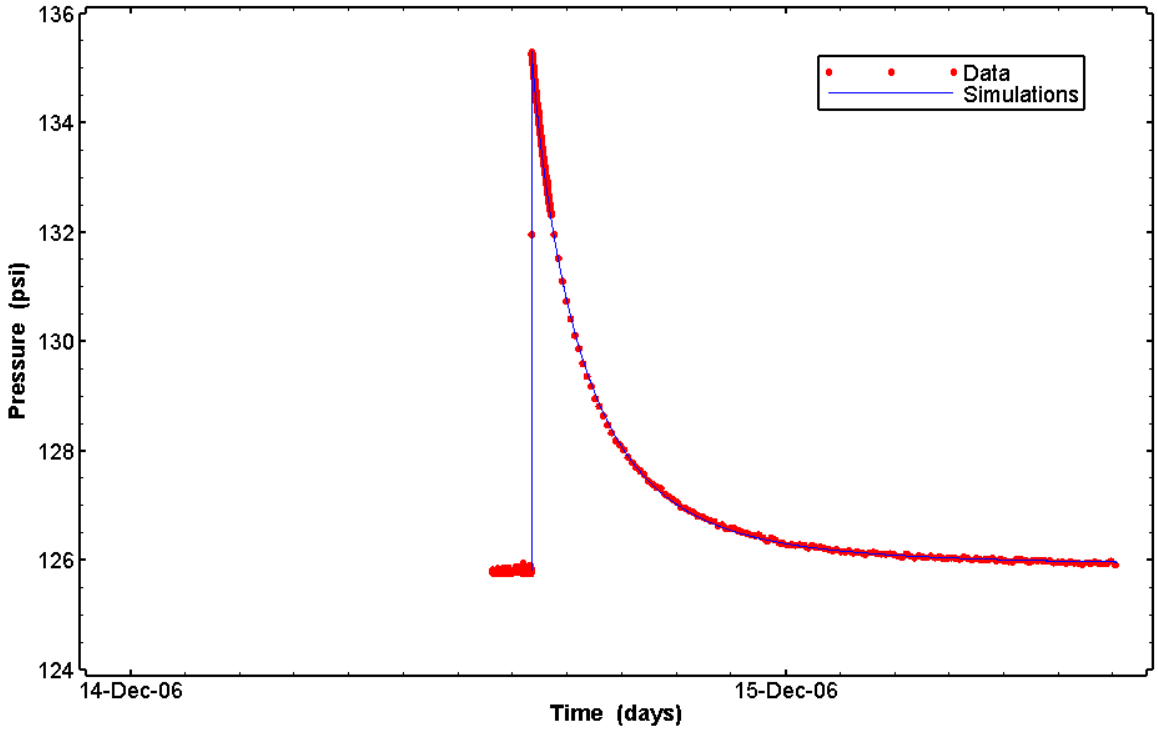

Figure 7. Linear plot showing 495 simulations of the SNL-8 pressure response.

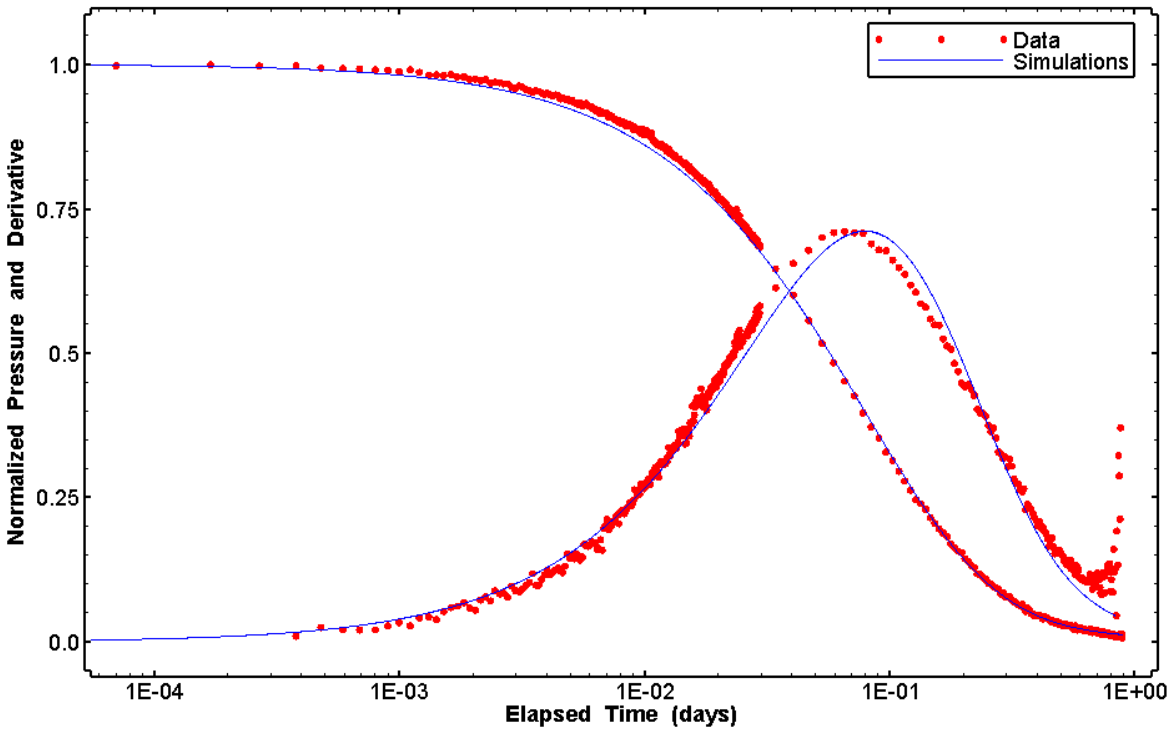

Figure 8. Semilog plot showing 495 simulations of the SNL-8 Ramey A and derivative response.

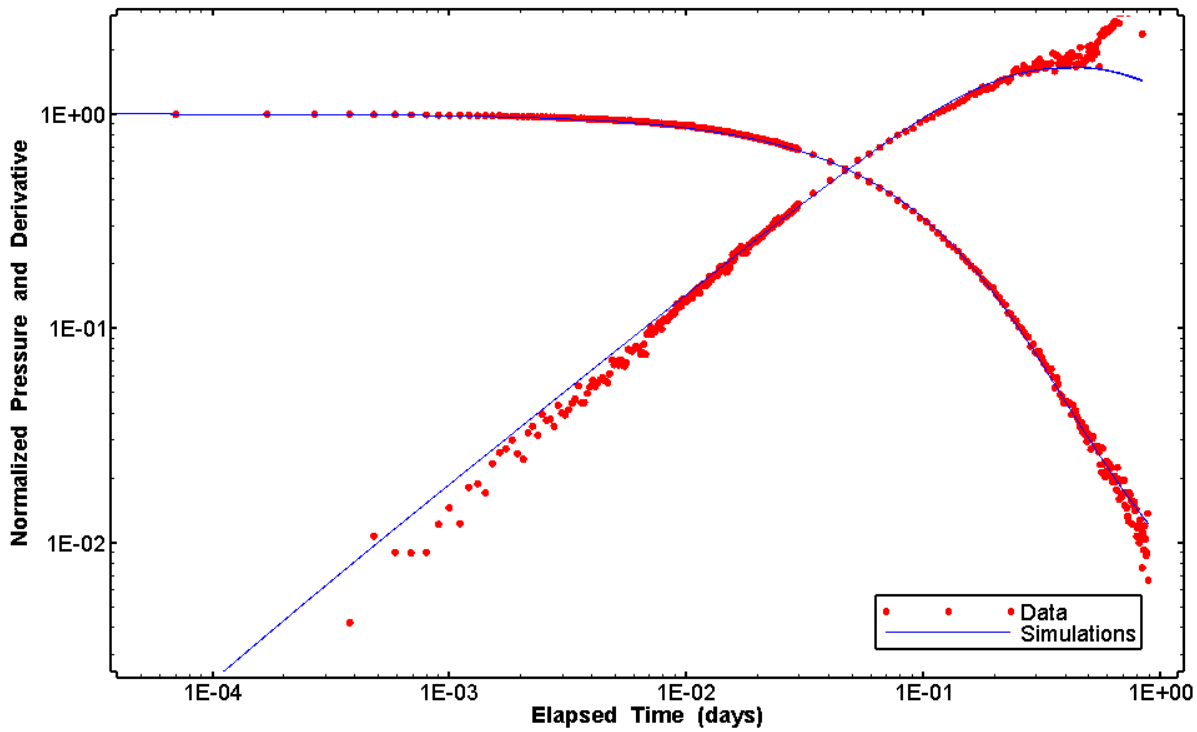

Figure 9. Log-log plot showing 495 simulations of the SNL-8 Ramey B and derivative response.

4.2 SNL-10

A constant-rate (0.25 gpm) pumping test was initiated in SNL-10 on October 30, 2006 and continued for approximately 4 days. Figure 10 shows the pressure record from SNL-10 used in this analysis. The pre-test pressures beginning on October 27, 2006 were included in the nSIGHTS simulation as a pressure history. The pressures measured during the first 26 minutes of the pumping test that began on October 30, 2006, and also during the final 118 minutes of pumping on November 3, 2006, were also included in the nSIGHTS simulation as pressure histories due to irregularities in the pumping rates during these periods. The pressures shown in Figure 10 were separated into four nSIGHTS sequences for this analysis. The details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-10.nPre file and are listed in Appendix B.2.

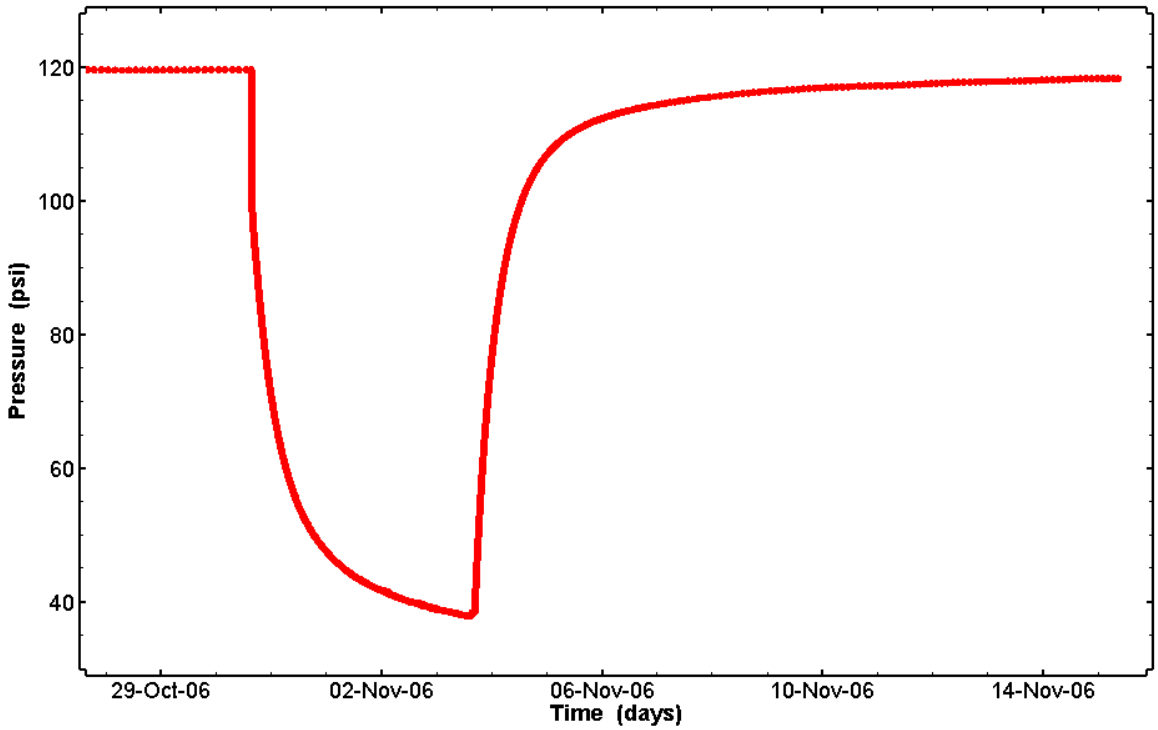

Figure 10. Pressure data from SNL-10.

The specified SNL-10 conceptual model, based on the characteristics of the buildup-period diagnostic plot shown in Figure 11, was an infinite-acting, homogeneous, radial system with wellbore storage and skin. The pressure derivative begins to stabilize around an elapsed time of 10 days (Figure 11). The range of *T* values estimated from the SNL-10 analysis is shown in Figure 12. The geometric mean *T* value was 3.26E-7 m^2/s. The Cartesian, log-log pressure-drawdown, and log-log pressure-buildup diagnostic simulations corresponding to these 498 *T* values are shown in Figures 13, 14, and 15, respectively.

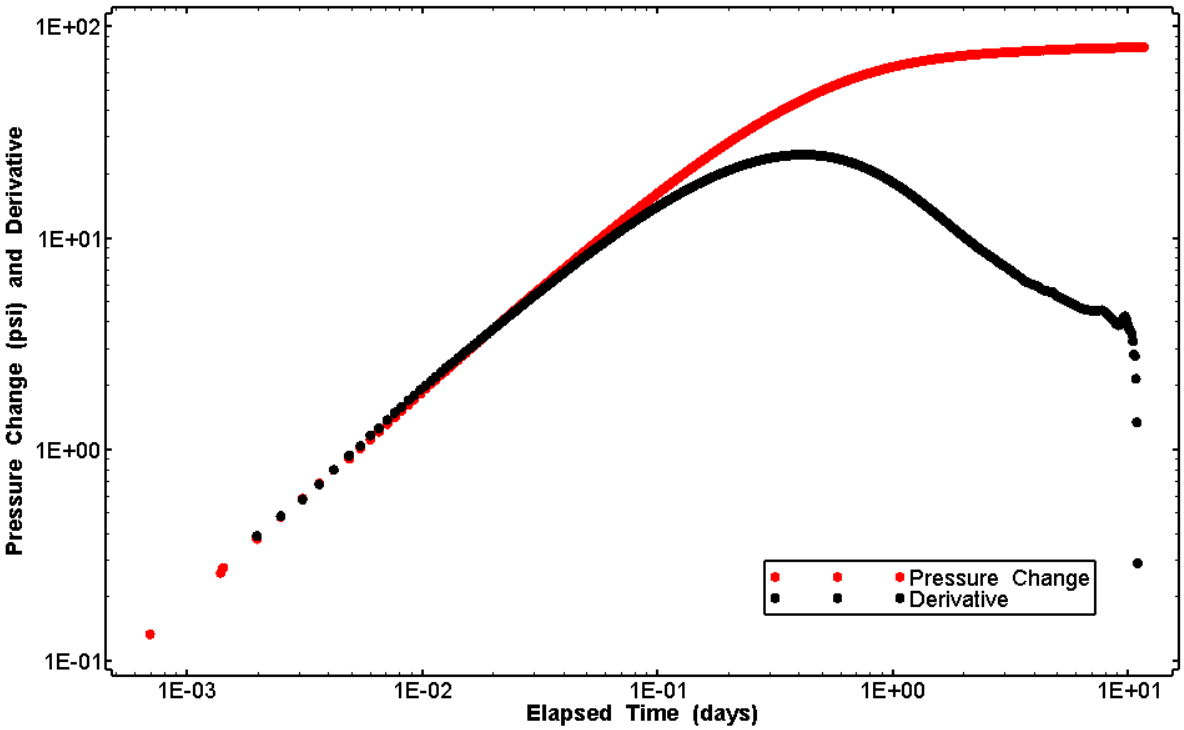

Figure 11. Log-log diagnostic plot of the SNL-10 pressure-buildup test.

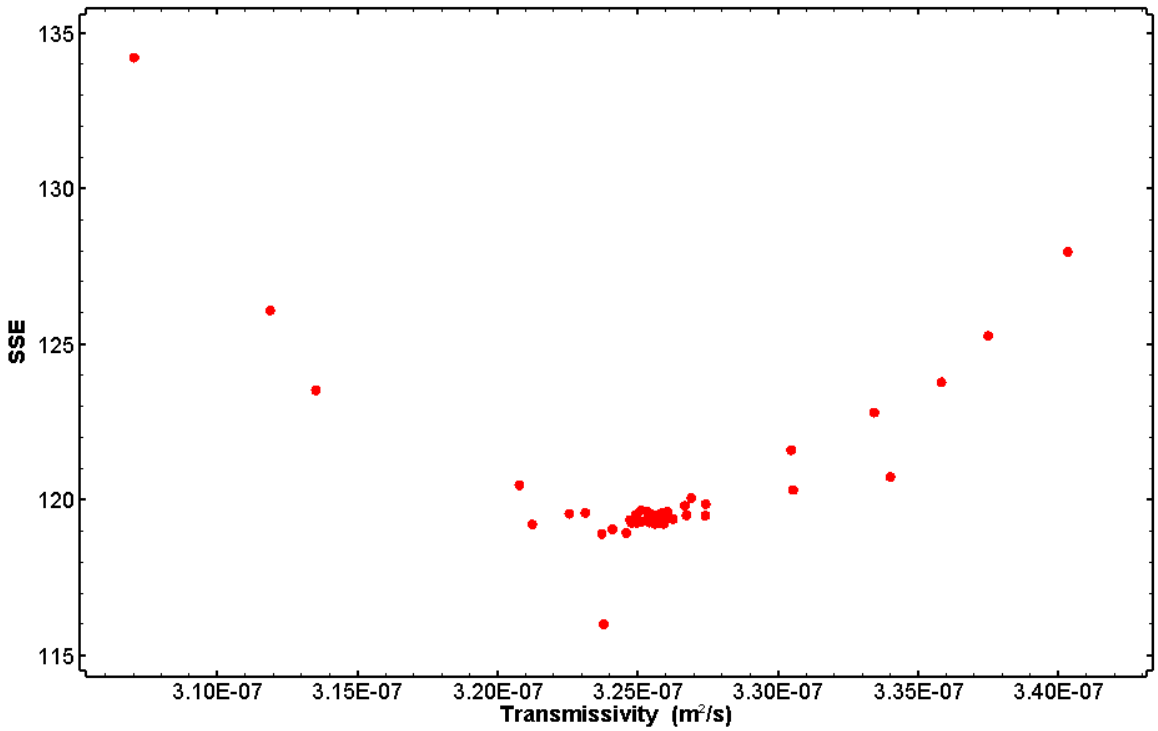

Figure 12. XY-scatter plot showing 498 estimates of transmissivity derived from the SNL-10 perturbation analysis.

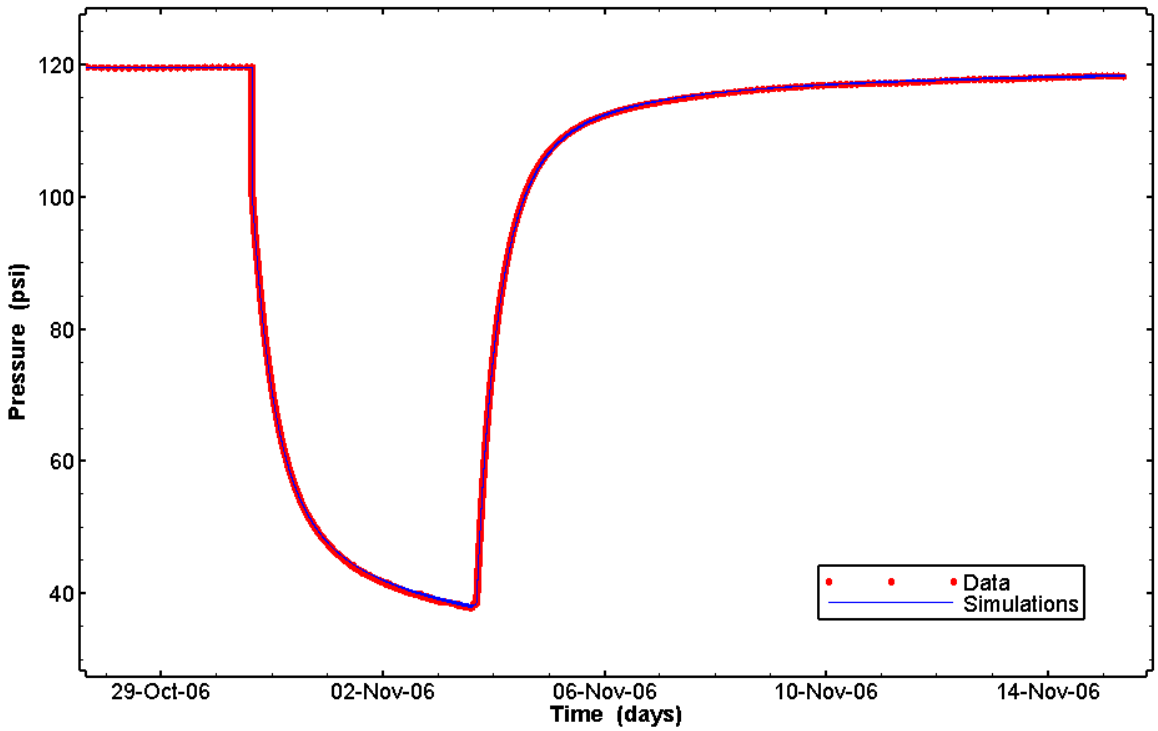

Figure 13. Linear plot showing 498 simulations of the SNL-10 pressure response.

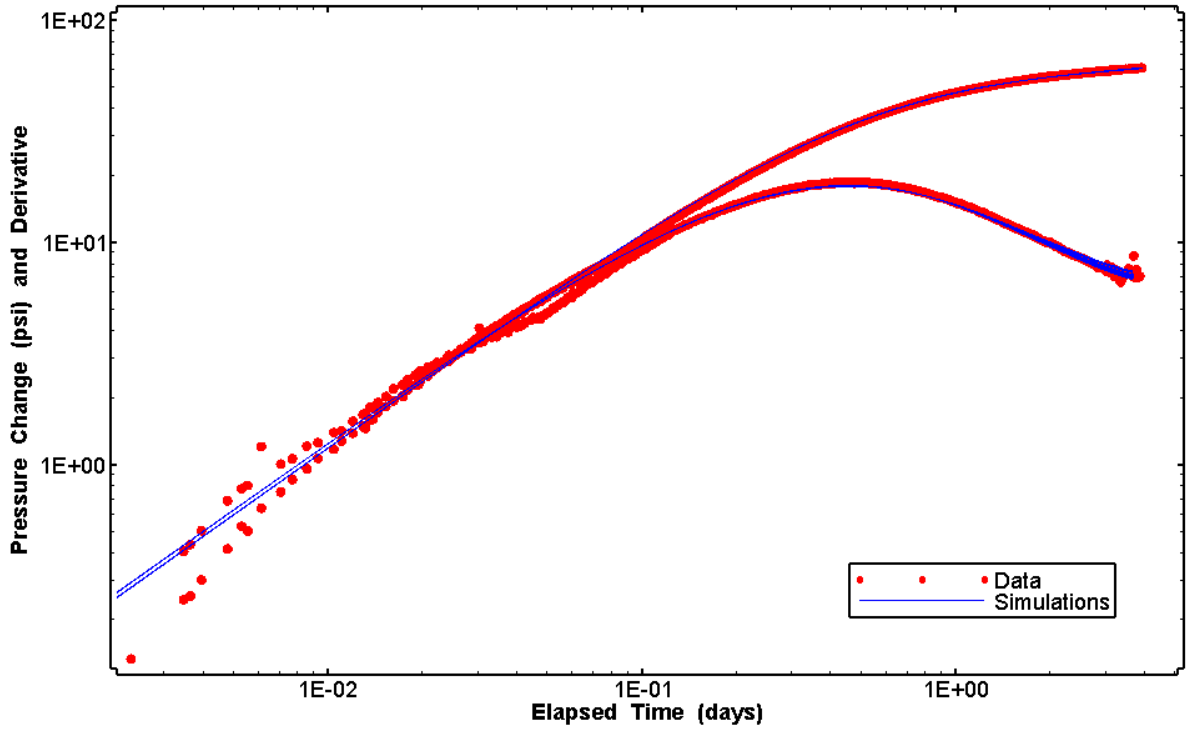

Figure 14. Log-Log plot showing 498 simulations of pressure change and derivative during the SNL-10 pressure-drawdown test.

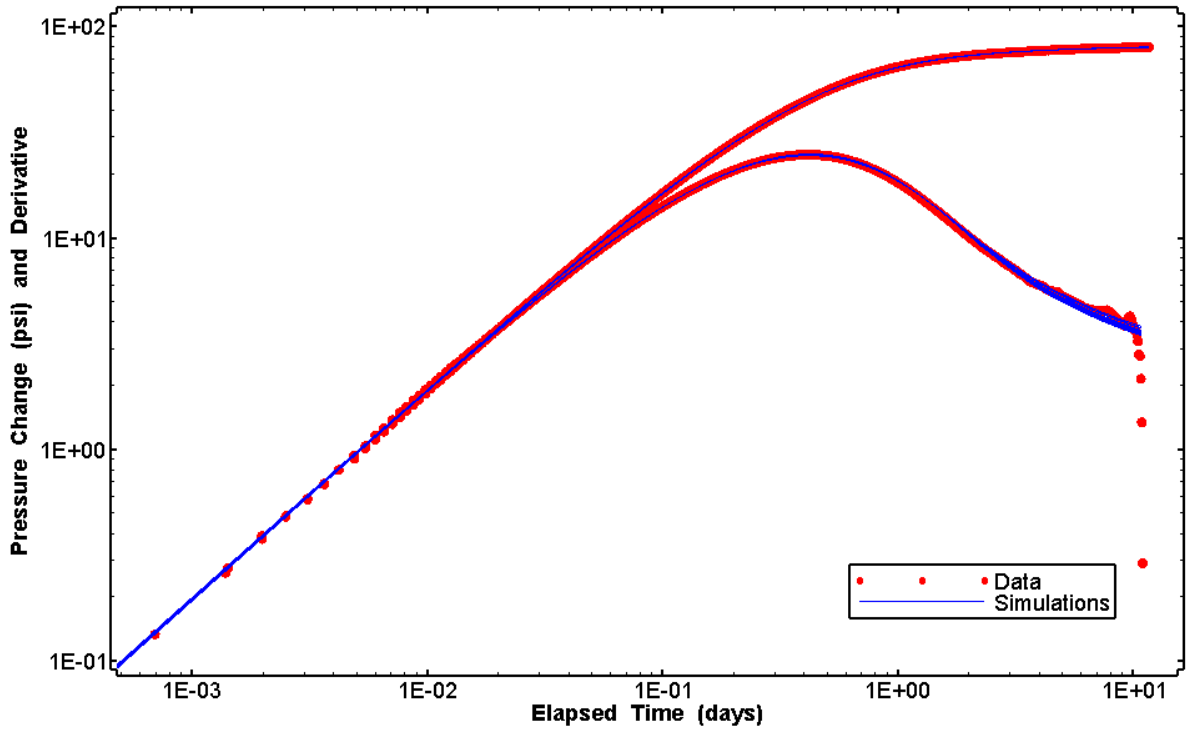

Figure 15. Log-Log plot showing 498 simulations of pressure change and derivative during the SNL-10 pressure-buildup test.

4.3 SNL-13

On June 29, 2006, a Bennett pump was installed in SNL-13 and a pumping test was initiated. However, the test was terminated within 30 minutes due to technical difficulties. The Bennett pump was re-installed and the actual pumping test began on July 12, 2006 and continued for approximately 7 days. During this time, the air compressor for the pump frequently shut down due to various alarms. Figure 16 shows the pressure record from SNL-13 used in this analysis. Pressure data prior to the start of pumping on July 12, 2006, were included in the analysis as a pressure history. The pressures shown in Figure 16 were separated into four nSIGHTS sequences; details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-13.nPre file and are listed in Appendix B.3.

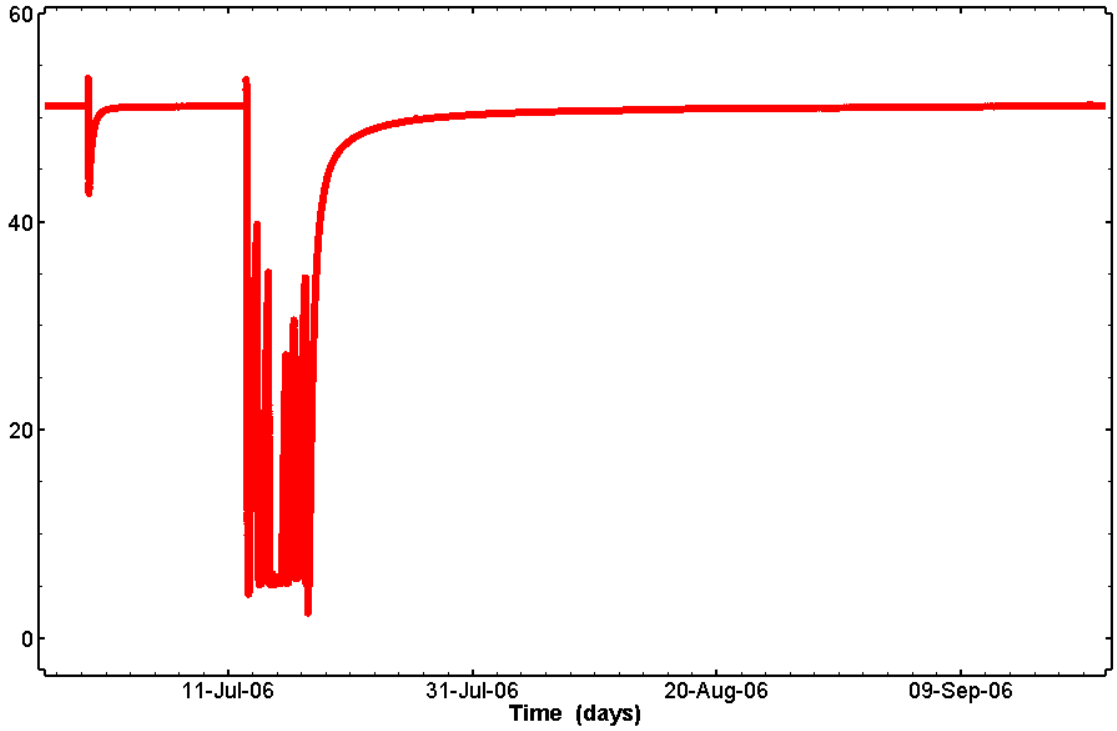

Figure 16. Pressure data from SNL-13.

The specified SNL-13 conceptual model, based on the characteristics of the pressure-buildup diagnostic plot shown in Figure 17, was an infinite-acting, homogeneous, radial system with wellbore storage and skin. The estimated *T* values correspond to the derivative stabilization level seen after approximately six days (Figure 17) elapsed time. The range of *T* values estimated from the SNL-13 analysis is shown in Figure 18. The geometric mean of these *T* values is 3.83E-07 m^2/s. The simulated SNL-3 Cartesian and log-log pressure-buildup diagnostic responses corresponding to the 2325 *T* values shown in Figure 18 are shown in Figures 19 and 20, respectively.

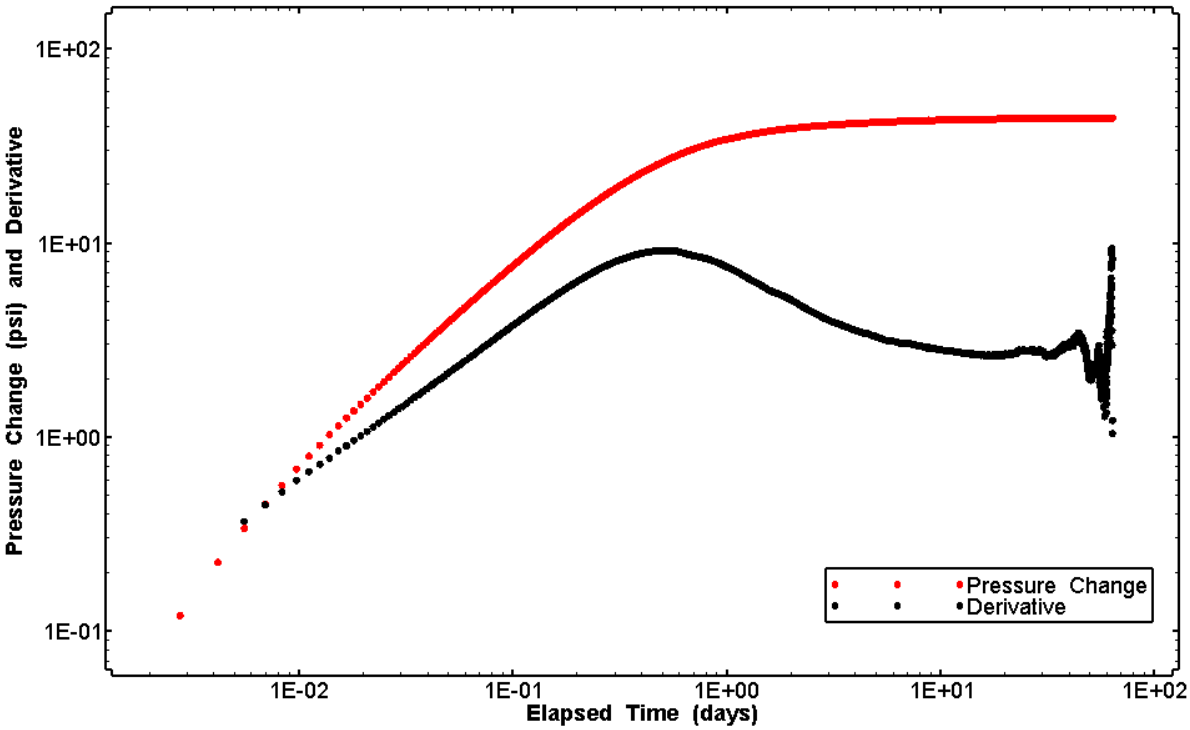

Figure 17. Log-log diagnostic plot of the SNL-3 pressure-buildup test.

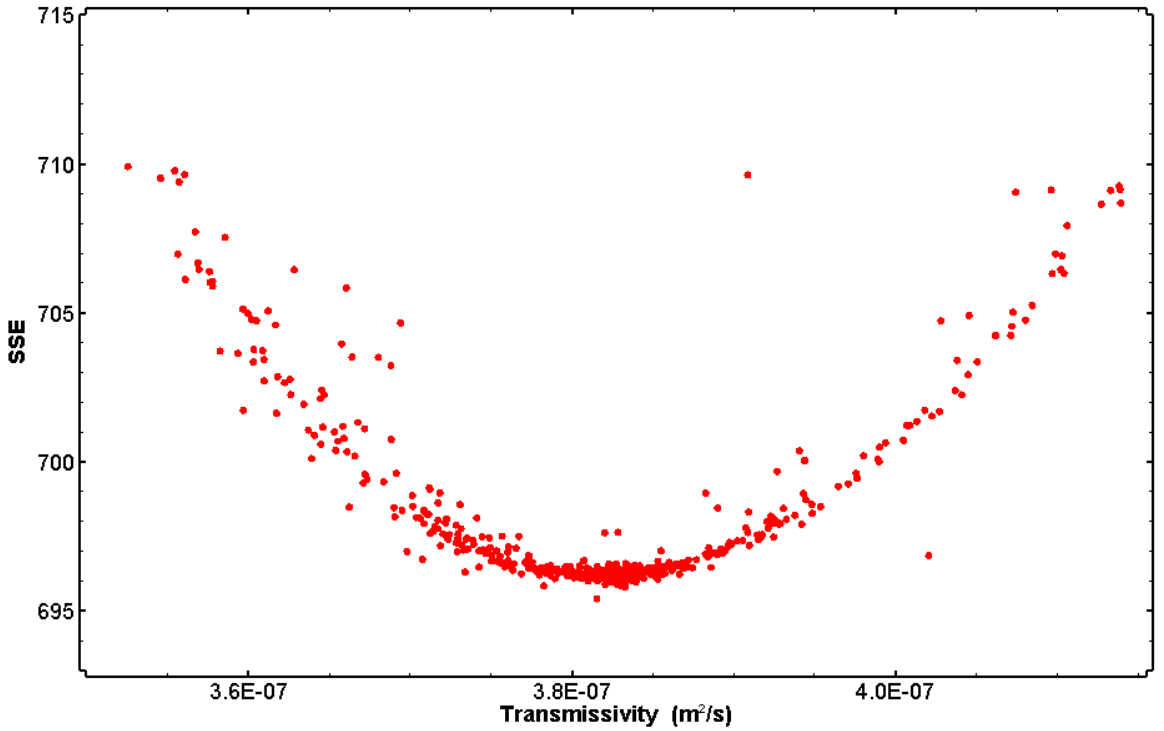

Figure 18. X-Y scatter plot showing 2325 estimates of transmissivity derived from the SNL-13 perturbation analysis.

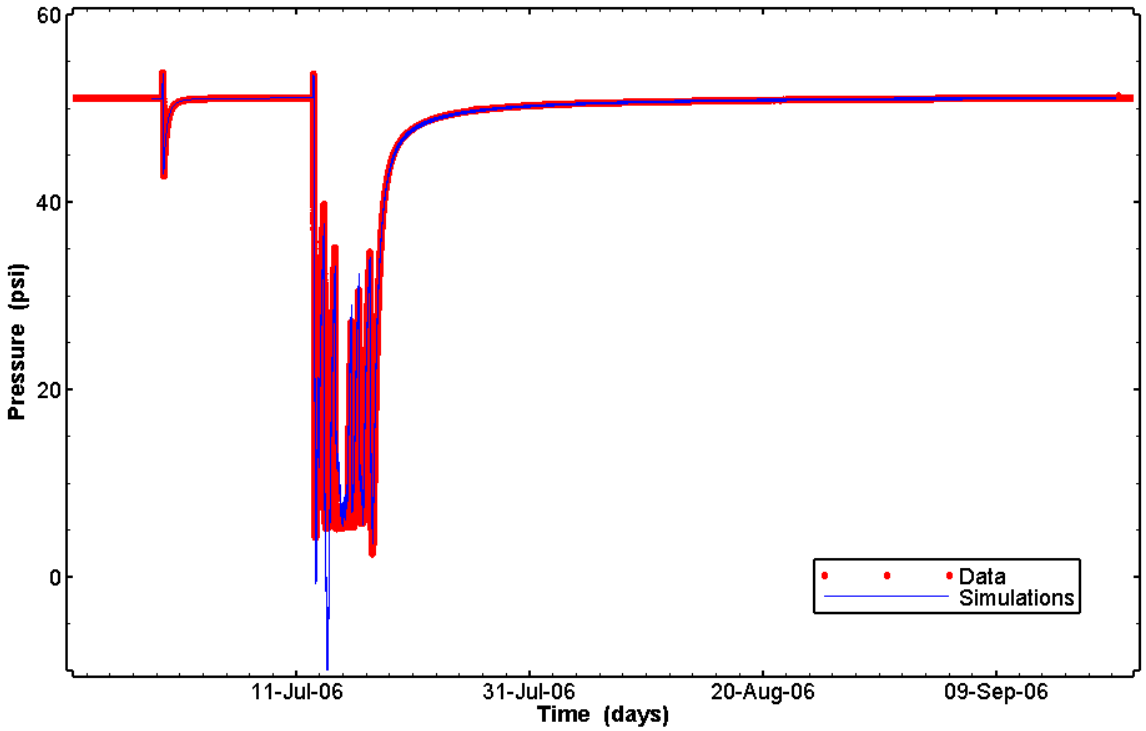

Figure 19. Linear plot showing 2325 simulations of the SNL-13 pressure response.

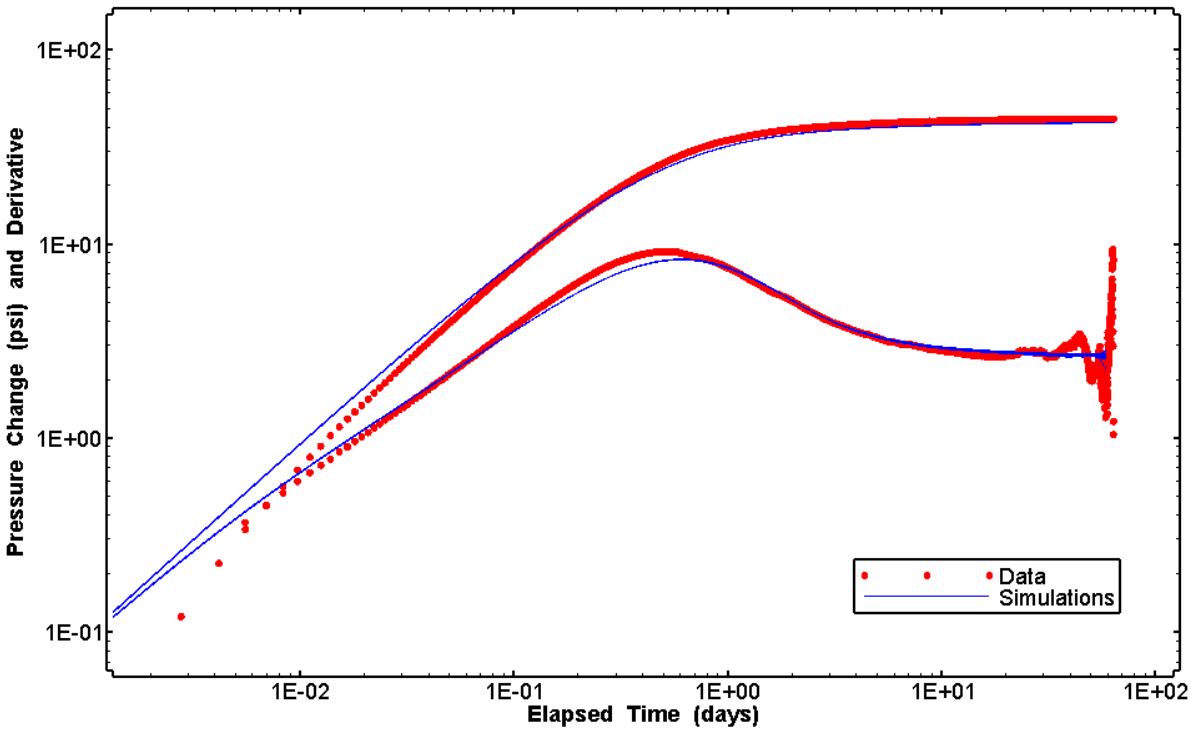

Figure 20. Log-log plot showing 2325 simulations of pressure change and derivative during the SNL-13 pressure-buildup test.

4.4 SNL-16

A pumping rate of 25 gpm was evaluated in well SNL-16 over a one-hour period on May 9, 2006. The actual pumping test began on June 5, 2006, had an average rate of 28 gpm, and lasted approximately 96 hr. The pressure response from May 2 – June 29, 2006 (Figure 21) was included in this analysis. Pressure data prior to the start of pumping on June 5, 2006, were included in the analysis as a pressure history. The pressures shown in Figure 21 were separated into four nSIGHTS sequences for this analysis. The details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-16.nPre file and are listed in Appendix B.4.

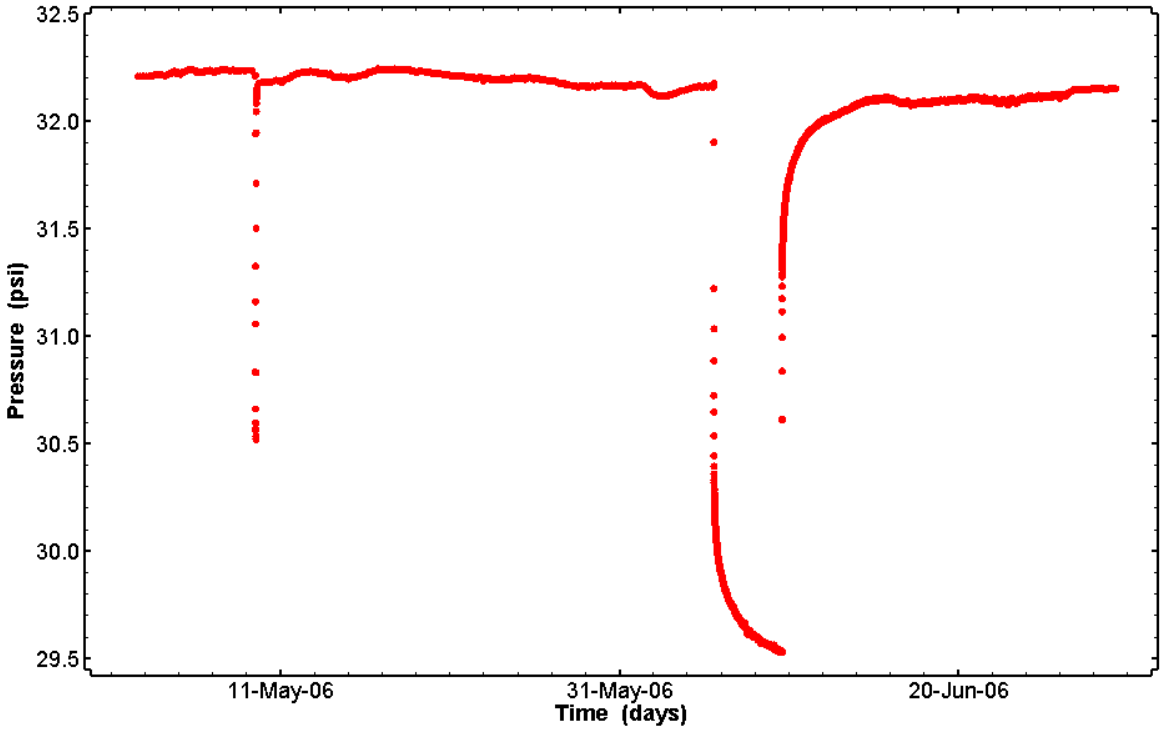

Figure 21. Pressure data from SNL-16.

The specified SNL-16 conceptual model, based on the characteristics of the pressure-drawdown diagnostic plot shown in Figure 22, was an infinite-acting, dual-porosity system with wellbore storage and skin. The estimated fracture *T* values correspond to the derivative stabilization level seen after approximately 0.5 days (Figure 22) elapsed time. The range of *T* values estimated from the SNL-16 analysis is shown in Figure 23. The geometric mean *T* estimate was 1.30E-3 m^2/s. The simulated SNL-16 Cartesian and log-log pressure-drawdown diagnostic responses corresponding to the 410 *T* values shown in Figure 23 are shown in Figures 24 and 25, respectively. Note that pressure-buildup data after 12:00 p.m. on June 13, 2006 were not used in the regression analysis to estimate the SNL-16 hydraulic parameters. The pressure response after

this time was significantly affected by factors not related to the SNL-16 pumping test, similar to the observed pressure response prior to testing (Figure 21).

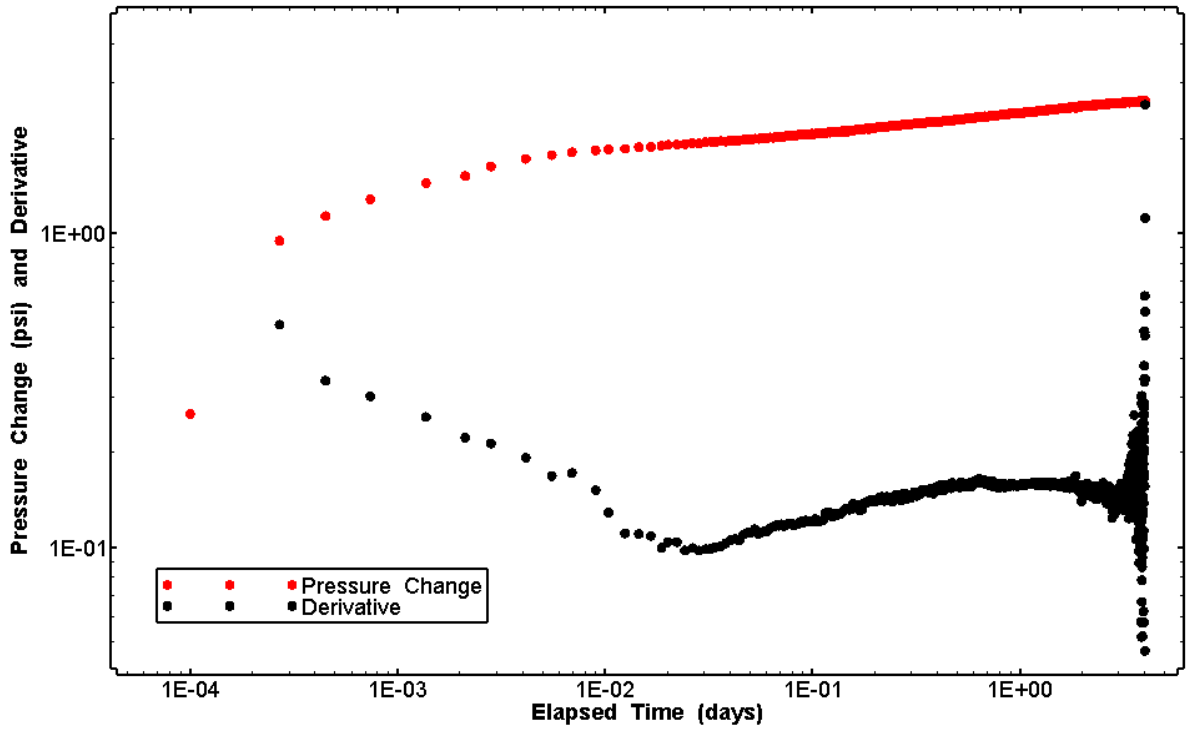

Figure 22. Log-log diagnostic plot of the SNL-16 pressure-drawdown test.

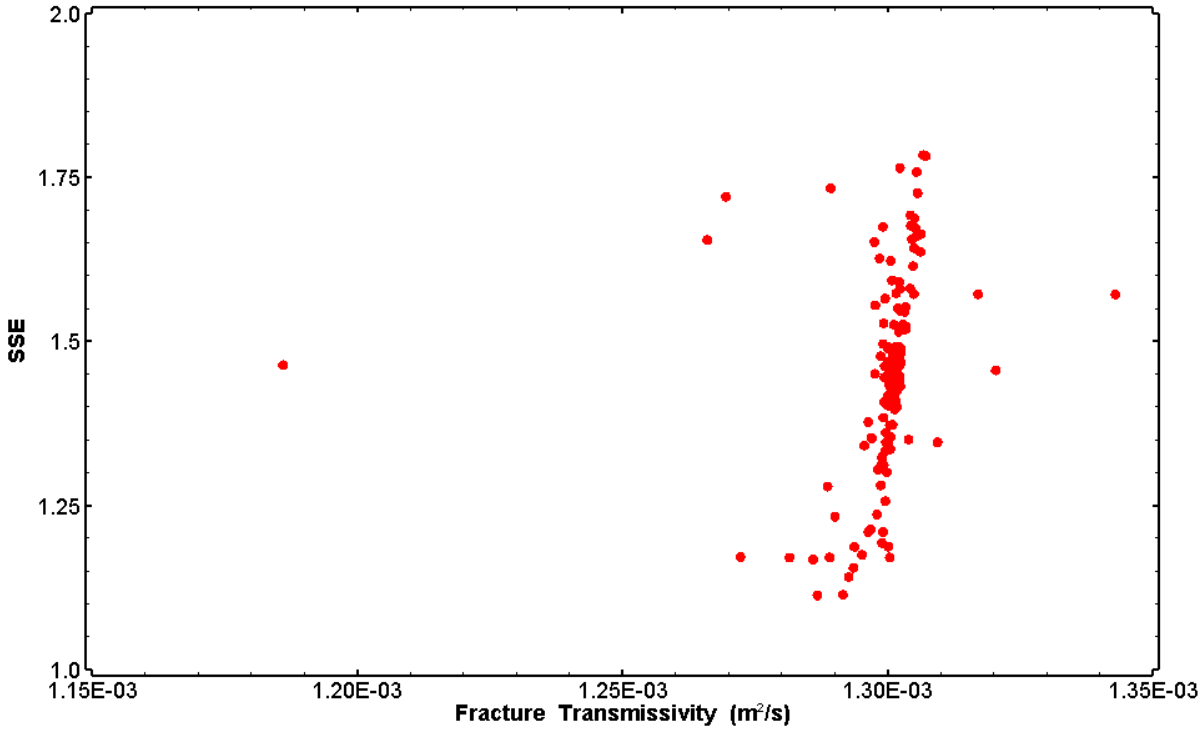

Figure 23. X-Y scatter plot showing 410 estimates of transmissivity derived from the SNL-16 perturbation analysis.

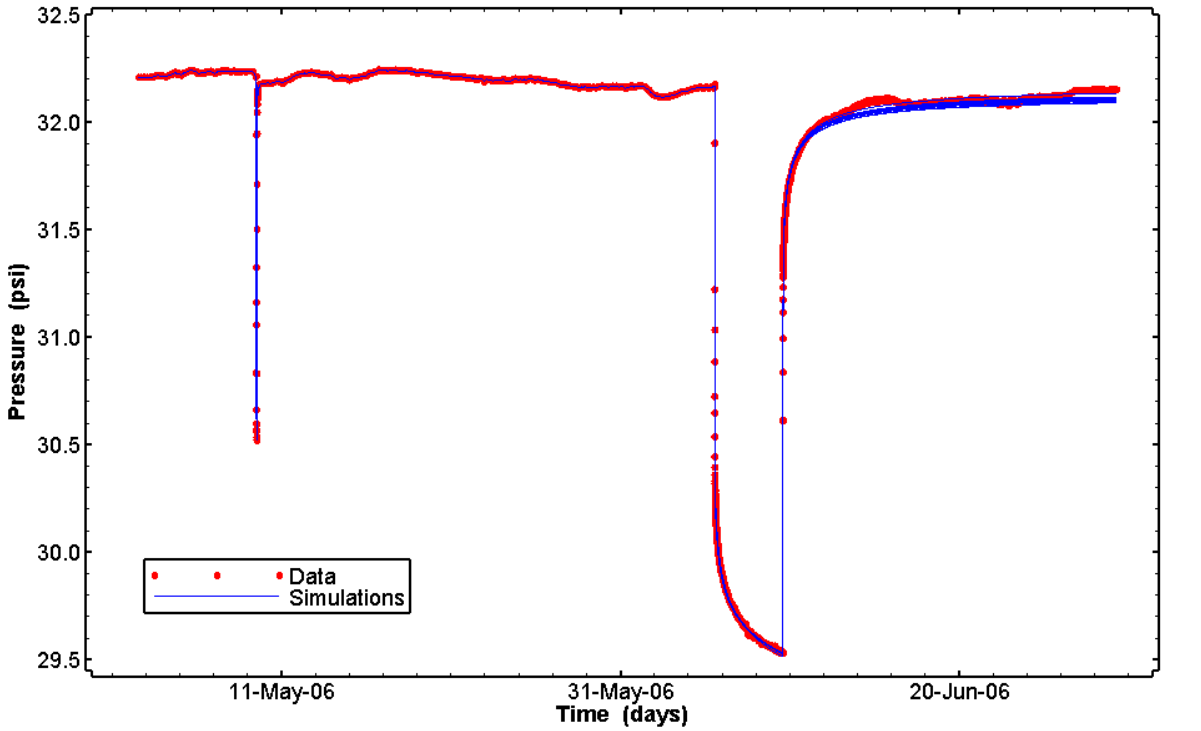

Figure 24. Linear plot showing 410 simulations of the SNL-16 pressure response.

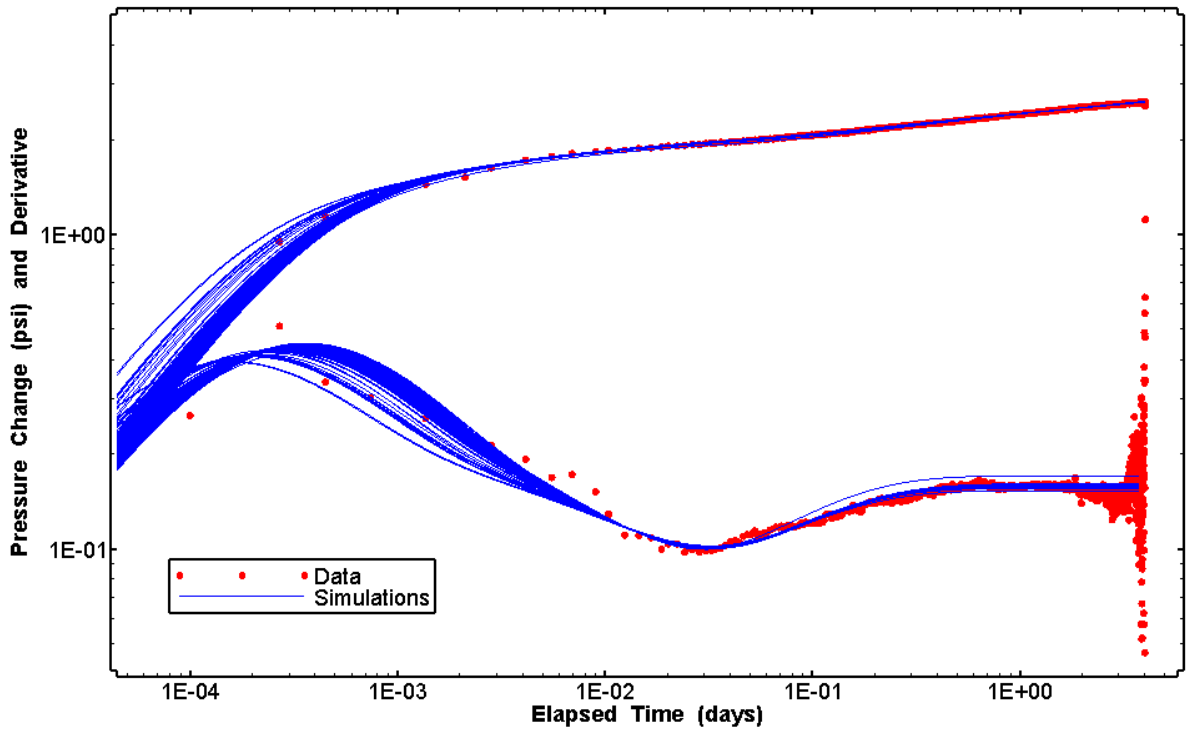

Figure 25. Log-log plot showing 410 simulations of pressure change and derivative during the SNL-16 pressure-drawdown test.

4.5 SNL-17A

A pumping rate of 32 gpm was evaluated in well SNL-17A over a ten-minute period on September 11, 2006, approximately 40 minutes before the start of the actual pumping test. The actual constant-rate (32 gpm) pumping test was initiated in SNL-17A on September 11, 2006 and continued for approximately 4 days. The pressure response from August 13, 2006 – November 6, 2006 (Figure 26) was included in this analysis. Pressure data prior to the start of pumping on September 11, 2006, were included in the analysis as a pressure history. The pressures shown in Figure 26 were separated into five nSIGHTS sequences for this analysis. The details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-17.nPre file and are listed in Appendix B.5.

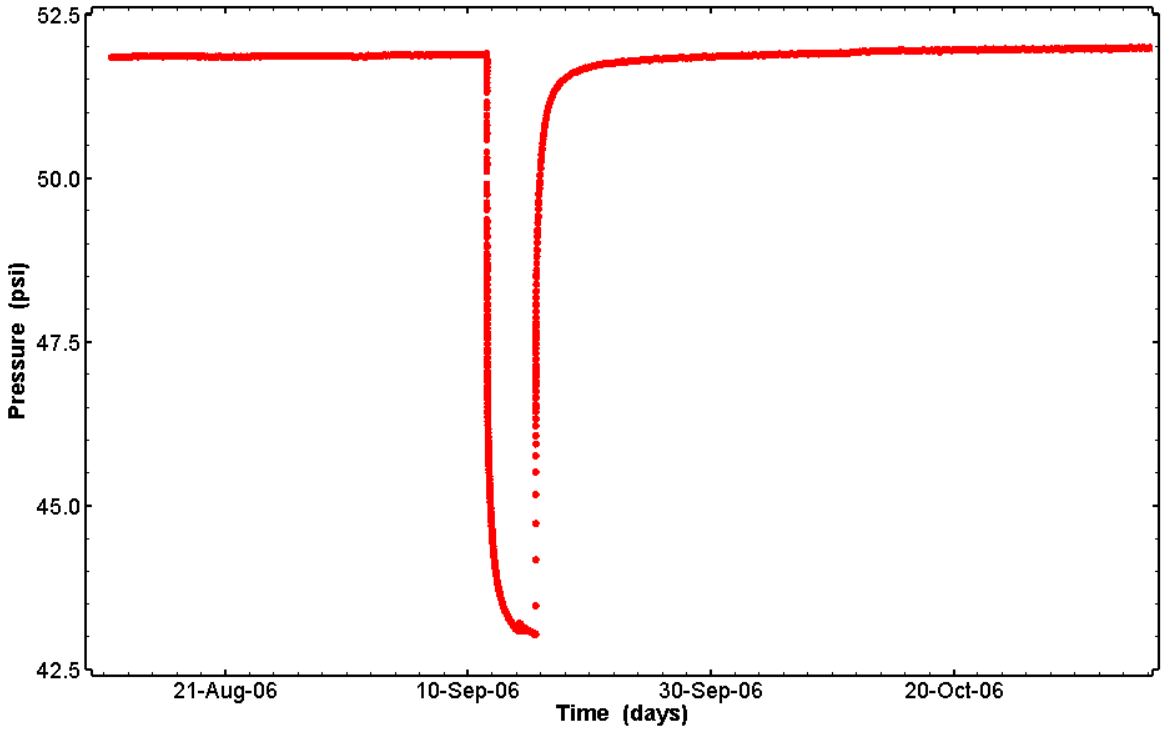

Figure 26. Pressure data from SNL-17A.

The specified SNL-17A conceptual model, based on the characteristics of the pressure-buildup diagnostic plot shown in Figure 27, was a dual-porosity and composite-*n* system with wellbore storage and skin. The near-field *n* was specified to be radial. The range of fracture *T* values (Figure 28) estimated from this analysis corresponds to the inferred derivative stabilization level shown as a horizontal line in Figure 27. The geometric mean *T* estimate was 3.35E-04 m^2/s. At approximately 0.02 days elapsed time, the derivative begins to trend upward, indicating decreasing flow area and/or *T*. A subsequent increase in flow area and/or T is then indicated by the downward trend in the derivative that begins at approximately 0.5 days elapsed time (Figure 27). The simulated SNL-17A Cartesian and log-log pressure-buildup diagnostic responses corresponding to the 246 *T* values shown in Figure 28 are shown in Figures 29 and 30, respectively.

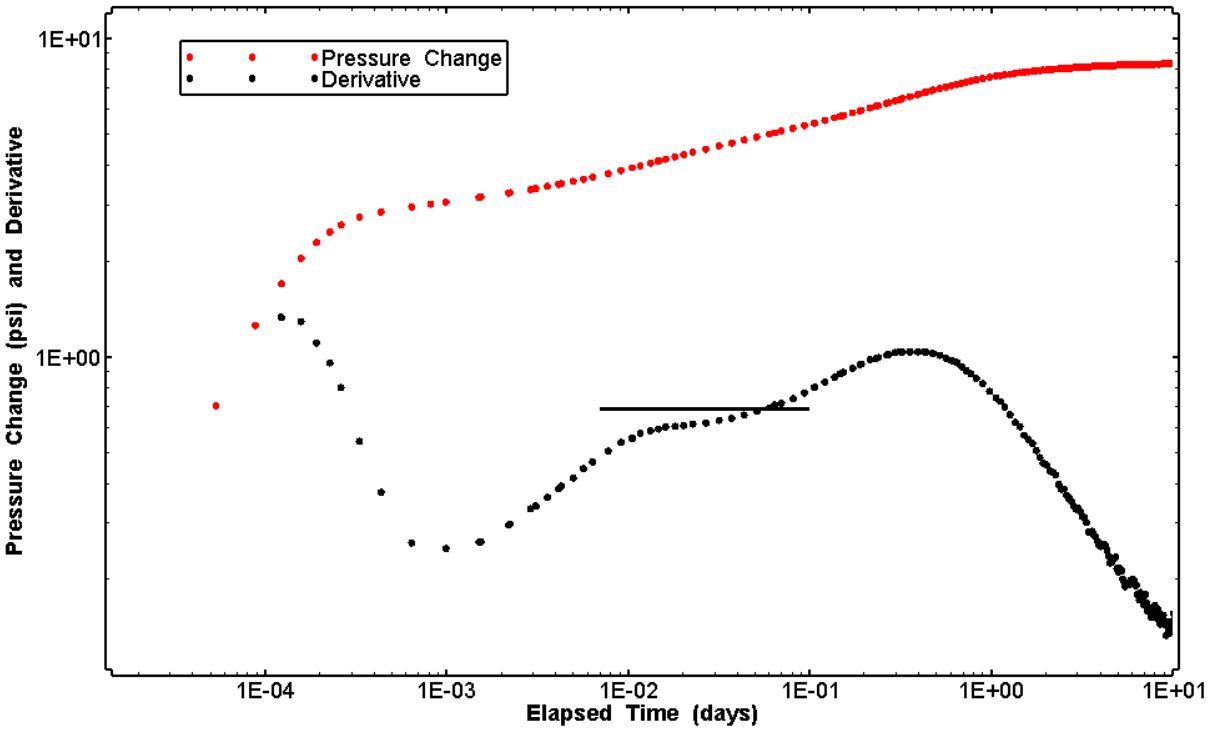

Figure 27. Log-log diagnostic plot of the SNL-17A pressure-buildup test.

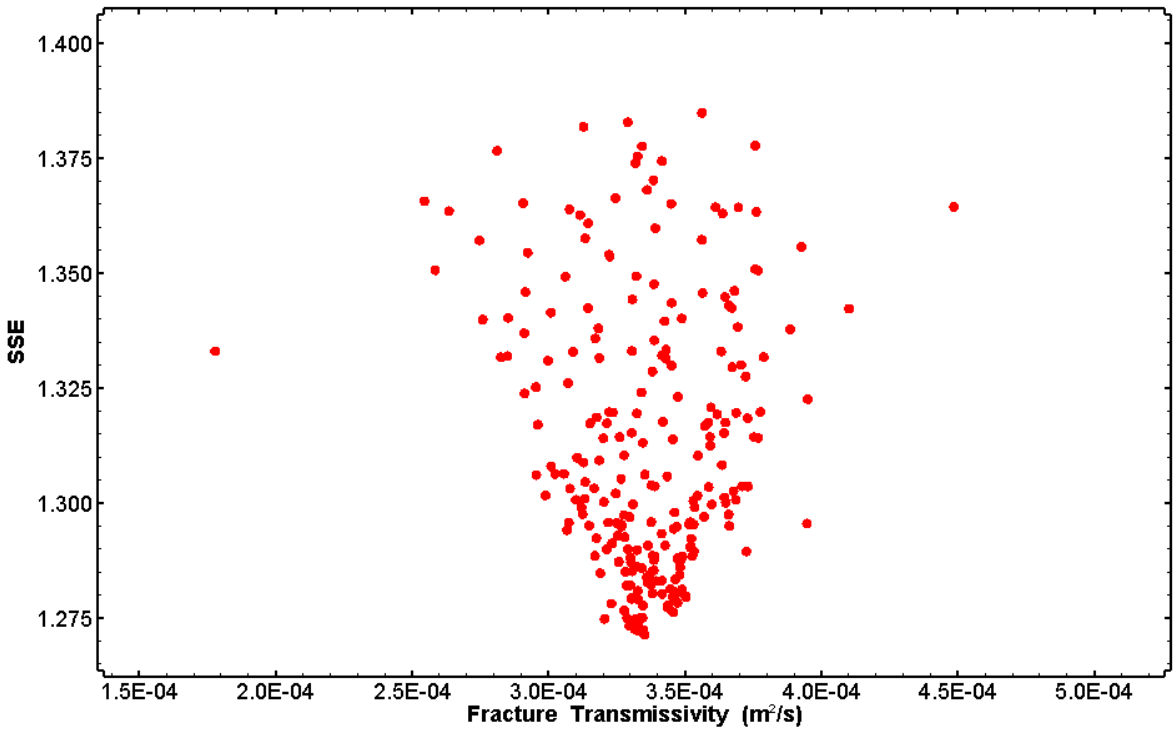

Figure 28. X-Y scatter plot showing 246 estimates of transmissivity derived from the SNL-17A perturbation analysis.

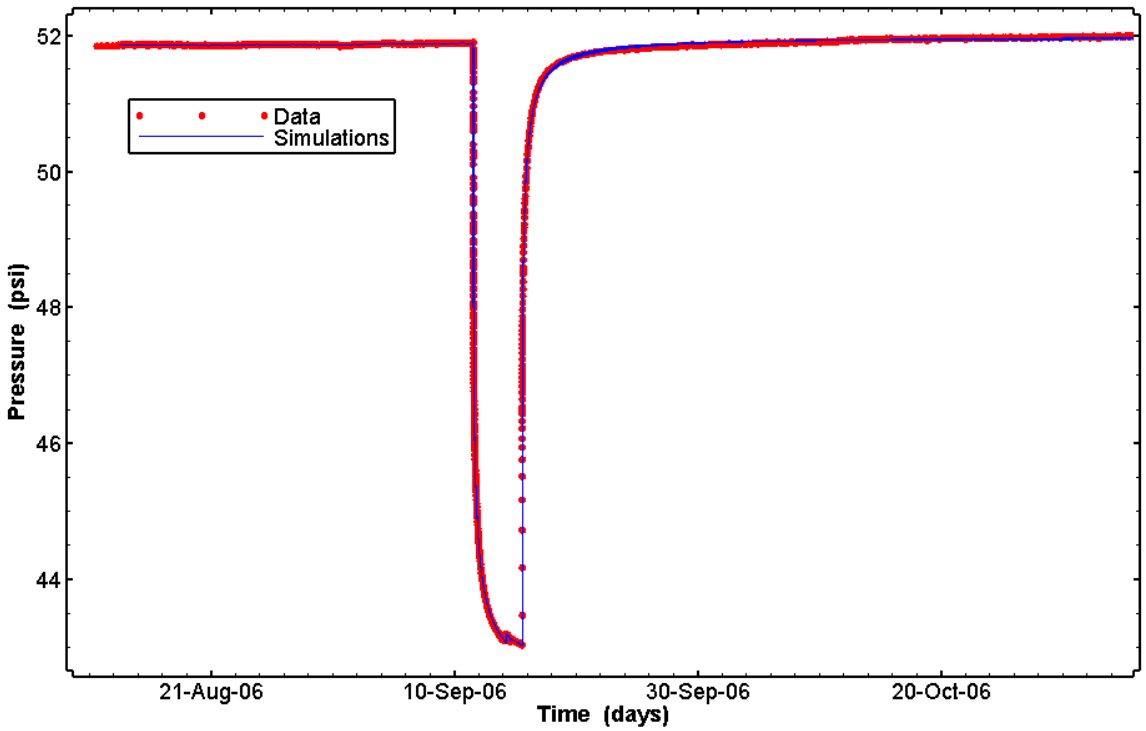

Figure 29. Linear plot showing 246 simulations of the SNL-17A pressure response.

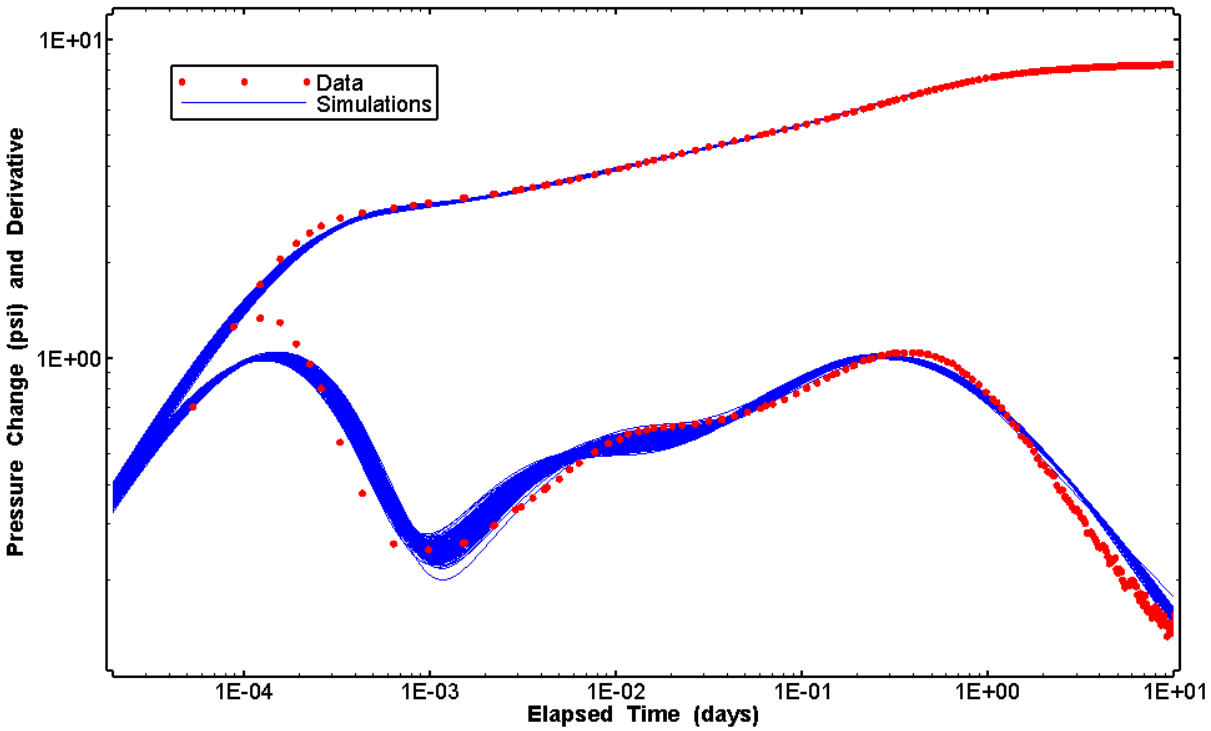

Figure 30. Log-log plot showing 246 simulations of pressure change and derivative during the SNL-17A pressure-buildup test.

4.6 SNL-18

A constant-rate (30 gpm) pumping test was initiated in SNL-18 on August 14, 2006 and continued for approximately four days. The pressure response from July 30 – August 20, 2006 (Figure 31) was included in this analysis. Pressures from July 30 – August 14, 2006 were included as a pressure history in the nSIGHTS simulations. The pressures shown in Figure 31 were separated into four nSIGHTS sequences for this analysis. The details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-18.nPre file and are listed in Appendix B.6.

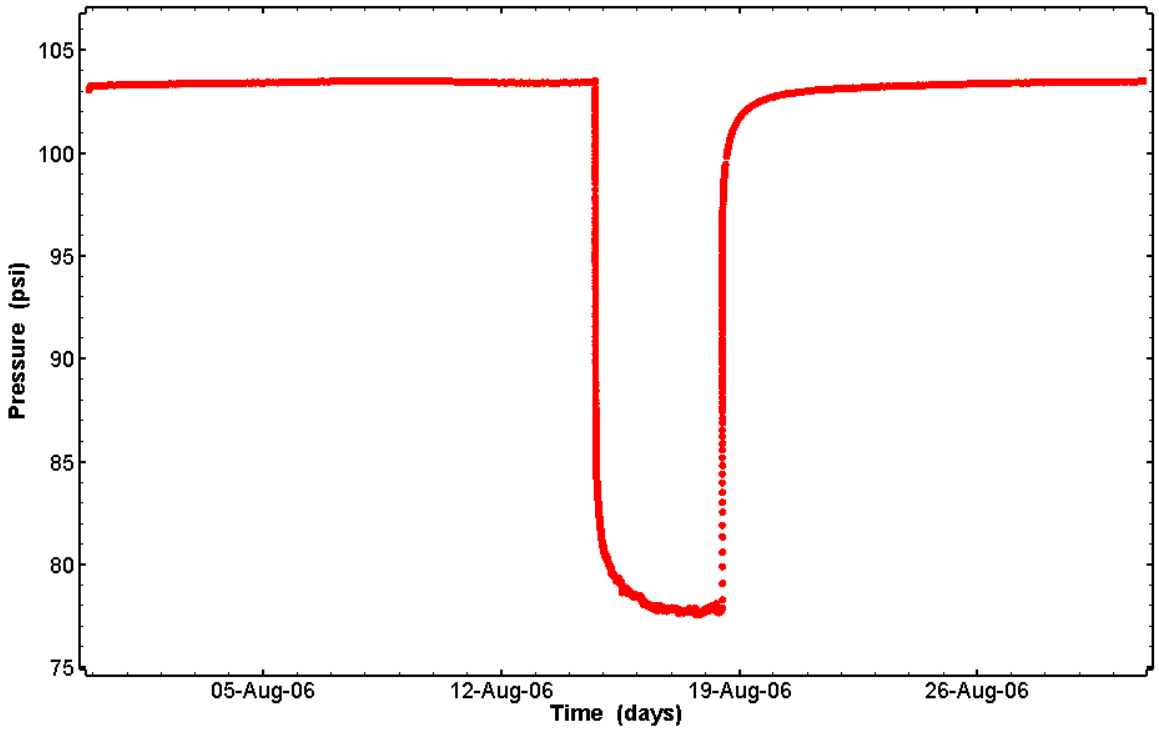

Figure 31. Pressure data from SNL-18.

The specified SNL-18 conceptual model, based on the characteristics of the pressure-buildup diagnostic plot shown in Figure 32, was a dual-porosity and composite-*T* system with wellbore storage. The range of near-field fracture-*T* values (Figure 33) estimated from this analysis corresponds to the inferred derivative stabilization level shown as a horizontal line in Figure 32. The geometric mean *T* value was 1.36E-04 m^2/s. The simulated SNL-18 Cartesian and log-log pressure-buildup diagnostic responses corresponding to the 218 *T* values shown in Figure 33 are shown in Figures 34 and 35, respectively.

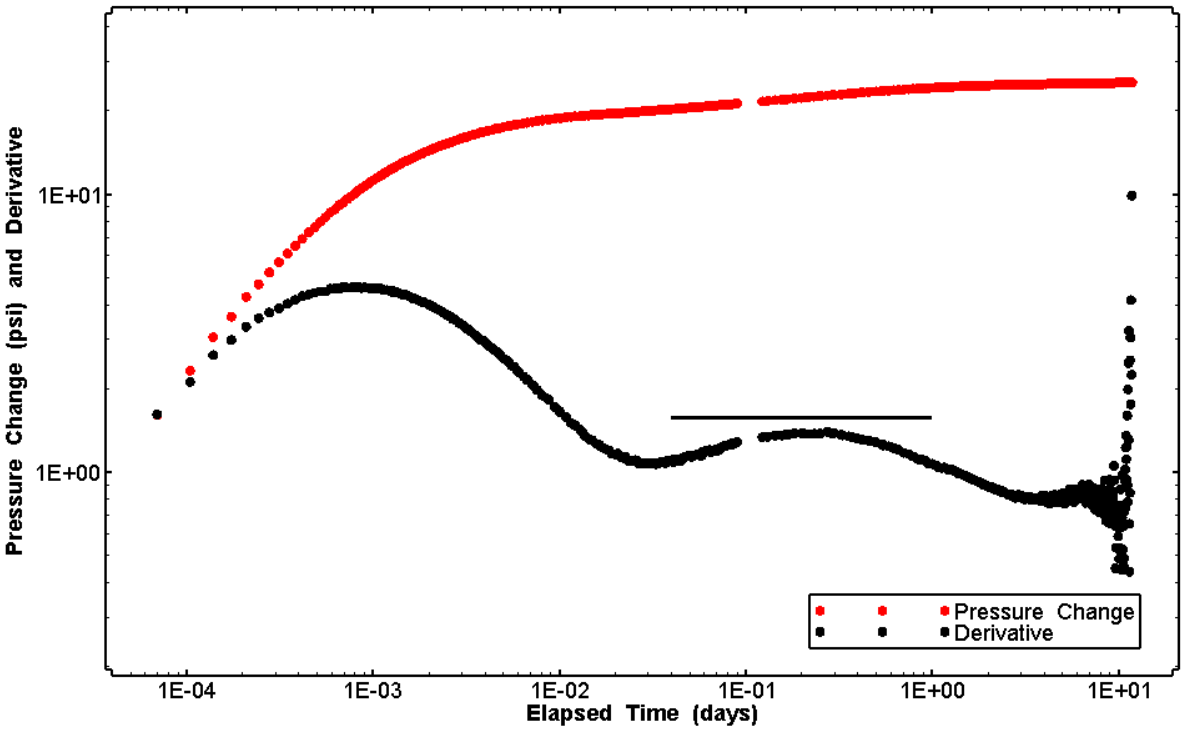

Figure 32. Log-log diagnostic plot of the SNL-18 pressure-buildup test.

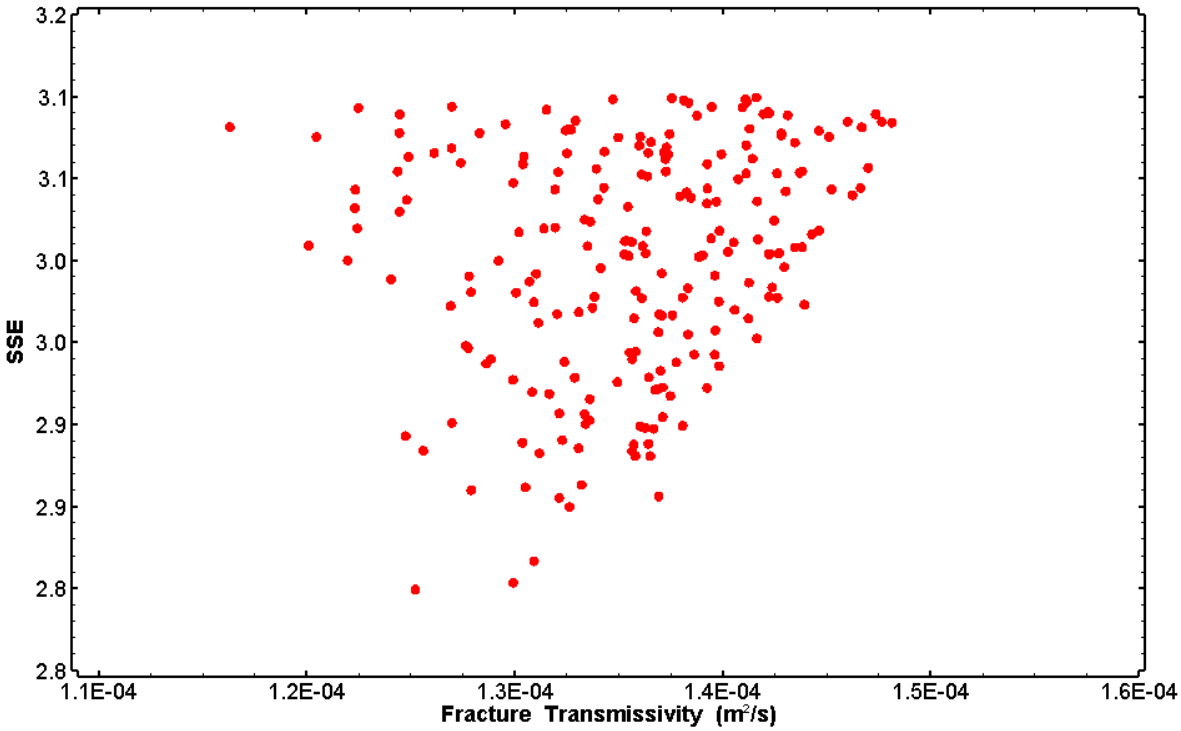

Figure 33. X-Y scatter plot showing 218 estimates of transmissivity derived from the SNL-18 perturbation analysis.

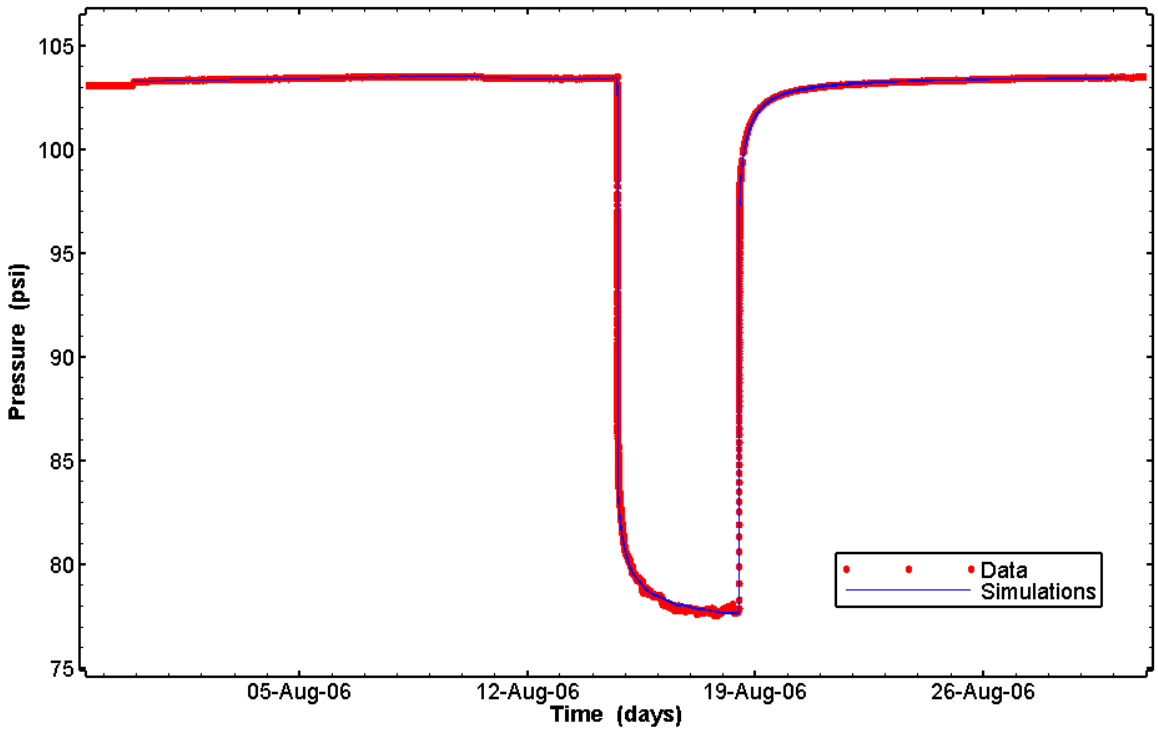

Figure 34. Linear plot showing 218 simulations of the SNL-18 pressure response.

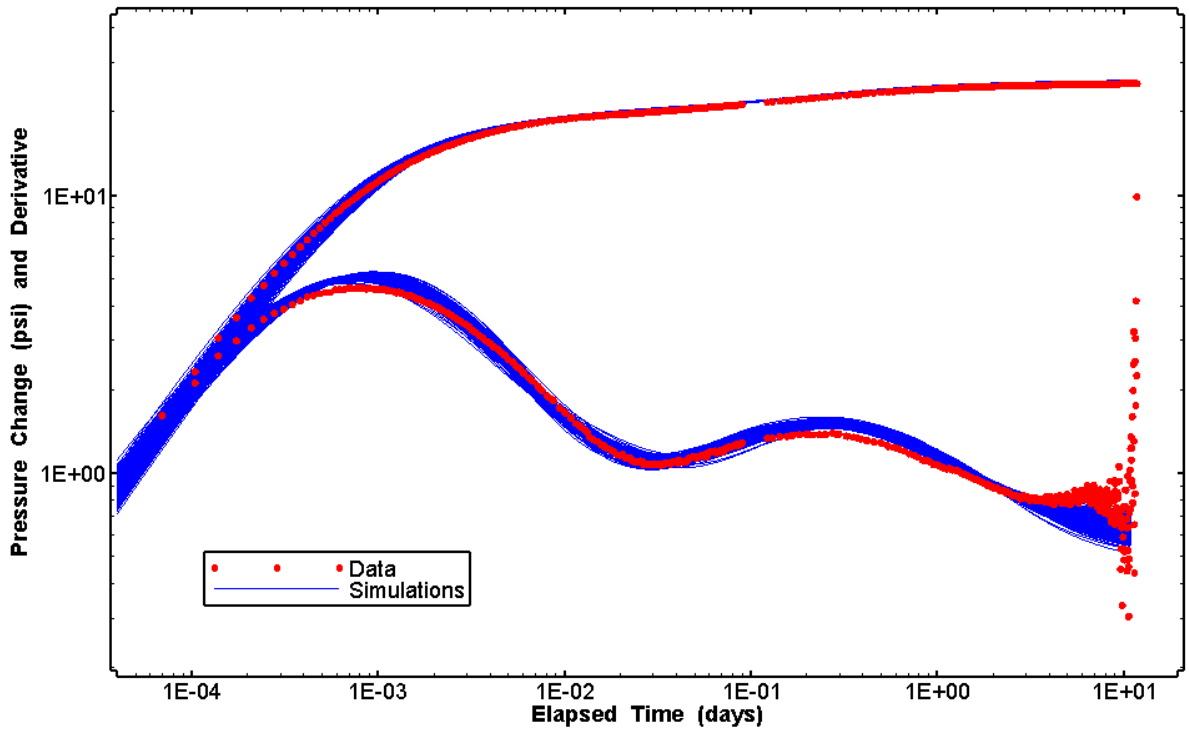

Figure 35. Log-log plot showing 218 simulations of pressure change and derivative during the SNL-18 pressure-buildup test.

4.7 SNL-19

A constant-rate (30 gpm) pumping test was initiated in SNL-19 on July 24, 2006 and continued for approximately 4 days. The pressure response from June 17 – August 10, 2006 was included in this analysis (Figure 36). The pressures shown in Figure 36 were separated into three nSIGHTS sequences for this analysis. SNL-19 pressures from June 17 – July 24, 2006 were included in the nSIGHTS simulations as a pressure history. The details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-19.nPre file and are listed in Appendix B.7.

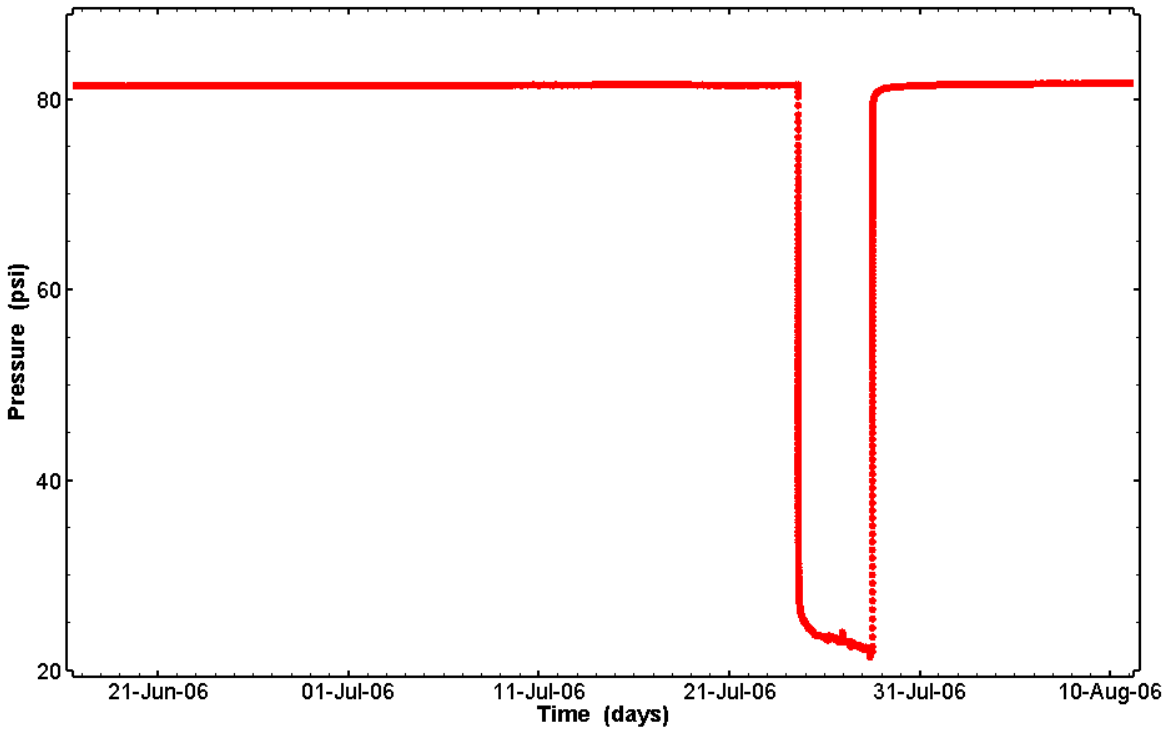

Figure 36. Pressure data from SNL-19.

The specified SNL-19 conceptual model, based on the characteristics of the pressure-buildup diagnostic plot shown in Figure 37, was a radial composite-*T* system with wellbore storage and time-dependent skin. The range of *T* values (Figure 38) estimated from this analysis corresponds to the derivative stabilization that begins at approximately 0.04 days in Figure 37. The transition to a zone of higher T is reflected in the decreasing derivative beginning at about 0.2 days (Figure 37). The near-field *T* estimates are shown in Figure 38. The geometric mean *T* estimate derived from this analysis was 4.26E-04 m^2/s. The simulated SNL-19 Cartesian and log-log pressure-buildup diagnostic responses corresponding to the 239 *T* values shown in Figure 38 are shown in Figures 39 and 40, respectively.

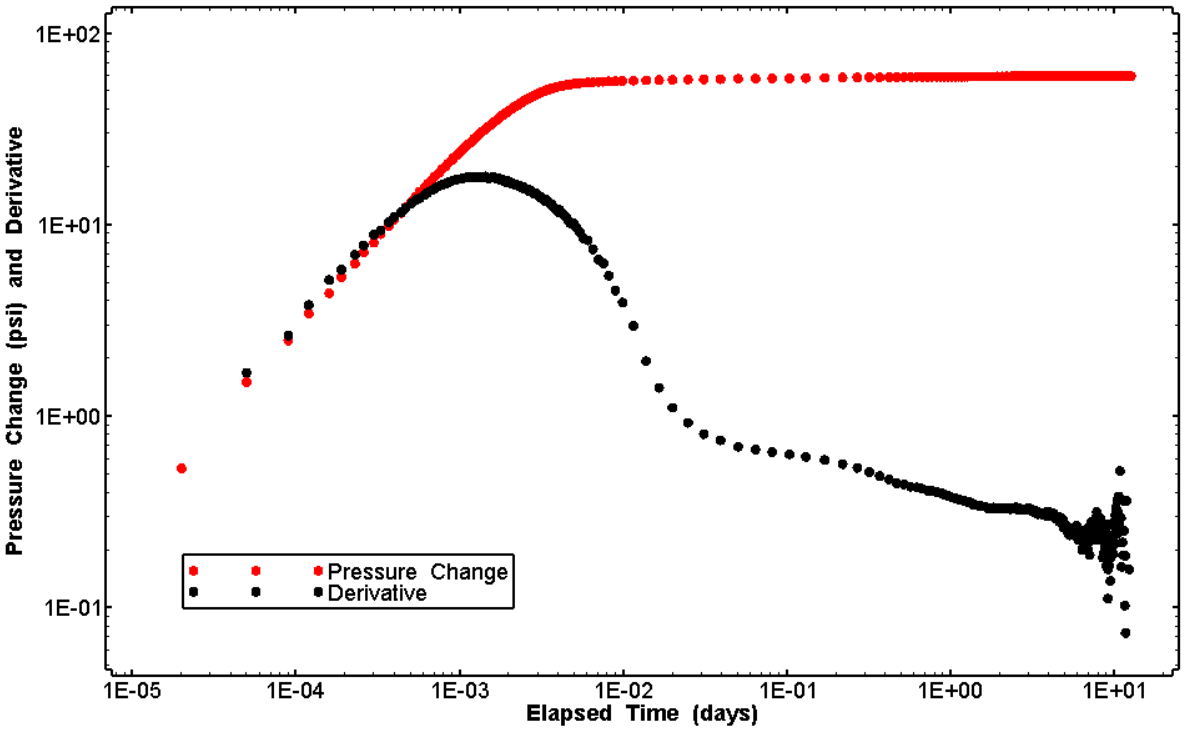

Figure 37. Log-log diagnostic plot of the SNL-19 pressure-buildup test.

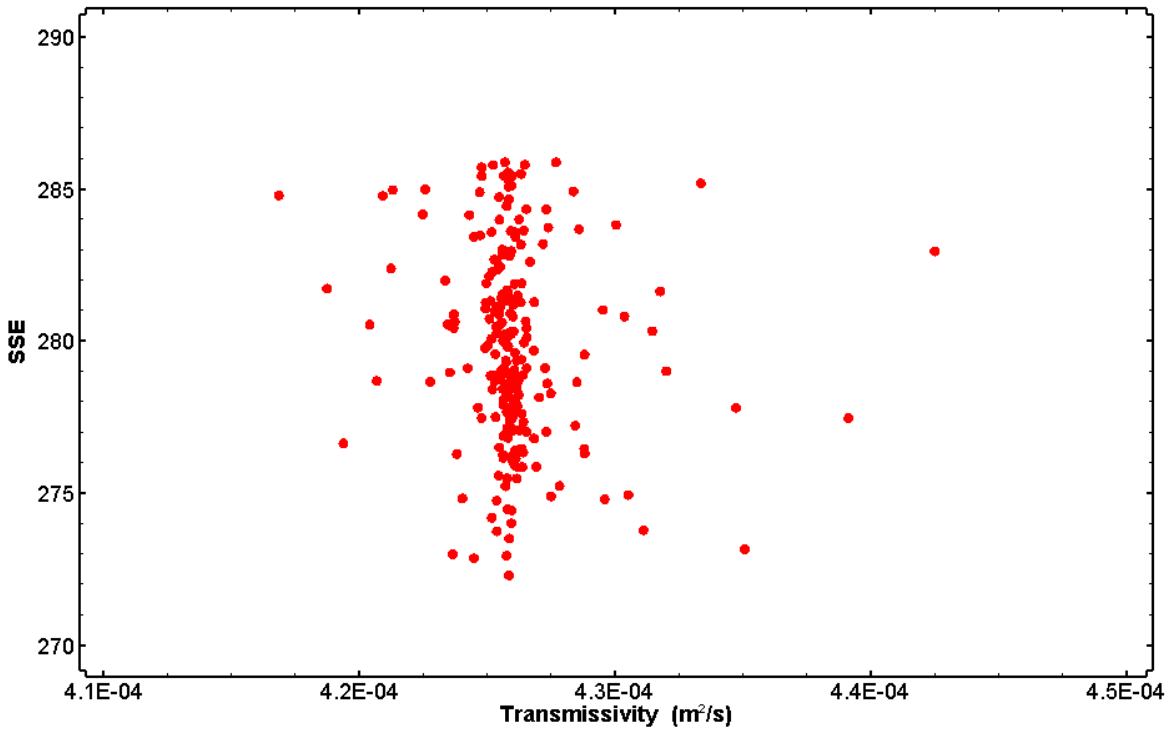

Figure 38. X-Y scatter plot showing 239 estimates of transmissivity derived from the SNL-19 perturbation analysis.

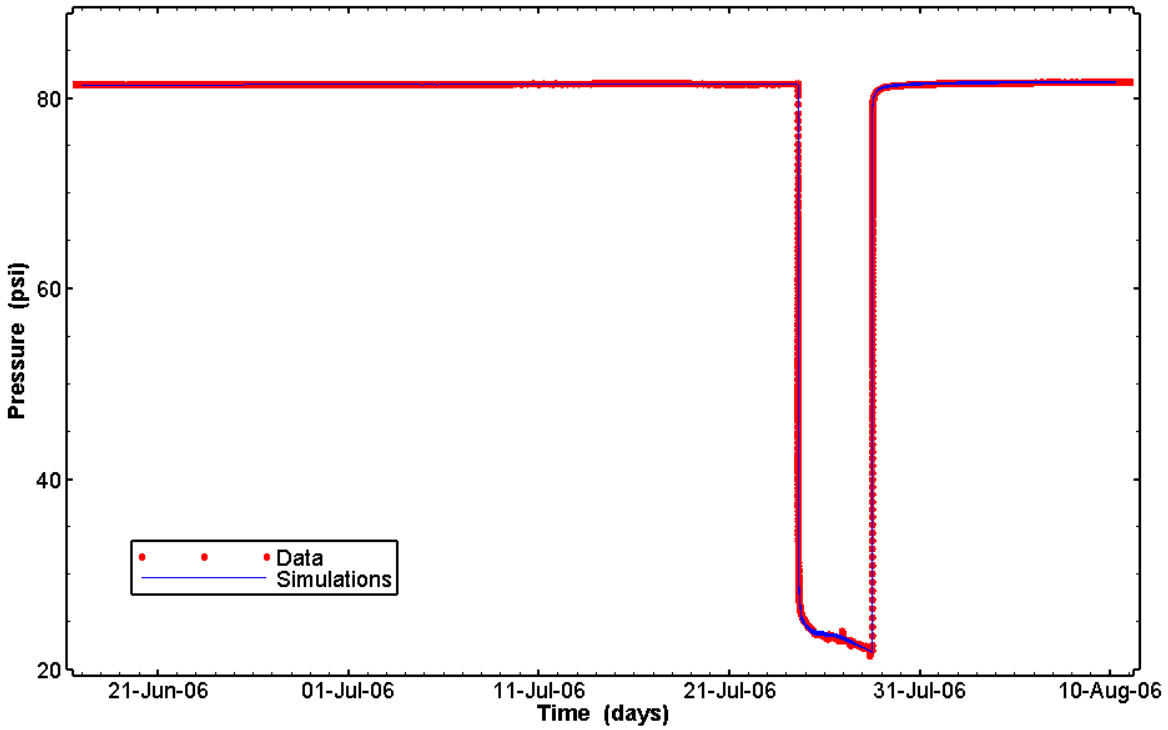

Figure 39. Linear plot showing 239 simulations of the SNL-19 pressure response.

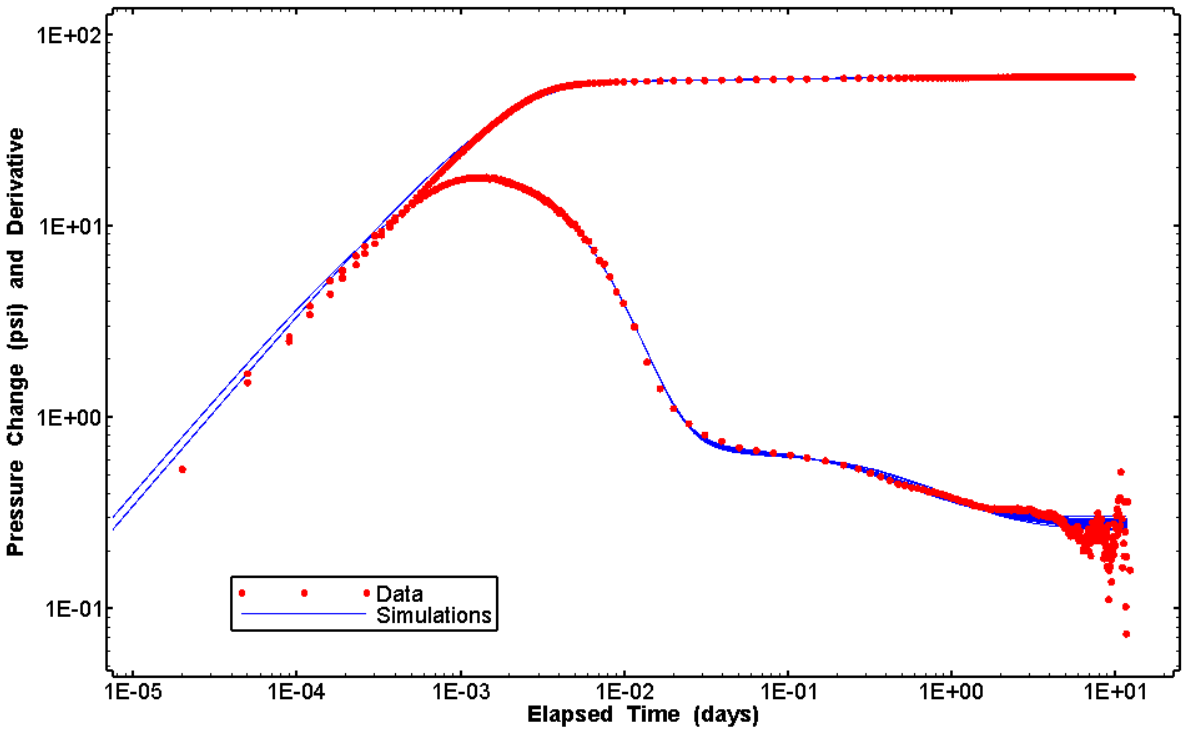

Figure 40. Log-log plot showing 239 simulations of pressure change and derivative during the SNL-19 pressure-buildup test.

4.8 SNL-15

SNL-15 was drilled from June 1-5, 2005 using compressed air to remove cuttings (Powers and Richardson, 2007a). The well was cased with 2.88-inch outside diameter (OD), 2.48-inch inside diameter (ID) fiberglass casing on June 7, 2005, at which time the well was dry. Monitoring of the water level in the well with a Troll began on June 23, 2005. On March 30, 2007, approximately 13 gallons were pumped from the well over a 26-minute period, amounting to an approximately 52-ft slug removal. A LevelTroll was installed approximately 41 minutes later to monitor water-level (or pressure-head) recovery.

The pressure response from June 23, 2005 to September 10, 2007 was included in this analysis (Figure 41). The pressures shown in Figure 41 were separated into four nSIGHTS sequences for this analysis. In the SNL-15 analysis, it was assumed that the borehole was dry for two days immediately following drilling completion, so an initial two-day pressure history was included at the start of the simulation with a specified pressure of zero psi. The details of each sequence, i.e., start/end time, flow rate, etc., are specified in the SNL-15.nPre file and are listed in Appendix B.8. All of the data shown in Figure 41 were used in the SNL-15 regression analysis, i.e., both the initial pressure buildup following drilling and the subsequent slug-test response were simulated.

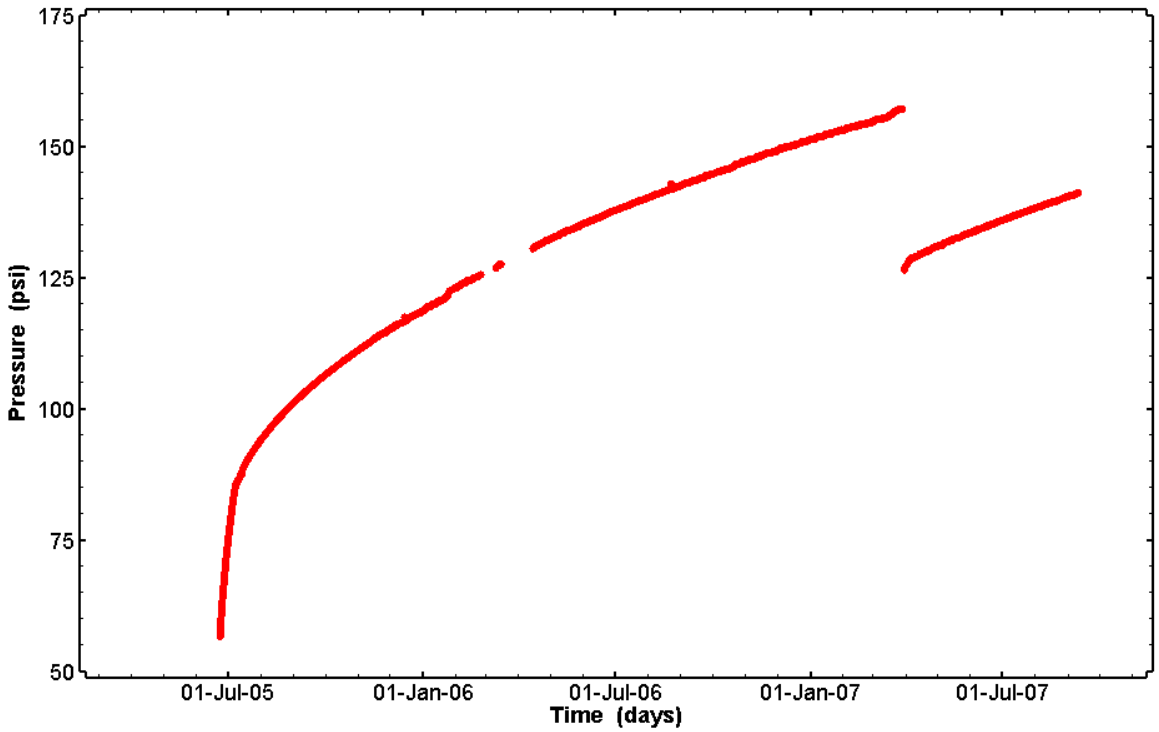

Figure 41. Pressure data from SNL-15.

The SNL-15 data were not suitable for creating a diagnostic plot to help determine the appropriate conceptual model, so the simplest model that was consistent with the borehole completion characteristics and produced an adequate fit to the data ("adequate" as determined by the analyst) was used: an infinite-acting radial system with wellbore storage and skin. The range of *T* values estimated from this analysis is shown in Figure 42. The geometric mean *T* estimate derived from this analysis was 1.38E-13 m^2/s. The simulated SNL-15 Cartesian responses corresponding to the 332 *T* values shown in Figure 42 are shown in Figure 43.

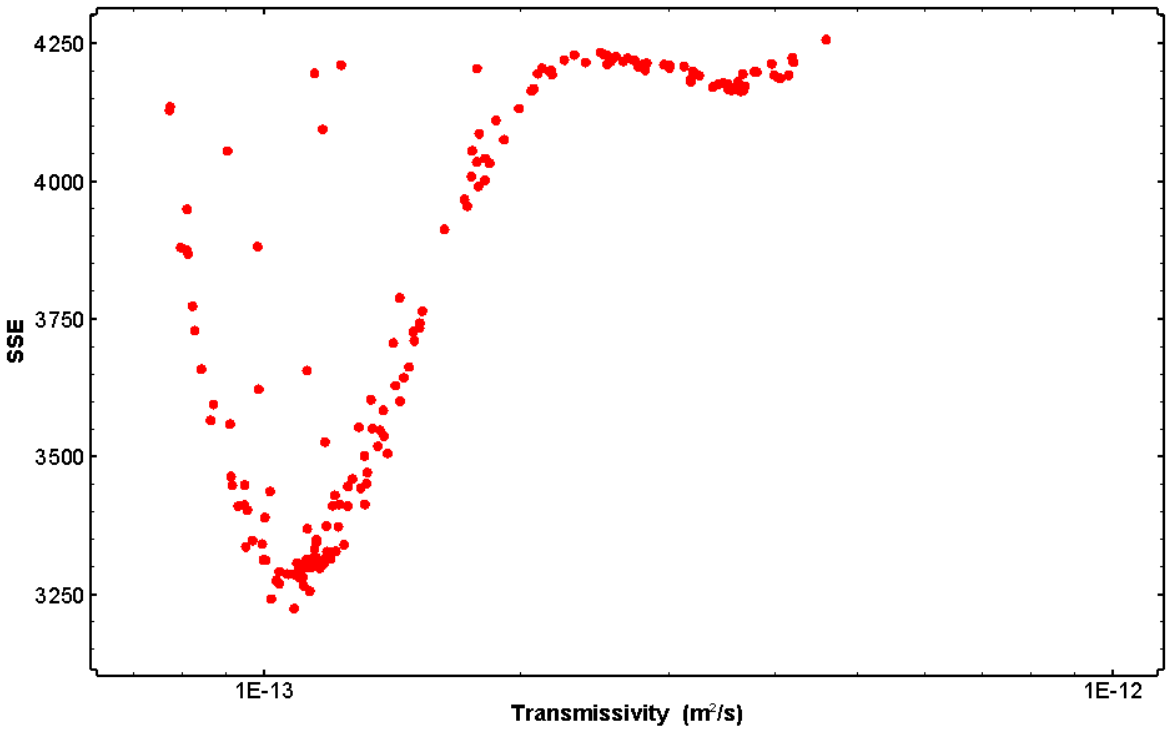

Figure 42. X-Y scatter plot showing 332 estimates of transmissivity derived from the SNL-15 perturbation analysis.

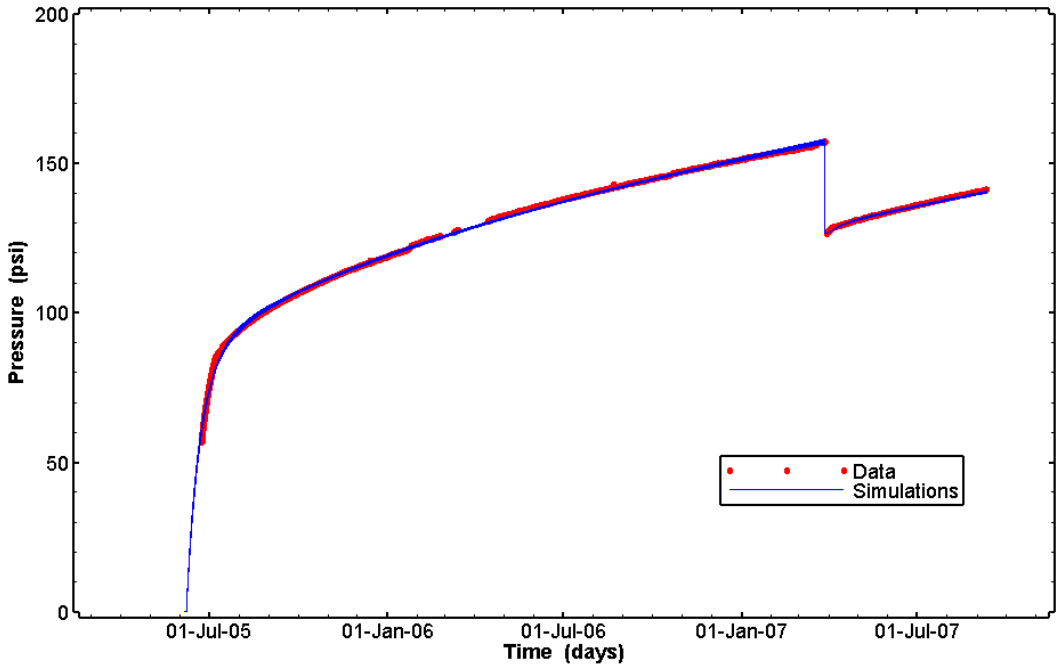

Figure 43. Linear plot showing 332 simulations of the SNL-15 pressure response.

5. References

Beauheim, R.L. 2004. Analysis Plan for Non-Salado Hydraulic-Test Interpretations, AP-070, Revision 1. ERMS# 537479. Carlsbad, NM: Sandia National Laboratories, WIPP Records Center.

Beauheim R.L., R.M. Roberts, T.F. Dale, M.D. Fort, and W.A. Stensrud. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report*. SAND92-0533. Albuquerque, NM: Sandia National Laboratories.

Powers, D.W., and R.G. Richardson. 2007a. *Basic Data Report for Drillhole SNL-15 (C-3152) (Waste Isolation Pilot Plant).* DOE/WIPP 05-3325. Carlsbad, NM: U.S. Department of Energy.

Powers, D.W., and R.G. Richardson. 2007b. *Basic Data Report for Drillhole SNL-13 (C-3139) (Waste Isolation Pilot Plant).* DOE/WIPP 05-3319. Carlsbad, NM: U.S. Department of Energy.

Ramey H.J., Agarwal R.G., and Martin I. 1975. *Analysis of 'Slug Test' or DST Flow Period Data.* J. Can. Petroleum Technol. 14(3), 37-47**.**

Roberts R.M., R.L. Beauheim, and P.S. Domski. 1999. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Final Report*. SAND98-2537. Albuquerque, NM: Sandia National Laboratories.

Appendix A – Culebra Hydraulic Tests – June 2006 to September 2007

Well	Date and Time Start DAS	Date and Time Stop DAS	Date and Time Start Pump	Date and Time Stop Pump	Borehole Diameter (in)	Inside Casing Diameter (in)	Culebra Interval (ft)	Specific Gravity (g/cm^3)	Troll Filenames (ERMS# 539221)	DAS Filenames (ERMS# 543540)	Field Notebook (ERMS# 540244)	Reports
SNL-8	**12/14/2006 11:29** **12/14/2006 12:00** **12/14/2006 13:15** **12/14/2006 15:25** **12/14/2006 12:05** **12/15/2006 11:15**	**12/19/2006 8:22** **12/14/2006 13:11** **12/14/2006 15:25** **12/19/2006 10:29** **12/15/2006 11:00** **12/28/2006 10:44**	NA	NA	11	4.85	953-978	1.1	SN11358 SNL-8(Cslugtube) SN110382 SNL-8(C14slug) SN110382 SNL-8(C15slug) SN110382 SNL-8(C16slug) SN102926 SNL-8(Cslug-annulus2) SN102926 SNL-8(Cslug-annulus3)	NA	WSWT #10	Memo: Screen Interval for Culebra Dolomite Member in SNL-8 and Email: Well Information (ERMS# 539318)
SNL-10	10/30/2006 13:50	11/3/2006 16:43	10/30/2006 15:19	11/3/2006 16:37	11	4.85	599-621	1.008	SN17353 SNL-10 (C3) SN17353 SNL-10(Cpump1)	SNL-10 (C) Pumping Test 1	WSWT #10	Memo: Screen Interval for Culebra Dolomite Member in SNL-10 and Email: Well Information (ERMS# 539318)
SNL-13	7/12/2006 12:00	7/17/2006 14:26	7/12/2006 12:06	7/17/2006 13:28	11	4.85	388-412	1.016	SN18823 SNL-13(Bennett1) SN18823 SNL-13(C9) SN18823 SNL-13(Bennett2) SN18823 SNL-13(C10) SN18823 SNL-13(C11) SN4558 SNL-13(C12)	SNL-13 bennett	WSWT #8	Powers and Richardson (2007b)
SNL-16	6/5/2006 11:46	6/9/2006 14:35	6/5/2006 13:51	6/9/2006 14:25	11	4.85	193-217	1.014	SNL-16(Cpump2) SNL-16(Cpmplev2)	SNL-16 (C) Pumping Test	WSWT #8	Memo: Screen Interval for Culebra Dolomite Member in SNL-16 and Email: Well Information (ERMS# 539318)
SNL-17	9/11/2006 11:49	9/15/2006 14:03	9/11/2006 13:46	9/15/2006 13:55	11	4.85	332-362	1.003	SNL-17(Cpump1)	SNL-17 (C) Pumping Test 1	WSWT #9	Memo: Screen Interval for Culebra Dolomite Member in SNL-17A (ERMS# 539318)
SNL-18	8/14/2006 16:56	8/18/2006 12:17	8/14/2006 18:21	8/18/2006 12:03	11	4.85	538-557	1.015	SNL-18(CLevelpmp1); SNL-18(CPump1)	SNL-18 (C) Pumping Test 1	WSWT #9	Memo: Screen Interval for Culebra Dolomite Member in SNL-18 and Email: Well Information (ERMS# 539318)
SNL-19	7/24/2006 14:02	7/28/2006 12:29	7/24/2006 15:00	7/28/2006 12:18	11	4.85	341-362	1.007	SN 17621 SNL-19(C3) SN 17621 SNL-19(Cpump2) SN 17621 SNL-19(C4)	SNL-19 (C) Pumping Test 1	WSWT #9	Memo: Screen Interval for Culebra Dolomite Member in SNL-19 and Email: Well Information (ERMS# 539318)
SNL-15	**6/23/2005 14:00**	**7/7/2005 13:50**	NA	NA	7.875	2.48	902-932	1.205	SN18778 SNL-15 (C)	NA	WSWT #7, 8, & 10	Powers and Richardson (2007a)

	7/7/2005 15:00	**7/14/2005 10:15**						SN18778 SNL-15 (C1)			
	7/14/2005 11:00	**11/14/2005 9:50**						SN18778 SNL-15 (C2)			
	11/15/2005 14:00	**1/23/2006 11:05**						SN11358 SNL-15 (C3)			
	1/23/2006 12:00	**2/25/2006 20:13**						SN11358 SNL-15 (C4slug)			
	10/20/2006 1:00	**3/16/2007 11:00:39**						SN102926 SNL-15 (CBENNET) 4-14-06 2006-10-20 10.35.02			
	3/16/2007 3:00	**3/28/2007 8:00**						SN110962 10-20-2006 SNL-15 (CX) 2007-03-16 23-18-06			
	3/30/2007 2:26:37	**4/18/2007 10:37:07**						SN110962 031607 SNL-15 (CX1) 2007-03-30 14.12.21			
	4/18/2007 11:00	**8/27/2007 10:00**						SN110962 3-30-07 SNL-15 (C8) 2007-04-18 09.38.58			
	8/27/2007 10:46:47	**9/10/2007 1:46:47**						SN110962 041807 SNL-15 (C9) 2007-06-18 09.44.34			

Notes:
- WSWT = WIPP Site Well Testing Scientific Notebook

- SNL-8 The bold start and stop DAS time is start and stop time of the Troll files. Each corresponds with the file in the Troll filenames column.
  Shut-in valve opened on 12/14/06 12:15:00 – Shut-in valve closed on 12/15/06 12:10:00.
- SNL-15 The bold start and stop DAS time is start and stop time of the Troll files. Each corresponds with the file in the Troll filenames column.
  The slug test on 3/30/07 was initiated by pumping from 13:03 to 13:29.
- Data presented in columns titled Date and Time Start DAS, Date and Time Stop DAS, Date and Time Start Pump, Date and Time Stop Pump, Specific Gravity, Troll Filenames, and DAS Filenames were found in Scientific Notebooks referenced in the column titled Field Notebook
- Data presented in columns titled Borehole Diameter (in), Inside Casing Diameter (in), and Culebra Interval (ft) were found in reports referenced in the column titled Reports

Appendix B – nSIGHTS Listings

B.1 SNL-8 nSIGHTS Listings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   31 May 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 8\SNL-8 Slug.nPre
```

Control Settings

Main Settings

Simulation type	Forward	
Simulation subtype	Normal	
Phase to simulate	Liquid	
Skin zone ?	no	
External boundary	Fixed Pressure	
Curve data source	Objects	

Liquid Phase Settings

Aquifer type	Confined	
Aquifer horizontal permeability	Isotropic	
System porosity	Single	
Compensate flow dimension geometry	yes	
Leakage	None	

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	26.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	125.800	[psi]
External boundary radius	1000000	[m]
Formation conductivity	1.21994E-08	[m/sec]
Formation spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1100.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	1.0	[in]

Numeric

# of radial nodes	250	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.00000E-15	[m^3/sec]

Calculated Parameters

Formation

Transmissivity	9.66781E-08	[m^2/sec]
Storativity	7.92480E-06	[]
Diffusivity	1.21994E-02	[m^2/sec]

Test Zone

Open hole well-bore storage	1.87899E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.06339	[]
First grid increment	9.14208E-03	[m]

Sequences

Sequence: H_01

Sequence type	History	
Start time	39065.612360	[day]
Duration	0.000560	[day]
Time step type	Static	
Static time step	0.000010	[day]
Type	Curve	
Wellbore storage	None	

Sequence: S_01

Sequence type	Slug	
Start time	39065.612920	[day]
Duration	0.894080	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Initial pressure type	Absolute	
Initial pressure	135.295	[psi]

Test Zone Curves

Curve object to use	Create Curve
Curve type	Pressure
Start sequence	H_01
End sequence	H_01
Curve time base	Test
Curve Y data units	[psi]
Curve Y data is log 10	no

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]

Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[m^3/sec]

SNL-8 nSIGHTS Optimization Settings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   31 May 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 8\SNL-8 Slug.nPre
```

Control Settings

Main Settings

Simulation type	Optimization
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	no
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Single
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	26.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	125.000	[psi]
Maximum value	130.000	[psi]
Estimate value	125.800	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-09	[m/sec]
Maximum value	1.00000E-07	[m/sec]
Estimate value	1.21994E-08	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	Optimization	
Minimum value	1.00000E-07	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	1.00000E-06	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1100.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	1.0	[in]

Numeric

# of radial nodes	250	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.00000E-15	[m^3/sec]

SNL-8 Fitting-Parameter Estimates

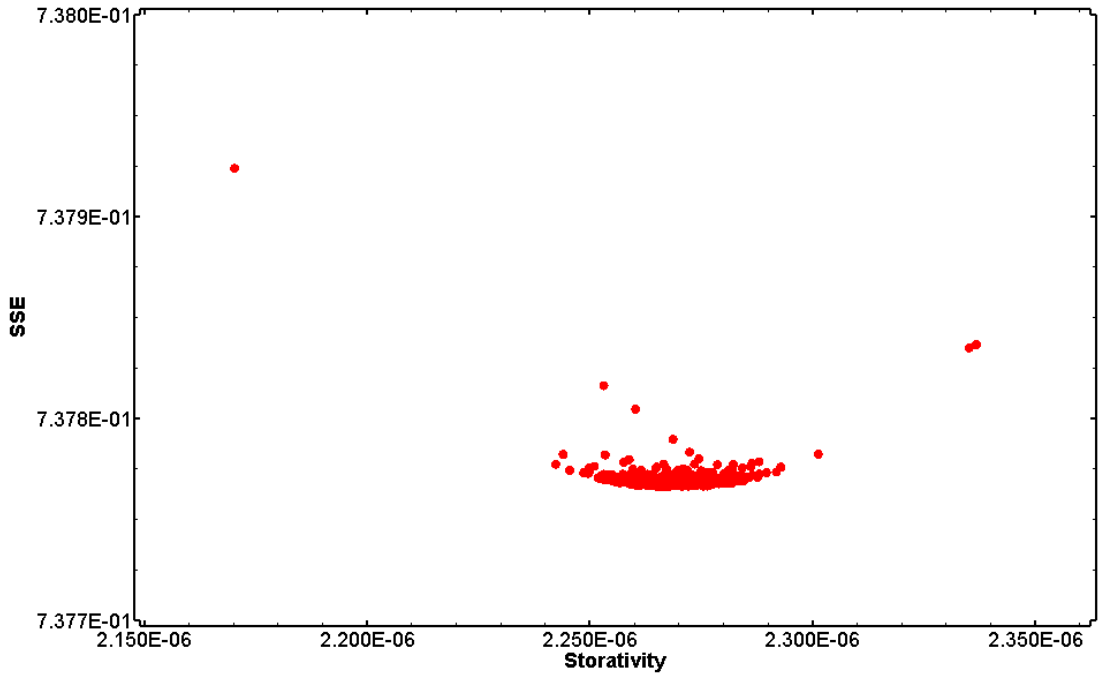

Figure B-1. Estimates of storativity derived from the SNL-8 perturbation analysis.

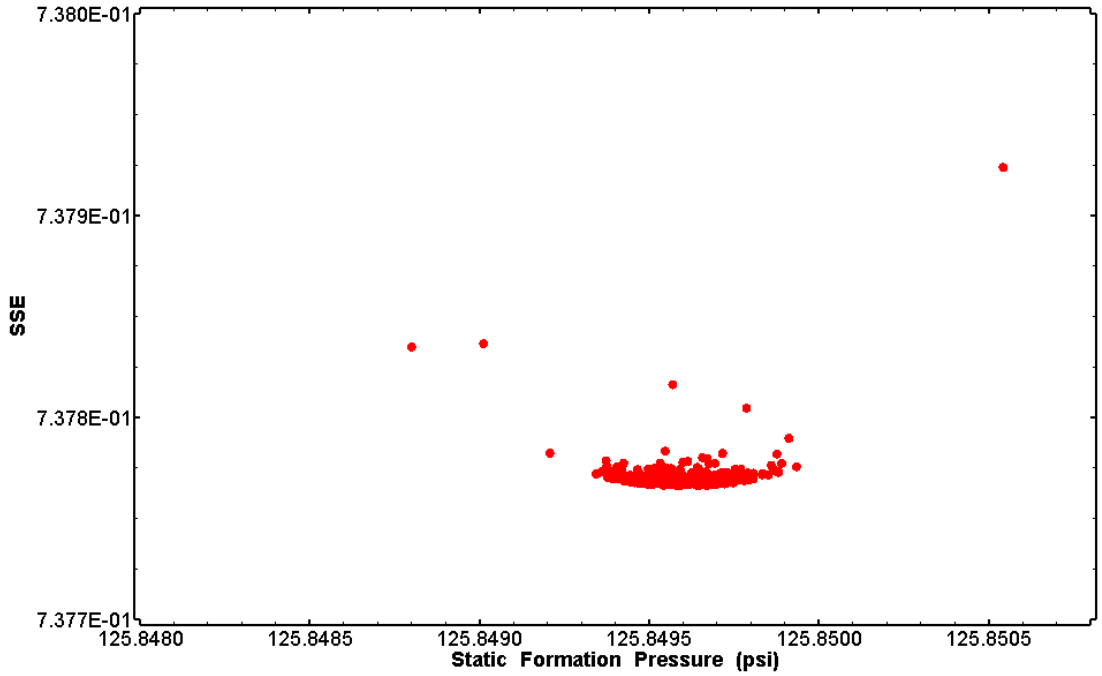

Figure B-2. Estimates of static formation pressure derived from the SNL-8 perturbation analysis.

B.2 SNL-10 nSIGHTS Listings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   11 Jun 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 10\SNL 10.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Single
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	22.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	120.172	[psi]
External boundary radius	1000000	[m]
Formation conductivity	4.83945E-08	[m/sec]
Formation spec. storage	5.75710E-07	[1/m]

Skin

Radial thickness of skin	0.025298	[m]
Skin zone conductivity	3.07306E-08	[m/sec]
Skin zone spec. storage	1.00000E-07	[1/m]

Fluid

Fluid density	1008.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	2.195184	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.58503E-11	[USgpm]

Calculated Parameters

Formation

Transmissivity	3.24514E-07	[m^2/sec]
Storativity	3.86048E-06	[]
Diffusivity	8.40606E-02	[m^2/sec]

Skin Zone

Transmissivity	2.06067E-07	[m^2/sec]
Storativity	6.70560E-07	[]
Diffusivity	3.07306E-01	[m^2/sec]
Skin factor	9.56668E-02	[]

Test Zone

Open hole well-bore storage	9.88092E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.07848	[]
First grid increment	1.34706E-02	[m]
Skin grid increment delta	0.00340	[]
Skin first grid increment	4.75319E-04	[m]
Skin last grid increment	5.59490E-04	[m]
Increment ratio	2.40765E+01	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	39020.637500	[day]
Duration	0.018056	[day]

Time step type	Static	
Static time step	0.000116	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	39020.655556	[day]
Duration	3.954861	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-0.248	[USgpm]
Wellbore storage	Open	

Sequence: H_02

Sequence type	History	
Start time	39024.610417	[day]
Duration	0.081944	[day]
Time step type	Static	
Static time step	0.000116	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	39024.692361	[day]
Duration	11.707639	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	Pressure Curve	
Curve type	Pressure	
Start sequence	H_01	
End sequence	H_02	
Curve time base	Test	
Curve Y data units	[psi]	
Curve Y data is log 10	no	

Curve object to use	Create Curve	
Curve type	Flow Rate	
Start sequence	F_01	
End sequence	F_01	
Curve time base	Test	
Curve Y data units	[USgpm]	
Curve Y data is log 10	no	

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]

Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[USgpm]

SNL-10 Optimization Settings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   25 Jun 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 10\SNL 10.nPre
```

Parameters

Formation

Formation thickness	22.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	118.000	[psi]
Maximum value	125.000	[psi]
Estimate value	120.172	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-09	[m/sec]
Maximum value	1.00000E-06	[m/sec]
Estimate value	4.83945E-08	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	Optimization	
Minimum value	1.00000E-08	[1/m]
Maximum value	1.00000E-04	[1/m]
Estimate value	5.75710E-07	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	0.0001	[m]
Maximum value	10.0	[m]
Estimate value	0.025298	[m]

Range type	Log	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-09	[m/sec]
Maximum value	1.00000E-06	[m/sec]
Estimate value	3.07306E-08	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	1.00000E-07	[1/m]

Fluid

Fluid density	1008.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	Optimization	
Minimum value	2.0	[in]
Maximum value	3.0	[in]
Estimate value	2.195184	[in]
Range type	Linear	
Sigma	1.00000E+00	

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.58503E-11	[USgpm]

SNL-10 Fitting Parameter Estimates

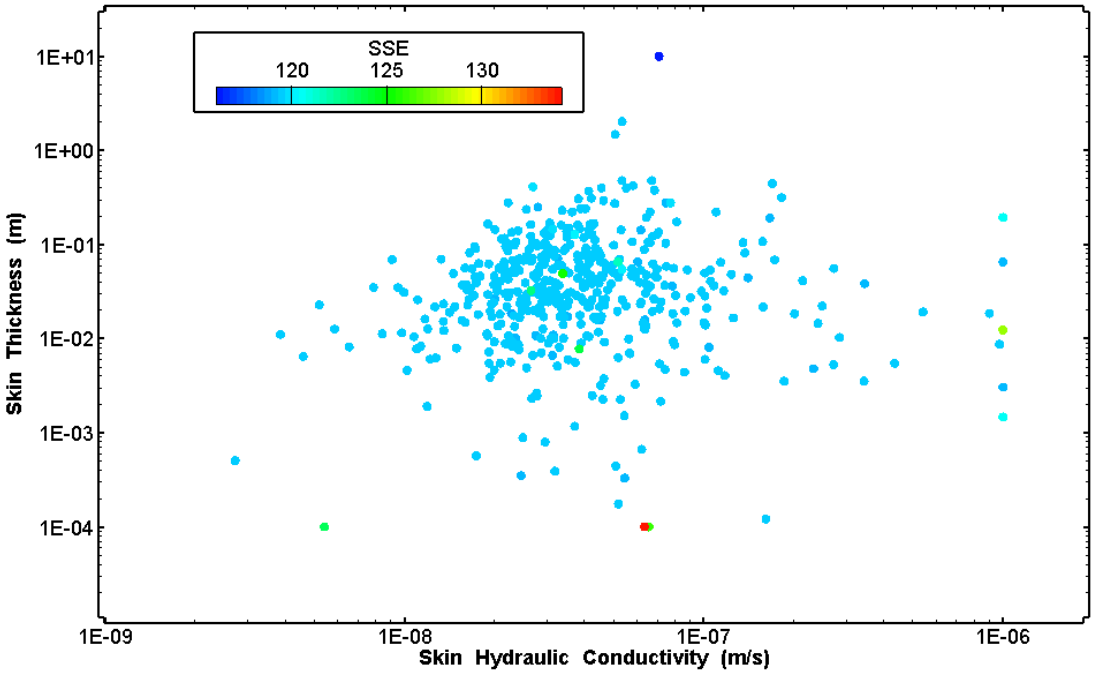

Figure B-3. Estimates of skin hydraulic conductivity and thickness derived from the SNL-10 perturbation analysis.

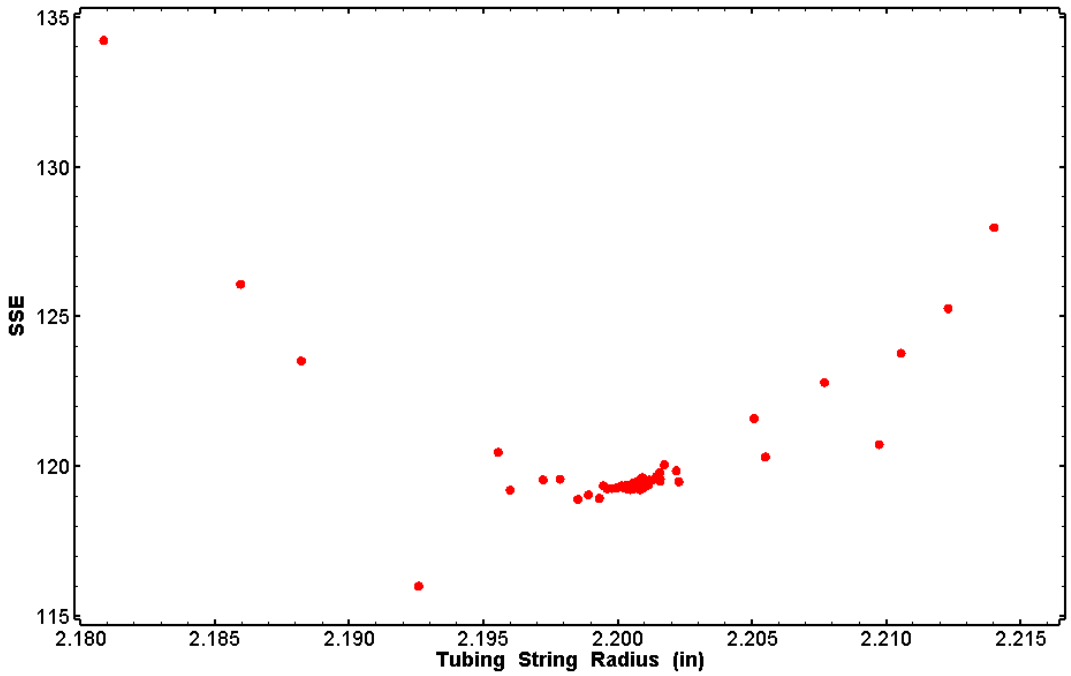

Figure B-4. Estimates of tubing string radius derived from the SNL-10 perturbation analysis.

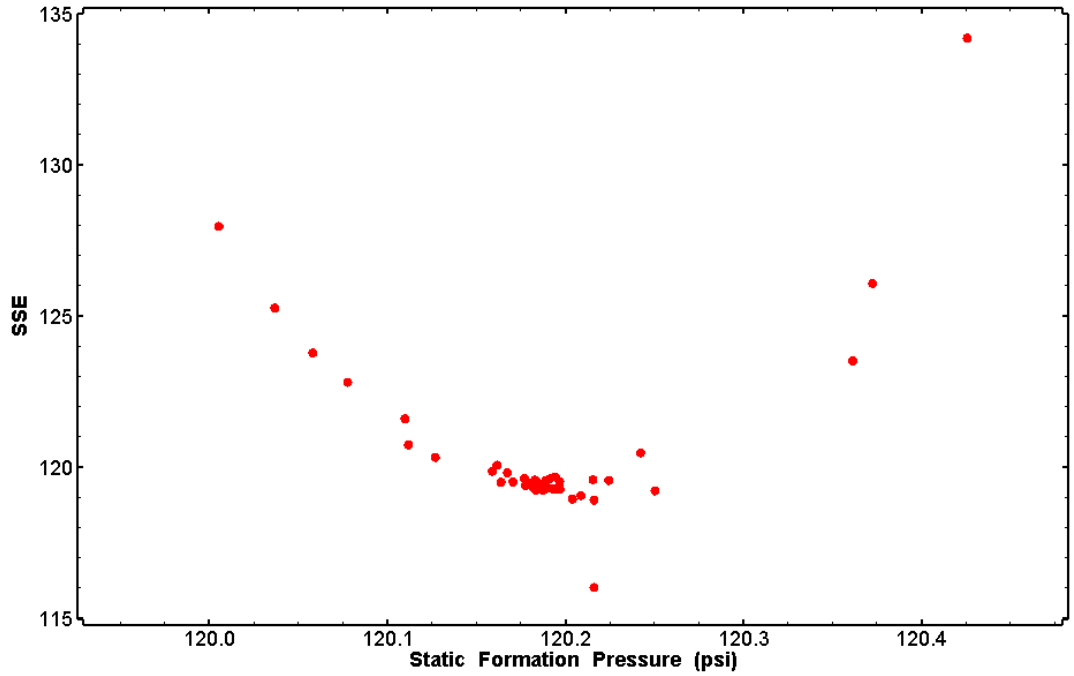

Figure B-5. Estimates of static formation pressure derived from the SNL-10 perturbation analysis.

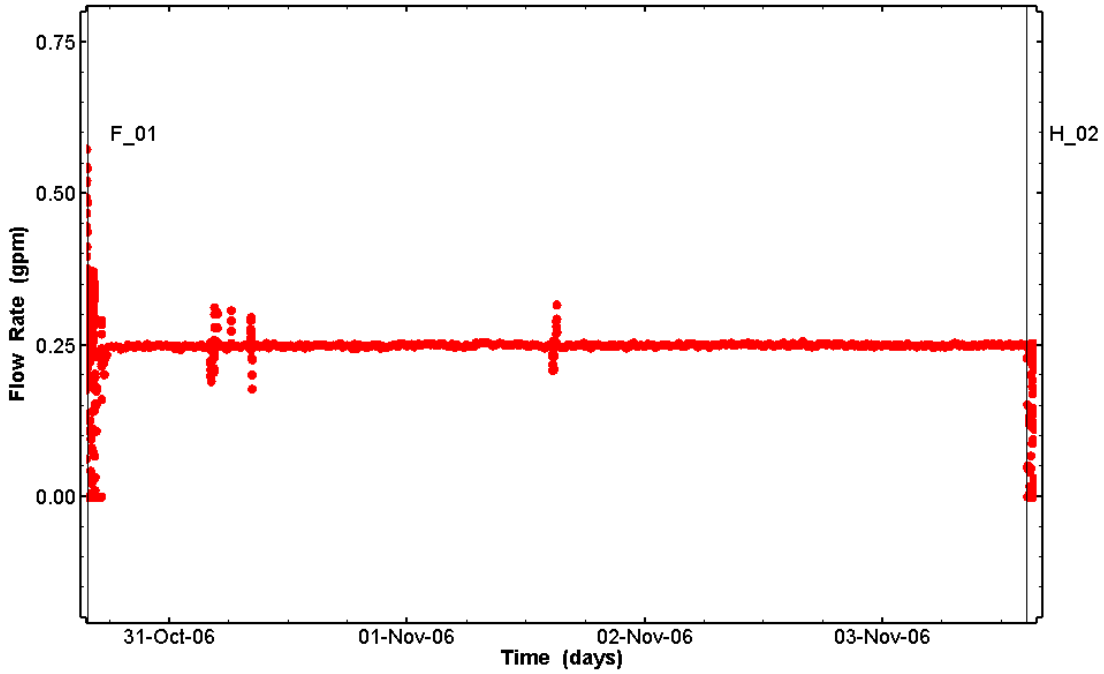

Figure B-6. Flow rates measured during the SNL-10 testing.

B.3 SNL-13 nSIGHTS Listings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   26 Jun 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 13\ SNL-13.nPre
```

Control Settings

Test Description

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Single
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	24.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	51.409	[psi]
External boundary radius	1000000	[m]
Formation conductivity	5.21134E-08	[m/sec]
Formation spec. storage	5.84796E-06	[1/m]

Skin

Radial thickness of skin	0.0030183	[m]
Skin zone conductivity	1.67014E-03	[m/sec]
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1016.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	2.7032435	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.58503E-11	[USgpm]

Calculated Parameters

Formation

Transmissivity	3.81220E-07	[m^2/sec]
Storativity	4.27790E-05	[]
Diffusivity	8.91138E-03	[m^2/sec]

Skin Zone

Transmissivity	1.22174E-02	[m^2/sec]
Storativity	7.31520E-06	[]
Diffusivity	1.67014E+03	[m^2/sec]
Skin factor	-2.13751E-02	[]

Test Zone

Open hole well-bore storage	1.48660E-06	[m^3/Pa]

Grid Properties

Grid increment delta	0.07921	[]
First grid increment	3.85964E-02	[ft]
Skin grid increment delta	0.00044	[]
Skin first grid increment	1.99987E-04	[ft]
Skin last grid increment	2.04219E-04	[ft]
Increment ratio	1.88995E+02	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	38896.583333	[day]
Duration	13.847222	[day]

Time step type	Static	
Static time step	0.010000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: H_02

Sequence type	History	
Start time	38910.430556	[day]
Duration	0.074184	[day]
Time step type	Static	
Static time step	0.001000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	38910.504740	[day]
Duration	5.133200	[day]
Time step type	Static	
Static time step	0.000343	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	38915.637940	[day]
Duration	63.737060	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	Curve P	
Curve type	Pressure	
Start sequence	H_01	
End sequence	H_02	
Curve time base	Test	
Curve Y data units	[psi]	
Curve Y data is log 10	no	
Curve object to use	Flow Curve	
Curve type	Flow Rate	
Start sequence	F_01	
End sequence	F_01	
Curve time base	Test	
Curve Y data units	[USgpm]	
Curve Y data is log 10	no	

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]

Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[USgpm]

SNL-13 Optimization Settings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   26 Jun 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 13\SNL-13.nPre
```

Parameters

Formation

Formation thickness	24.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	50.000	[psi]
Maximum value	55.000	[psi]
Estimate value	51.409	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]
Maximum value	1.00000E+00	[m/sec]
Estimate value	5.21134E-08	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	Optimization	
Minimum value	1.00000E-10	[1/m]
Maximum value	1.00000E-03	[1/m]
Estimate value	5.84796E-06	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	1.0E-05	[m]
Maximum value	5.0	[m]
Estimate value	0.0030183	[m]

Range type	Log	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-09	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	1.67014E-03	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1016.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	Optimization	
Minimum value	0.5	[in]
Maximum value	4.0	[in]
Estimate value	2.7032435	[in]
Range type	Linear	
Sigma	1.00000E+00	

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.58503E-11	[USgpm]

SNL-13 Fitting Parameter Estimates

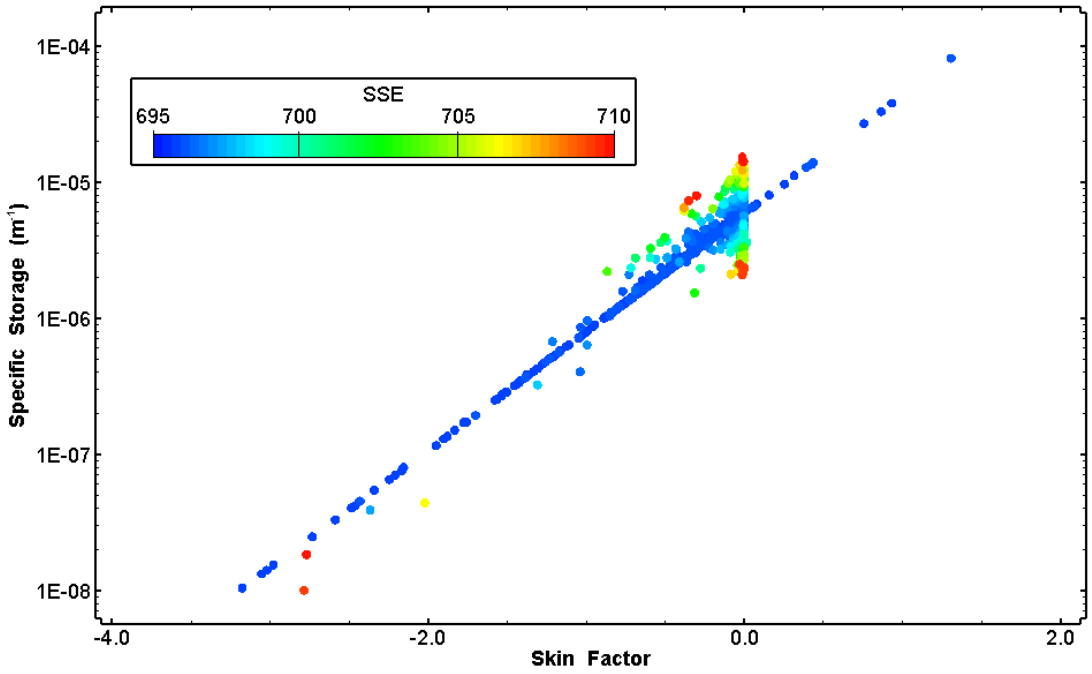

Figure B-7. Estimates of skin factor and formation specific storage derived from the SNL-13 perturbation analysis.

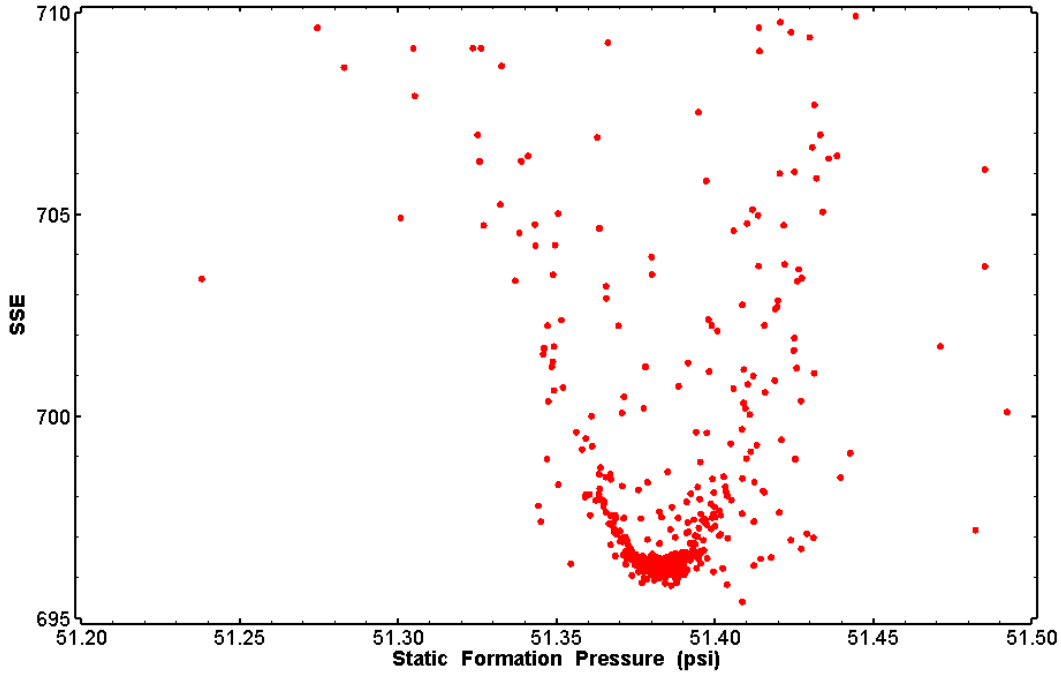

Figure B-8. Estimates of static formation pressure derived from the SNL-13 perturbation analysis.

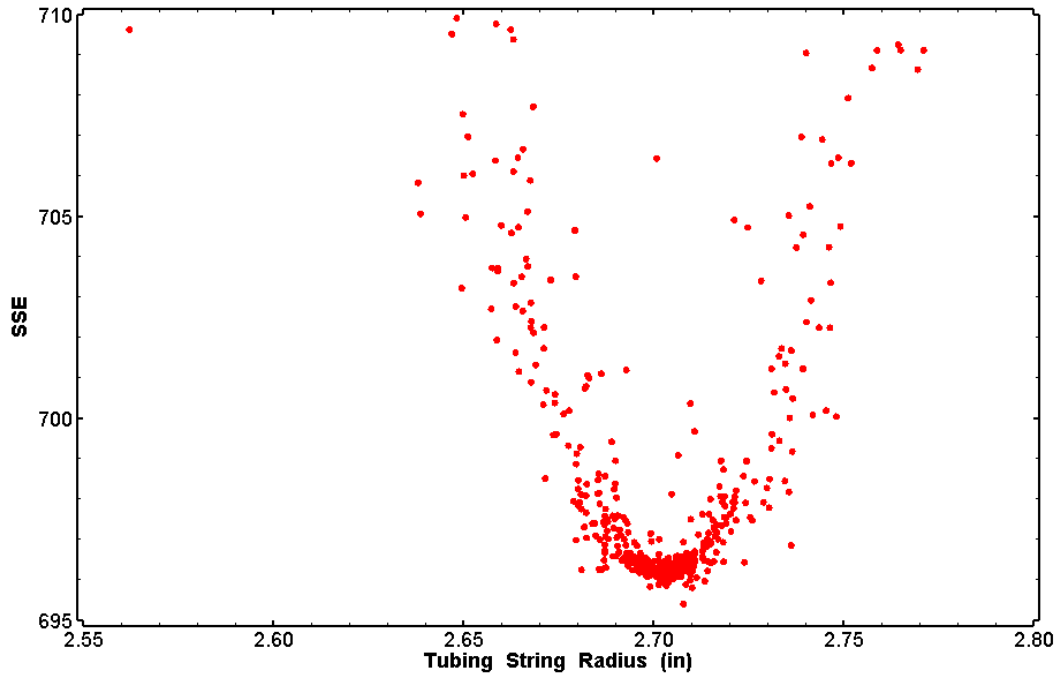

Figure B-9. Estimates of tubing string radius derived from the SNL-13 perturbation analysis.

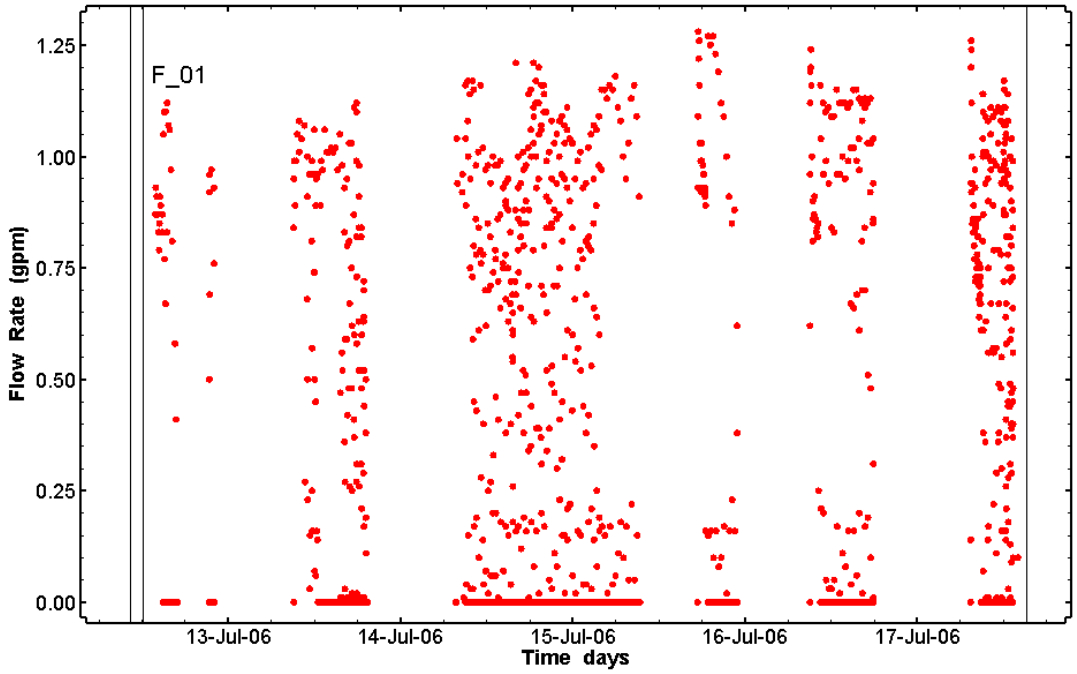

Figure B-10. Flow rates measured during the SNL-13 testing.

B.4 SNL-16 nSIGHTS Listings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   02 Jul 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 16\SNL 16.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Dual
Matrix block type	Prismatic
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	24.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	32.131	[psi]
External boundary radius	1000000	[m]

Fracture

Fracture conductivity	1.77976E-02	[m/sec]
Fracture spec. storage	5.54184E-04	[1/m]

Matrix

Matrix volume factor	0.990000	[decimal]
Geometry factor (Alpha)	1200	[1/m^2]
Matrix conductivity	2.22696E-12	[m/sec]
Matrix spec. storage	1.46887E-05	[1/m]

Skin

Radial thickness of skin	1.7606943	[m]
Skin zone conductivity	4.04338E-02	[m/sec]
Skin zone spec. storage	1.00000E-09	[1/m]

Fluid

Fluid density	1014.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	4.5836152	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
# of matrix nodes	1	[]

Calculated Parameters

Dual Porosity

Fracture thickness	0.073152	[m]
Matrix thickness	7.242048	[m]
Lambda - interporosity flow	2.93038E-07	[]
Omega - storativity ratio	2.75937E-01	[]
Beta - transient parameter	1.06197E-06	[]

Skin Zone

Transmissivity	2.95781E-01	[m^2/sec]
Storativity	7.31520E-09	[]
Diffusivity	4.04338E+07	[m^2/sec]
Skin factor	-1.46134E+00	[]

Test Zone

Open hole well-bore storage	4.28247E-06	[m^3/Pa]

Grid Properties

Grid increment delta	0.06620	[]
First grid increment	1.30060E-01	[m]
Skin grid increment delta	0.05327	[]
Skin first grid increment	7.64387E-03	[m]
Skin last grid increment	9.85882E-02	[m]
Increment ratio	1.31923E+00	[]

Number of nodes	249	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	38839.583330	[day]
Duration	33.875000	[day]
Time step type	Static	
Static time step	0.100000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: H_02

Sequence type	History	
Start time	38873.458330	[day]
Duration	0.118770	[day]
Time step type	Static	
Static time step	0.001000	[day]
Type	Fixed	
Fixed value	32.166	[psi]
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	38873.577100	[day]
Duration	4.023400	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-28.0	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	38877.600500	[day]
Duration	19.699500	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	Create Curve	
Curve type	Pressure	
Start sequence	H_01	
End sequence	H_02	
Curve time base	Test	

Curve Y data units	[psi]
Curve Y data is log 10	no

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]

Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[USgpm]

SNL-16 Optimization Settings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   02 Jul 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 16\SNL 16.nPre
```

Parameters

Formation

Formation thickness	24.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	31.000	[psi]
Maximum value	33.000	[psi]
Estimate value	32.131	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]

Fracture

Fracture conductivity	Optimization	
Minimum value	1.00000E-05	[m/sec]
Maximum value	5.00000E-01	[m/sec]
Estimate value	1.77976E-02	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Fracture spec. storage	Optimization	
Minimum value	1.00000E-08	[1/m]
Maximum value	1.00000E-03	[1/m]
Estimate value	5.54184E-04	[1/m]

Range type	Log	
Sigma	1.00000E+00	

Matrix

Matrix volume factor	0.990000	[decimal]
Geometry factor (Alpha)	1200	[1/m^2]
Matrix conductivity	Optimization	
Minimum value	1.00000E-14	[m/sec]
Maximum value	1.00000E-08	[m/sec]
Estimate value	2.22696E-12	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Matrix spec. storage	Optimization	
Minimum value	1.00000E-07	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	1.46887E-05	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	1.0E-05	[m]
Maximum value	10.0	[m]
Estimate value	1.7606943	[m]
Range type	Log	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-07	[m/sec]
Maximum value	1.00000E-01	[m/sec]
Estimate value	4.04338E-02	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	1.00000E-09	[1/m]

Fluid

Fluid density	1014.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	Optimization	
Minimum value	2.0	[in]
Maximum value	10.0	[in]
Estimate value	4.5836152	[in]
Range type	Linear	
Sigma	1.00000E+00	

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
# of matrix nodes	1	[]

SNL-16 Fitting Parameter Estimates

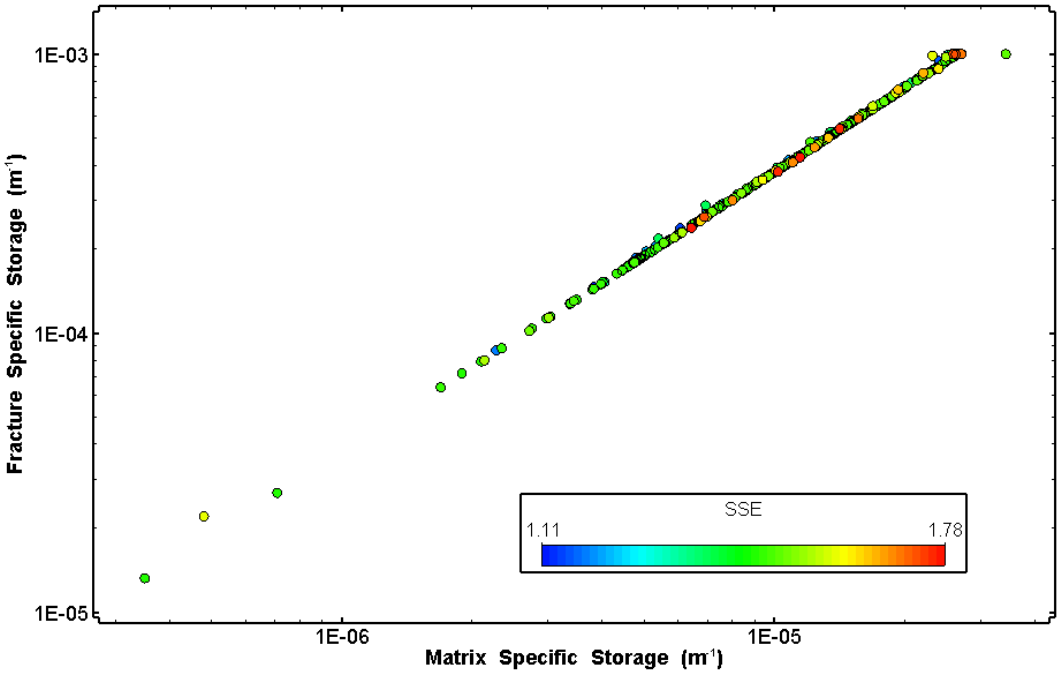

Figure B-11. Estimates of matrix and fracture specific storage derived from the SNL-16 perturbation analysis.

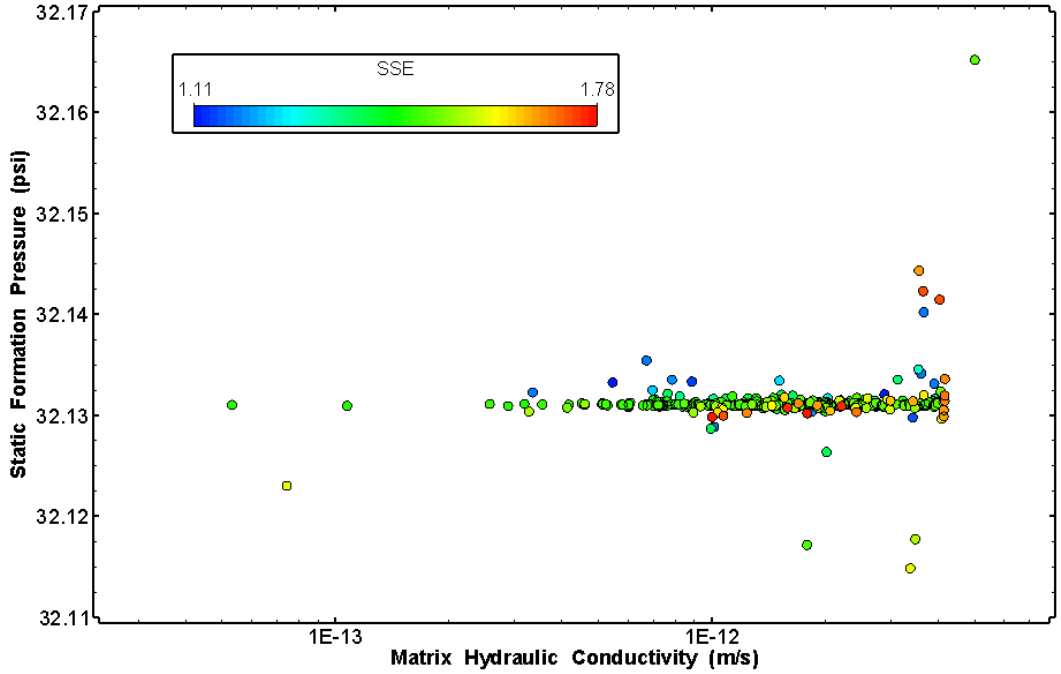

Figure B-12. Estimates of matrix hydraulic conductivity and static formation pressure derived from the SNL-16 perturbation analysis.

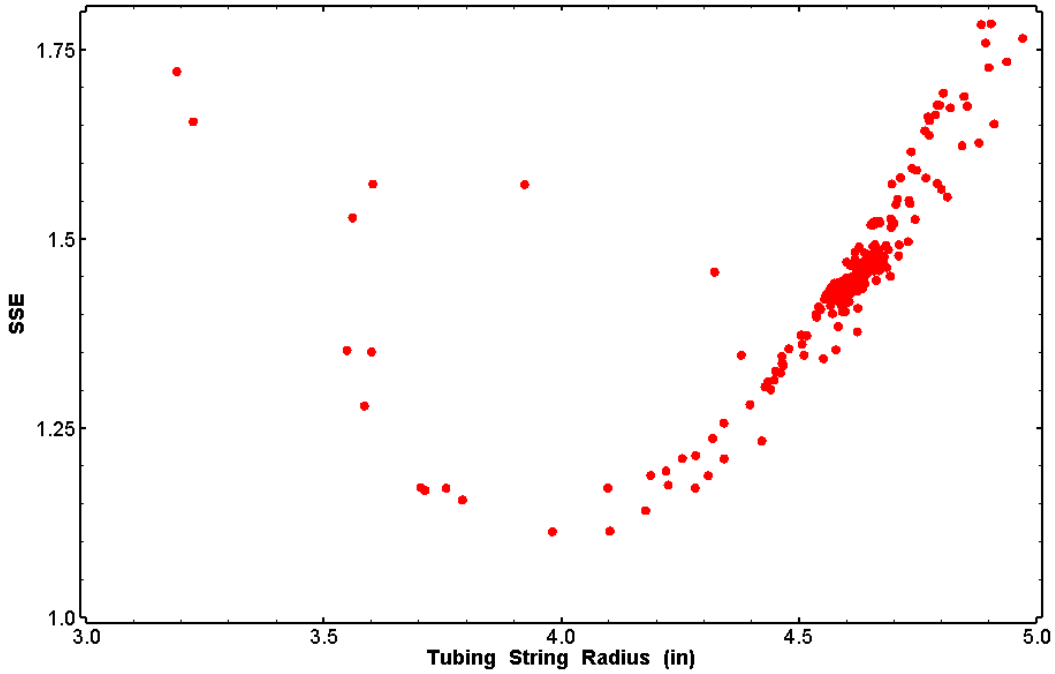

Figure B-13. Estimates of tubing string radius derived from the SNL-16 perturbation analysis.

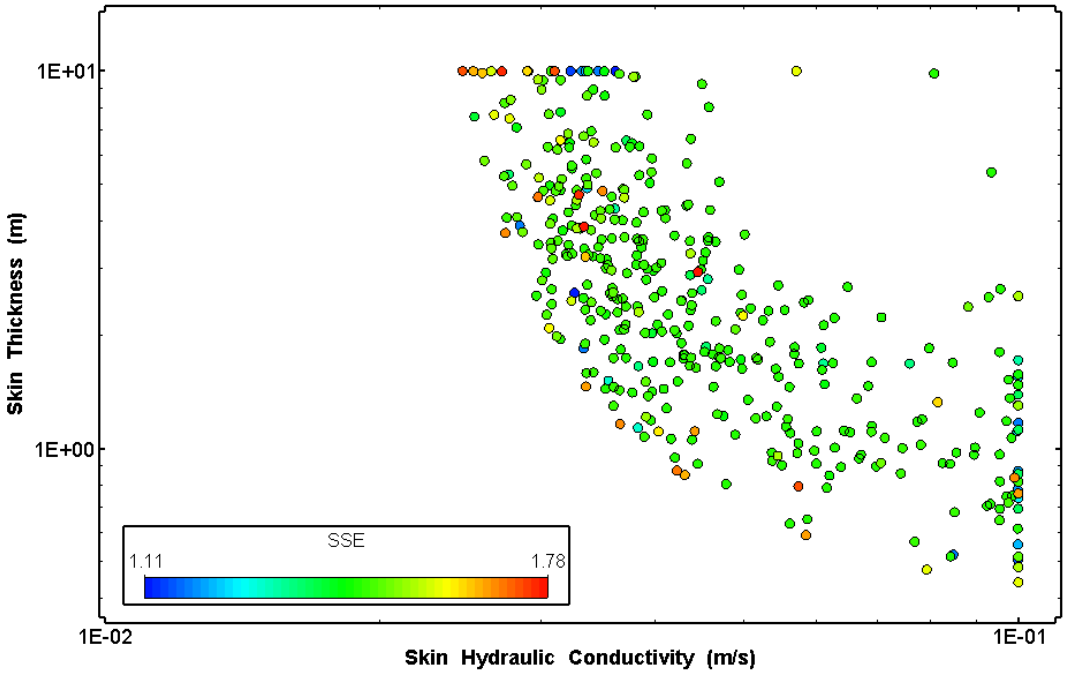

Figure B-14. Estimates of skin hydraulic conductivity and thickness derived from the SNL-16 perturbation analysis.

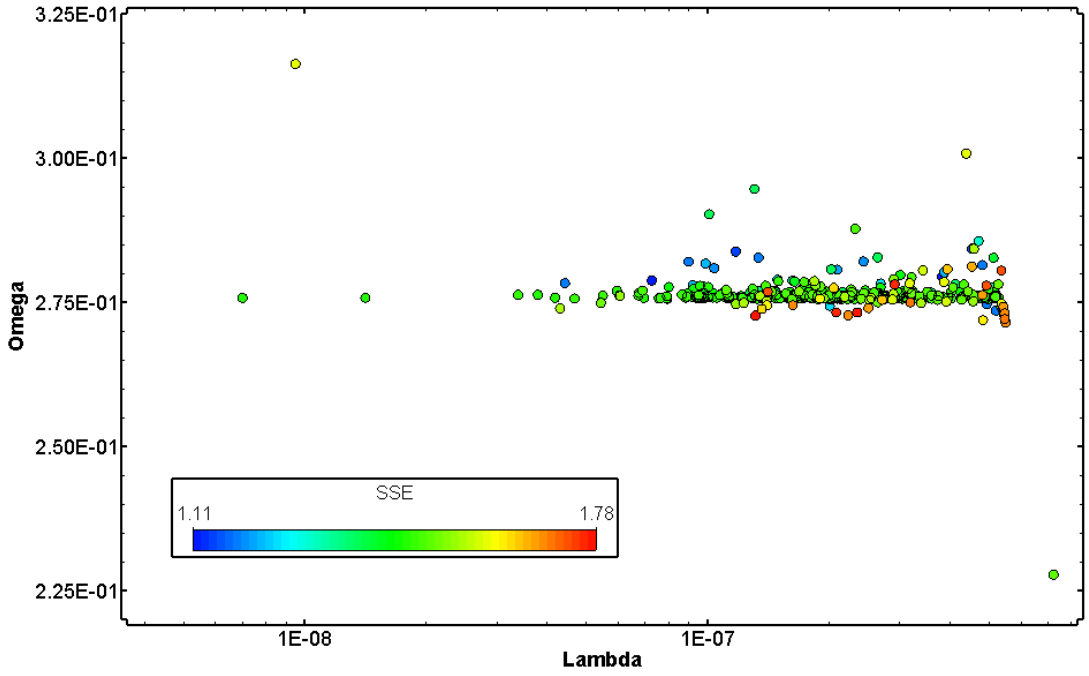

Figure B-15. Estimates of lambda and omega derived from the SNL-16 perturbation analysis.

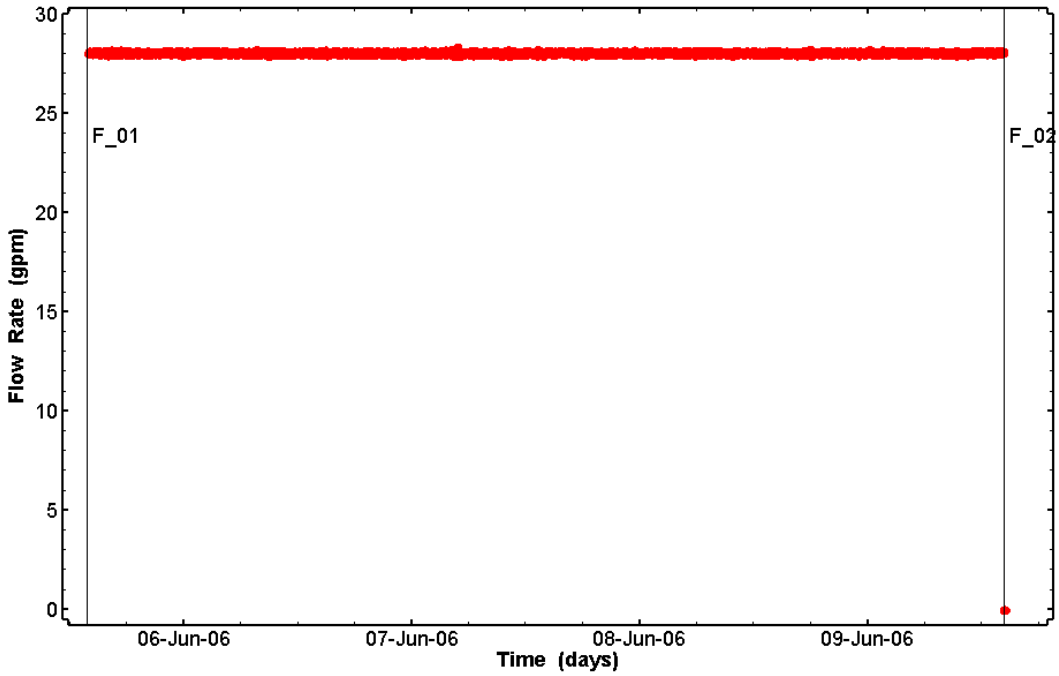

Figure B-16. Flow rates measured during the SNL-16 testing.

B.5 SNL-17A nSIGHTS Listings

```
*************
nPre/32 2.41Q
*************

Version date   1 Mar 2007
Listing date   07 Nov 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 17\SNL 17.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Dual
Matrix block type	Prismatic
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	30.000	[ft]
Flow dimension	f(r) point	
Static formation pressure	51.962	[psi]
External boundary radius	1000000	[m]

Fracture

Fracture conductivity	3.99001E-03	[m/sec]
Fracture spec. storage	8.06342E-05	[1/m]

Matrix

Matrix volume factor	0.990000	[decimal]
Geometry factor (Alpha)	1200	[1/m^2]
Matrix conductivity	4.65148E-11	[m/sec]
Matrix spec. storage	2.20778E-03	[1/m]

Skin

Radial thickness of skin	0.3689017	[m]
Skin zone conductivity	1.70463E-02	[m/sec]
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1003.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	2.2992284	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
# of matrix nodes	2	[]

---

f(x) Points Parameters

Flow dimension

Points type	f(r)	
Radius #1	6.5907359	[m]
Y value#1	2.0	[]
Radius #2	20.4666708	[m]
Y value#2	0.8100978	[]
Radius #3	22.4031795	[m]
Y value#3	2.6256025	[]
Parameter curve type	Linear	

Calculated Parameters

Dual Porosity

Fracture thickness	0.09144	[m]
Matrix thickness	9.05256	[m]
Lambda - interporosity flow	2.73018E-05	[]
Omega - storativity ratio	3.68780E-04	[]
Beta - transient parameter	7.40329E-02	[]

Skin Zone

Transmissivity	1.55871E-01	[m^2/sec]

Storativity	9.14400E-06	[]
Diffusivity	1.70463E+04	[m^2/sec]
Skin factor	-9.89711E-01	[]

Test Zone

Open hole well-bore storage	1.08938E-06	[m^3/Pa]

Grid Properties

Grid increment delta	0.07282	[]
First grid increment	3.84194E-02	[m]
Skin grid increment delta	0.02637	[]
Skin first grid increment	3.73300E-03	[m]
Skin last grid increment	1.32369E-02	[m]
Increment ratio	2.90244E+00	[]
Number of nodes	448	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	38942.500000	[day]
Duration	29.043750	[day]
Time step type	Static	
Static time step	0.250000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: H_02

Sequence type	History	
Start time	38971.543750	[day]
Duration	0.029990	[day]
Time step type	Static	
Static time step	0.000500	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	38971.573740	[day]
Duration	2.654732	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-32.0	[USgpm]
Wellbore storage	Open	

Sequence: H_03

Sequence type	History	
Start time	38974.228472	[day]
Duration	1.351266	[day]

Time step type	Static	
Static time step	0.010000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	38975.579738	[day]
Duration	51.711929	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	P Curve
Curve type	Pressure
Start sequence	H_01
End sequence	H_03
Curve time base	Test
Curve Y data units	[psi]
Curve Y data is log 10	no

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]

Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[USgpm]

SNL-17 Optimization Settings

```
*************
nPre/32 2.41Q
*************

Version date   1 Mar 2007
Listing date   07 Nov 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 17\SNL 17.nPre
```

Parameters

Formation

Formation thickness	30.000	[ft]
Flow dimension	f(r) point	
Static formation pressure	Optimization	
Minimum value	45.000	[psi]
Maximum value	60.000	[psi]
Estimate value	51.962	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]

Fracture

Fracture conductivity	Optimization	
Minimum value	1.00000E-05	[m/sec]
Maximum value	1.00000E-01	[m/sec]
Estimate value	3.99001E-03	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Fracture spec. storage	Optimization	
Minimum value	1.00000E-08	[1/m]
Maximum value	1.00000E-03	[1/m]
Estimate value	8.06342E-05	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Matrix

Matrix volume factor	0.990000	[decimal]
Geometry factor (Alpha)	1200	[1/m^2]
Matrix conductivity	Optimization	
Minimum value	1.00000E-14	[m/sec]
Maximum value	1.00000E-06	[m/sec]
Estimate value	4.65148E-11	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Matrix spec. storage	Optimization	
Minimum value	1.00000E-07	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	2.20778E-03	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	0.0001	[m]
Maximum value	10.0	[m]
Estimate value	0.3689017	[m]
Range type	Log	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-09	[m/sec]
Maximum value	1.00000E-01	[m/sec]

Estimate value	1.70463E-02	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1003.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	Optimization	
Minimum value	2.0	[in]
Maximum value	3.0	[in]
Estimate value	2.2992284	[in]
Range type	Linear	
Sigma	1.00000E+00	

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
# of matrix nodes	2	[]

SNL-17A Fitting Parameter Estimates

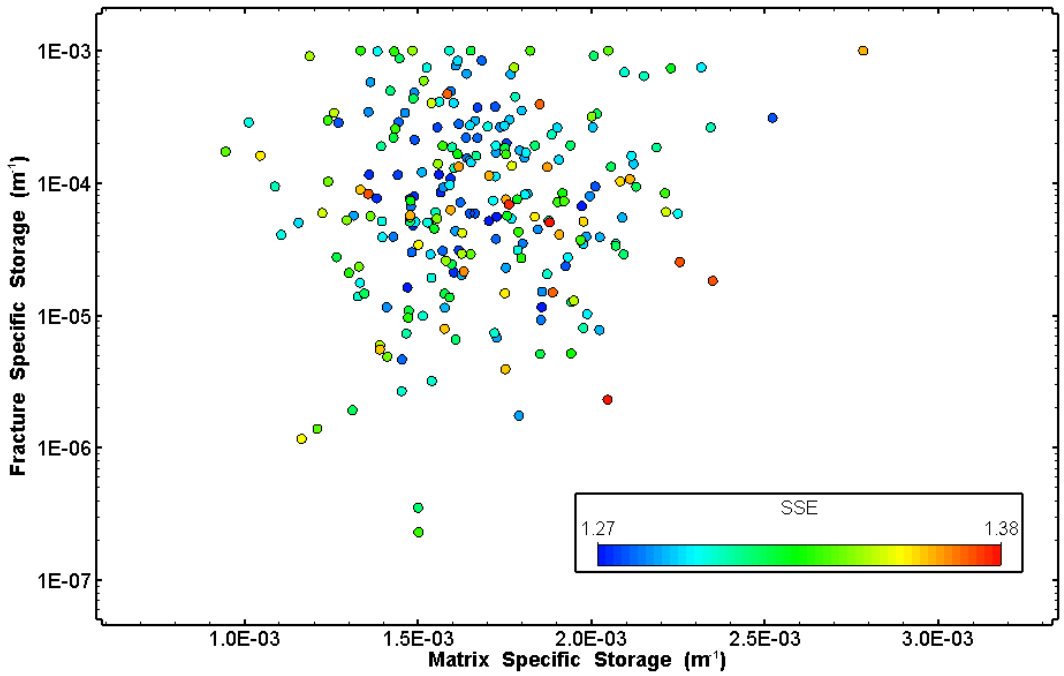

Figure B-17. Estimates of matrix and fracture specific storage derived from the SNL-17A perturbation analysis.

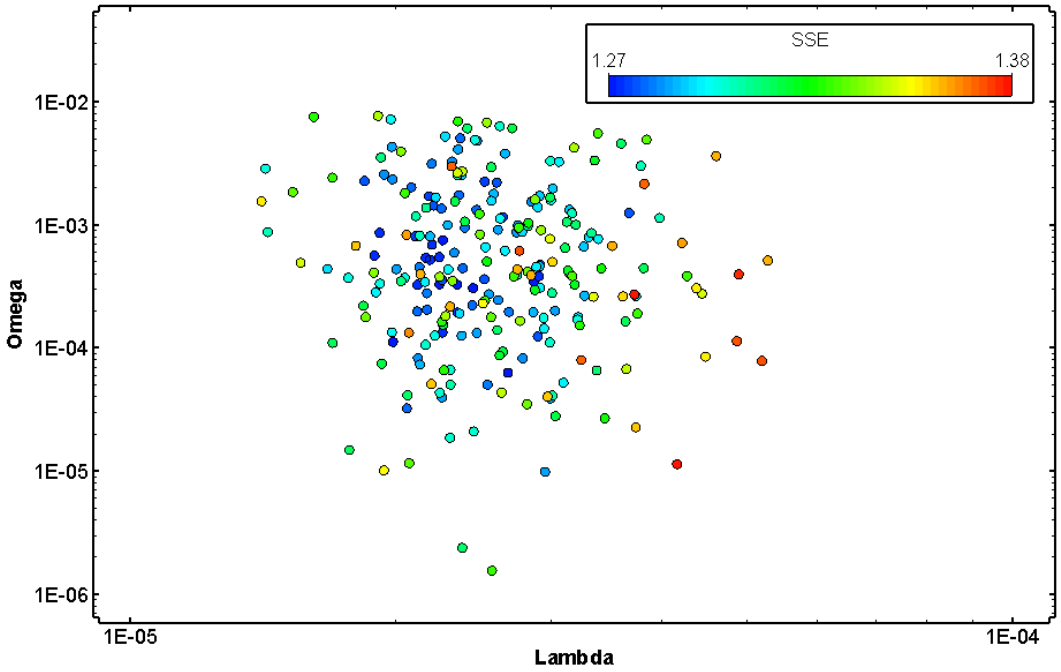

Figure B-18. Estimates of lambda and omega derived from the SNL-17A perturbation analysis.

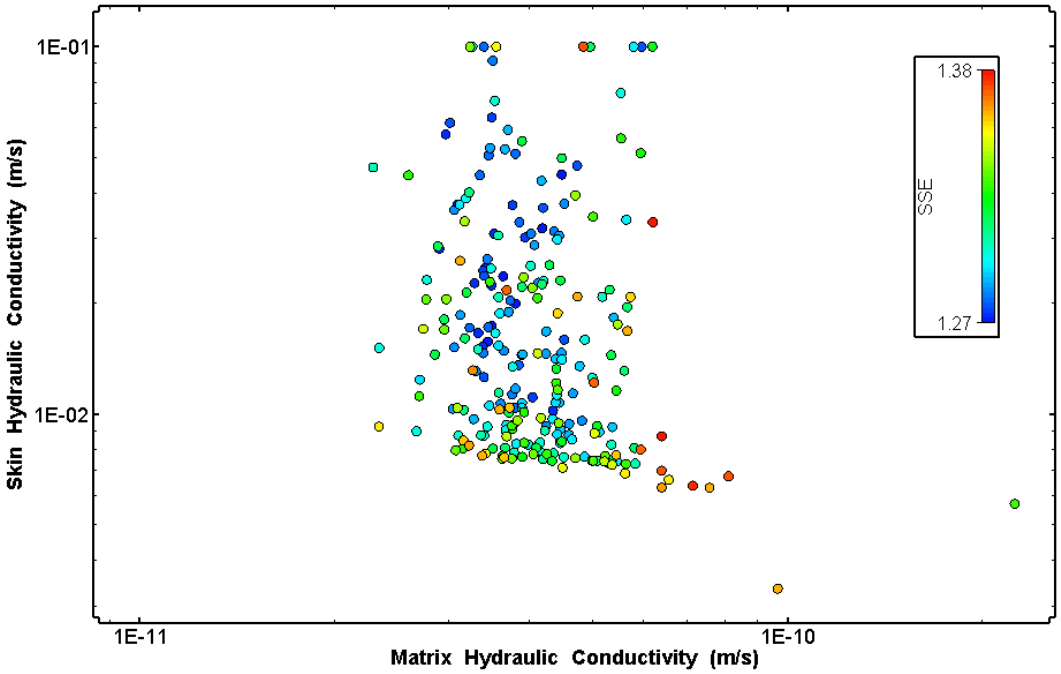

Figure B-19. Estimates of matrix and skin hydraulic conductivity derived from the SNL-17A perturbation analysis.

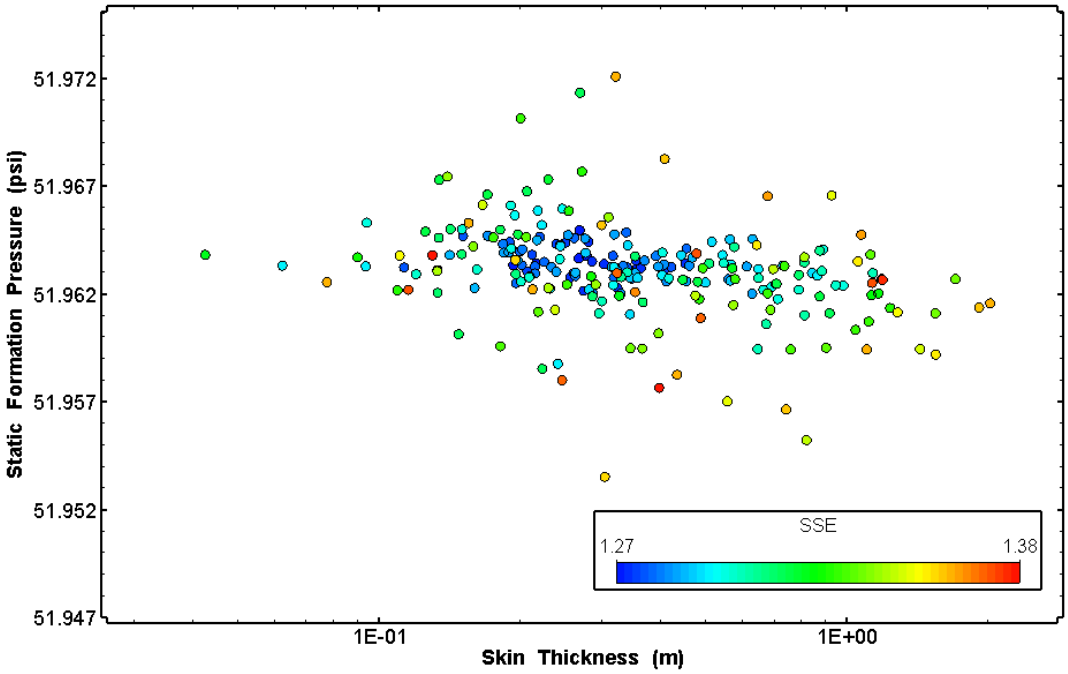

Figure B-20. Estimates of skin thickness and static formation pressure derived from the SNL-17A perturbation analysis.

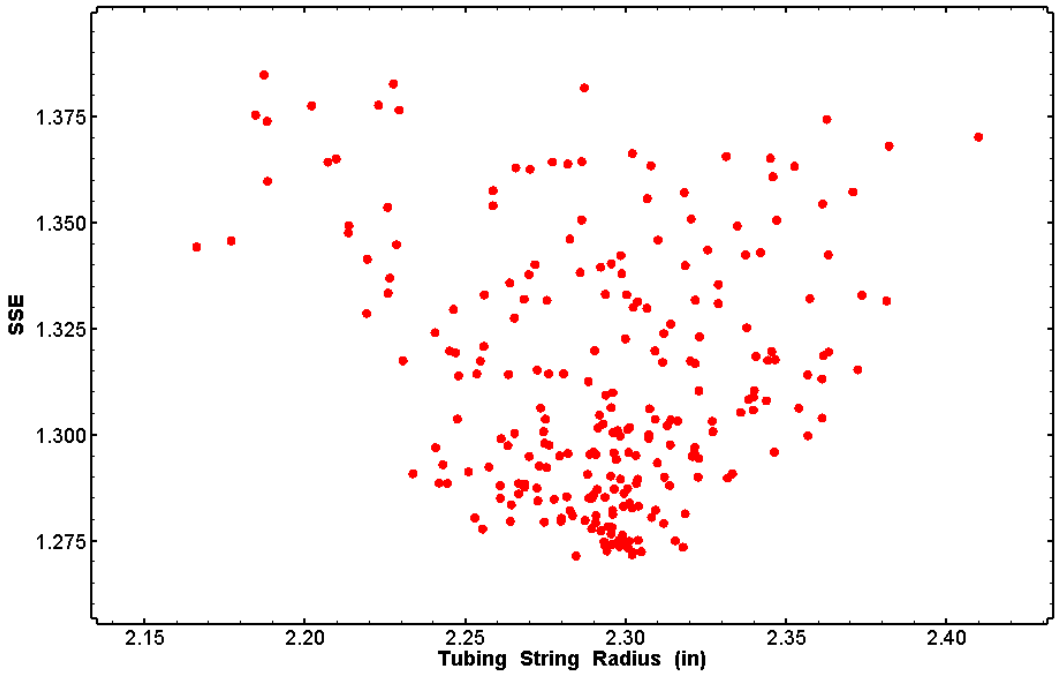

Figure B-21. Estimates of tubing string radius derived from the SNL-17A perturbation analysis.

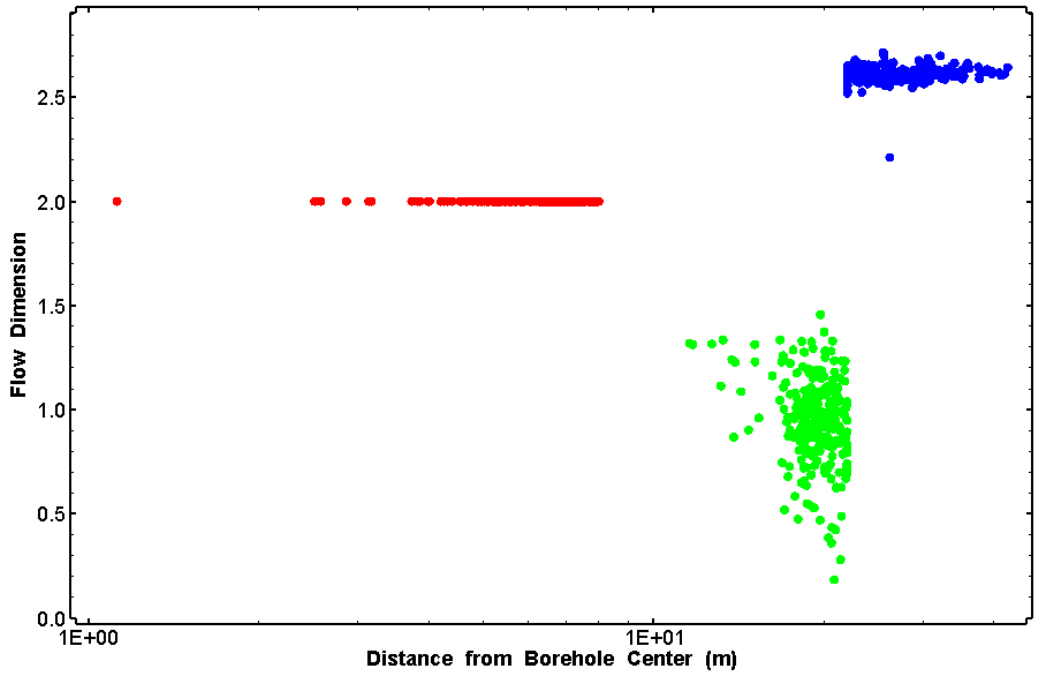

Figure B-22. Estimates of radially varying flow dimension derived from the SNL-17A perturbation analysis.

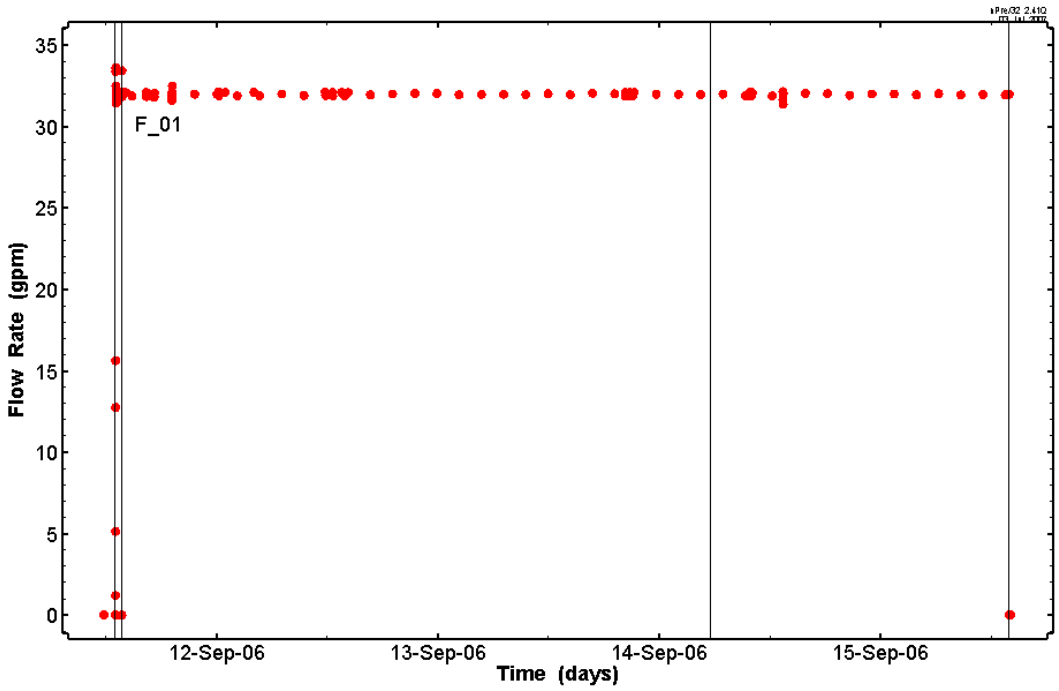

Figure B-23. Flow rates measured during the SNL-17A testing.

B.6 SNL-18 nSIGHTS Listings

```
*************
nPre/32 2.41Q
*************

Version date   1 Mar 2007
Listing date   07 Nov 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 18\SNL-18 Dual Porosity.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	no
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Dual
Matrix block type	Prismatic
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	19.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	103.658	[psi]
External boundary radius	1000000	[m]

Fracture

Fracture conductivity	f(r) point	
Fracture spec. storage	6.84102E-04	[1/m]

Matrix

Matrix volume factor	0.990000	[decimal]
Geometry factor (Alpha)	1200	[1/m^2]
Matrix conductivity	2.56428E-12	[m/sec]
Matrix spec. storage	1.64288E-05	[1/m]

Fluid

Fluid density	1015.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	2.2139283	[in]

Numeric

# of radial nodes	250	[]
# of matrix nodes	1	[]

---

f(x) Points Parameters

Fracture conductivity

Points type	f(r)	
Radius #1	1.0	[m]
Y value#1	1.51183E-03	[m/sec]
Radius #2	230.4350106	[m]
Y value#2	3.77788E-03	[m/sec]
Parameter curve type	Step Full	

Calculated Parameters

Dual Porosity

Fracture thickness	0.057912	[m]
Matrix thickness	5.733288	[m]
Lambda - interporosity flow	f(r)	
Omega - storativity ratio	2.96077E-01	[]
Beta - transient parameter	f(r)	

Test Zone

Open hole well-bore storage	9.98107E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.06339	[]
First grid increment	9.14208E-03	[m]
Number of nodes	249	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	38928.916667	[day]
Duration	14.847917	[day]
Time step type	Static	
Static time step	0.010000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: H_02

Sequence type	History	
Start time	38943.764583	[day]
Duration	0.006250	[day]
Time step type	Static	
Static time step	0.000030	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	38943.770833	[day]
Duration	3.731528	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	38947.502361	[day]
Duration	11.830972	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	P Curve	
Curve type	Pressure	
Start sequence	H_01	
End sequence	H_02	
Curve time base	Test	
Curve Y data units	[psi]	
Curve Y data is log 10	no	
Curve object to use	Q Curve	
Curve type	Flow Rate	

Start sequence	F_01
End sequence	F_01
Curve time base	Test
Curve Y data units	[USgpm]
Curve Y data is log 10	no

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]

Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[USgpm]

SNL-18 nSIGHTS Optimization Settings

```
*************
nPre/32 2.41Q
*************

Version date   1 Mar 2007
Listing date   07 Nov 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 18\SNL-18 Dual Porosity.nPre
```

Parameters

Formation

Formation thickness	19.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	95.000	[psi]
Maximum value	110.000	[psi]
Estimate value	103.658	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]

Fracture

Fracture conductivity	f(r) point	
Fracture spec. storage	Optimization	
Minimum value	1.00000E-09	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	6.84102E-04	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Matrix

Matrix volume factor	0.990000	[decimal]
Geometry factor (Alpha)	1200	[1/m^2]
Matrix conductivity	Optimization	
Minimum value	1.00000E-14	[m/sec]
Maximum value	1.00000E-10	[m/sec]
Estimate value	2.56428E-12	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Matrix spec. storage	Optimization	
Minimum value	1.00000E-08	[1/m]
Maximum value	1.00000E-03	[1/m]
Estimate value	1.64288E-05	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1015.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	Optimization	
Minimum value	1.5	[in]
Maximum value	3.0	[in]
Estimate value	2.2139283	[in]
Range type	Linear	
Sigma	1.00000E+00	

Numeric

# of radial nodes	250	[]
# of matrix nodes	1	[]

SNL-18 Fitting Parameter Estimates

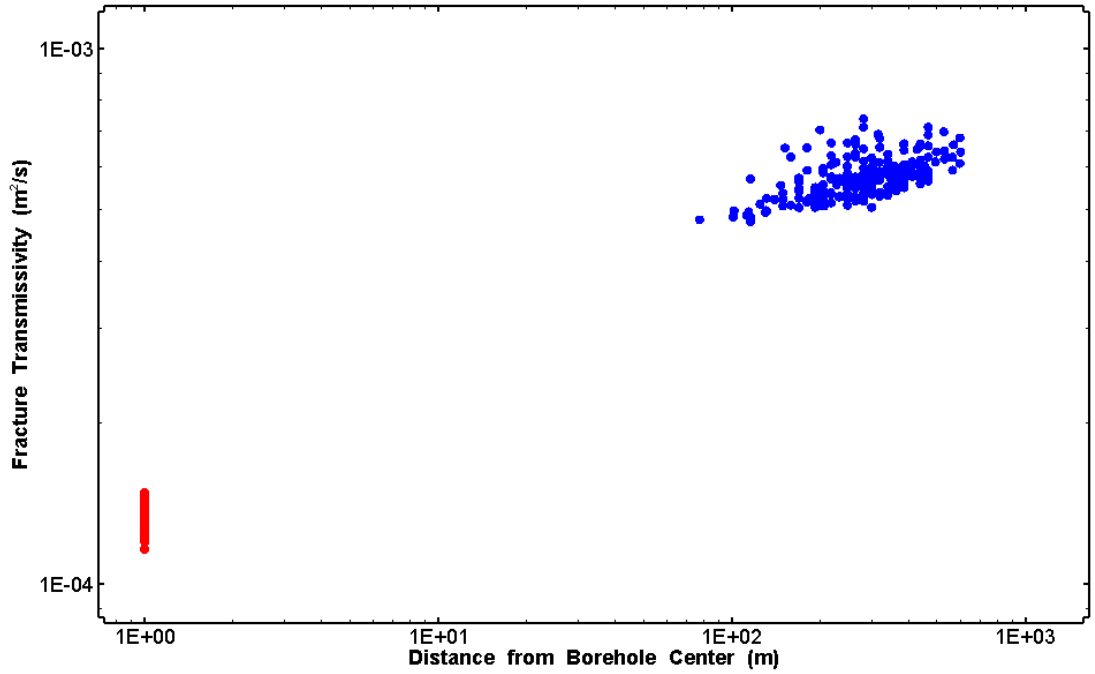

Figure B-24. Estimates of radially varying fracture transmissivity derived from the SNL-18 perturbation analysis.

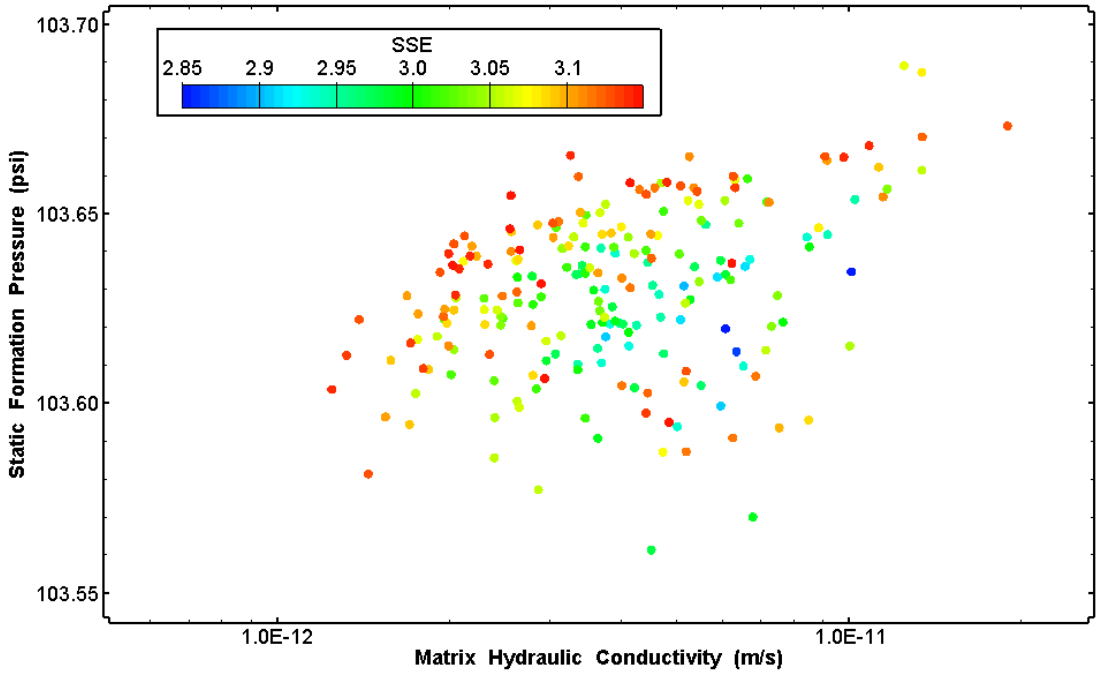

Figure B-25. Estimates of matrix hydraulic conductivity and static formation pressure derived from the SNL-18 perturbation analysis.

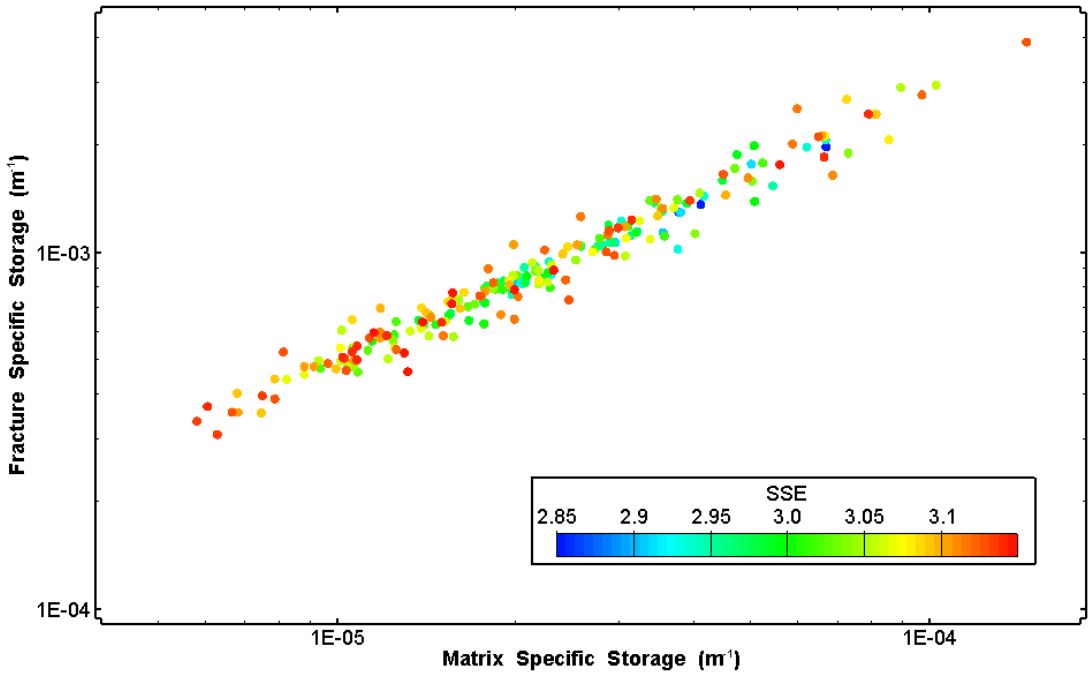

Figure B-26. Estimates of matrix and fracture specific storage derived from the SNL-18 perturbation analysis.

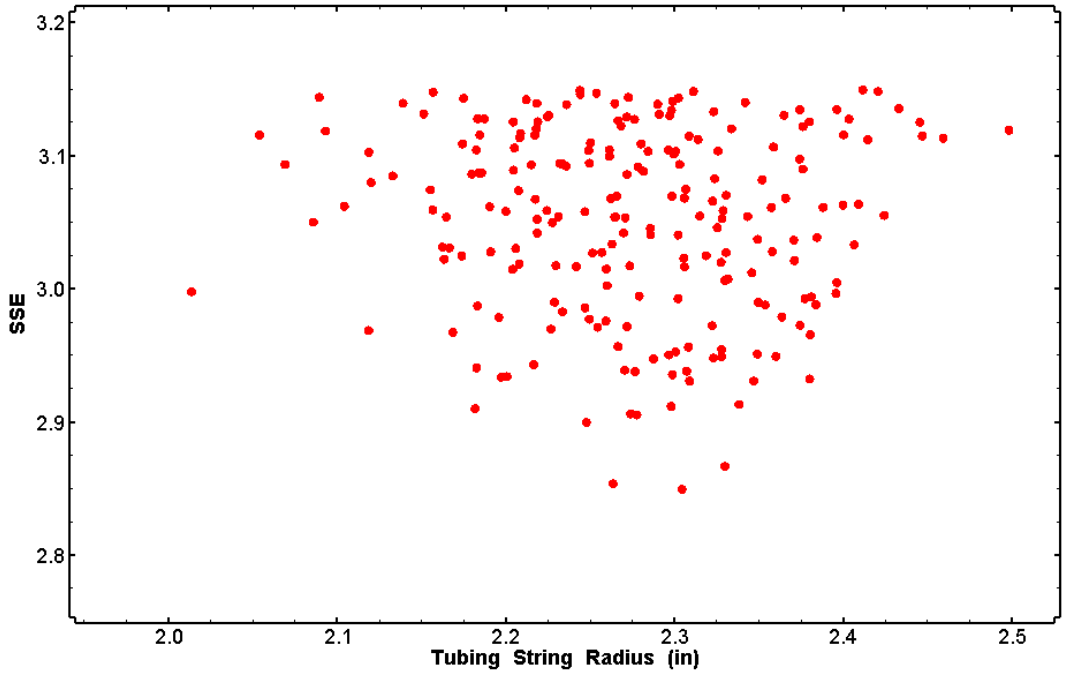

Figure B-27. Estimates of tubing string radius derived from the SNL-18 perturbation analysis.

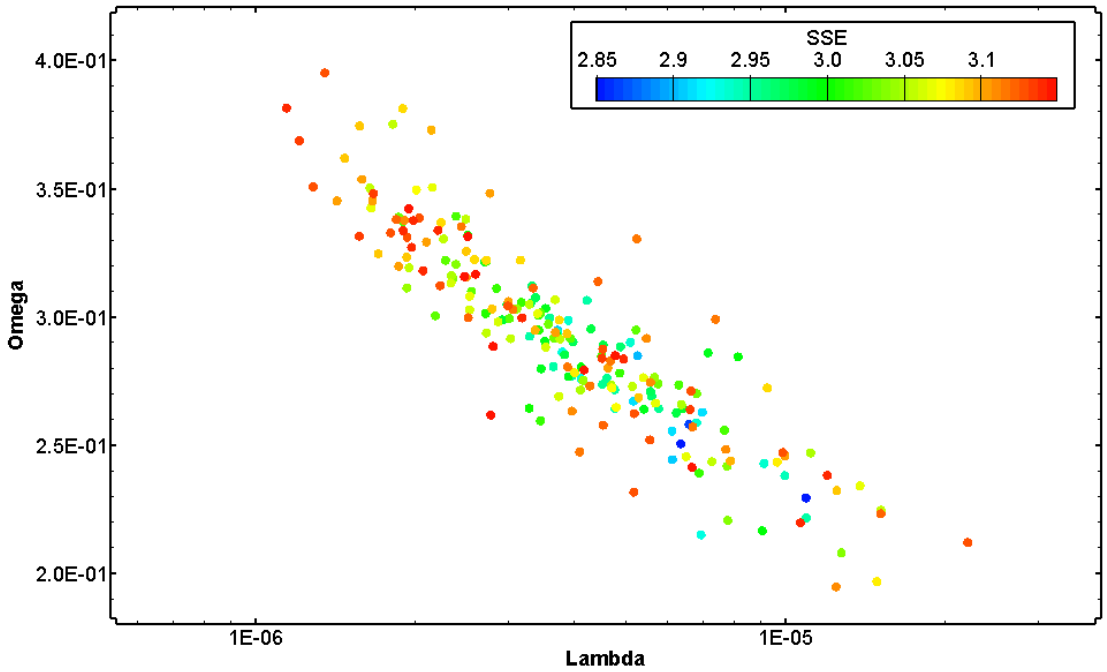

Figure B-28. Estimates of lambda and omega derived from the SNL-18 perturbation analysis.

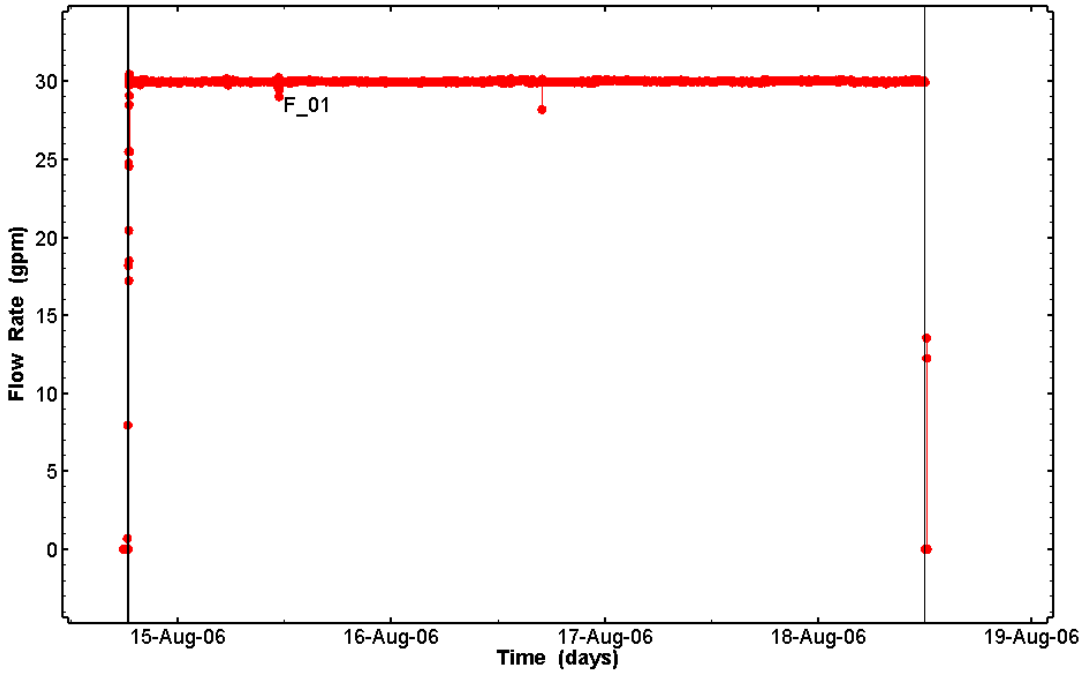

Figure B-29. Flow rates measured during the SNL-18 testing.

B.7 SNL-19 nSIGHTS Listings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   02 Jul 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 19\SNL-19.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Single
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	6.4008	[m]
Flow dimension	2.0	[]
Static formation pressure	81.734	[psi]
External boundary radius	1000000	[m]
Formation conductivity	f(r) point	
Formation spec. storage	3.79189E-07	[1/m]

Skin

Radial thickness of skin	0.0202957	[m]
Skin zone conductivity	f(t) point	

Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1007.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	2.004755	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.58503E-11	[USgpm]

---

f(x) Points Parameters

Formation conductivity

Points type	f(r)	
Radius #1	0.0	[m]
Y value#1	6.65381E-05	[m/sec]
Radius #2	2828.4227517	[m]
Y value#2	1.55321E-04	[m/sec]
Parameter curve type	Step Full	

Skin zone conductivity

Points type	f(t)	
Time #1	3362913920.000000	[day]
Y value#1	8.08269E-06	[m/sec]
Time #2	3362914870.100000	[day]
Y value#2	4.75442E-07	[m/sec]
Time #3	3362915089.500000	[day]
Y value#3	3.16743E-07	[m/sec]
Time #4	3362915694.000000	[day]
Y value#4	2.61642E-07	[m/sec]
Time #5	3362929773.900000	[day]
Y value#5	2.45510E-07	[m/sec]
Time #6	3362974314.400000	[day]
Y value#6	2.41547E-07	[m/sec]
Time #7	3363109635.200000	[day]
Y value#7	2.40767E-07	[m/sec]
Time #8	3363365116.700000	[day]
Y value#8	2.27155E-07	[m/sec]
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	f(r)	
Storativity	2.42711E-06	[]
Diffusivity	f(r)	

Skin Zone

Transmissivity	f(t)	
Storativity	6.40080E-06	[]
Diffusivity	f(t)	
Skin factor	f(r)	

Test Zone

Open hole well-bore storage	8.24915E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.07863	[]
First grid increment	1.30889E-02	[m]
Skin grid increment delta	0.00277	[]
Skin first grid increment	3.87276E-04	[m]
Skin last grid increment	4.42313E-04	[m]
Increment ratio	2.95920E+01	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	38885.000000	[day]
Duration	37.624900	[day]
Time step type	Static	
Static time step	0.050000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	38922.624900	[day]
Duration	3.887650	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-36.0	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	38926.512550	[day]
Duration	12.820780	[day]

Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	History Curve
Curve type	Pressure
Start sequence	H_01
End sequence	H_01
Curve time base	Test
Curve Y data units	[psi]
Curve Y data is log 10	no

Simulation Results Setup

Output ID	DAT	
Output type	Pressure	
Pressure capture type	Test Zone	
Output units	[psi]	

Output ID	DAT	
Output type	Flow Rate	
Flow rate output type	Well	
Output units	[USgpm]	

SNL-19 Optimization Settings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   02 Jul 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 19\SNL-19.nPre
```

Parameters

Formation

Formation thickness	6.4008	[m]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	80.000	[psi]
Maximum value	85.000	[psi]
Estimate value	81.734	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]
Formation conductivity	f(r) point	

Formation spec. storage	Optimization	
Minimum value	1.00000E-08	[1/m]
Maximum value	1.00000E-04	[1/m]
Estimate value	3.79189E-07	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	0.0001	[m]
Maximum value	1.0	[m]
Estimate value	0.0202957	[m]
Range type	Log	
Sigma	1.00000E+00	
Skin zone conductivity	f(t) point	
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1007.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	5.5	[in]
Tubing string radius	Optimization	
Minimum value	1.0	[in]
Maximum value	5.0	[in]
Estimate value	2.004755	[in]
Range type	Linear	
Sigma	1.00000E+00	

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.58503E-11	[USgpm]

SNL-19 Fitting Parameter Estimates

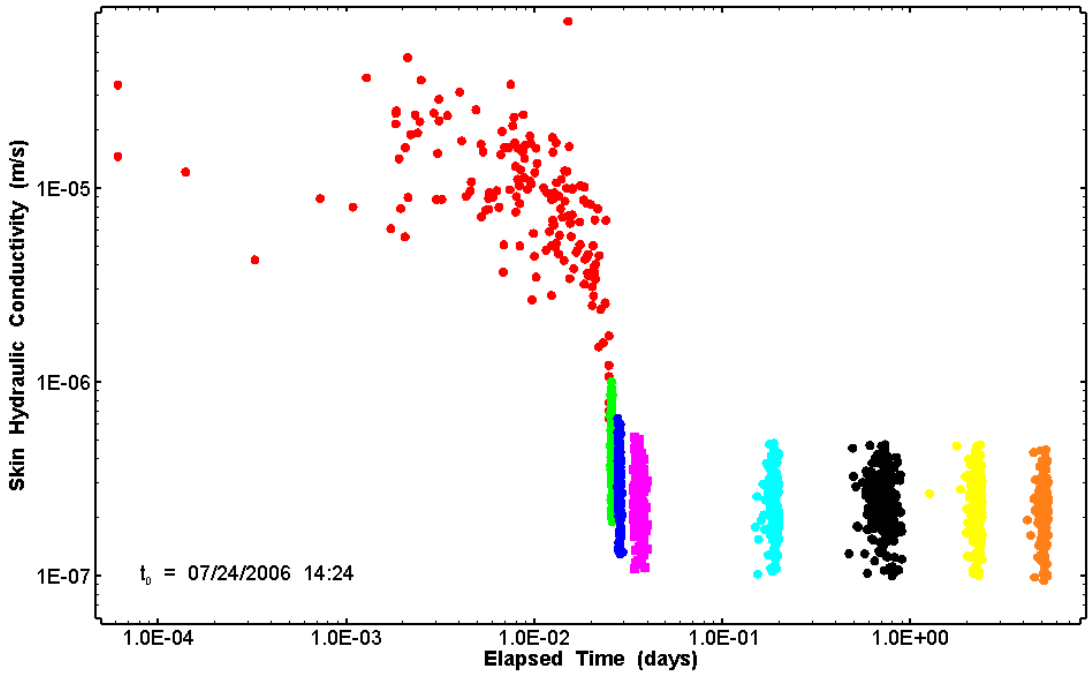

Figure B-30. Estimates of time-varying skin hydraulic conductivity derived from the SNL-19 perturbation analysis.

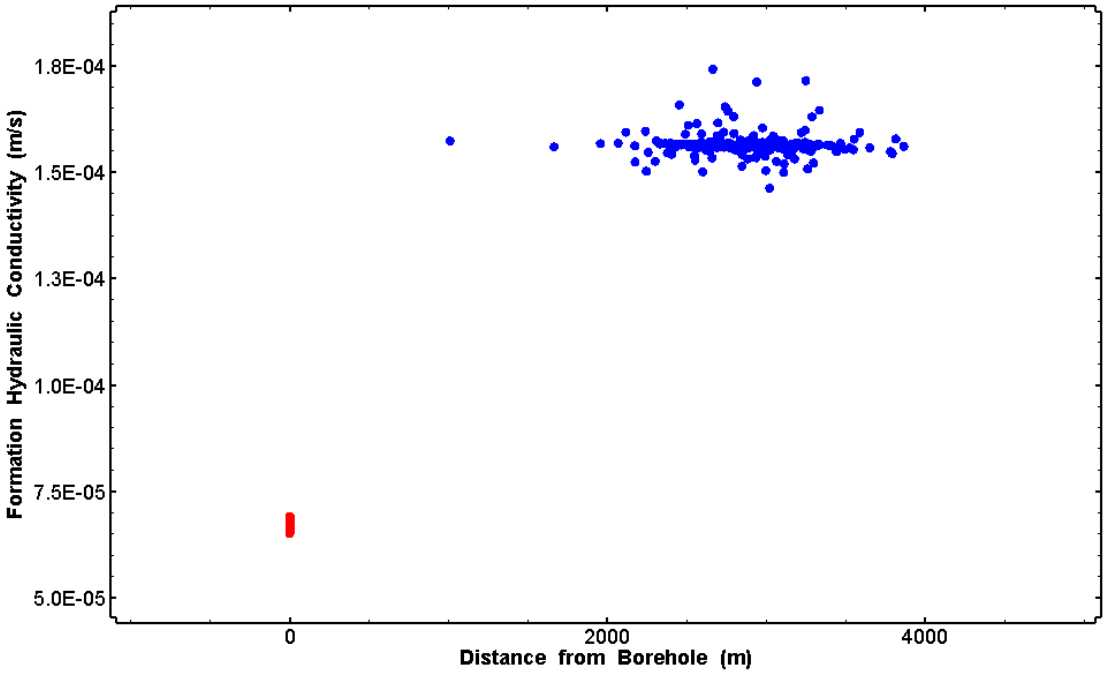

Figure B-31. Estimates of radially varying hydraulic conductivity derived from the SNL-19 perturbation analysis.

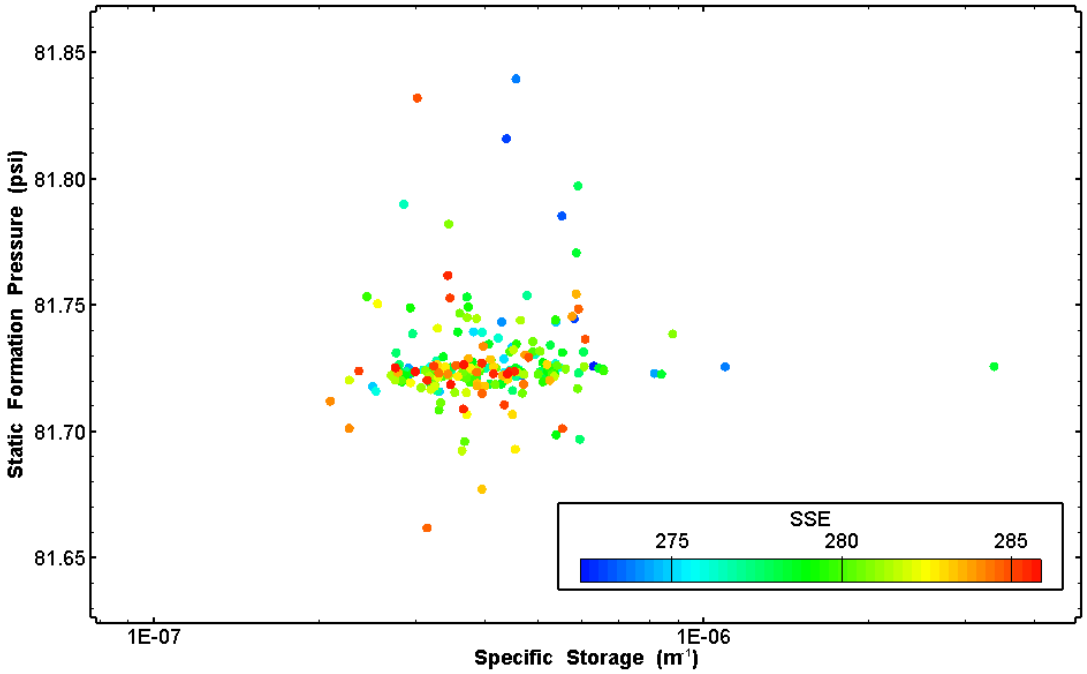

Figure B-32. Estimates of specific storage and static formation pressure derived from the SNL-19 perturbation analysis.

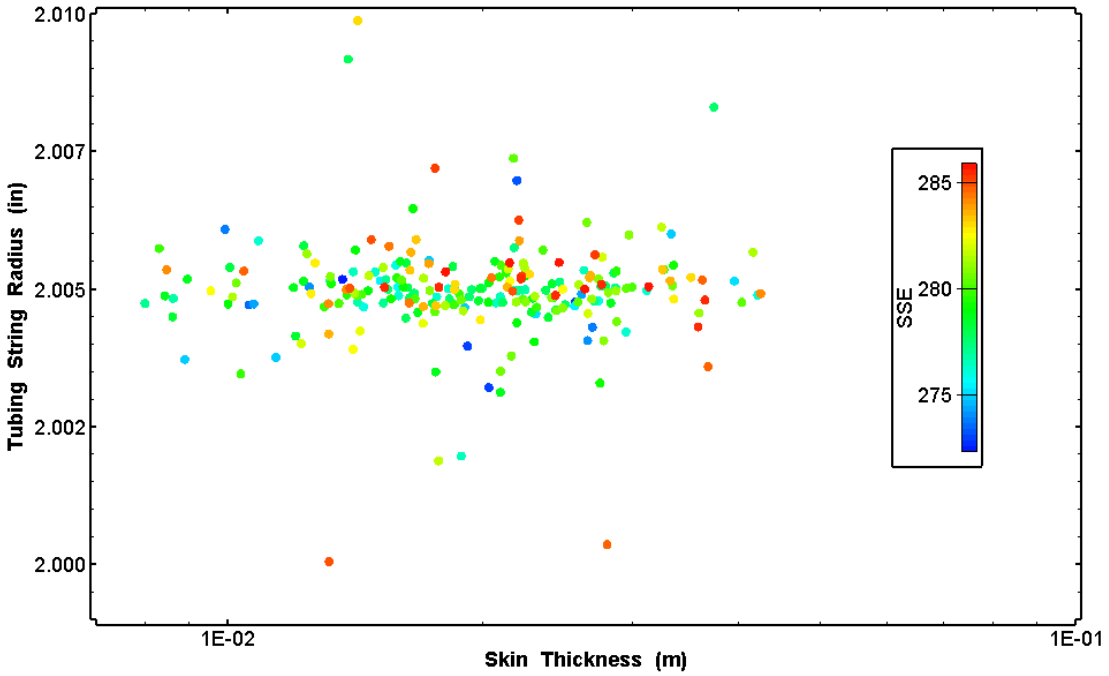

Figure B-33. Estimates of skin thickness and tubing string radius derived from the SNL-19 perturbation analysis.

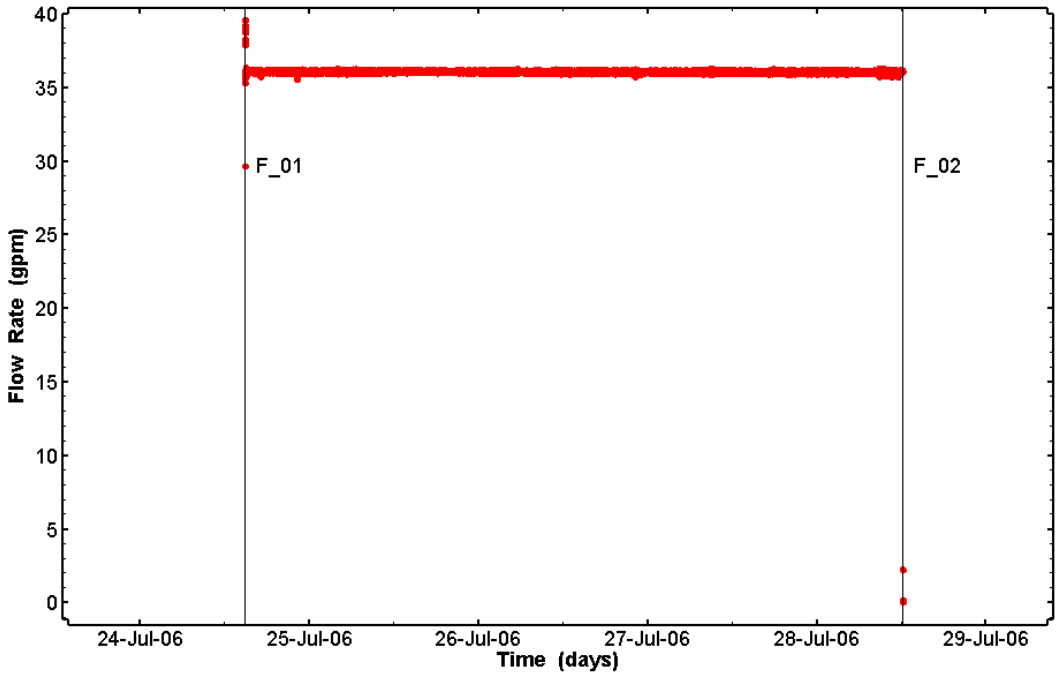

Figure B-34. Flow rates measured during the SNL-19 testing.

B.8 SNL-15 nSIGHTS Listings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
Listing date   02 Oct 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 15\ SNL 15.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes
External boundary	Fixed Pressure
Curve data source	Objects

Liquid Phase Settings

Aquifer type	Confined
Aquifer horizontal permeability	Isotropic
System porosity	Single
Compensate flow dimension geometry	yes
Leakage	None

Test Zone Settings

Test zone volume can vary	no	
Test zone compressibility can vary	no	
Test zone temperature can vary	no	
Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	30.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	961.897	[psi]
External boundary radius	1000000	[m]
Formation conductivity	1.24086E-14	[m/sec]
Formation spec. storage	3.85010E-06	[1/m]

Skin

Radial thickness of skin	3.1519478	[m]
Skin zone conductivity	1.42902E-11	[m/sec]

Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1205.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	3.9375	[in]
Tubing string radius	1.24	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.00000E-15	[m^3/sec]

Calculated Parameters

Formation

Transmissivity	1.13464E-13	[m^2/sec]
Storativity	3.52053E-05	[]
Diffusivity	3.22293E-09	[m^2/sec]

Skin Zone

Transmissivity	1.30670E-10	[m^2/sec]
Storativity	9.14400E-06	[]
Diffusivity	1.42902E-05	[m^2/sec]
Skin factor	-3.47869E+00	[]

Test Zone

Open hole well-bore storage	2.64837E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.06350	[]
First grid increment	2.13193E-01	[m]
Skin grid increment delta	0.07106	[]
Skin first grid increment	7.36500E-03	[m]
Skin last grid increment	2.23051E-01	[m]
Increment ratio	9.55801E-01	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	38508.583330	[day]
Duration	2.000000	[day]
Time step type	Static	
Static time step	0.100000	[day]

Type	Fixed	
Fixed value	0.000	[psi]
Wellbore storage	Open	

Sequence: S_01

Sequence type	Slug	
Start time	38510.583330	[day]
Duration	658.791770	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Initial pressure type	Absolute	
Initial pressure	0.000	[psi]

Sequence: H_02

Sequence type	History	
Start time	39169.375100	[day]
Duration	2.268380	[day]
Time step type	Static	
Static time step	0.050000	[day]
Type	Fixed	
Fixed value	126.519	[psi]
Wellbore storage	Open	

Sequence: S_02

Sequence type	Slug	
Start time	39171.643480	[day]
Duration	164.356520	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Initial pressure type	Absolute	
Initial pressure	126.519	[psi]

Simulation Results Setup

Output ID	DAT	
Output type	Pressure	
Pressure capture type	Test Zone	
Output units	[psi]	

Output ID	DAT	
Output type	Flow Rate	
Flow rate output type	Well	
Output units	[m^3/sec]	

SNL-15 Optimization Settings

```
*************
nPre/32 2.40Q
*************

Version date   26 Oct 2006
```

```
Listing date   02 Oct 2007
QA status      QA: Q
Config file    C:\nSIGHTS\Culebra\SNL 15\SNL 15.nPre
```

Parameters

Formation

Formation thickness	30.000	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	150.000	[psi]
Maximum value	1500.000	[psi]
Estimate value	961.897	[psi]
Range type	Linear	
Sigma	1.00000E+00	
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-16	[m/sec]
Maximum value	1.00000E-08	[m/sec]
Estimate value	1.24086E-14	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	Optimization	
Minimum value	1.00000E-08	[1/m]
Maximum value	1.00000E-04	[1/m]
Estimate value	3.85010E-06	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	0.0001	[m]
Maximum value	100.0	[m]
Estimate value	3.1519478	[m]
Range type	Log	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-14	[m/sec]
Maximum value	1.00000E-06	[m/sec]
Estimate value	1.42902E-11	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

Fluid density	1205.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	3.9375	[in]
Tubing string radius	1.24	[in]

Numeric

# of radial nodes	250	[]
# of skin nodes	50	[]
Pressure solution tolerance	1.45038E-11	[psi]
STP flow solution tolerance	1.00000E-15	[m^3/sec]

SNL-15 Fitting Parameter Estimates

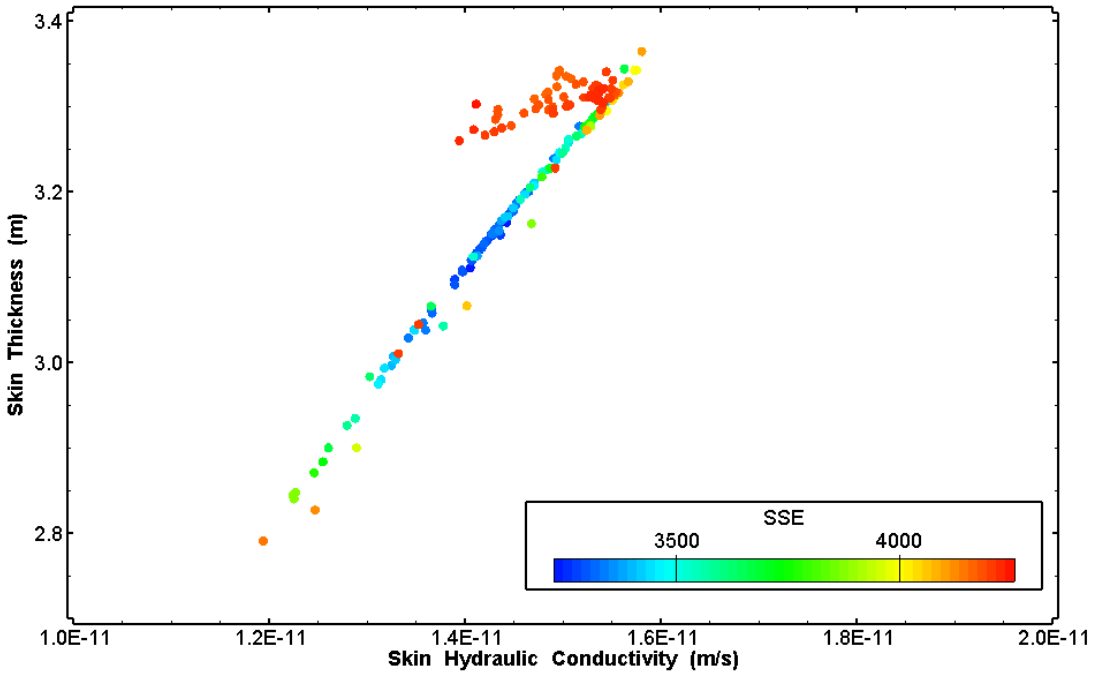

Figure B-35. Estimates of skin hydraulic conductivity and skin thickness derived from the SNL-15 perturbation analysis.

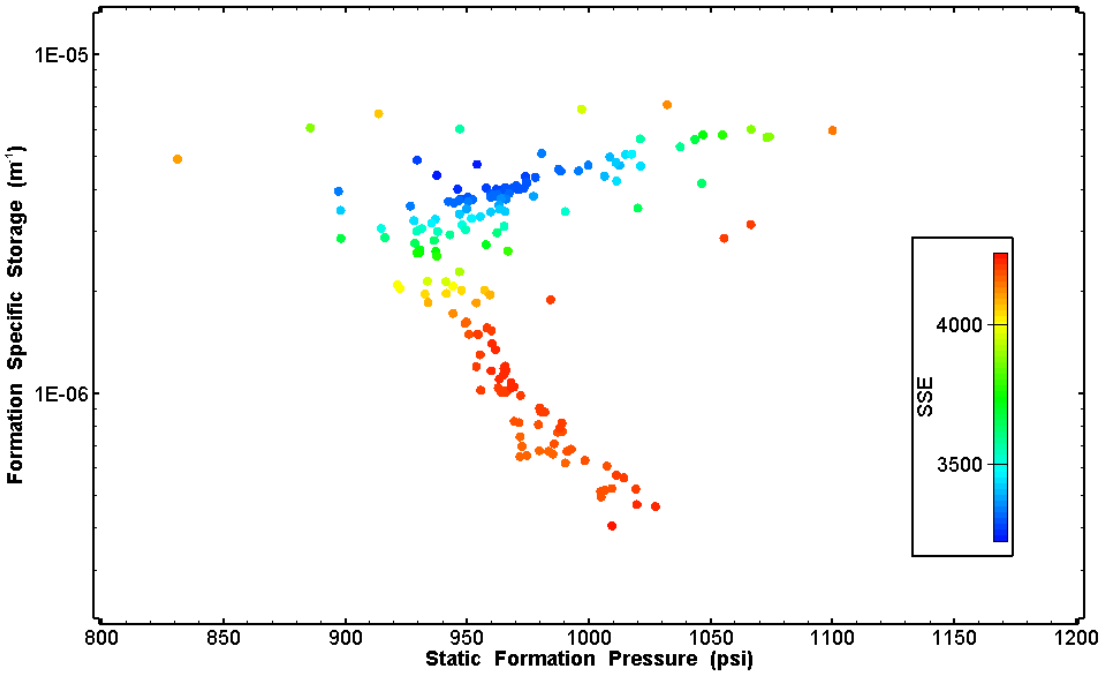

Figure B-36. Estimates of static formation pressure and formation specific storage derived from the SNL-15 perturbation analysis.