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Analysis Report for AP-070

Analysis of the H-9bR Pumping Test Conducted From 8/6/12 to 8/22/12

AP-070: Analysis Plan for Hydraulic-Test Interpretations

Task Number 4.4.2.3.1

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1. Introduction

This report discusses the analyses of hydraulic tests performed in the Culebra Member of the Rustler Formation (Figure 1) at the Waste Isolation Pilot Plant (WIPP) site at the H-9 well pad (Figure 2). These analyses were performed in accordance with the Sandia National Laboratories (SNL) Analysis Plan for Hydraulic-Test Interpretations, AP-070, Revision 2 (Beauheim, 2009). The computer code used for analysis was nSIGHTS (n-dimensional Statistical Inverse Graphical Hydraulic Test Simulator), version 2.41a. 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).

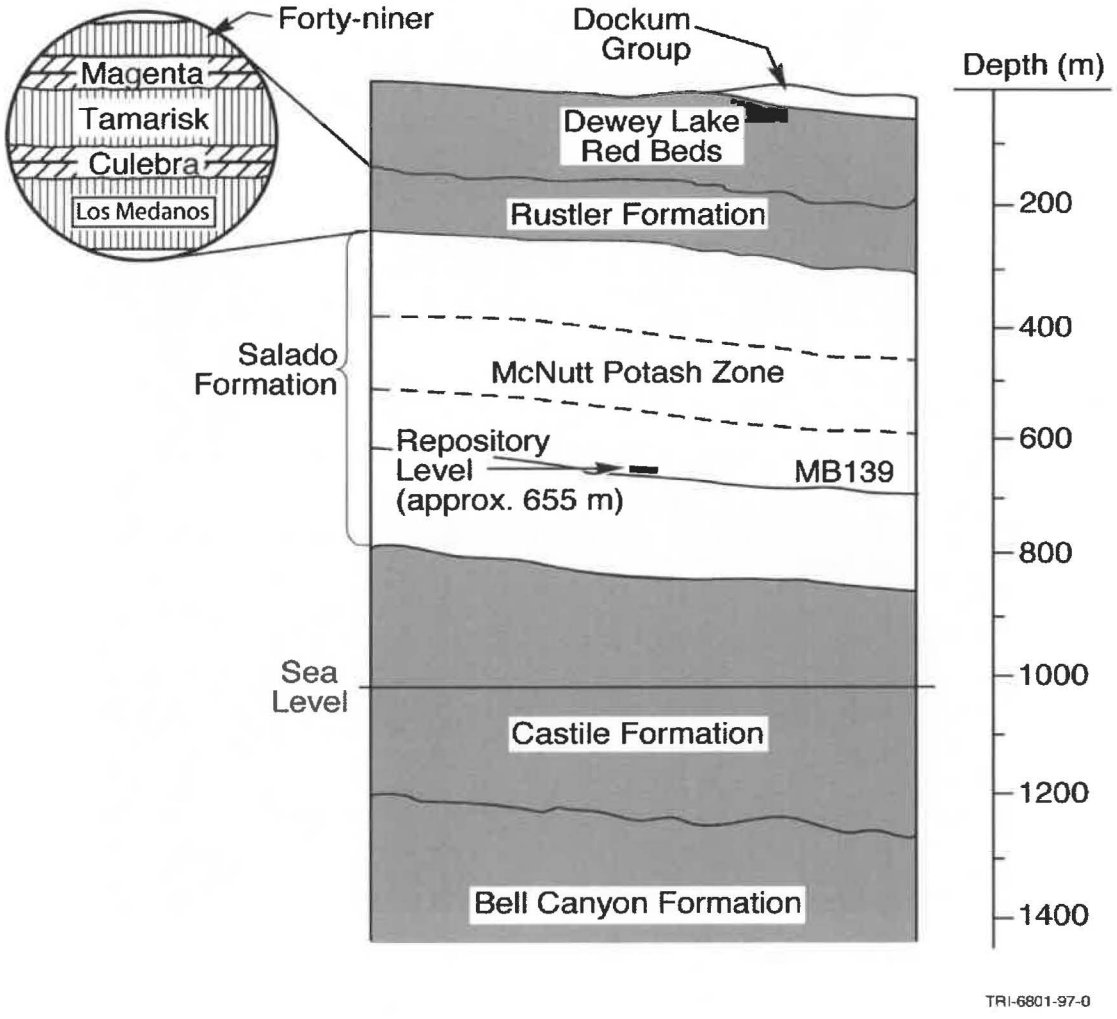


Figure 1. WIPP stratigraphy.

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2. Test and Analysis Procedures

Three constant-rate purge tests were performed in the H-9bR replacement well on 9/28/10, 3/2/11, and 6/28/11 for the purpose of removing non-formation water and obtaining water quality samples. These tests removed 2299 gal., 981 gal., and 974 gal., respectively. Analysis of the first and second tests indicated that the well could sustain approximately a 45 gpm pumping rate. Purge test analyses (Section 3.1.1) show the initial fit of the data and its corresponding aquifer parameter estimations. We note that this was just a preliminary fit used solely for guidance for the full test and its model parameters do not represent the final aquifer parameter estimates. The location of the H-9 well pad in the WIPP well network is show in Figure 2. Pumping test analyses included the fitting of Cartesian pressure data, pressure change, and pressure derivative (log-log diagnostic) as described by Bourdet (1989).

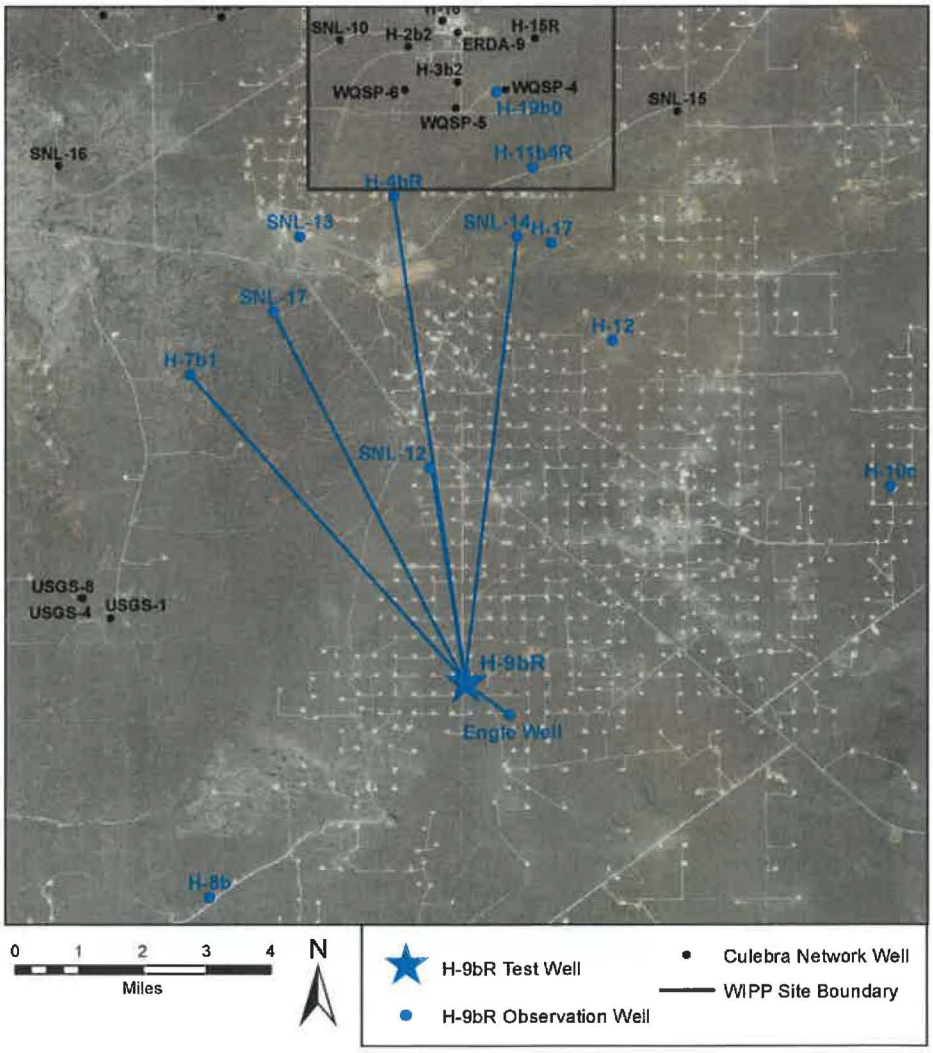


Figure 2. Location of the H-9bR Culebra well located on the H-9 wellpad. The H-9bR pumping well is designated by a blue star, observation wells for the testing of H-9bR are designated in blue, and those with lines to the pumping well are those that observed pressure changes due to pumping in H-9bR.

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All the nSIGHTS test simulations incorporated pre-test pressure records of various durations as "history" periods where the observed pressures were specified in the simulations.

Test analysis involved finding the values of the fitting parameters that produced the best-simulated matches to the pressure data collected during the constant-rate test and subsequent recovery period. In addition to the formation properties of interest (principally transmissivity (T)), 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 this analysis is to estimate T for subsequent use in T-field generation and WIPP performance assessment calculations, and to validate the construction of the replacement well against analyses conducted on data from previous Culebra wells on the H-9 wellpad. 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, however, is relatively small, so any correlation between T and other fitting parameters is not of concern.

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 sample the parameter space adequately 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 unweighted 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 unweighted SSE. If multiple data types are included in the match, e.g., if pressures, pressure derivatives, etc., are matched simultaneously, then the weighted SSE values for each component are combined and the overall goodness-of-fit measure is denoted in nSIGHTS as the *fit value*.

Five hundred perturbation/optimization runs were performed for each of the analyses discussed in this report. A visual assessment of parameter-space plots for each fitting variable and a visual assessment of the fits themselves were all used to determine the value of the "fit discriminant". The fit discriminant is used to reduce the perturbations under consideration to only those within the best-fit minimum, and sufficiently close to be subjectively considered "acceptable" fits. All perturbation results for which the fit value was less than the fit discriminant were deemed acceptable solutions and are included in the final range of reported values for each fitting parameter. In some cases, the original baseline solution may not fall within the global minimum

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defined through perturbation analysis. The final number of satisfactory perturbation results for each test is reported in the Section 4 figure captions.

3. H-9bR Analysis Results

Discussions of H-9bR and associated test analyses are given below. A summary of the T 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 the sections below and a full listing is contained within the nPost configuration file for each analysis.

Table 1. Culebra Transmissivity and Storativity Estimates.

H-9bR Test	Mean S	T Radius (m)	Geo. Mean T (m^2/s)	Log Geo. Mean T (m^2/s)	Log Min. T (m^2/s)	Log Max. T (m^2/s)	Variance $(m^2/s)^2$
Purge 1	7.03E-02	-	2.91E-04	-	-	-	-
Purge 2	1.05E-02	-	5.33E-04	-	-	-	-
2012 Pumping Test:							
$T1$ (pumping well)*	2.52E-06	46.49	1.45E-04	-3.837	-4.242	-2	5.32E-02
$T2$ (pumping well)*	2.52E-06	1629.21	1.79E-05	-4.747	-4.75	-4.739	1.24E-06
$T1$(w/ H-4bR)*	6.11E-06	5.61	1.28E-04	-3.893	-4.333	-3.463	2.67E-02
$T2$(w/ H-4bR)*	6.11E-06	1083.92	1.73E-05	-4.762	-4.771	-4.758	6.60E-06
$T1$(w/ SNL-12)*	1.13E-05	6.14	6.34E-05	-4.198	-4.542	-4.027	1.96E-02
$T2$(w/ SNL-12)*	1.13E-05	2586.78	1.22E-05	-4.913	-4.948	-4.891	1.41E-04
Past Tests:							
H-9b (1983)[1]	5.90E-04	-	1.15E-05	-	-	-	-

*In cases where multiple transmissivities (typically called a Composite Model) were used to fit the data, each progressive T value was assigned a distance from the borehole.

[1] Beauheim and Ruskauff (1998)

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3.1. H-9bR

The Culebra interval of well H-9bR was drilled between 10/8/2010 and 10/22/2010 (DOE 2012). The well was drilled to a depth of 686 ft with the Culebra interval screened from 667 ft to 640.5 ft. At the Culebra, the inner diameter (ID) of the well is 4.375-in and the pump is hanging on 1.5-in ID tubing. The siting and creation of the H-9bR well was based on the need to replace the previous H-9 well in support of hydrologic testing and monitoring of the Culebra Dolomite south of the WIPP site. A physical description of the well is detailed in Figure 3.

Three purge tests were initiated in the Culebra at H-9bR on 9/28/10, 3/2/11, and 6/28/11. All purge tests concluded on the days they were initiated. These tests were analyzed to gain insight on the hydraulic parameters associated with the replacement well to better frame the pumping rate and duration for the later multi-day 3 acre-foot test. Data was recorded for the drawdown of the well for only two of the purge tests; subsequently we only created simulations for those in which data was recorded. The simulations for the purge tests both consisted of a history period prior to drawdown, a drawdown period while purging was active, and a recovery period once purging concluded. The data and model used in each analysis are shown in Figures 4 and 5.

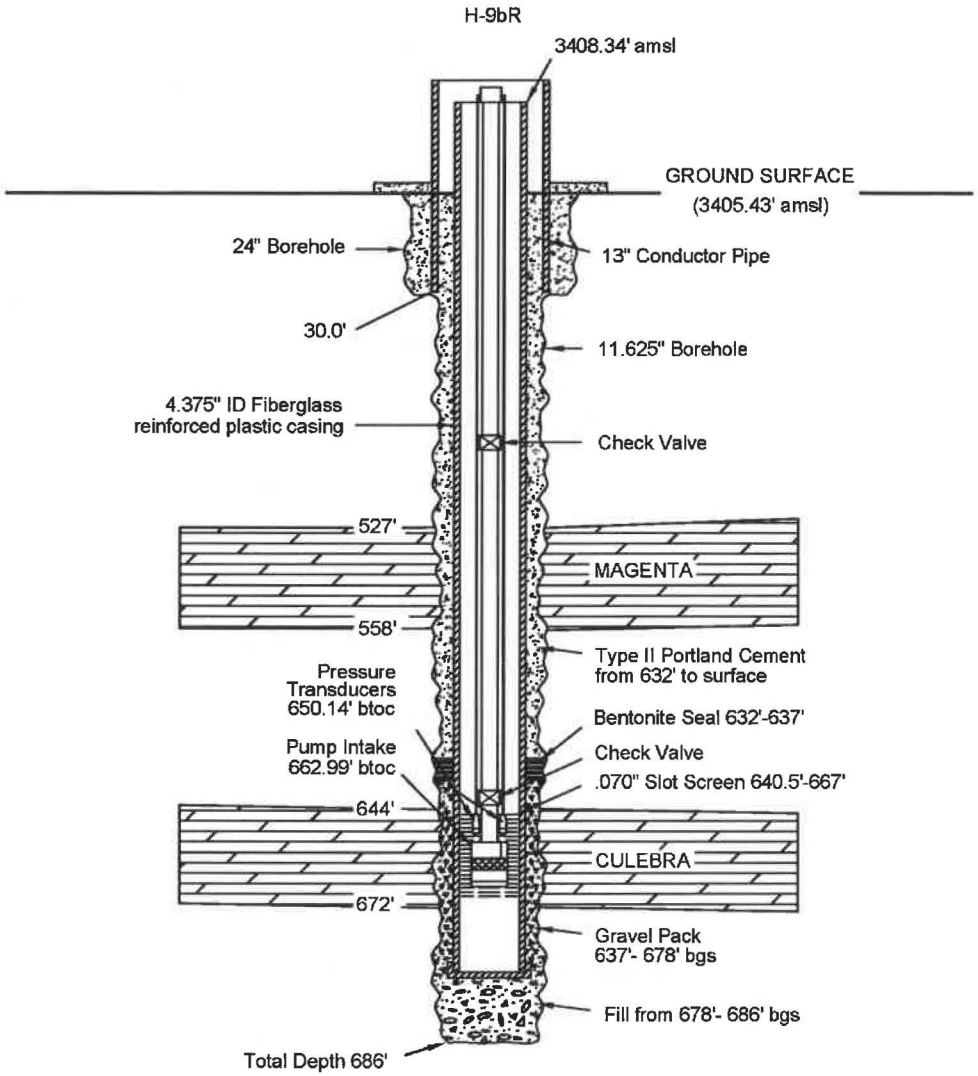
A 3 acre-foot pumping test was initiated in the Culebra at H-9bR from 8/6/12 to 8/22/12. The simulation of this pumping test consisted of a history period that extended partially after pumping began, a drawdown period, and a recovery period. The recovery period simply began once pumping was stopped, but the period was concluded prior to full recovery due to changes in water level caused by pumping in the adjacent wells. We presume the late time fluctuations in the water level recovery are due to pumping in the adjacent Engle well. The data acquired for the test is shown in Figure 6 and an overlay of H-9bR data and normalized Engle well data (Figure 7) shows the interactivity of the two wells.

The H-9bR nSIGHTS simulations each consisted of three sequences. The details of each sequence, i.e., start/end time, pressure, etc., are specified in the H-9bR.nPre file and are listed in Appendix B.1.

The specified H-9bR conceptual models were chosen because they were the simplest models consistent with the available information that produced an acceptable fit to the data; acceptable by consensus of the modeler and an associate modeler. The three models used were in infinite-acting, radial systems with a variable T with respect to distance from the pumping well, a negative skin, and wellbore storage. Considering the large volume of water pumped from the well and the duration of the test, we were able to record and incorporate observation well responses in the well test analysis. Hydrologic activity at and around the WIPP site created interference in several of the observation wells and were subsequently disqualified from the analysis. We did obtain "clean" drawdown responses from SNL-12 and H-4bR and used them for parameter estimation. Given the available data, we used three separate models to fit the data: fits to the pumping well data and H-4bR observation data, fits to the pumping well data and SNL-12 observation data, and fits of just the pumping well data.

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Localized fracturing and gravel pack surrounding the screened portion of the well at the Culebra likely accounts for the negative skin with respect to the far-field *T* estimates. The near-field and far-field T variations required for adequate modeling of the data were thought to be due to heterogeneity or double porosity effects. The range of *T* values derived from these analyses are shown in Figures 4-24. The *T* estimates gained through this analysis are similar to those of the past test and are compared in the preceding Table 1.



NOTE:

1. Depths in feet below ground surface.
2. Not to scale.

Figure 3. H-9bR well configuration during testing.

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3.1.1 Purge Test Analysis

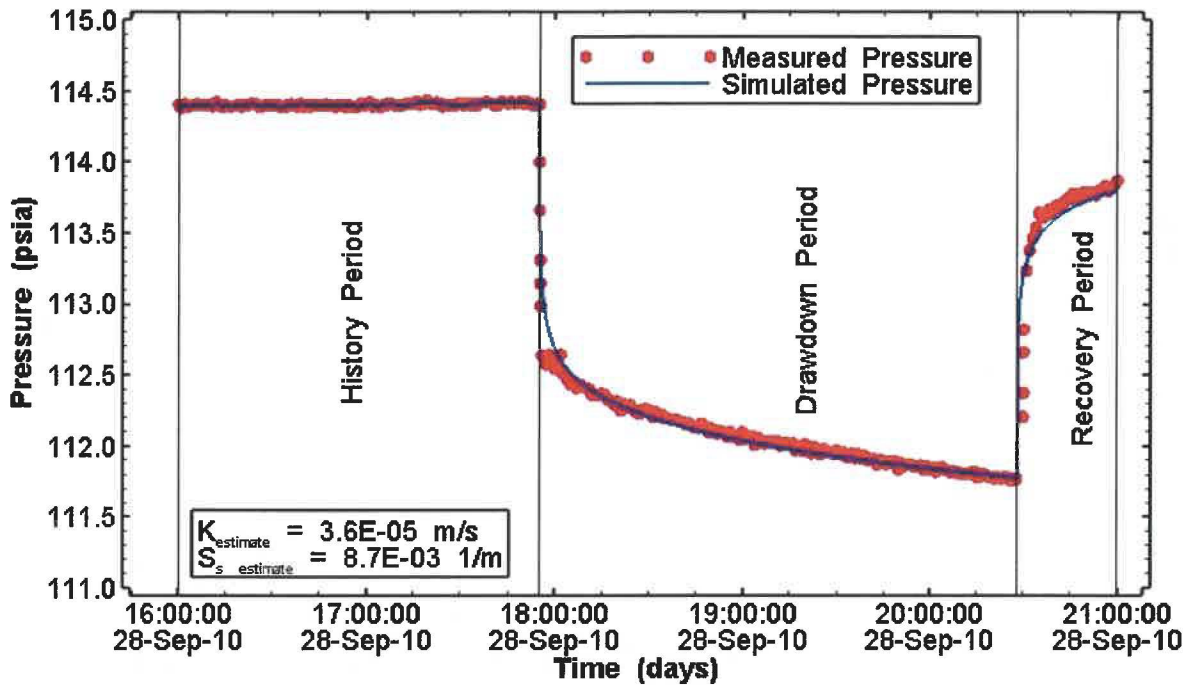


Figure 4. Pressure data from and model fit of the first Culebra purge test in H-9bR.

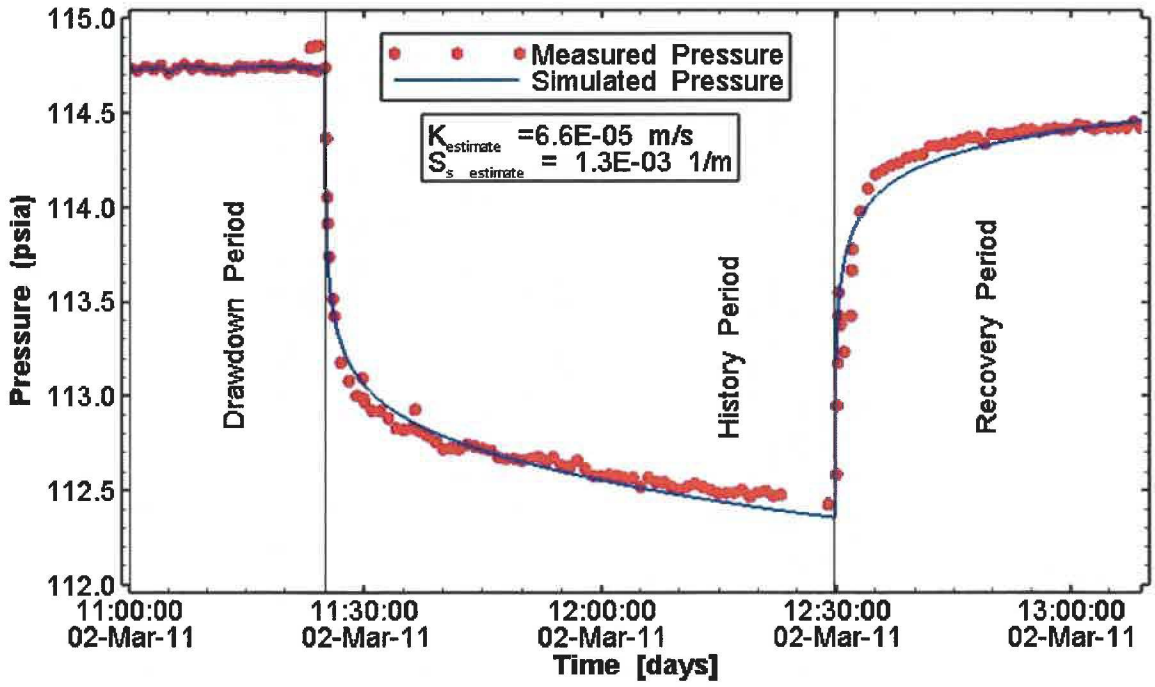


Figure 5. Pressure data from and model fit of the second Culebra purge test in H-9bR.

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3.1.2 Pumping Test Analysis Using No Observation Well Data

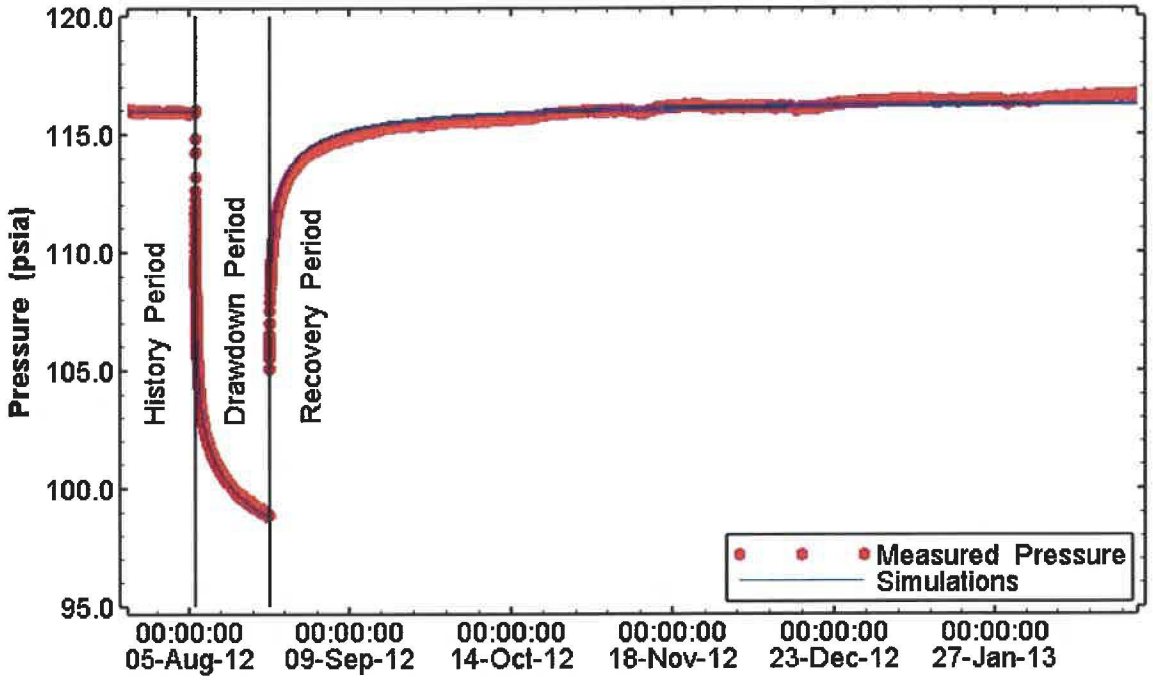


Figure 6. Pressure data and 362 model fits of the Culebra pumping test in H-9bR.

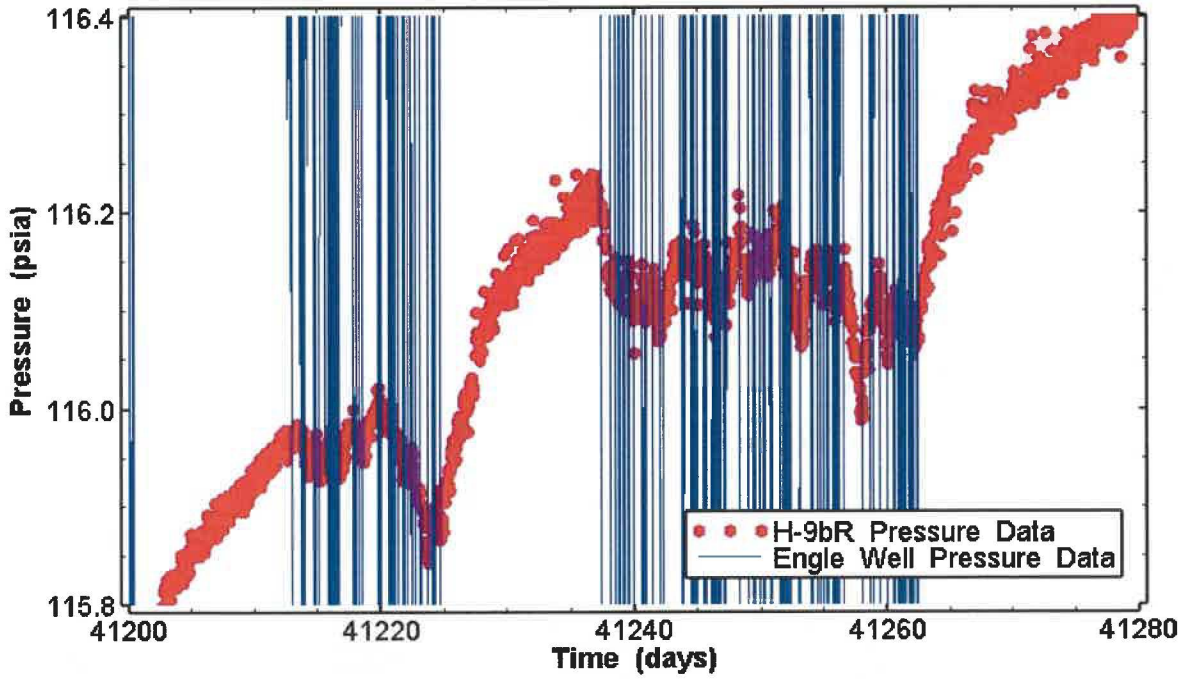


Figure 7. An overlay of H-9bR pressure data and Engle well pressure data showing their interactivity.

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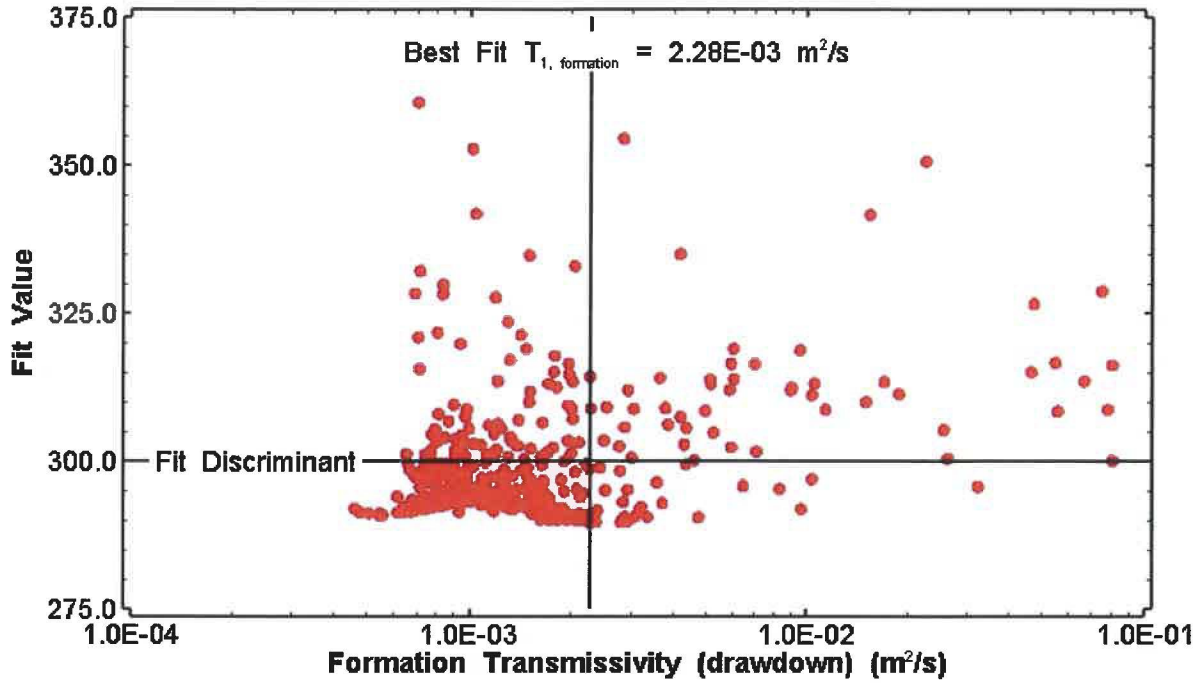


Figure 8. X-Y scatter plot showing the near-field transmissivity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

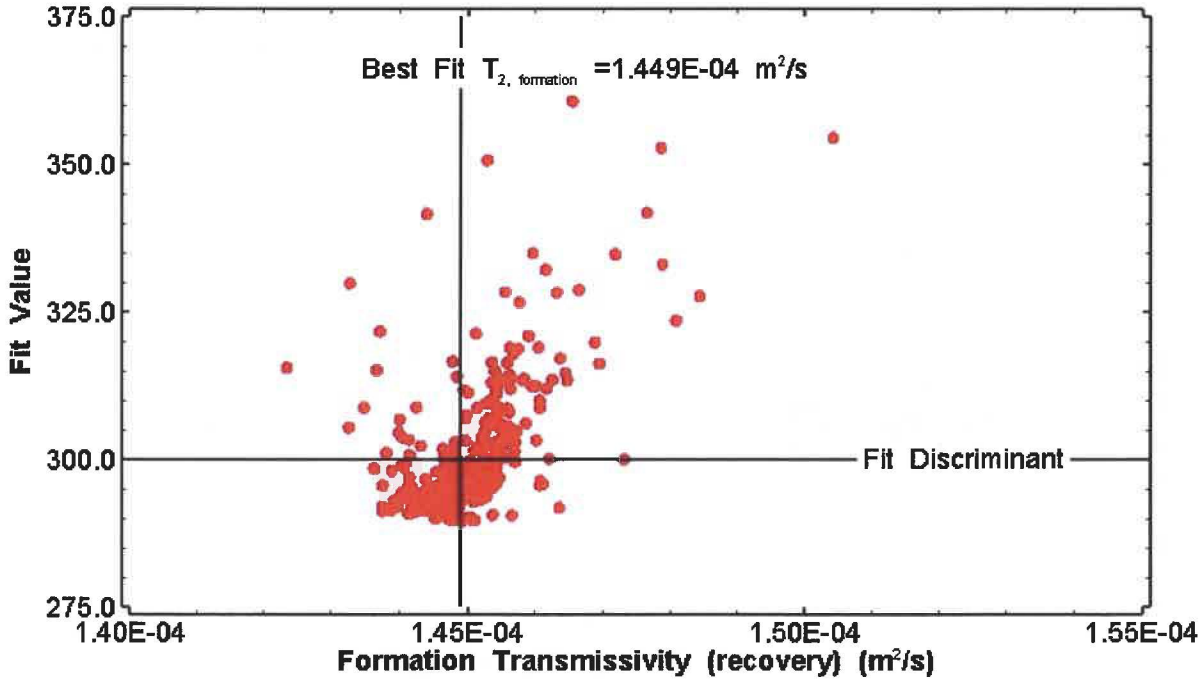


Figure 9. X-Y scatter plot showing the far-field transmissivity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

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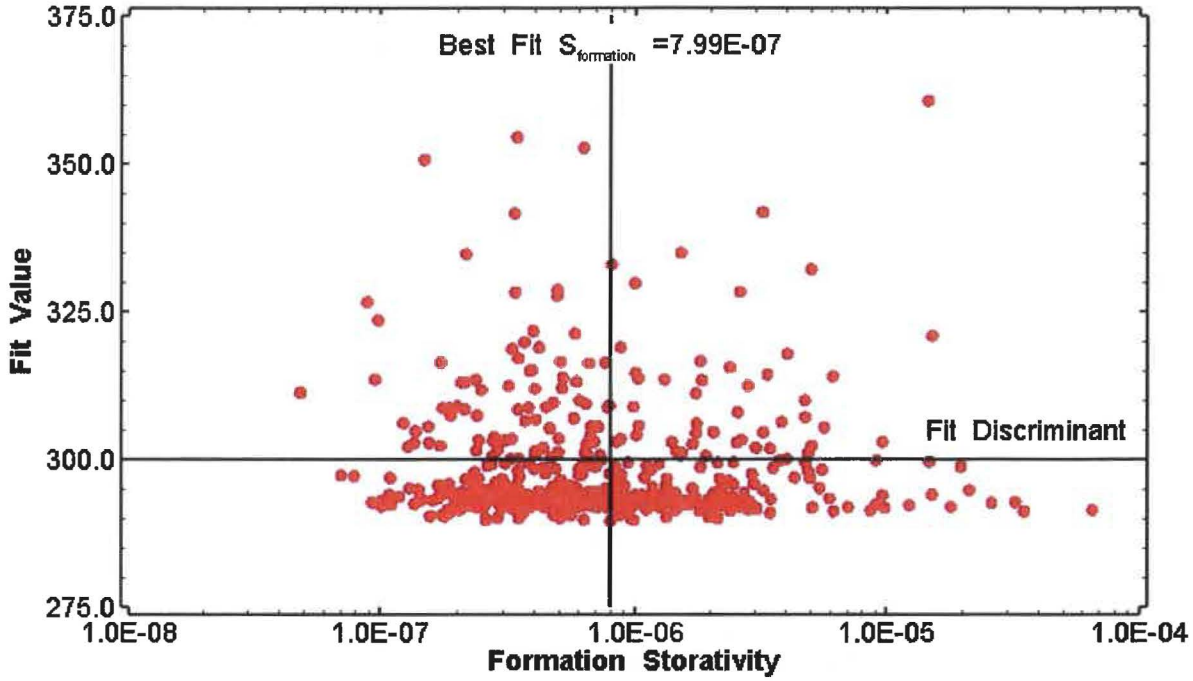


Figure 10. X-Y scatter plot showing the far-field storativity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

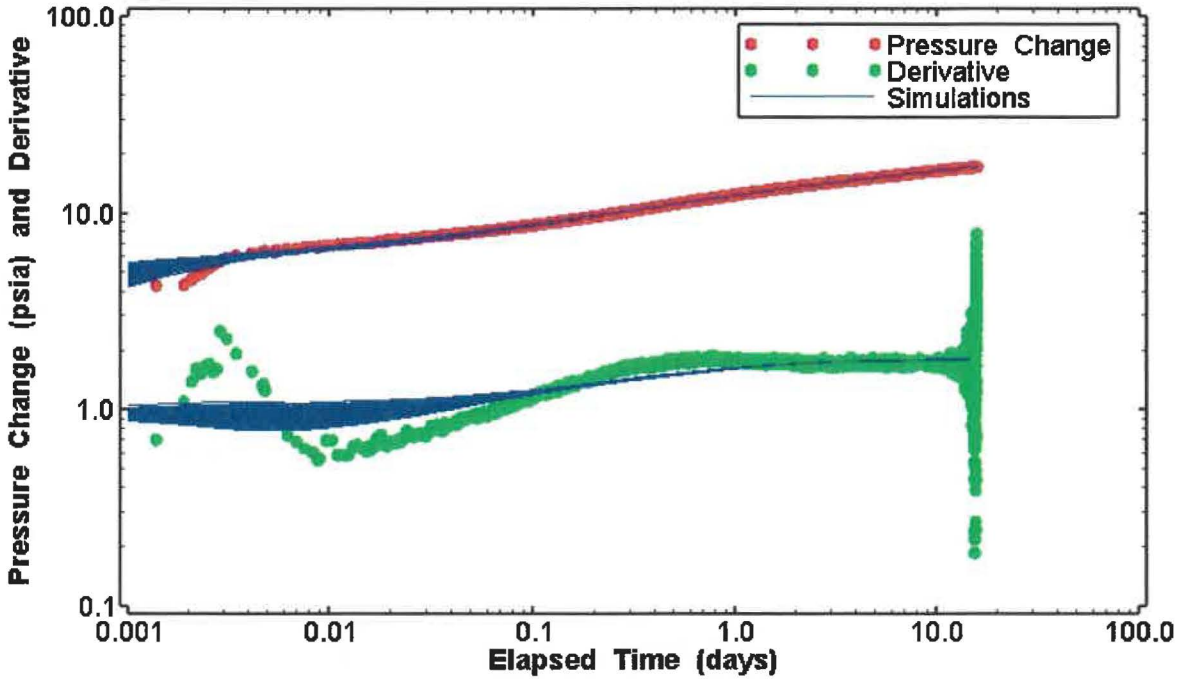


Figure 11. Log-log plot showing 362 simulations of the H-9bR drawdown period pressure change and derivative response.

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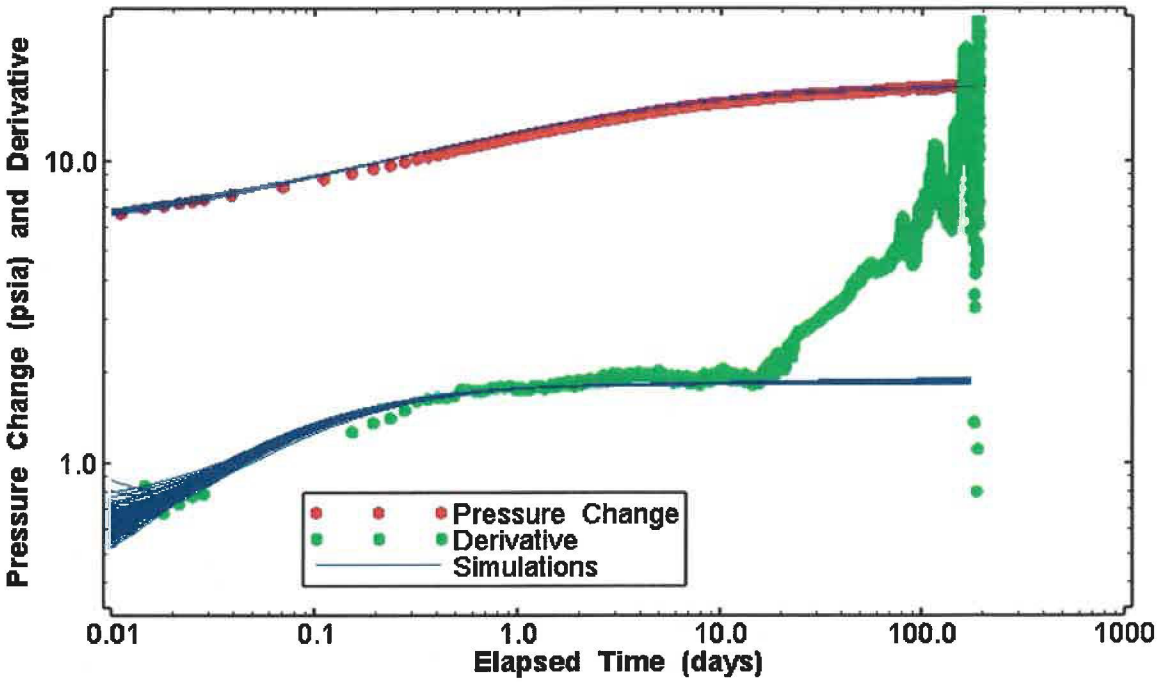


Figure 12. Log-log plot showing 362 simulations of the H-9bR recovery period pressure change and derivative response.

3.1.3 Pumping Test Analysis Using H-4bR Observation Well Data

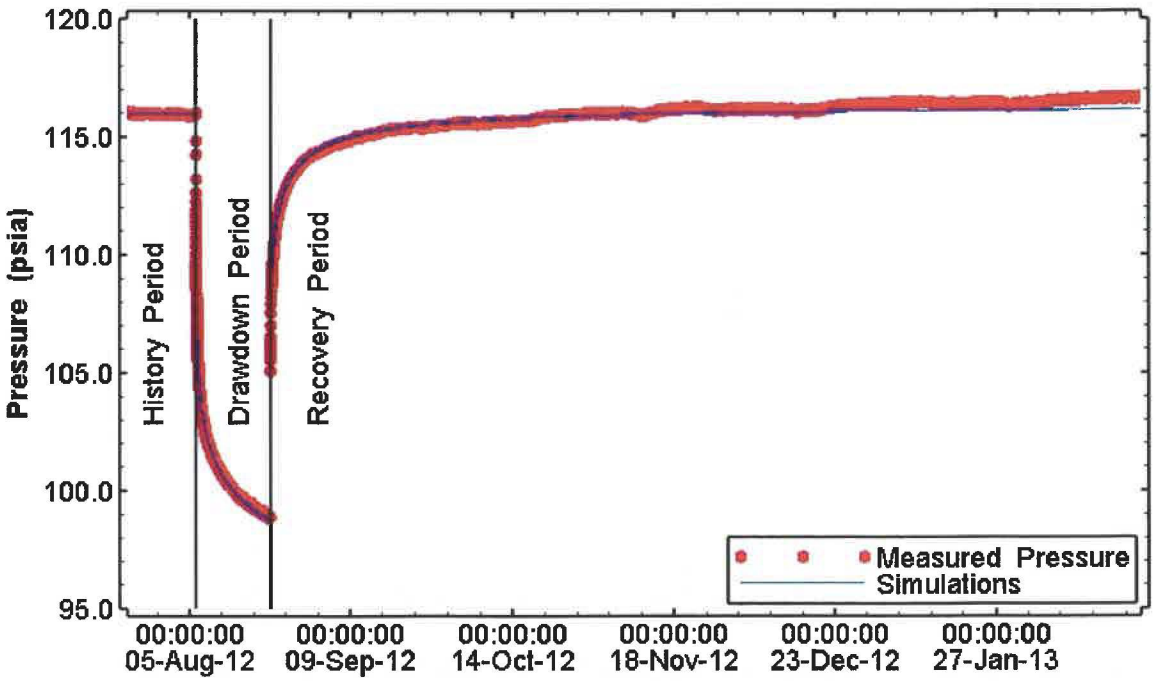


Figure 13. Pressure data and 123 model fits of the Culebra pumping test in H-9bR.

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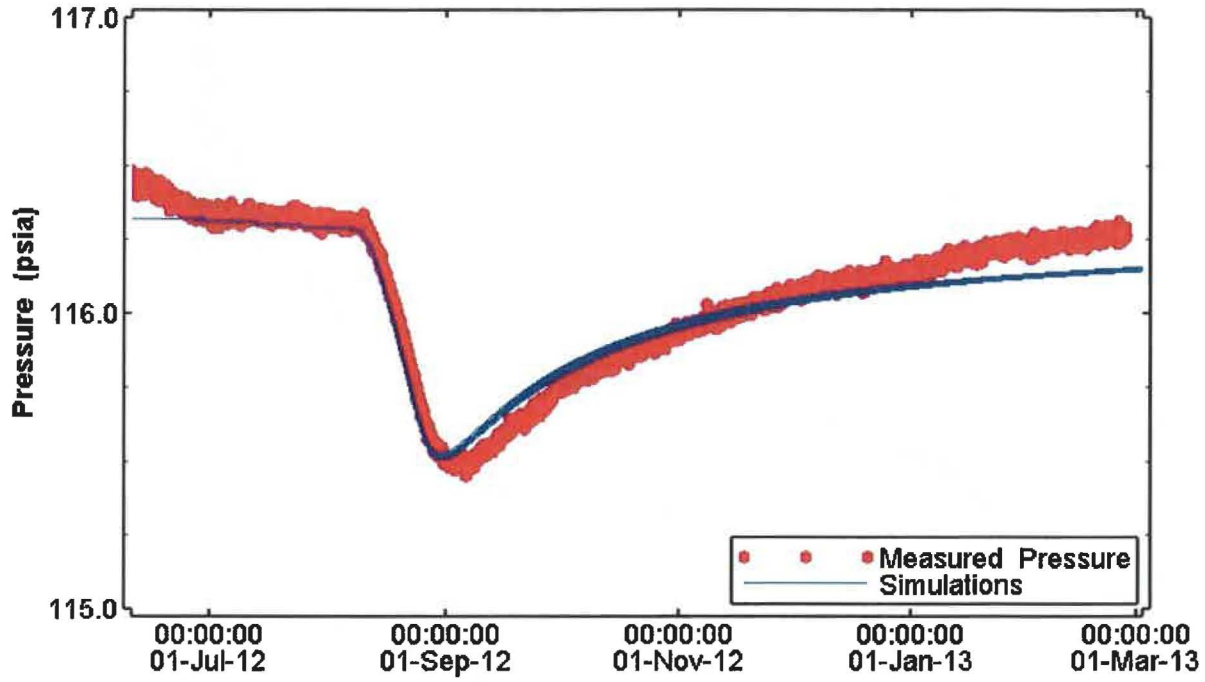


Figure 14. Pressure data and 123 model fits of the Culebra observation response in well H-4bR due to pumping in H-9bR.

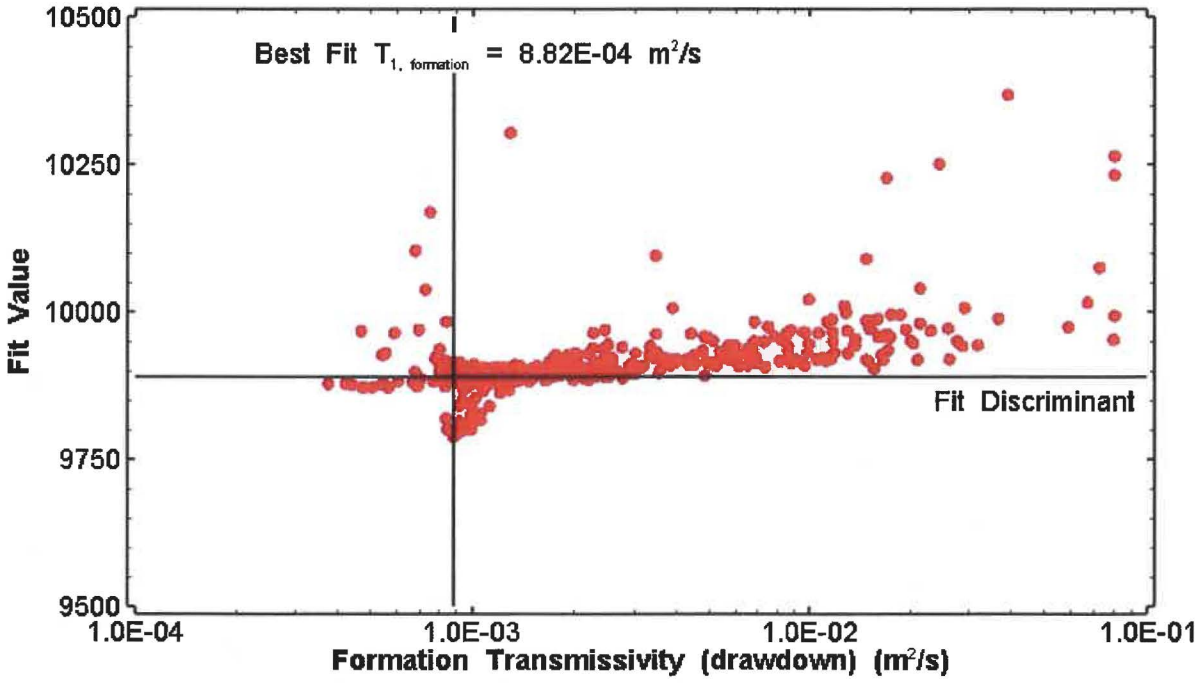


Figure 15. X-Y scatter plot showing the near-field transmissivity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

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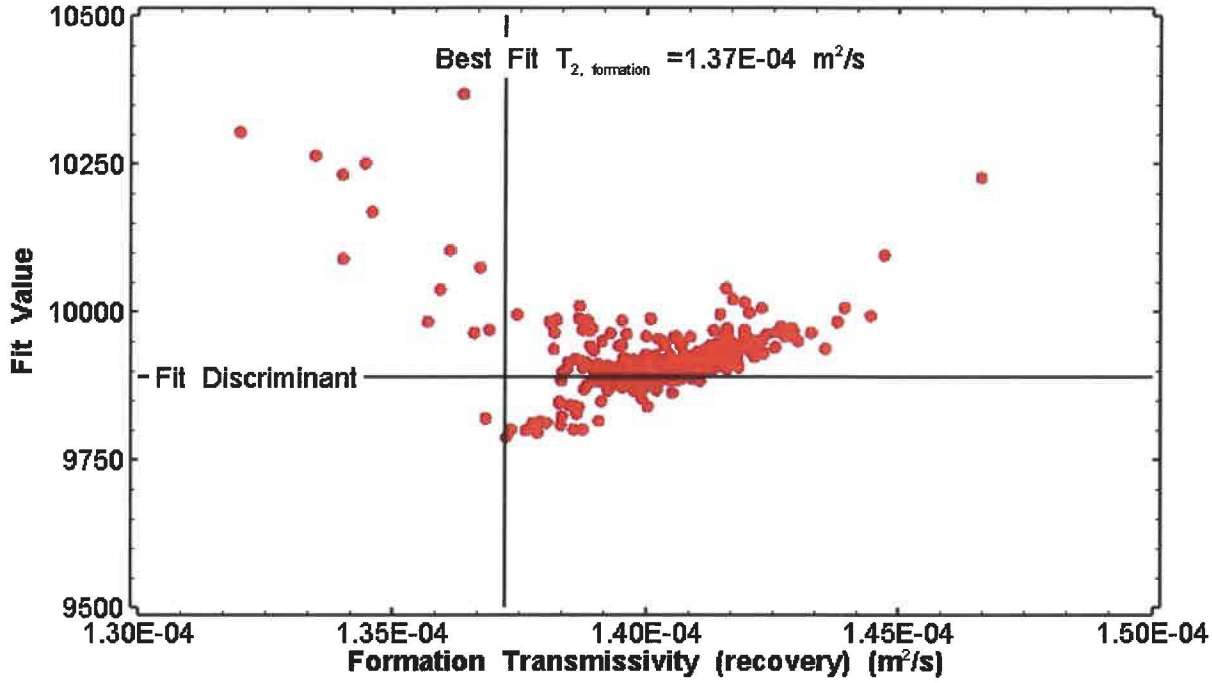


Figure 16. X-Y scatter plot showing the far-field transmissivity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

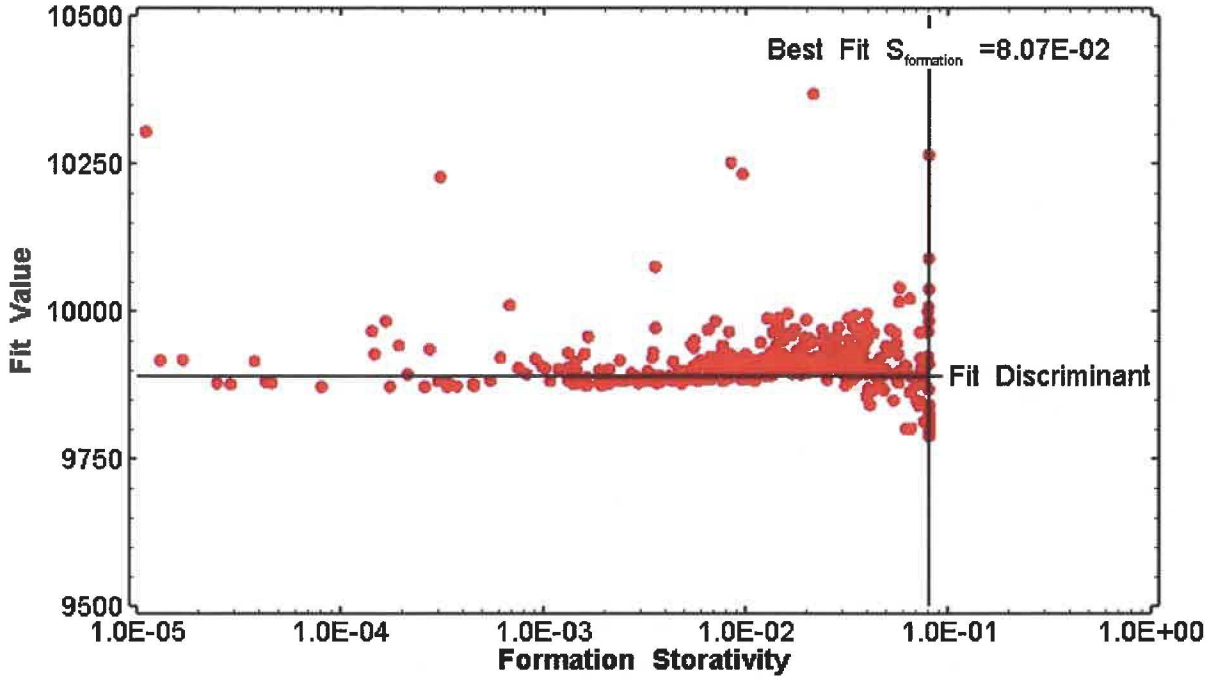


Figure 17. X-Y scatter plot showing the far-field storativity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

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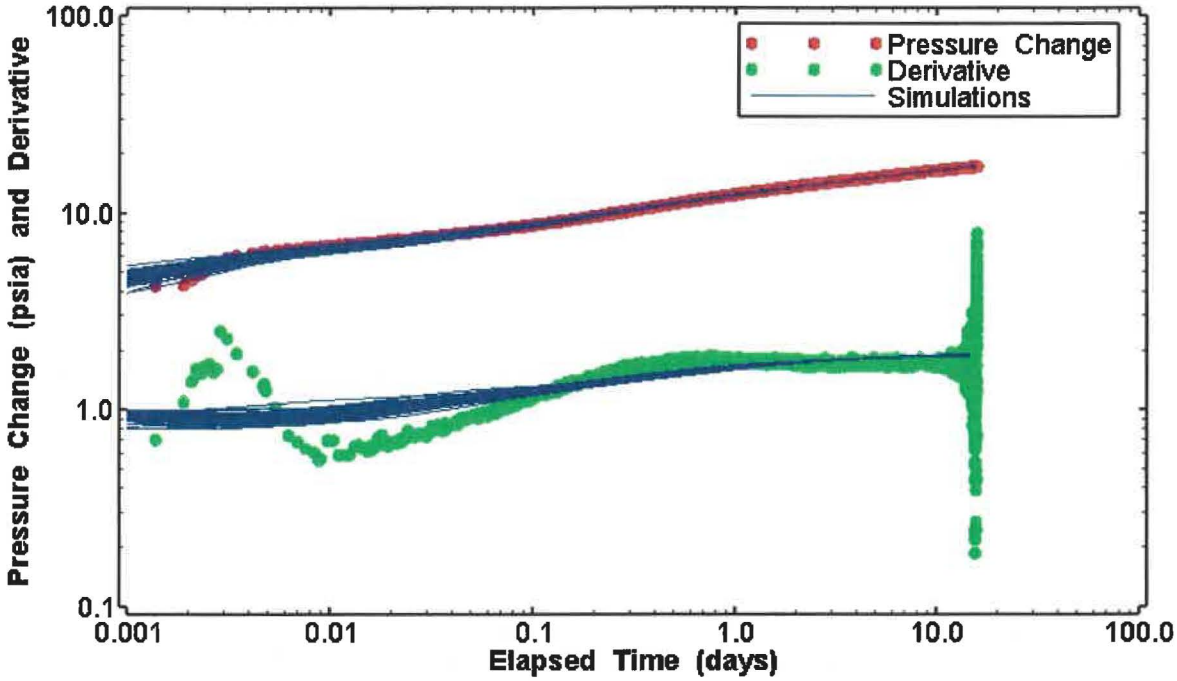


Figure 18. Log-log plot showing 123 simulations of the H-9bR drawdown period pressure change and derivative response.

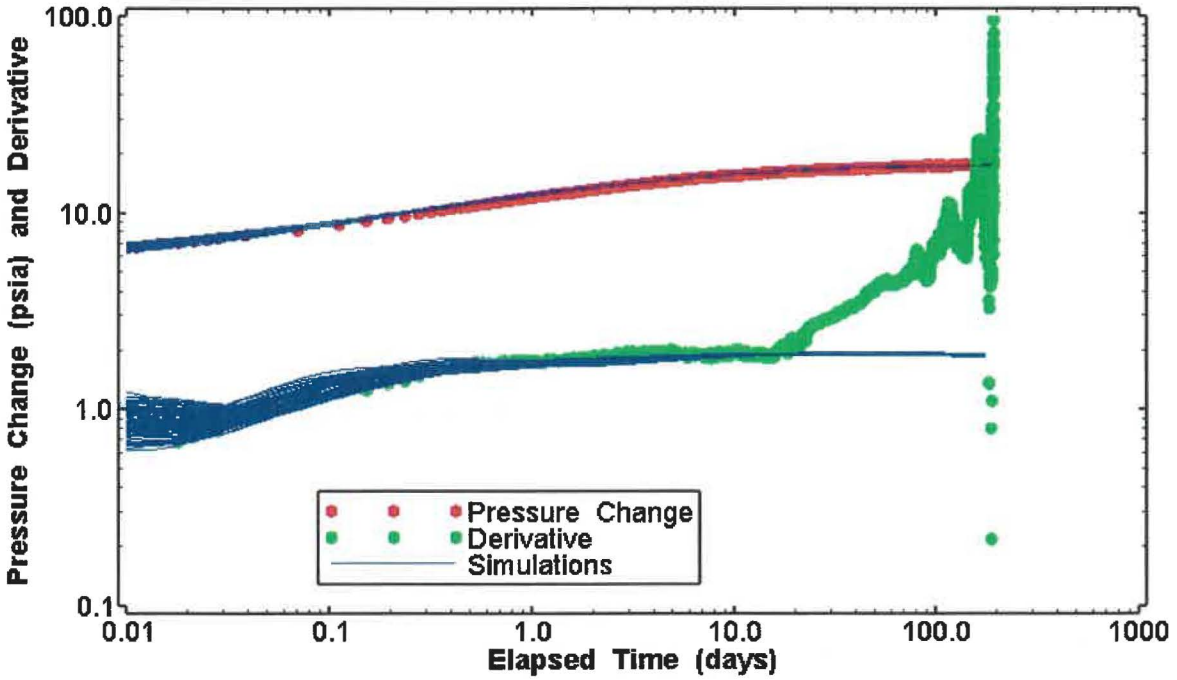


Figure 19. Log-log plot showing 123 simulations of the H-9bR recovery period pressure change and derivative response.

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3.1.4 Pumping Test Analysis Using SNL-12 Observation Well Data

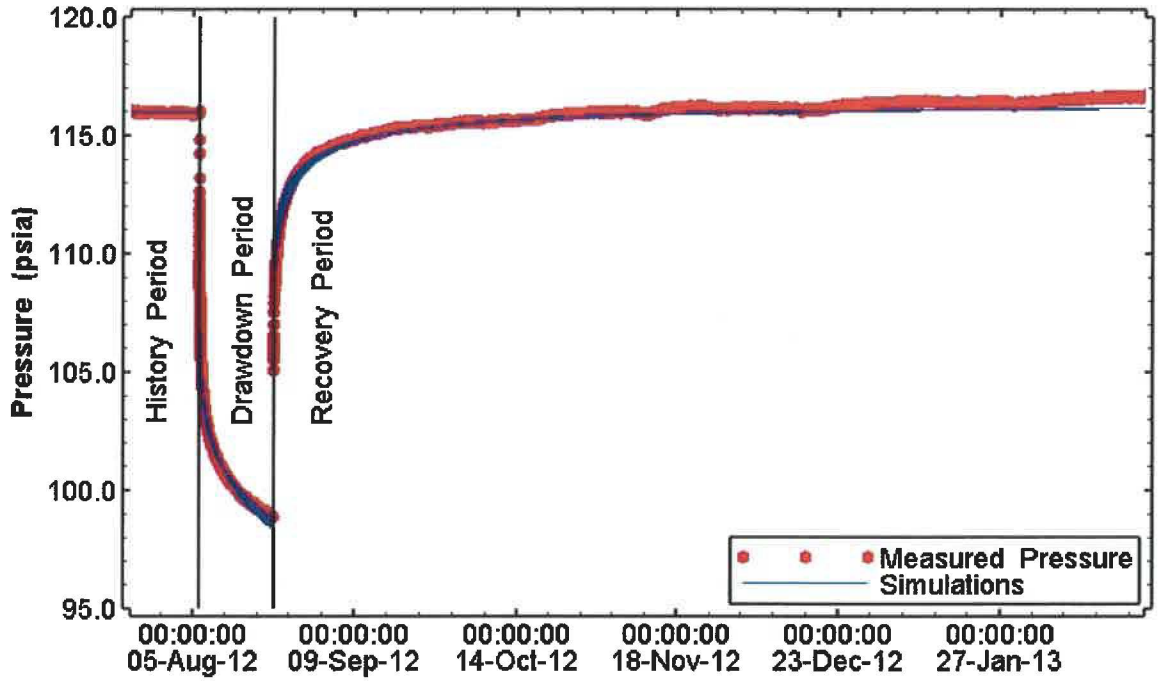


Figure 20. Pressure data and 41 model fits of the Culebra pumping test in H-9bR.

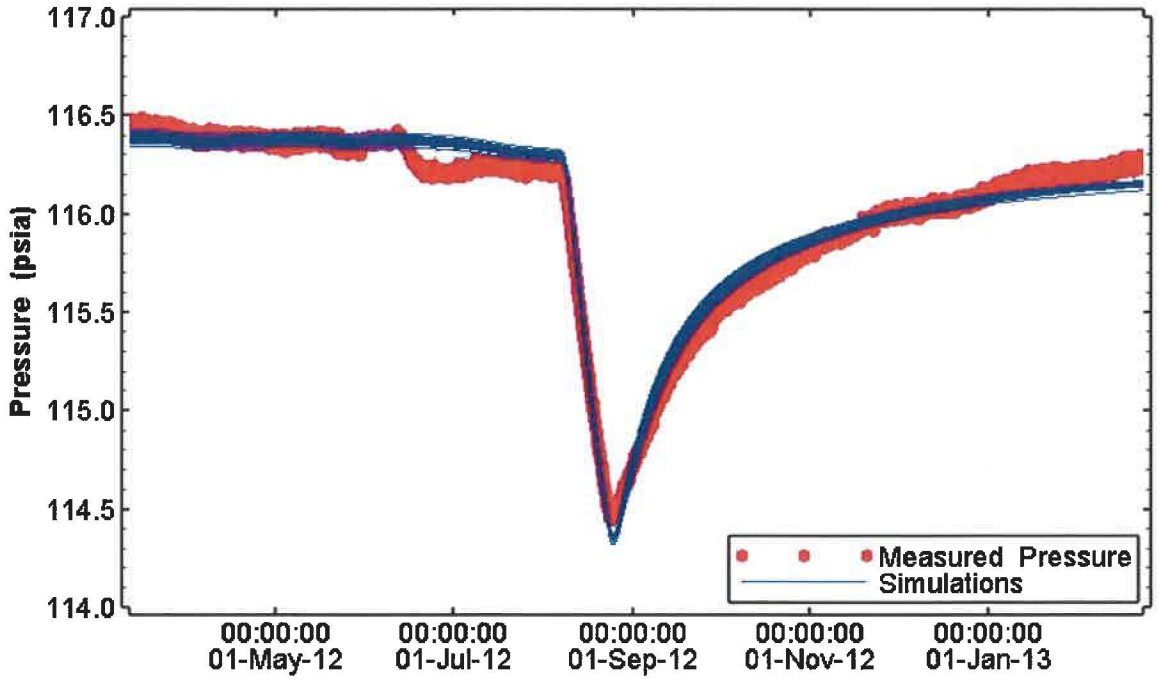


Figure 21. Pressure data and 41 model fits of the Culebra observation response in well SNL-12 due to pumping in H-9bR.

Information Only

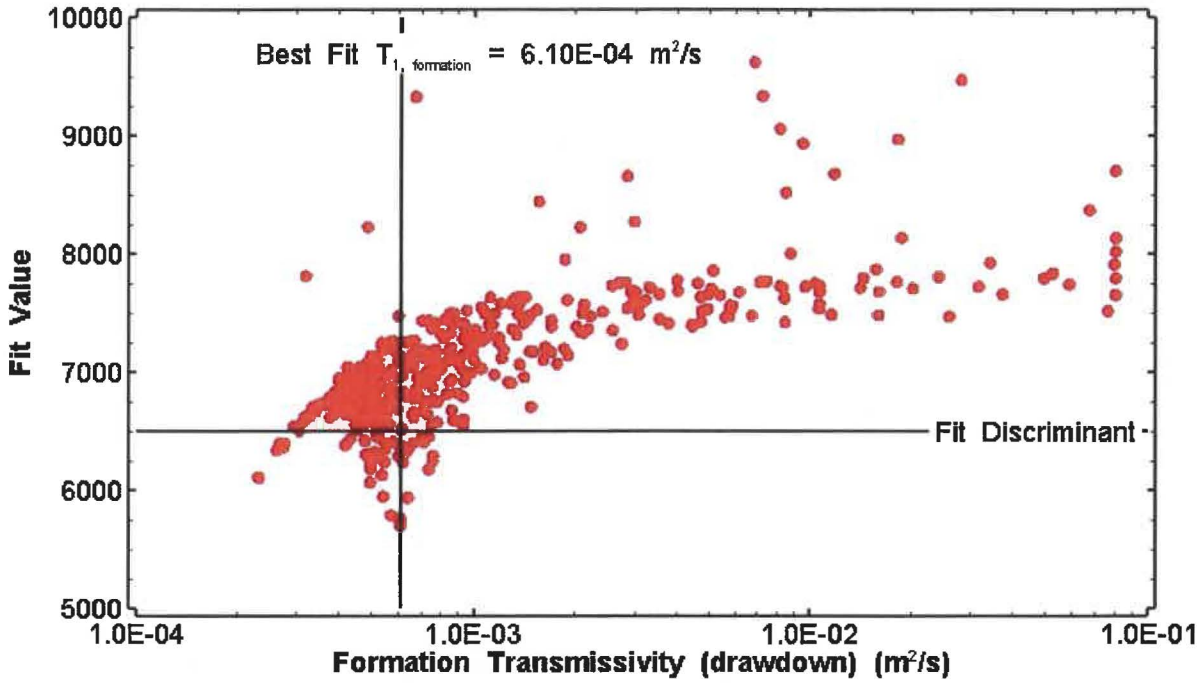


Figure 22. X-Y scatter plot showing the near-field transmissivity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

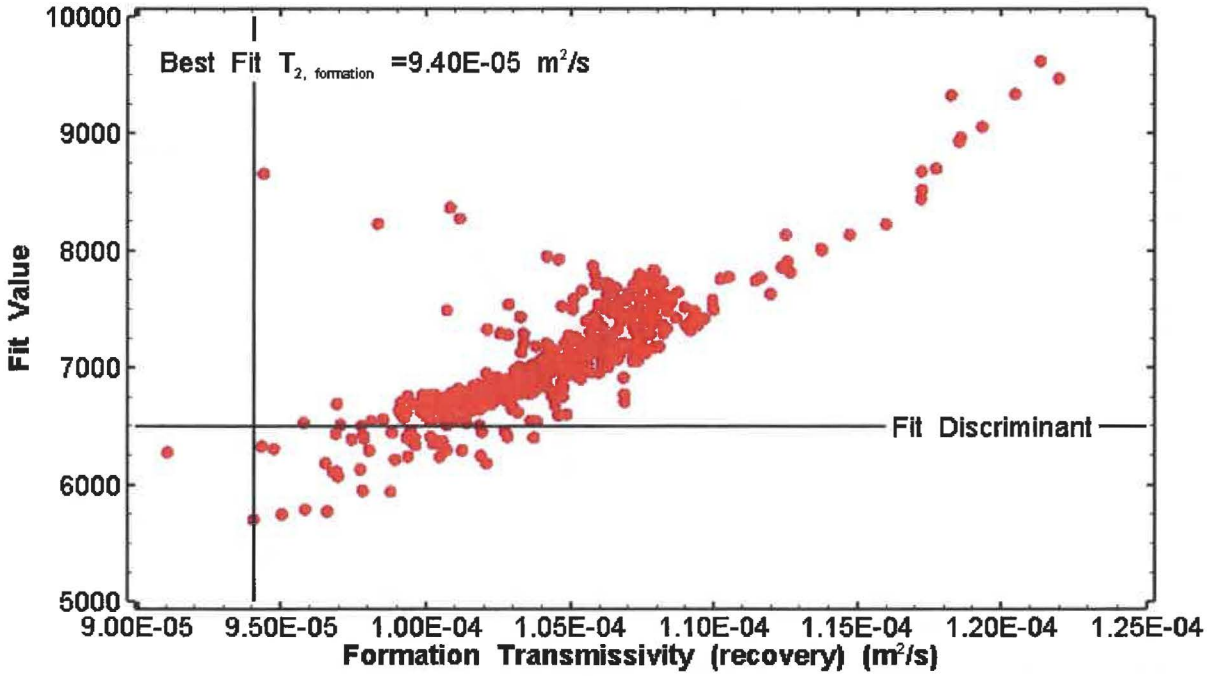


Figure 23. X-Y scatter plot showing the far-field transmissivity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

Information Only

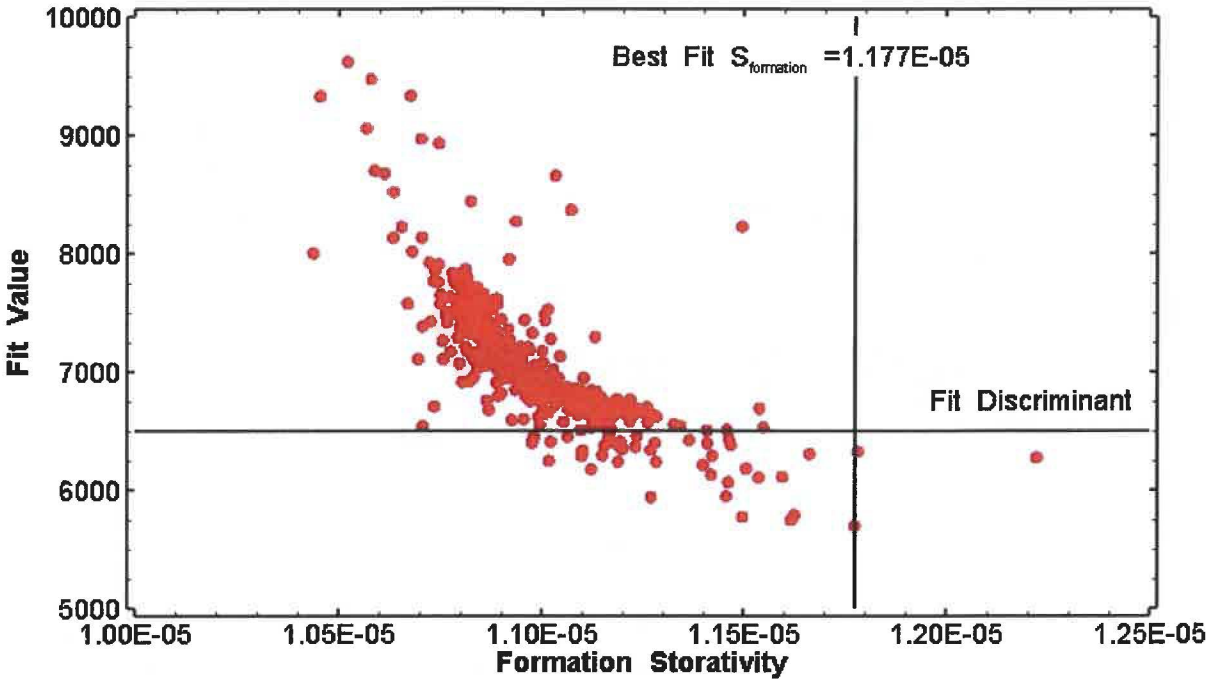


Figure 24. X-Y scatter plot showing the far-field storativity parameter space derived from the H-9bR perturbation analysis with fit discriminant and best fit values.

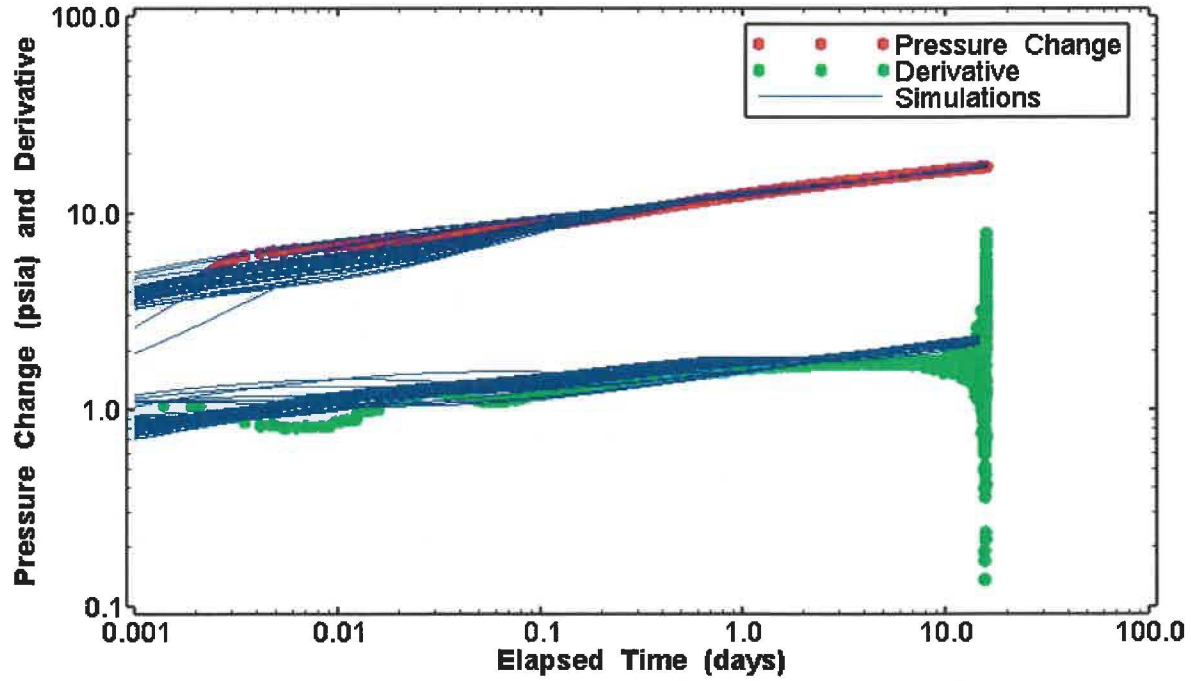


Figure 25. Log-log plot showing 41 simulations of the H-9bR drawdown period pressure change and derivative response.

Information Only

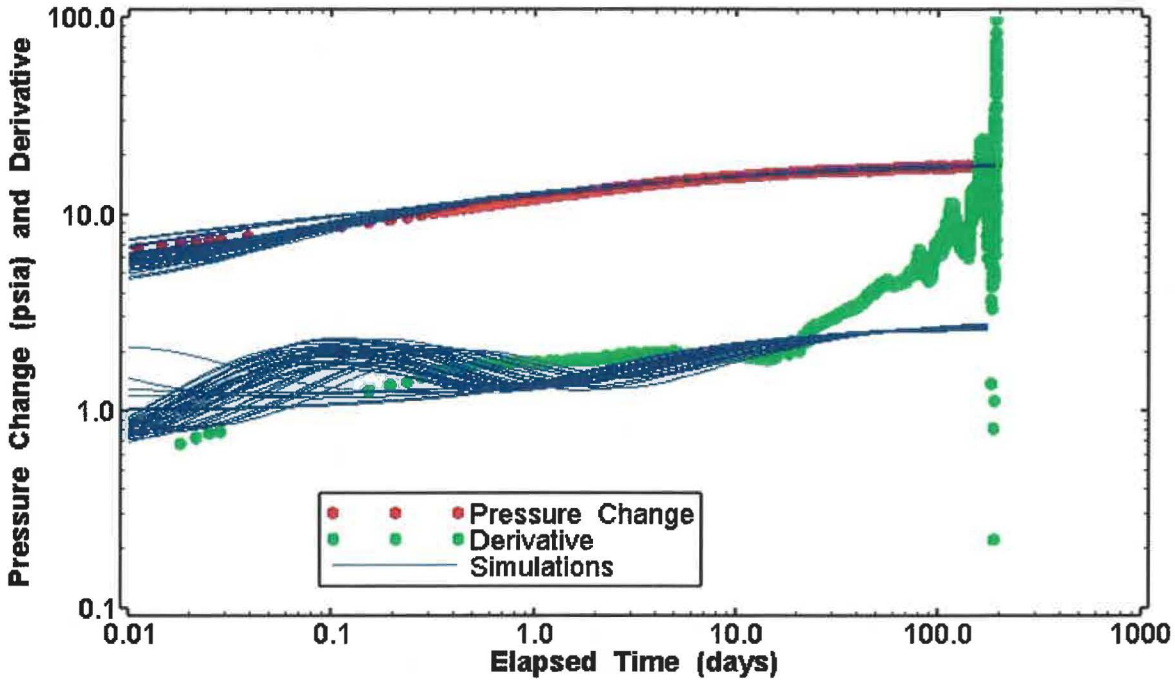


Figure 26. Log-log plot showing 41 simulations of the H-9bR recovery period pressure change and derivative response.

4. References

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Information Only

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Appendix A – H-9bR Hydraulic Test – 8/6/10 to 8/22/12

Well	Date and Time Start DAS	Date and Time Stop DAS	Date and Time Start Test	Date and Time Stop Test	Borehole Diameter (in)
H-9bR	8/16/12 09:56	8/22/12 14:18	8/16/12 13:00	8/22/12 14:02	4.3

Inside Tubing or Casing Diameter (in)	Culebra Interval (ft bgs)	Fluid Density (g/cm^3)	Field Notebook	Data Source Report(s)
1.5	640.5 - 667	1.005	WSWT-15	BDR (C-2783-POD2)

Information Only

Appendix B – nSIGHTS Listings

B.1 H-9bR nSIGHTS Listings

```
*************
nPre/32 2.41a
*************

Version date    1 April 2011
Listing date    03 Apr 2014
QA status       QA: Approved
Config file     E:\H-9bR\H-9bR_pumpX.nPre
```

Control Settings

Main Settings

Simulation type	Optimization	
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	26.500	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	116.000	[psi]
Maximum value	117.000	[psi]

Information Only

Estimate value	116.424	[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-10	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	6.55763E-08	[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	0.0012427	[m]
Range type	Linear	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	4.20853E-05	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	Optimization	
Minimum value	1.00000E-10	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	9.65690E-03	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1005.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	2.15	[in]
Tubing string radius	Optimization	
Minimum value	0.5	[in]
Maximum value	2.0	[in]
Estimate value	1.9999533	[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]

Information Only

f(x) Points Parameters

Formation conductivity

Points type	f(r)	
Radius #1	Optimized	
Minimum	1.0E-05	[m]
Estimat	48.0146518	[m]
Maximum	100.0	[m]
Y value#1	Optimized	
Radius #2	Optimized	
Minimum	100.0001	[m]
Estimat	1572.5465145	[m]
Maximum	10000	[m]
Y value#2	Optimized	
X opt range type	Linear	
X opt sigma	1.00000E+00	
Y opt minimum value	1.00000E-10	[m/sec]
Y opt maximum value	1.00000E-02	[m/sec]
Y opt range type	Log	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	f(r)	
Storativity	min/max	
Minimum	9.14400E-10	[]
Maximum	9.14400E-02	[]
Diffusivity	f(r)	

Skin Zone

Transmissivity	min/max	
Minimum	9.14400E-10	[m^2/sec]
Maximum	9.14400E-02	[m^2/sec]
Storativity	min/max	
Minimum	9.14400E-10	[]
Maximum	9.14400E-02	[]
Diffusivity	min/max	
Minimum	1.00000E-08	[m^2/sec]
Maximum	1.00000E+08	[m^2/sec]
Skin factor	f(r)	

Test Zone

Information Only

Open hole well-bore storage	min/max	
Minimum	5.14150E-08	[m^3/Pa]
Maximum	8.22640E-07	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.05783	[]
Maximum	0.08403	[]
First grid increment	min/max	
Minimum	5.98563E-01	[m]
Maximum	4.79574E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00004	[]
Maximum	0.10644	[]
Skin first grid increment	min/max	
Minimum	2.03899E-06	[m]
Maximum	6.13333E-03	[m]
Skin last grid increment	min/max	
Minimum	2.04265E-06	[m]
Maximum	1.01523E+00	[m]
Increment ratio	min/max	
Minimum	5.89586E-01	[]
Maximum	2.34781E+03	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	40912.583330	[day]
Duration	215.000000	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	41127.583330	[day]
Duration	16.039350	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-42.0	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	

Information Only

Start time	41143.622680	[day]
Duration	193.377320	[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_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]	
Output ID	P_OW_01	
Output type	Pressure	
Pressure capture type	Observation Well	
Observation well radius	8816	[m]
Output units	[psi]	

OutputFiles

XY Forward Output

Write file ?	yes
File name	C:\Work\H-9bR\Post\H-9bR_pump.nXYSim
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
File name	C:\Work\H-9bR\Post\H-9bR_Pump.nOpt

Information Only

Run ID	Run#1
If file exists	Overwrite
Write residuals ?	no
Write Jacobian ?	no
Write covariance matrices?	yes

Optimization Setup

Algorithm	Simplex
Simplex algorithm	NR
Calculate confidence limits ?	yes
Covariance matrix calculations	1st Order
Fixed derivative span ?	no
Fit tolerance	1.0000E-05
Parameter tolerance	not used
# of optimized variables	10
K_fm.R[01]	OK
K_fm.R[02]	OK
K_fm.V[01]	OK
K_fm.V[02]	OK
Skin zone conductivity	OK
Static formation pressure	OK
Tubing string radius	OK
Formation spec. storage	OK
Skin zone spec. storage	OK
Radial thickness of skin	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

# of calculated variables included	0

Suite/Range Setup

# of suite/range variables	0

****
nPre/32 2.41a
****

Version date	1 April 2011
Listing date	03 Apr 2014
QA status	QA: Approved
Config file	E:\H-9bR\H-9bR_H-4bRX.nPre

Control Settings

Information Only

Main Settings

Simulation type	Optimization	
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	26.500	[ft]
Flow dimension	2.0	[]
Static formation pressure	116.300	[psi]
External boundary radius	1000000	[m]
Formation conductivity	f(r) point	
Formation spec. storage	Optimization	
Minimum value	1.00000E-10	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	7.49416E-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	6.9785864	[m]
Range type	Linear	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]

Information Only

Maximum value	1.00000E-02	[m/sec]
Estimate value	4.16300E-05	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	Optimization	
Minimum value	1.00000E-10	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	3.86078E-03	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1005.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	2.15	[in]
Tubing string radius	Optimization	
Minimum value	0.5	[in]
Maximum value	2.15	[in]
Estimate value	1.6307962	[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]

---

f(x) Points Parameters

Formation conductivity

Points type	f(r)	
Radius #1	Optimized	
Minimum	1.0E-05	[m]
Estimat	0.3938464	[m]
Maximum	50.0	[m]
Y value#1	Optimized	
Radius #2	Optimized	
Minimum	50.0001	[m]
Estimat	832.2509375	[m]
Maximum	10000	[m]
Y value#2	Optimized	
X opt range type	**Linear**	
X opt sigma	1.00000E+00	
Y opt minimum value	1.00000E-10	[m/sec]

Information Only

Y opt maximum value	1.00000E-02	[m/sec]
Y opt range type	Log	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	f(r)	
Storativity	min/max	
Minimum	9.14400E-10	[]
Maximum	9.14400E-02	[]
Diffusivity	f(r)	

Skin Zone

Transmissivity	min/max	
Minimum	9.14400E-10	[m^2/sec]
Maximum	9.14400E-02	[m^2/sec]
Storativity	min/max	
Minimum	9.14400E-10	[]
Maximum	9.14400E-02	[]
Diffusivity	min/max	
Minimum	1.00000E-08	[m^2/sec]
Maximum	1.00000E+08	[m^2/sec]
Skin factor	f(r)	

Test Zone

Open hole well-bore storage	min/max	
Minimum	5.14150E-08	[m^3/Pa]
Maximum	9.50664E-07	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.05783	[]
Maximum	0.08403	[]
First grid increment	min/max	
Minimum	5.98563E-01	[m]
Maximum	4.79574E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00004	[]
Maximum	0.10644	[]
Skin first grid increment	min/max	
Minimum	2.03899E-06	[m]
Maximum	6.13333E-03	[m]
Skin last grid increment	min/max	
Minimum	2.04265E-06	[m]
Maximum	1.01523E+00	[m]
Increment ratio	min/max	

Information Only

Minimum	5.89586E-01	[]
Maximum	2.34781E+03	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	40912.583330	[day]
Duration	215.000000	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	41127.583330	[day]
Duration	16.039350	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-42.0	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	41143.622680	[day]
Duration	193.377320	[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_01
Curve time base	Test
Curve Y data units	[psi]
Curve Y data is log 10	no

Simulation Results Setup

Information Only

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]	
Output ID	P_OW_01	
Output type	Pressure	
Pressure capture type	Observation Well	
Observation well radius	10379	[m]
Output units	[psi]	

OutputFiles

XY Forward Output

Write file ?	yes
File name	C:\Work\H-9bR\Post\H-9bR_H-4bR.nXYSim
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
File name	C:\Work\H-9bR\Post\H-9bR_H-4bR.nOpt
Run ID	Run#1
If file exists	Overwrite
Write residuals ?	no
Write Jacobian ?	no
Write covariance matrices?	yes

Optimization Setup

Algorithm	Simplex
Simplex algorithm	NR
Calculate confidence limits ?	yes
Covariance matrix calculations	1st Order
Fixed derivative span ?	no
Fit tolerance	1.0000E-05
Parameter tolerance	not used
# of optimized variables	9
K_fm.R[01]	OK
K_fm.R[02]	OK
K_fm.V[01]	OK
K_fm.V[02]	OK
Skin zone conductivity	OK
Tubing string radius	OK

Information Only

Formation spec. storage	OK
Skin zone spec. storage	OK
Radial thickness of skin	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

# of calculated variables included	0

Suite/Range Setup

# of suite/range variables	0

```
*************
nPre/32 2.41a
*************

Version date   1 April 2011
Listing date   03 Apr 2014
QA status      QA: Approved
Config file    E:\H-9bR\H-9bR_SNL-12X.nPre
```

Control Settings

Main Settings

Simulation type	Optimization
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

Information Only

Default test-zone temperature	20.00	[C]
Solution variable	Pressure	
Allow negative head/pressure	yes	

Parameters

Formation

Formation thickness	26.500	[ft]
Flow dimension	2.0	[]
Static formation pressure	Optimization	
Minimum value	116.000	[psi]
Maximum value	117.000	[psi]
Estimate value	116.366	[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-10	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	1.33902E-06	[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	2.0726926	[m]
Range type	Linear	
Sigma	1.00000E+00	
Skin zone conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	3.31243E-05	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Skin zone spec. storage	Optimization	
Minimum value	1.00000E-10	[1/m]
Maximum value	1.00000E-02	[1/m]
Estimate value	9.99985E-03	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1005.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Information Only

Well radius	2.15	[in]
Tubing string radius	Optimization	
Minimum value	0.5	[in]
Maximum value	2.0	[in]
Estimate value	1.9980912	[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]

---

f(x) Points Parameters

Formation conductivity

Points type	f(r)	
Radius #1	Optimized	
Minimum	1.0E-05	[m]
Estimat	0.327551	[m]
Maximum	50.0	[m]
Y value#1	Optimized	
Radius #2	Optimized	
Minimum	50.0001	[m]
Estimat	1069.7741102	[m]
Maximum	10000	[m]
Y value#2	Optimized	
X opt range type	Linear	
X opt sigma	1.00000E+00	
Y opt minimum value	1.00000E-10	[m/sec]
Y opt maximum value	1.00000E-02	[m/sec]
Y opt range type	Log	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	f(r)	
Storativity	min/max	
Minimum	9.14400E-10	[]
Maximum	9.14400E-02	[]
Diffusivity	f(r)	

Information Only

Skin Zone

Transmissivity	min/max	
Minimum	9.14400E-10	[m^2/sec]
Maximum	9.14400E-02	[m^2/sec]
Storativity	min/max	
Minimum	9.14400E-10	[]
Maximum	9.14400E-02	[]
Diffusivity	min/max	
Minimum	1.00000E-08	[m^2/sec]
Maximum	1.00000E+08	[m^2/sec]
Skin factor	f(r)	

Test Zone

Open hole well-bore storage	min/max	
Minimum	5.14150E-08	[m^3/Pa]
Maximum	8.22640E-07	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.05783	[]
Maximum	0.08403	[]
First grid increment	min/max	
Minimum	5.98563E-01	[m]
Maximum	4.79574E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00004	[]
Maximum	0.10644	[]
Skin first grid increment	min/max	
Minimum	2.03899E-06	[m]
Maximum	6.13333E-03	[m]
Skin last grid increment	min/max	
Minimum	2.04265E-06	[m]
Maximum	1.01523E+00	[m]
Increment ratio	min/max	
Minimum	5.89586E-01	[]
Maximum	2.34781E+03	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	40912.583330	[day]
Duration	215.000000	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Information Only

Sequence: F_01

Sequence type	Flow	
Start time	41127.583330	[day]
Duration	16.039350	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-42.0	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	41143.622680	[day]
Duration	193.377320	[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_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]	
Output ID	P_OW_01	
Output type	Pressure	
Pressure capture type	Observation Well	
Observation well radius	4583	[m]
Output units	[psi]	

Information Only

OutputFiles

XY Forward Output

Write file ?	yes
File name	C:\Work\H-9bR\Post\H-9bR_SNL-12.nXYSim
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
File name	C:\Work\H-9bR\Post\H-9bR_SNL-12.nOpt
Run ID	Run#1
If file exists	Overwrite
Write residuals ?	no
Write Jacobian ?	no
Write covariance matrices?	yes

Optimization Setup

Algorithm	Simplex
Simplex algorithm	NR
Calculate confidence limits ?	yes
Covariance matrix calculations	1st Order
Fixed derivative span ?	no
Fit tolerance	1.0000E-05
Parameter tolerance	not used
# of optimized variables	10
K_fm.R[01]	OK
K_fm.R[02]	OK
K_fm.V[01]	OK
K_fm.V[02]	OK
Skin zone conductivity	OK
Static formation pressure	OK
Tubing string radius	OK
Formation spec. storage	OK
Skin zone spec. storage	OK
Radial thickness of skin	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

# of calculated variables included	0

Information Only

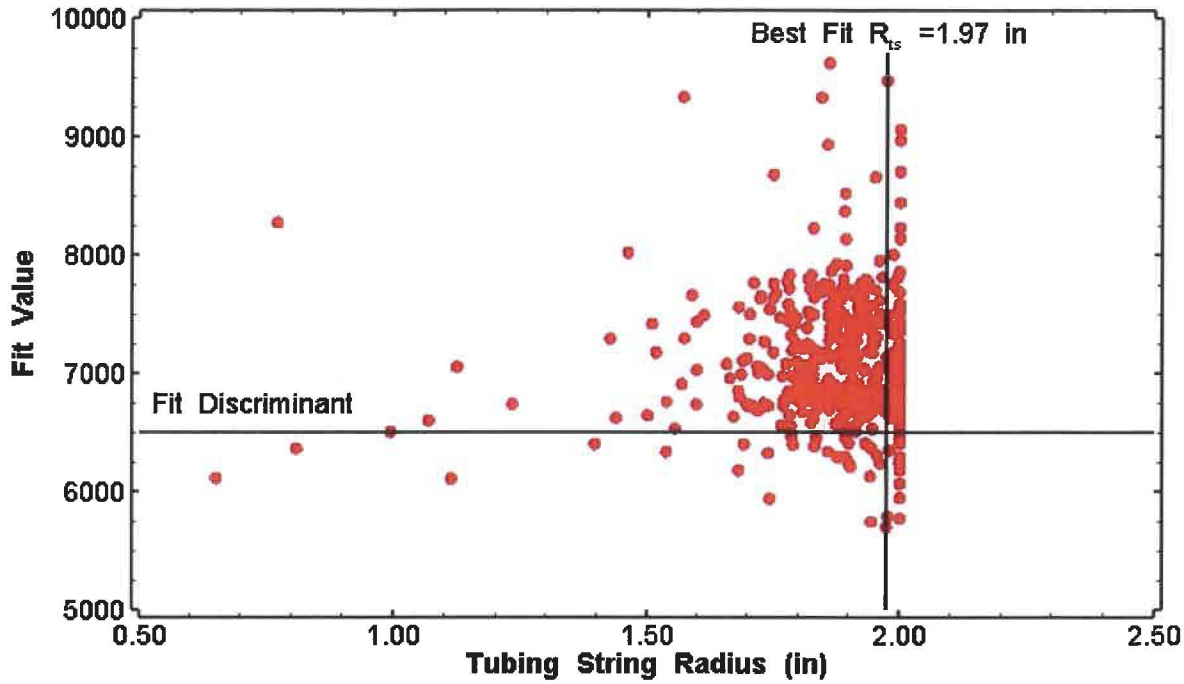


Figure B-1. X-Y scatter plot showing the tubing string radius parameter space derived from the H-9bR perturbation analysis with the fit discriminant and best fit values using no observation data.

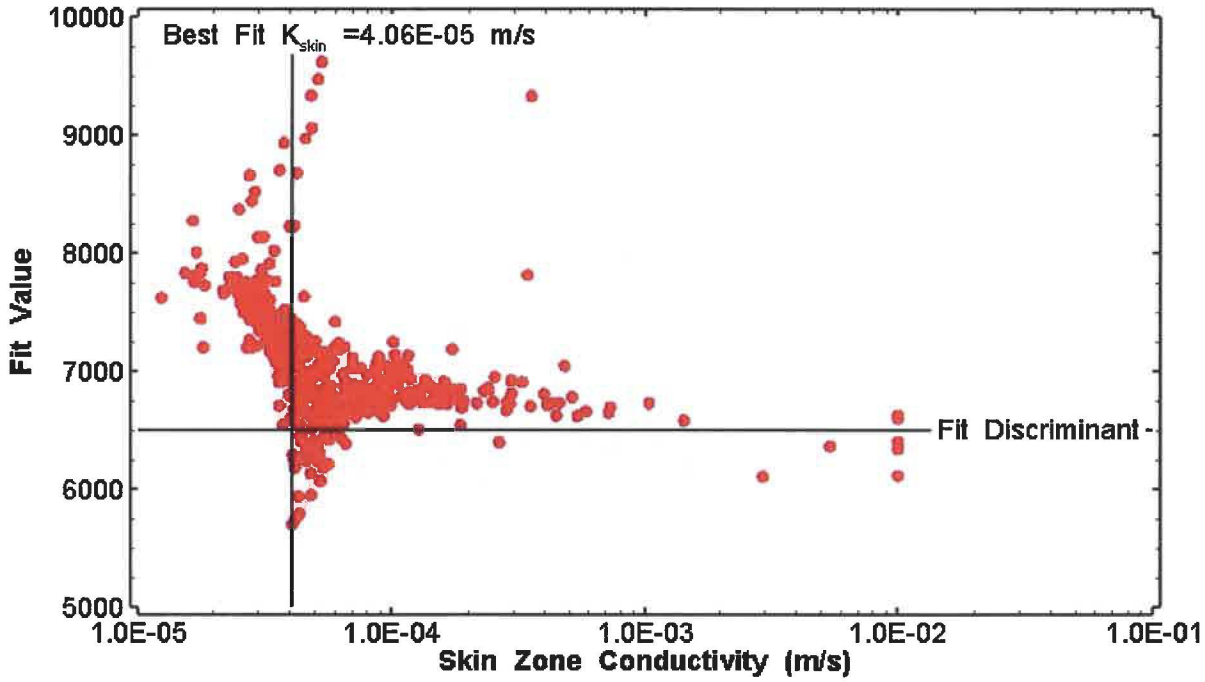


Figure B-2. X-Y scatter plot showing the skin conductivity parameter space derived from H-9bR perturbation analysis with the fit discriminant and best fit values using no observation data.

Information Only

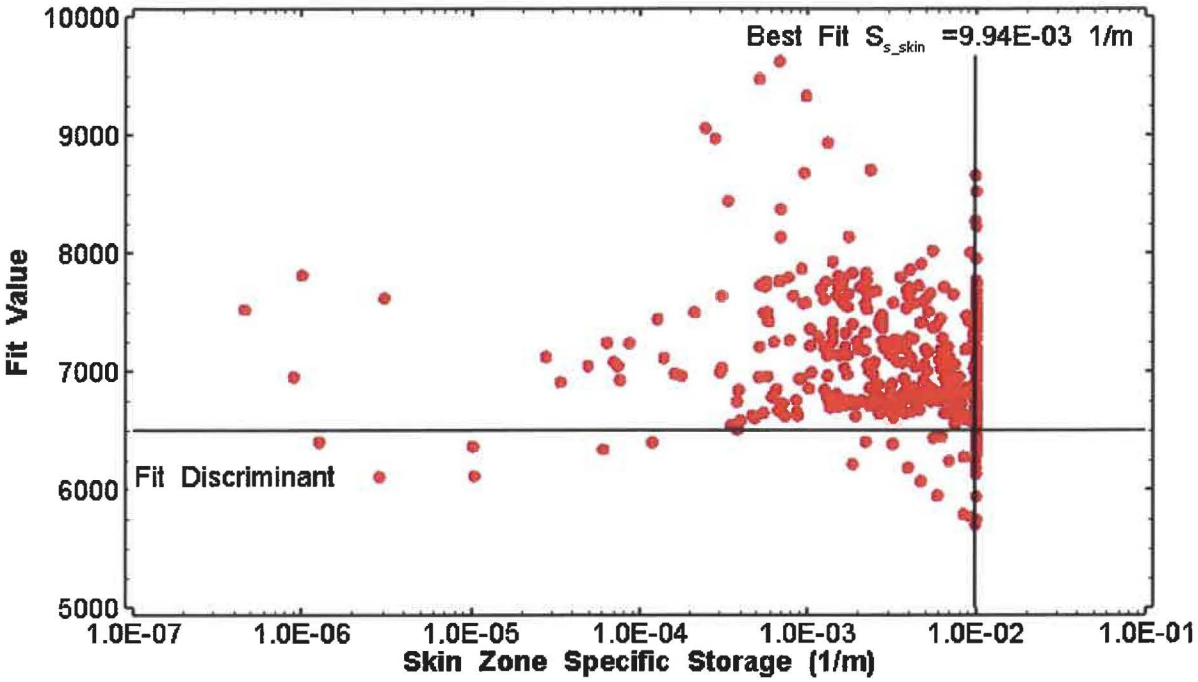


Figure B-3. X-Y scatter plot showing the skin zone specific storage parameter space derived from H-9bR perturbation analysis with the fit discriminant and best fit values using no observation data.

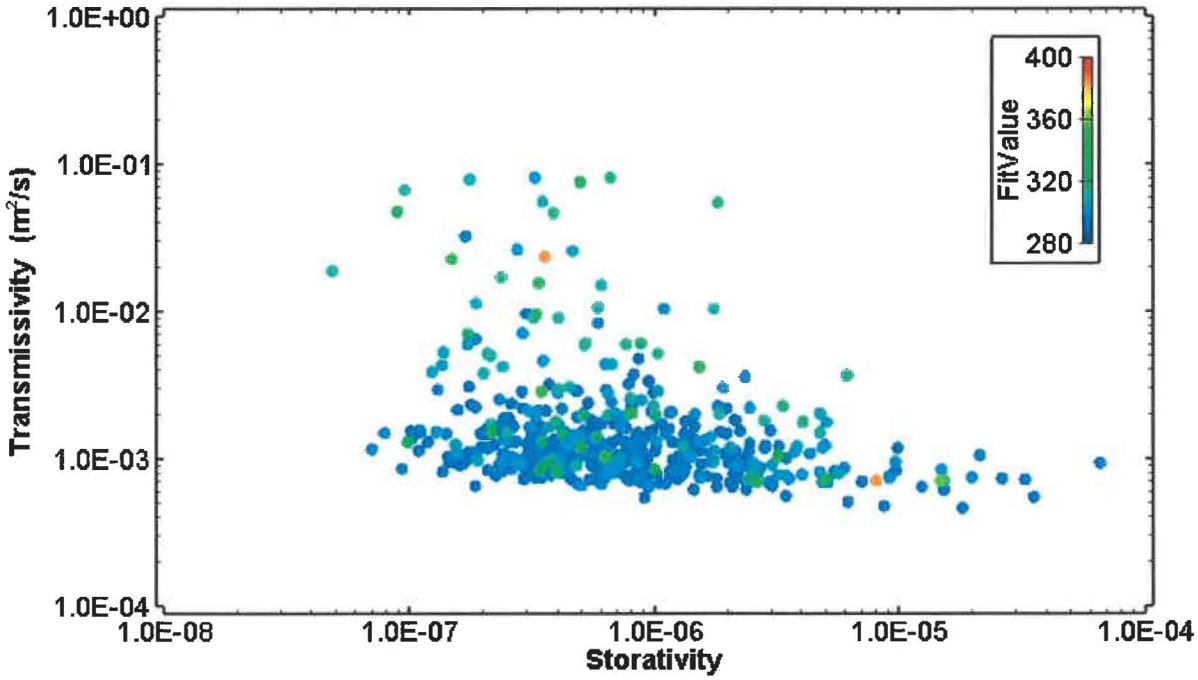


Figure B-4. Estimates of transmissivity (near-field) and storativity derived from the H-9bR perturbation analysis using no observation data.

Information Only

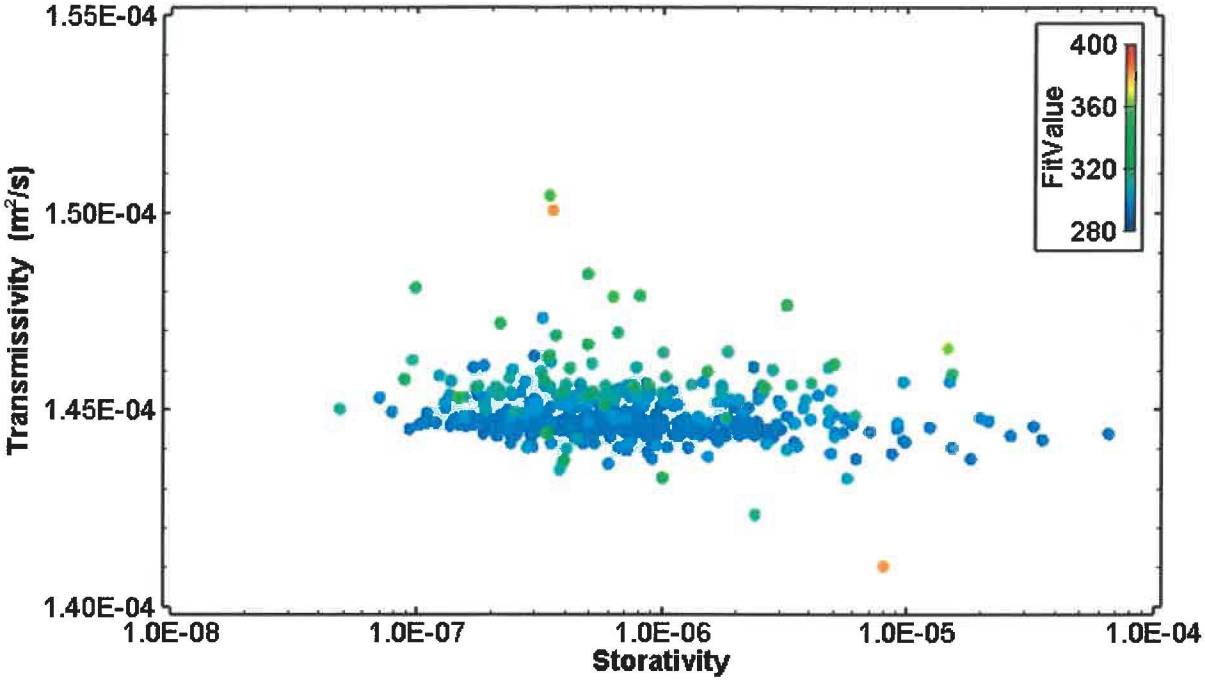


Figure B-5. Estimates of transmissivity (far-field) and storativity derived from the H-9bR perturbation analysis using no observation data.

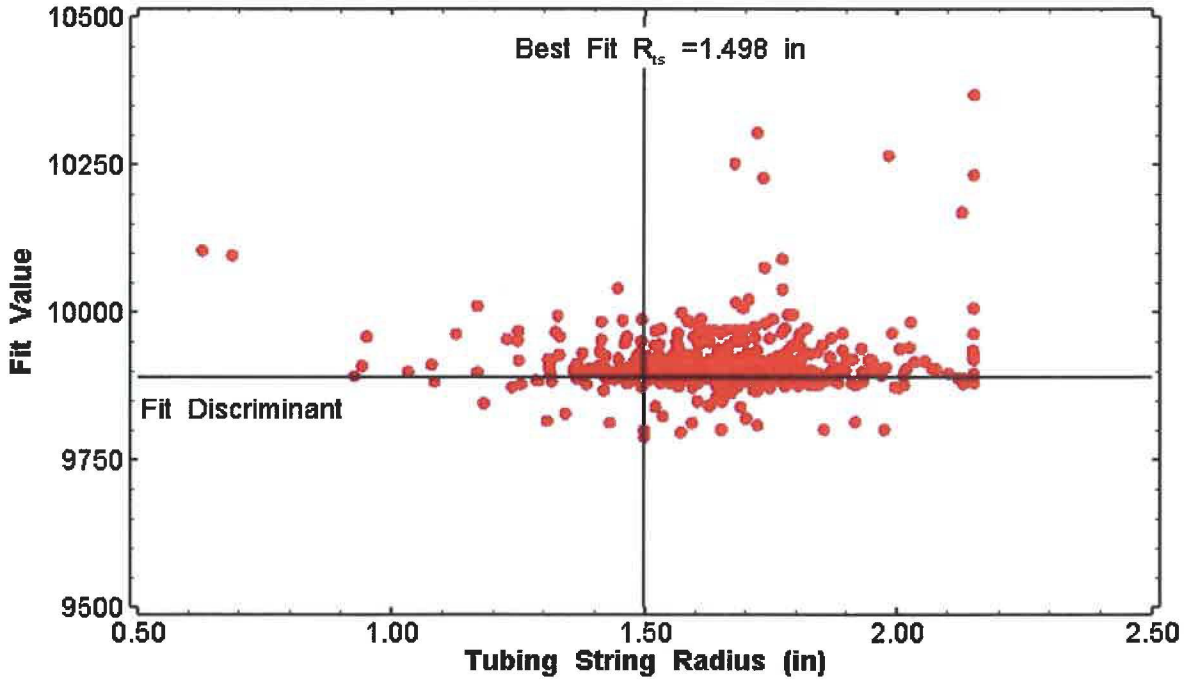


Figure B-6. X-Y scatter plot showing the tubing string radius parameter space derived from the H-9bR perturbation analysis with the fit discriminant and best fit values using H-4bR observation data.

Information Only

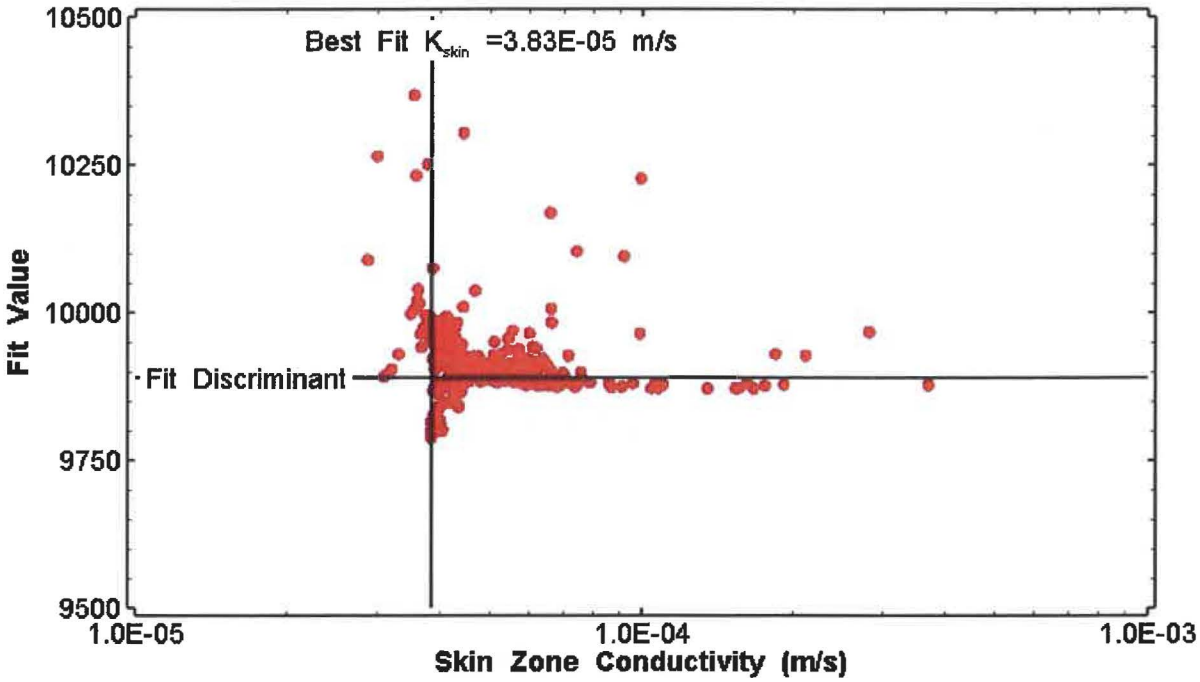


Figure B-7. X-Y scatter plot showing the skin conductivity parameter space derived from H-9bR perturbation analysis with the fit discriminant and best fit values using H-4bR observation data.

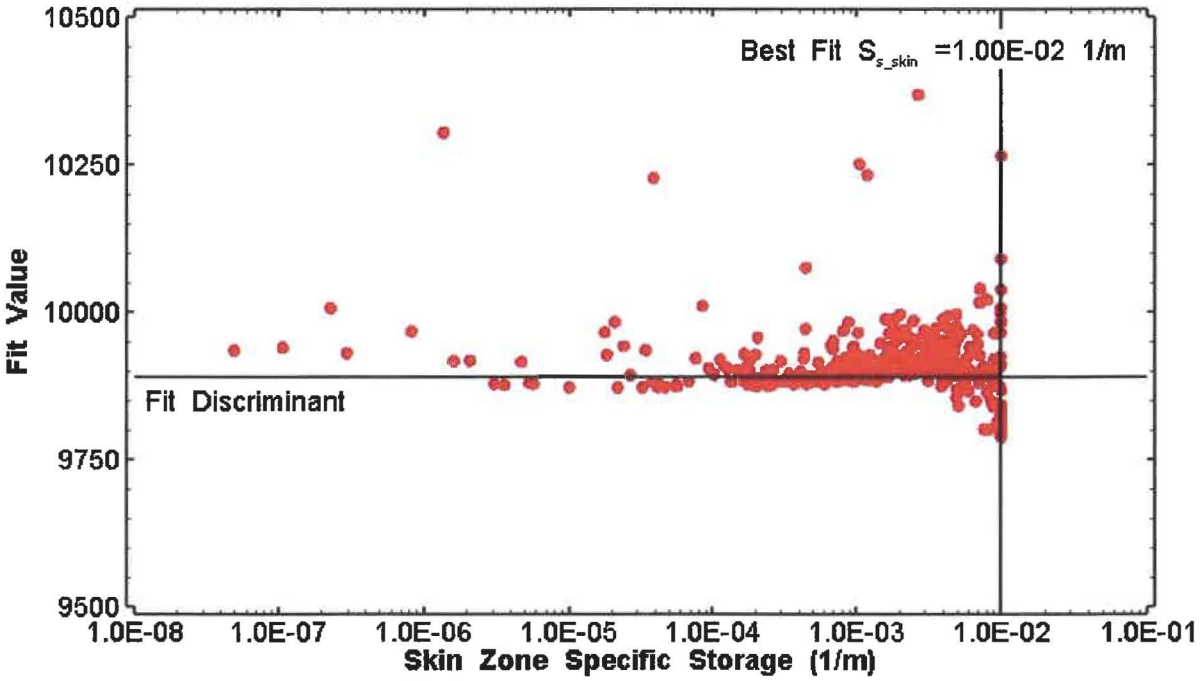


Figure B-8. X-Y scatter plot showing the skin zone specific storage parameter space derived from H-9bR perturbation analysis with the fit discriminant and best fit values using H-4bR observation data.

Information Only

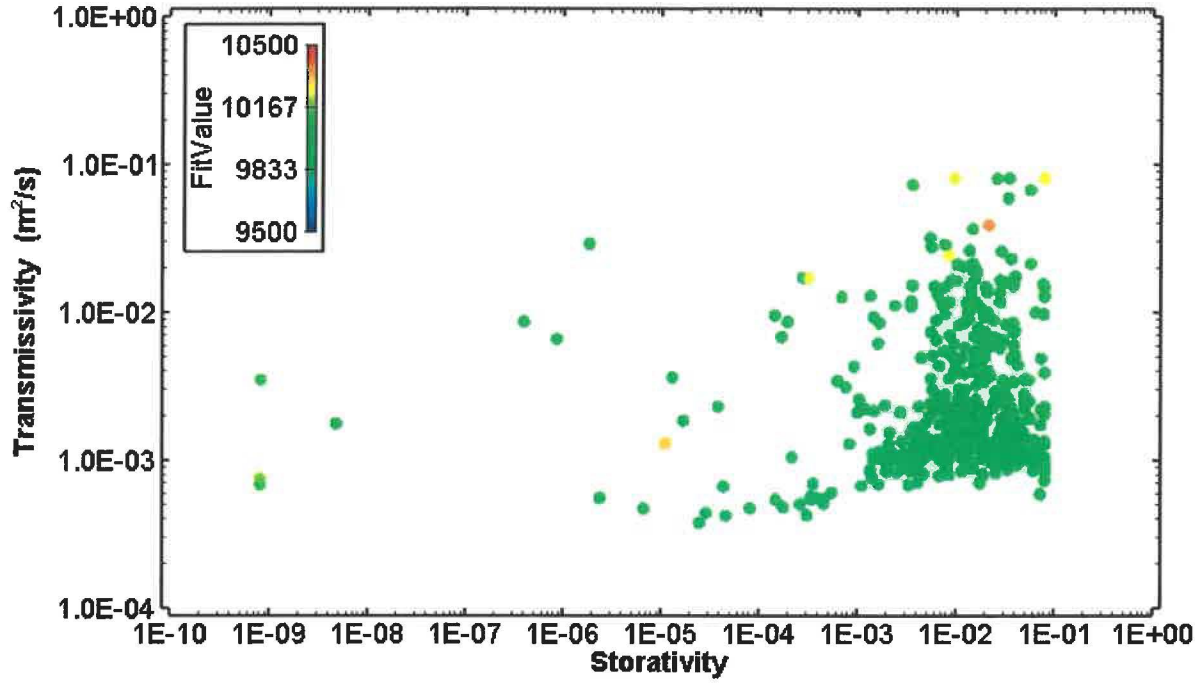


Figure B-9. Estimates of transmissivity (near-field) and storativity derived from the H-9bR perturbation analysis using H-4bR observation data.

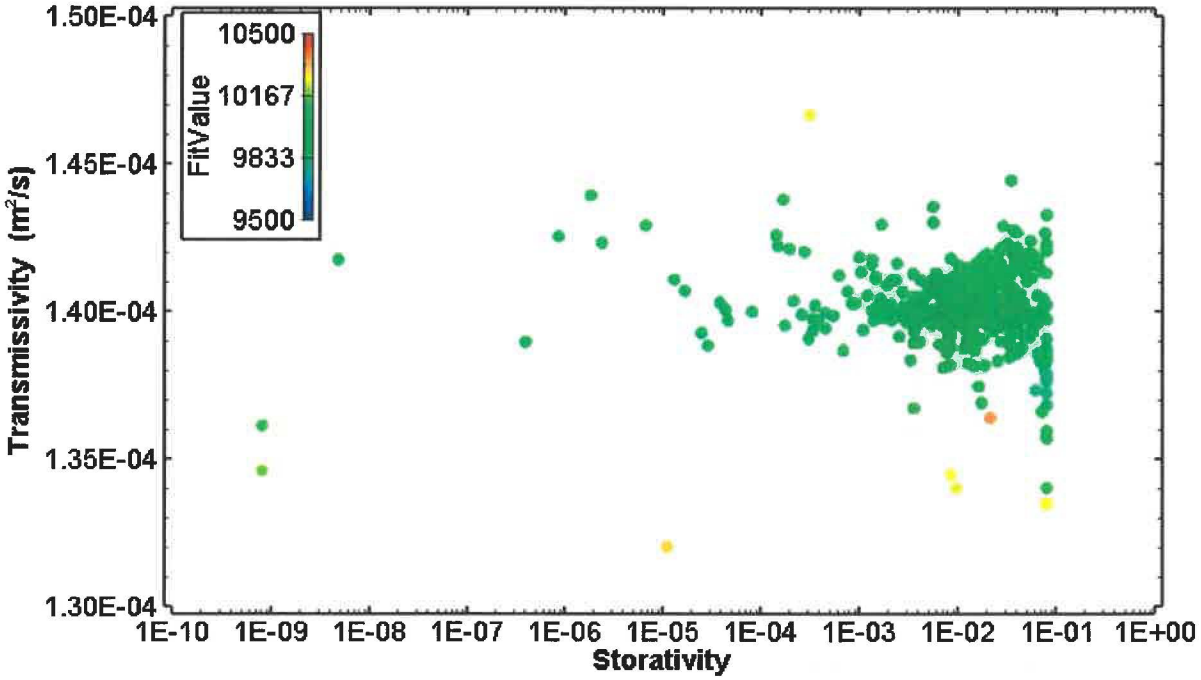


Figure B-10. Estimates of transmissivity (far-field) and storativity derived from the H-9bR perturbation analysis using H-4bR observation data.

Information Only

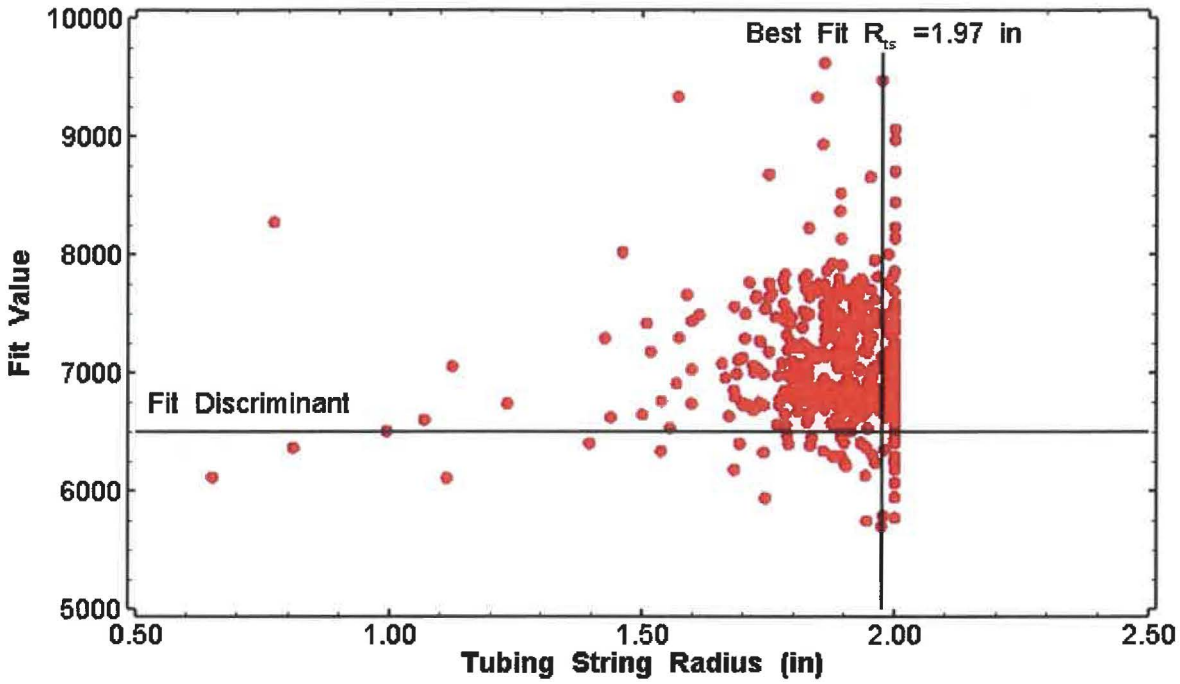


Figure B-11. X-Y scatter plot showing the tubing string radius parameter space derived from the H-9bR perturbation analysis with the fit discriminant and best fit values using SNL-12 observation data.

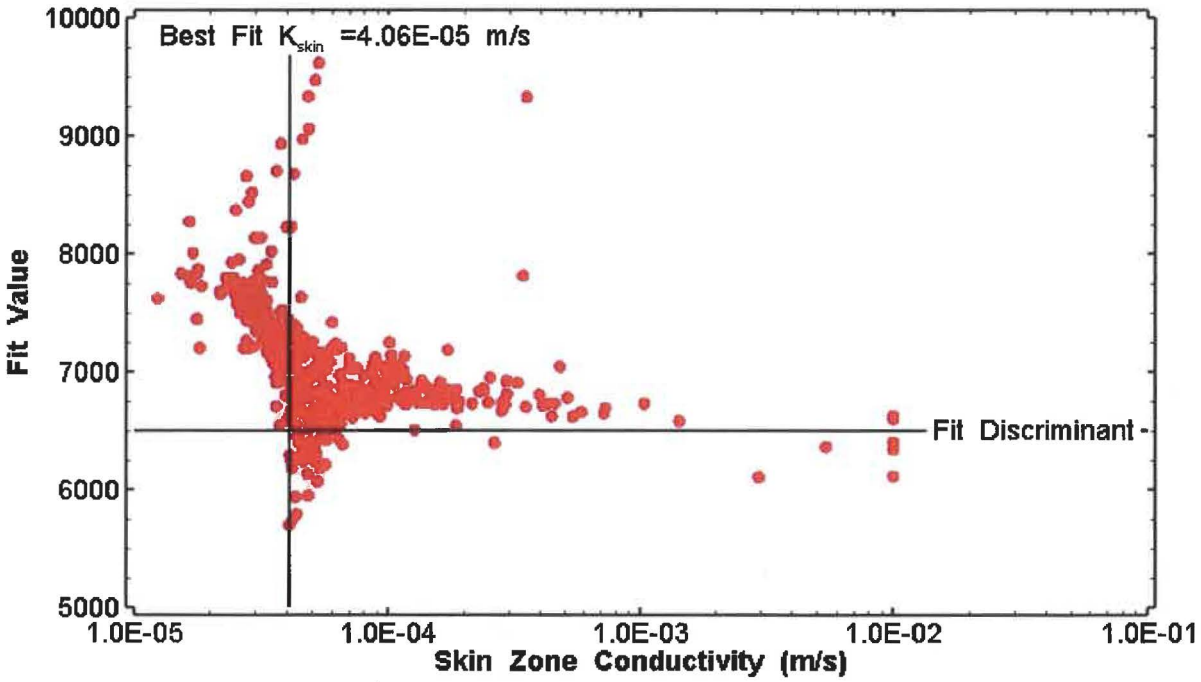


Figure B-12. X-Y scatter plot showing the skin conductivity parameter space derived from H-9bR perturbation analysis with the fit discriminant and best fit values using SNL-12 observation data.

Information Only

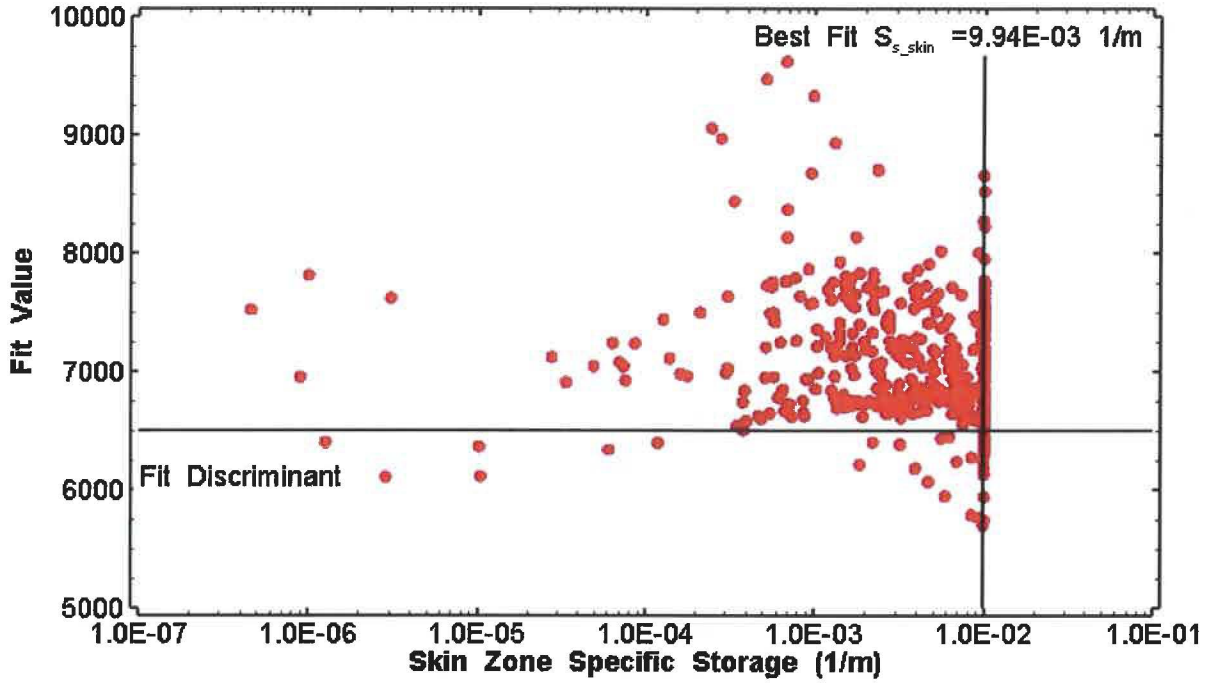


Figure B-13. X-Y scatter plot showing the skin zone specific storage parameter space derived from H-9bR perturbation analysis with the fit discriminant and best fit values using SNL-12 observation data.

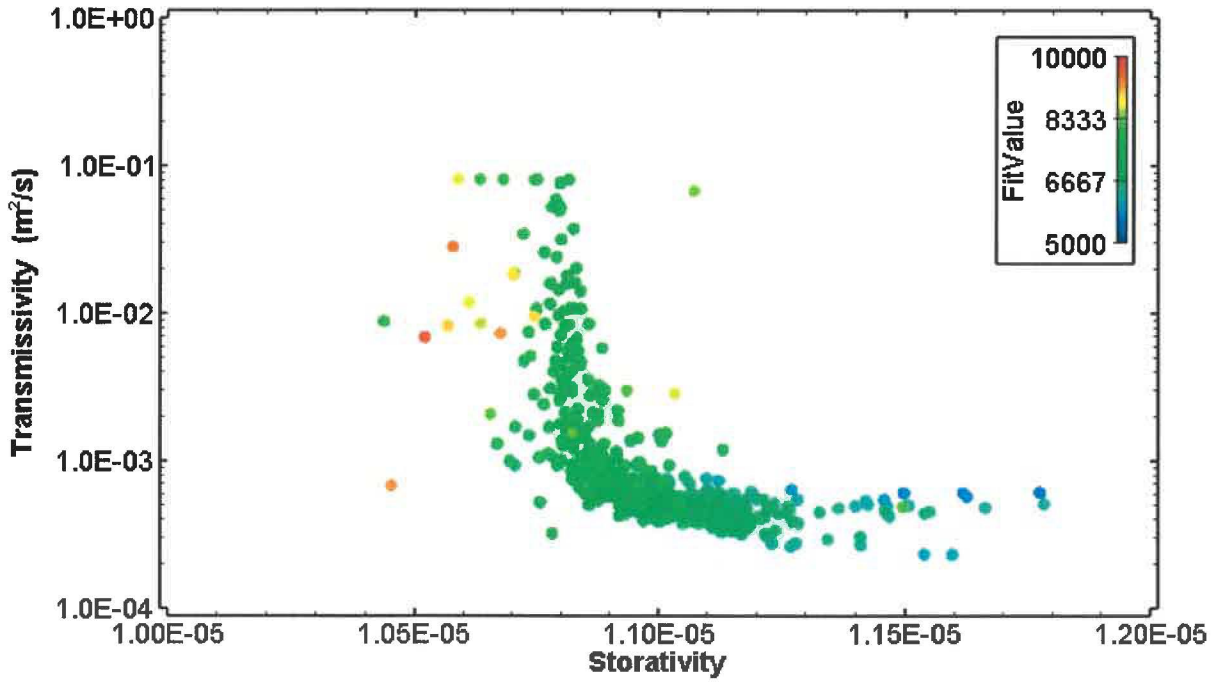


Figure B-14. Estimates of transmissivity (near-field) and storativity derived from the H-9bR perturbation analysis using SNL-12 observation data.

Information Only

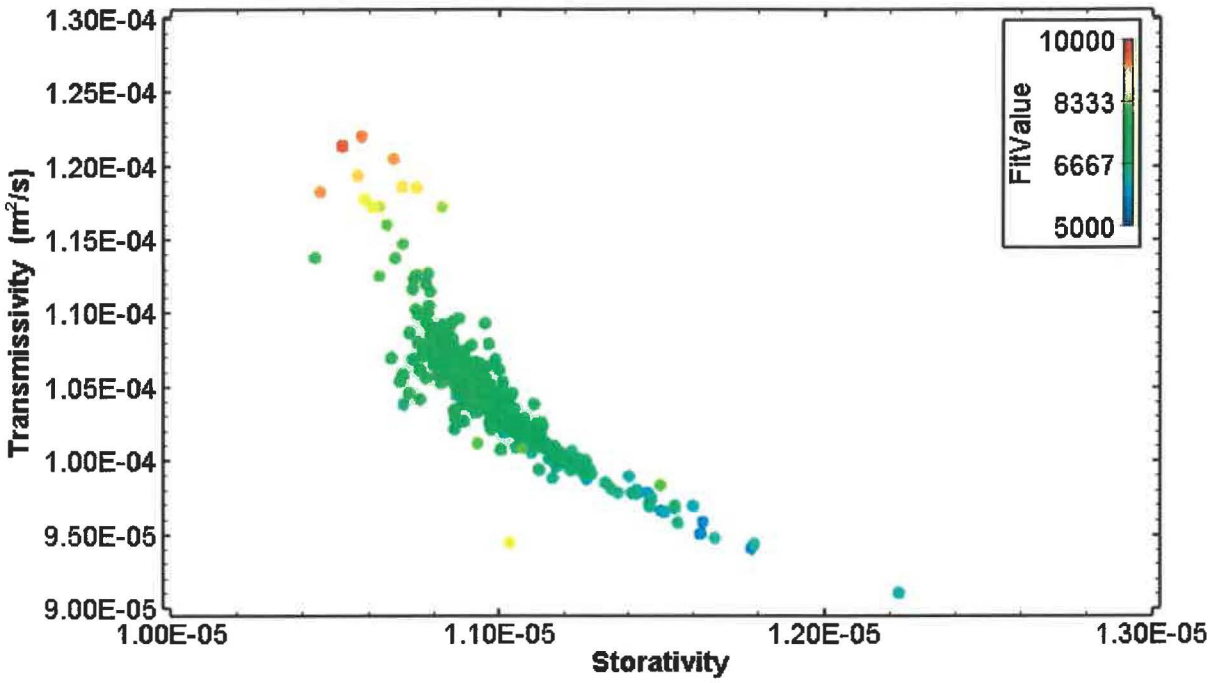


Figure B-15. Estimates of transmissivity (far-field) and storativity derived from the H-9bR perturbation analysis using SNL-12 observation data.

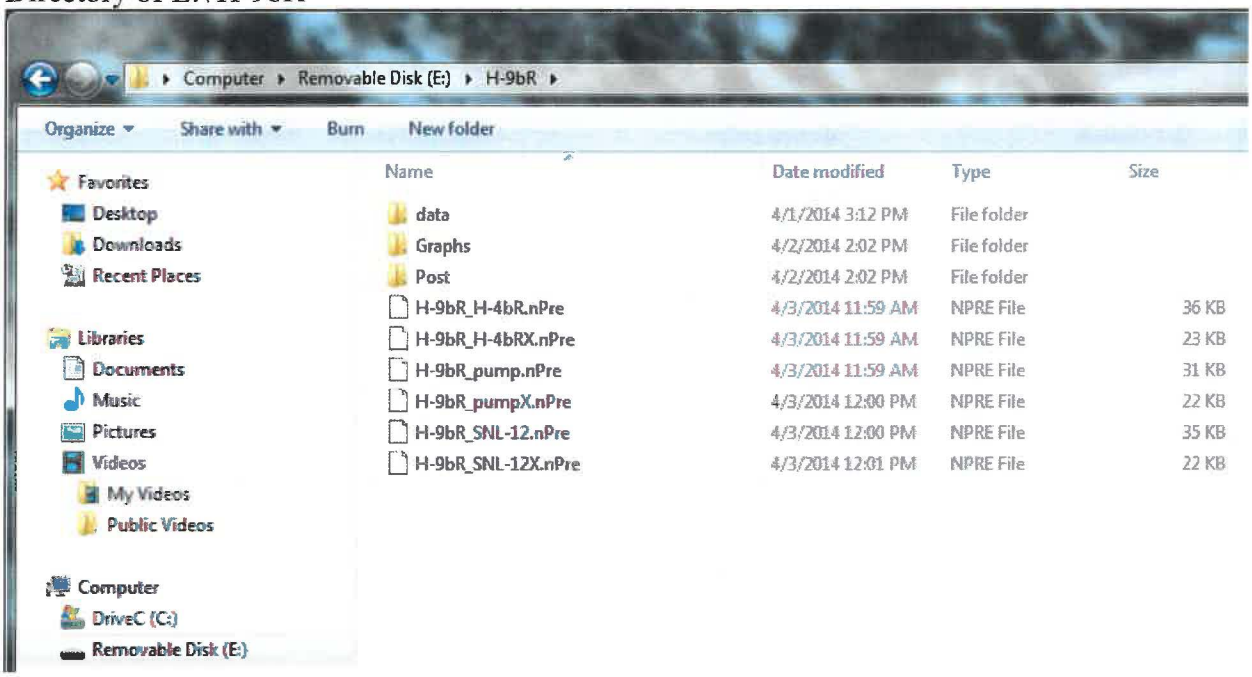
Appendix C – File Directories

Table C-1. File descriptions.

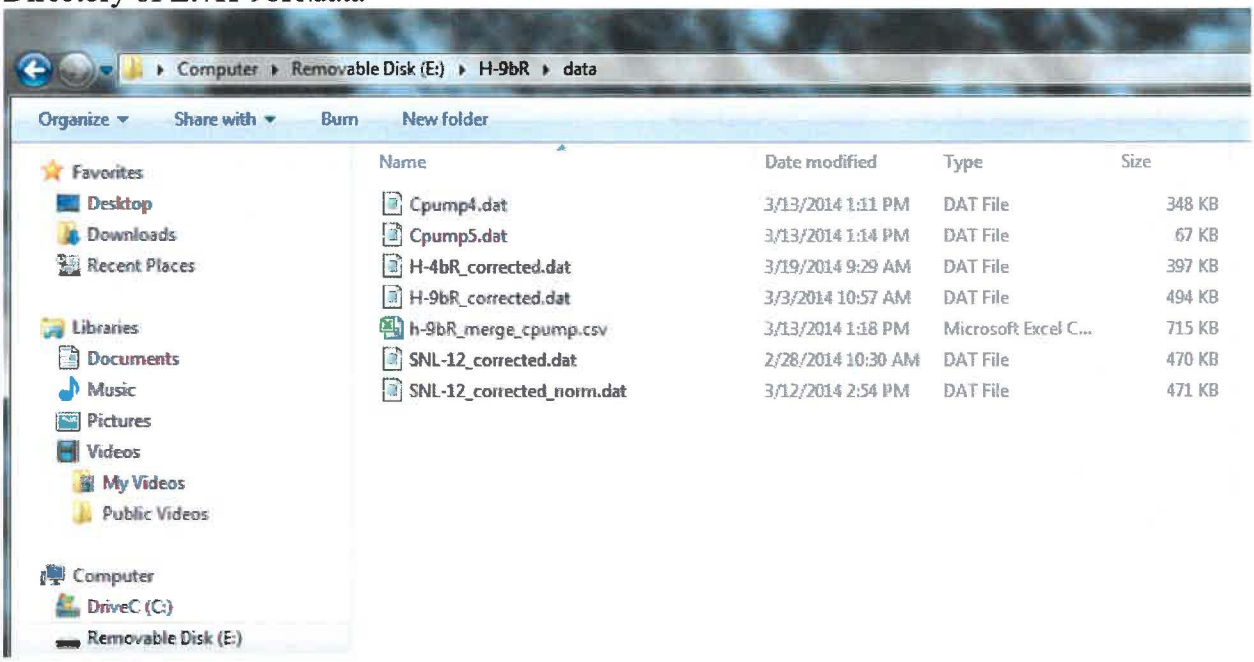
File Extension	Function/Use
<filename>.nPre	Files used for initial well test analysis.
<filename>X.nPre	Files used to generate perturbation analysis of .nPre results.
.nPost	Post-processing files used to visualize .nPre and perturbation analysis.
.nOpt	Optimization data used for post processing in .nPost files.
<filename>.nXYSim	Simulation data used for post processing in .nPost files.
<filename>FieldData.nXYSim	Field data used for post processing in .nPost files.
.jpg	Graphic output from .nPost files.
.csv,.xls, .dat	Data files used as input for .nPre files.

Information Only

Directory of E:\ H-9bR

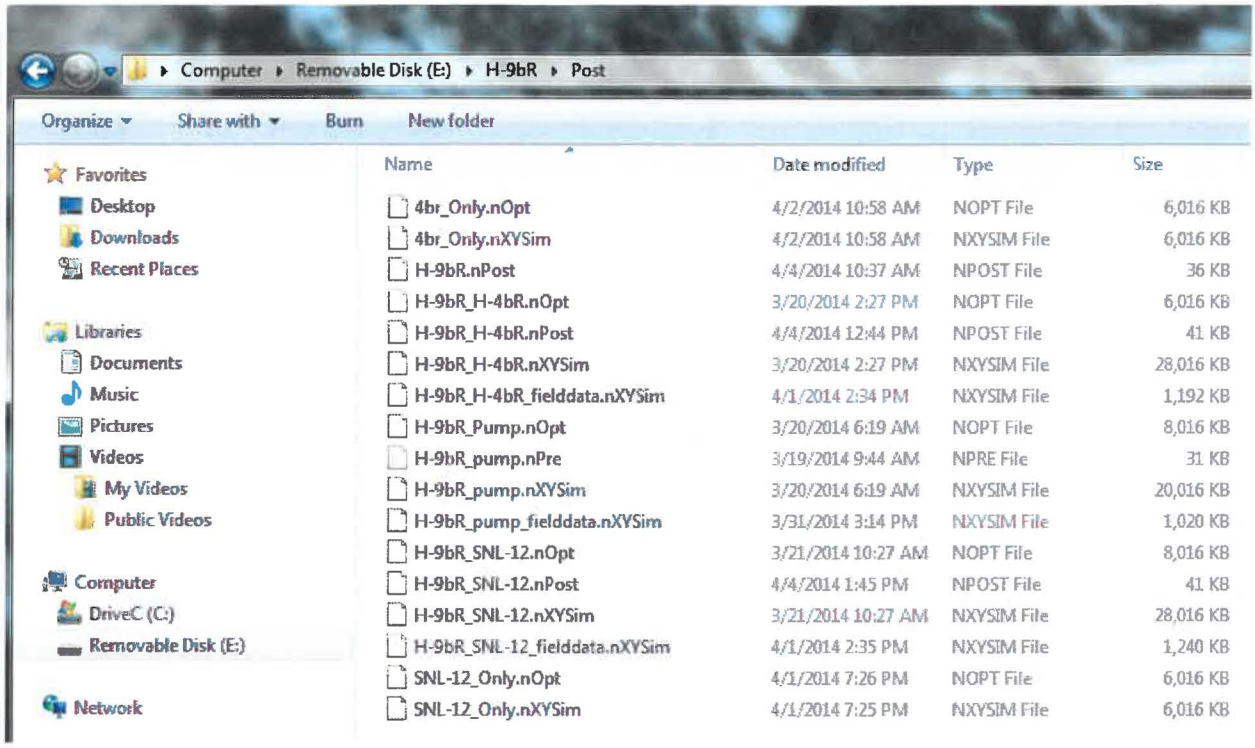


Directory of E:\ H-9bR\data

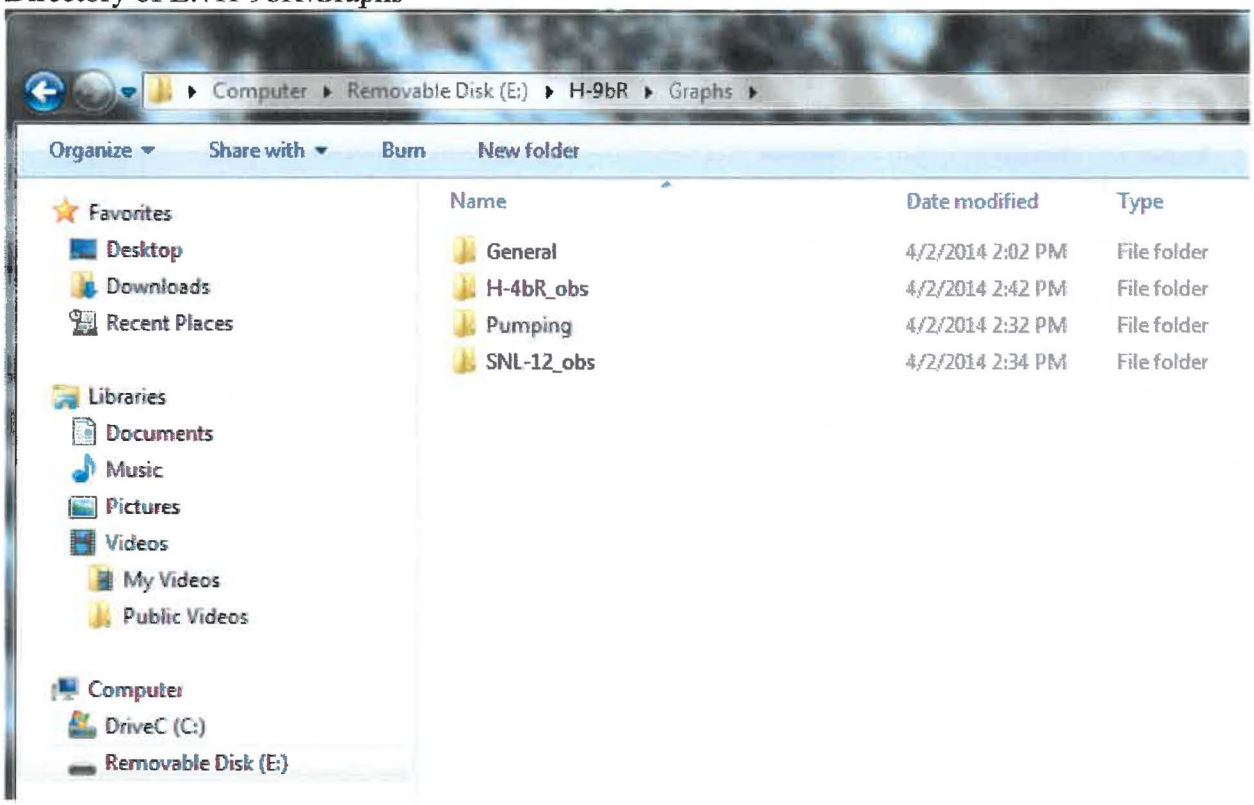


Directory of Directory of E:\ H-9bR\Post

Information Only

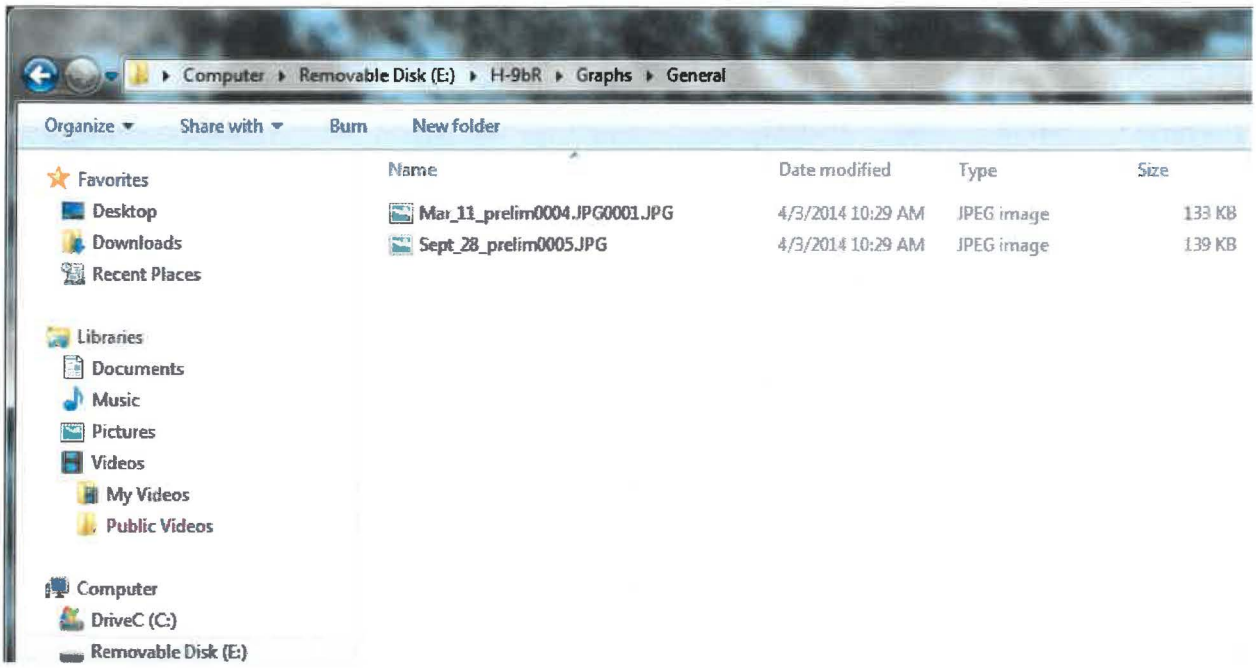


Directory of E:\ H-9bR\Graphs

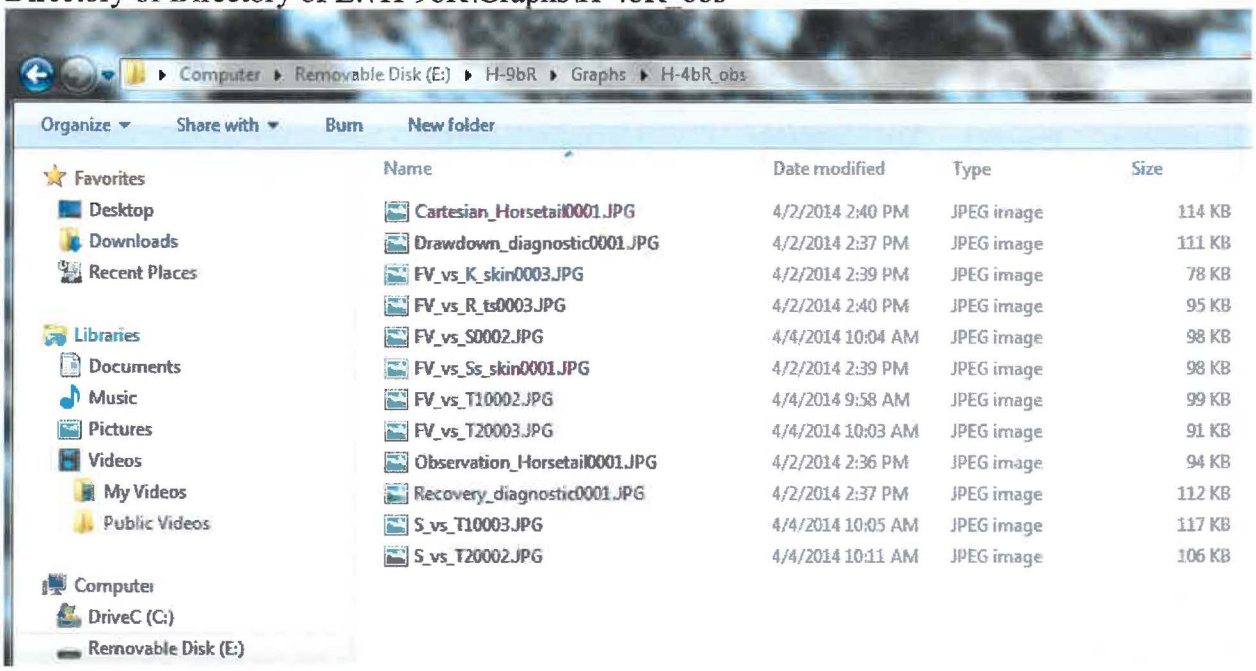


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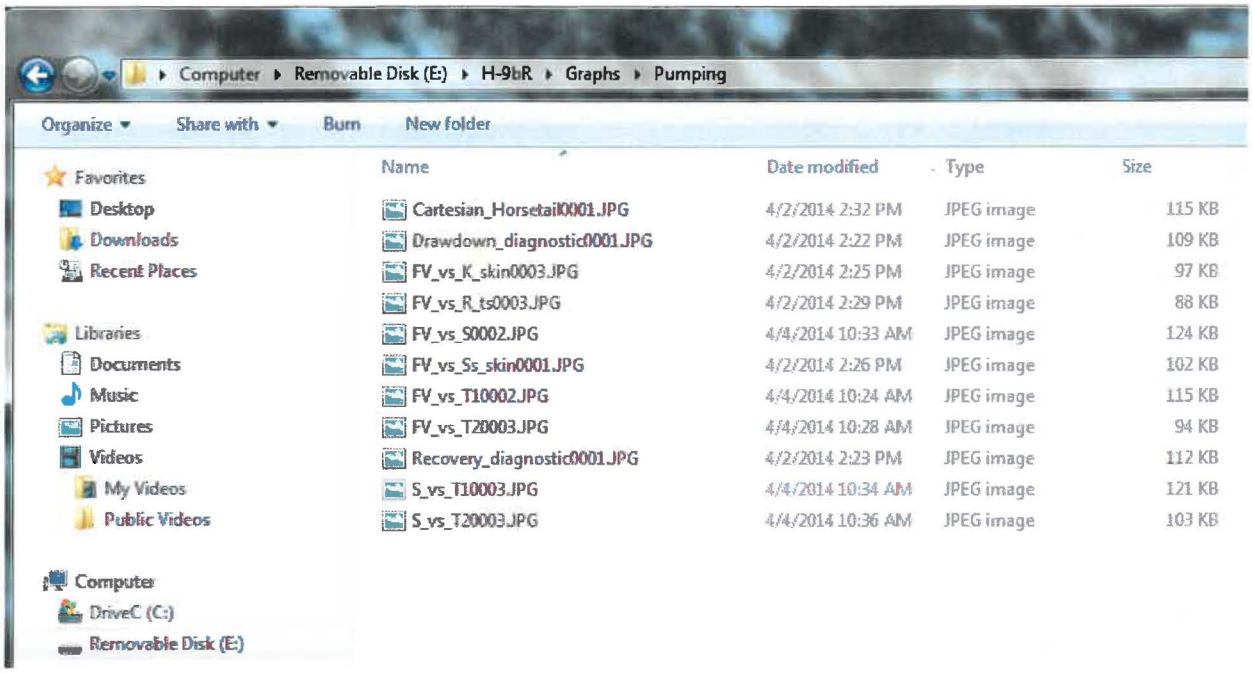


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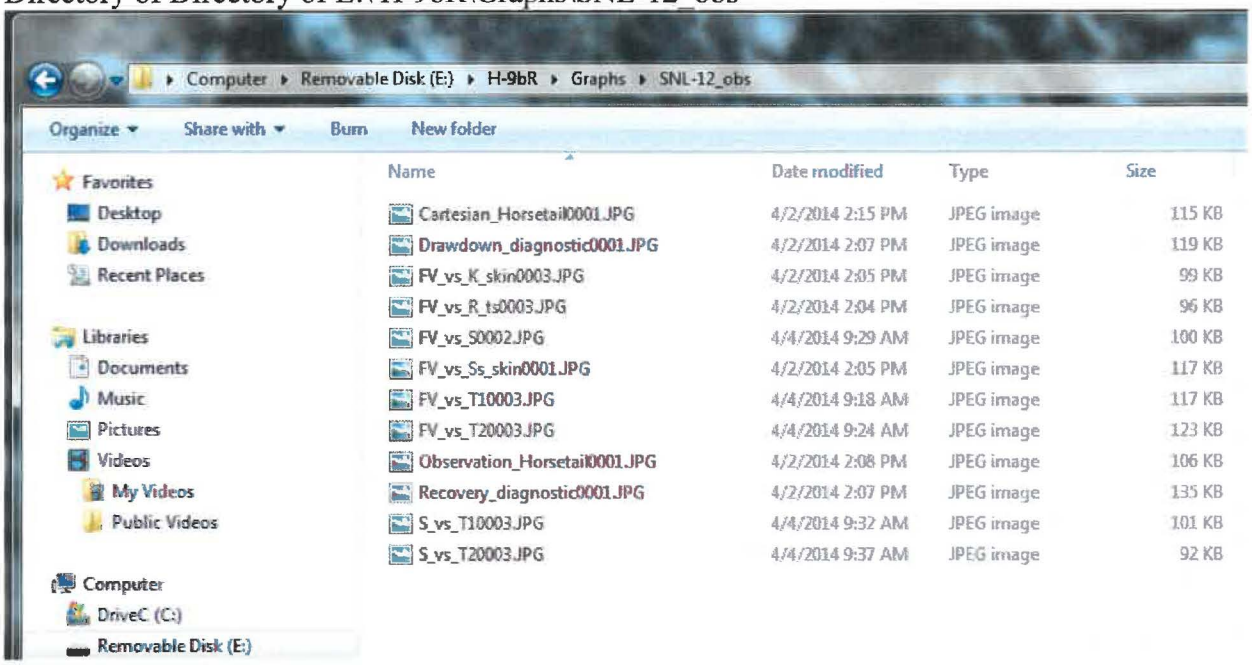


Directory of Directory of E:\ H-9bR\Graphs\Pumping

Information Only



Directory of Directory of E:\ H-9bR\Graphs\SNL-12_obs



Acknowledgements

The author of this report would like to acknowledge Jeff Palmer and Patricia Johnson of Intera, Inc. for contributing the well configuration plot and well location map to this report.

Information Only