573484

Analysis Report for AP-070

Analysis of the H-15R Pumping Test Conducted From 1/19/09 to 1/22/09

AP-070: Analysis Plan for Hydraulic-Test Interpretations

Task Number 4.4.2.3.1

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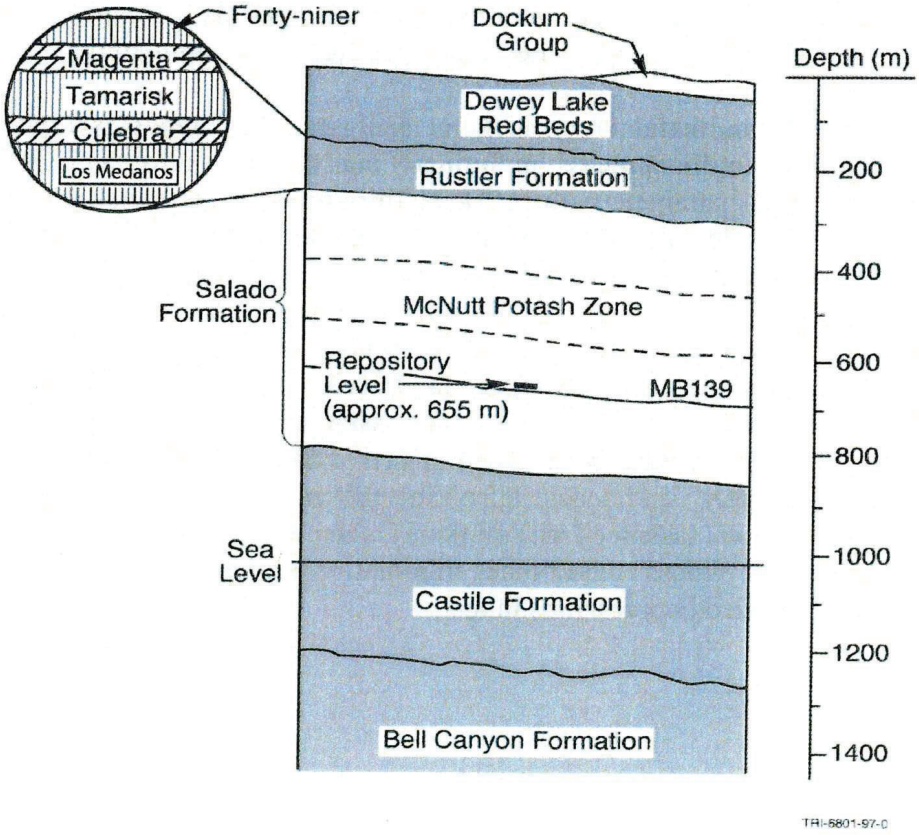
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1. Introduction

This Analysis Report discusses the analyses results of a hydraulic test performed in the Culebra Member of the Rustler Formation (Figure 1) at the Waste Isolation Pilot Plant (WIPP) site at the H-15 well pad (Figure 2). This analysis was 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 2.50, a 64-bit SNL-developed upgrade from version 2.41a (Kuhlman 2011). The author of this Analysis Report is a qualified hydraulic-test analyst per AP-070, Rev 2. A detailed description of the approach followed in this analysis can be found in Beauheim et al. (1993, Appendix B) and Roberts et al. (1999, Chapter 6). With respect to the objectives outlined in AP-070, transmissivity and storativity were the focused hydraulic properties. Even though an accurate storativity measurement requires an observation well, an accurate transmissivity value is tied to a storativity estimate through diffusivity. Flow dimension was considered in initial models, but the pressure response did not indicate non-radial flow. Subsequently, its value was held as radial (n=2). Formation pre pressure is described as static formation pressure for our model. The history data prior to our testing of the well allows us to hold this value as constant. Double porosity effects were also not observed, so fracture-matrix storativity and interporosity flow did not apply to the model.



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Figure 1. WIPP stratigraphy.

2. Test and Analysis Procedures

Four purge tests were performed in the H-15R replacement well on 8/21/08, 10/27/08, 11/04/08, and 11/12/08 to diagnose aquifer parameters, remove non-formation water, and obtain water quality samples. Analysis of the second purge data indicated that the well could sustain approximately a 0.3 gpm pumping rate for a 72-hour test which was conducted on 1/19/09. To evaluate aquifer parameters of the Culebra for the H-15R monitoring well, well test analysis was performed on the 2009 test data. The main objectives of this analysis were to estimate transmissivity (T) for subsequent use in T-field generation and WIPP performance assessment calculations, and to validate the construction of the Culebra replacement well on the H-15 wellpad. The location of the H-15R well pad in the WIPP well network is shown in Figure 2.

Pumping test analysis for the H-15R pumping test data included the fitting of simulated well response with wellbore storage and skin in an infinite-acting radial flow system to Cartesian pressure data, pressure change, and pressure derivative (log-log diagnostic) as described by Bourdet (1989). We designate this first model as the "best fit". Obtaining the "best fit" involved finding the values of model fitting parameters that produced the best-simulated matches to the pressure data collected during the pumping test and subsequent recovery period. 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.

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 which result in a single set of "best fit" fitting-parameter values. These fitting-parameter values are considered 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 hydraulic-test analyst). Perturbation analysis begins by assigning a plus/minus range corresponding to the parameter space of each baseline fitting-parameter values. These plus/minus fitting-parameter ranges for each fitting parameter are listed in Appendix B. Starting at the baseline value, the fitting parameters are randomly perturbed to fall somewhere within their assigned parameter space 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 *global minimum* (assumed true solution) is the minimum that contains the smallest sum of squared error (SSE) values, while other minima are referred to as *local minima*. Local minima are effectively localized depressions in the

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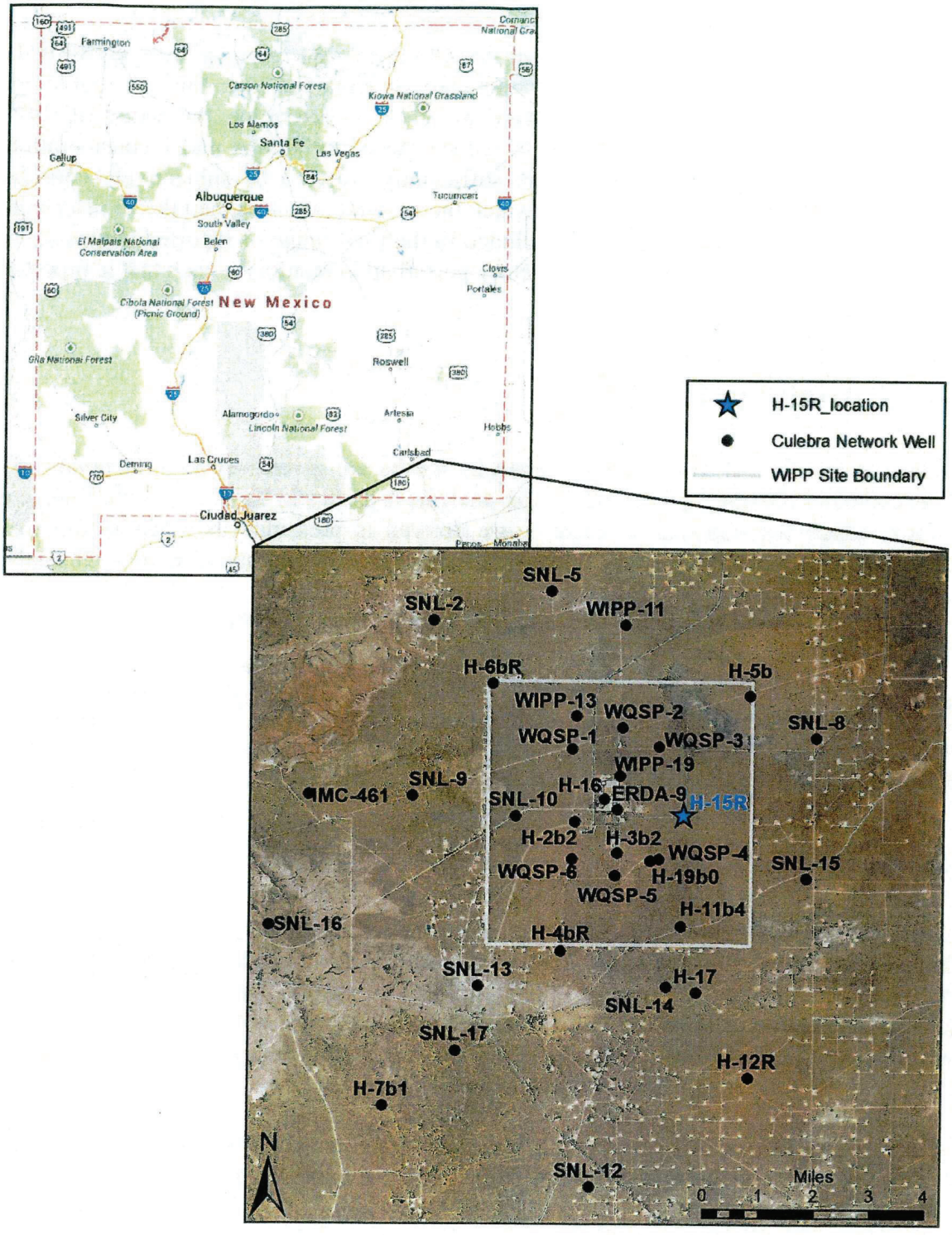


Figure 2. Location of the H-15R Culebra well located on the H-15 wellpad. The H-15R pumping well is designated by a blue star.

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parameter-space topography that can trap the inverse regression algorithm during its attempt to find the global minimum.

Five hundred perturbation/optimization runs of the simulated well response were performed per AP-070, Rev 2. 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. The final number of satisfactory perturbation results for each test is reported in the Section 3 figure captions.

3. H-15R Analysis Results

Discussions of H-15R and associated test analysis results are given below. A summary of the parameter estimates obtained from perturbation analysis 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-15R Test	Mean S *(fixed values)*	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 $(m^2/s)^2$
Pumping Test	8.10E-06	1.23E-07	-6.91038	-6.91204	-6.90815	8.47E-23

3.1. H-15R

The Culebra interval of well H-15R was drilled and completed in 2008 (Baker 2017). The well was drilled to a depth of 924 ft with the Culebra interval screened from 858 ft to 882 ft. At the Culebra, the inner diameter (ID) of the well is 2.4-in and the pump is hanging on 1.4-in ID tubing. The siting and creation of the H-15R well was based on the need to replace the previous H-15 well in support of hydrologic testing and monitoring of the Culebra Dolomite east of the WIPP site. A physical description of the well is detailed in Figure 3.

Four purge tests and a pumping test were initiated in the Culebra at H-15R between 8/21/08 and 1/22/09. The second purge test was analyzed to determine the optimal pumping rate and duration for the final pumping test.

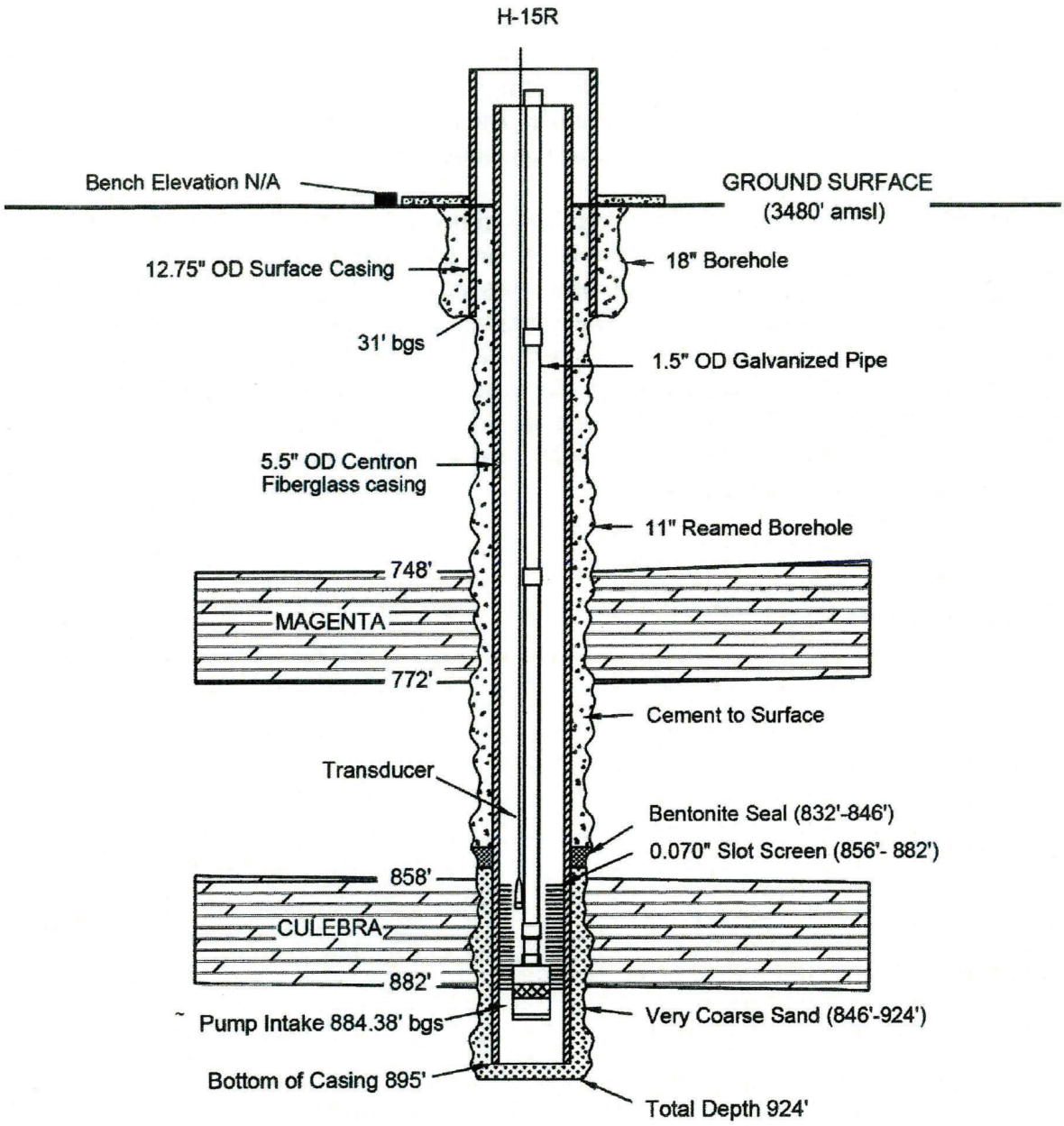
A ~1130-gallon pumping test was conducted in the Culebra at H-15R from 1/19/09 to 1/22/09. An initial pumping rate of 0.3 gpm was used for a majority of the pumping test but was reduced to approximately 0.2 gpm for the last evening of the test to extend test duration. The target constant 0.2 gpm rate was not maintained during the test, and a linear decrease in rate persisted

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until test completion. The H-15R nSIGHTS simulation consisted of four sequences: a history period that extended partially after pumping began, two drawdown periods, and a recovery period. The details of each sequence (start/end time, pressure, etc) are listed in Appendix B specified as the H-15R_Bourdet_ trim.nPre file. The pumping rates of the test are shown in Figure 4, and the data acquired during the test are shown in Figure 5

The specified H-15R conceptual model was chosen because it was the simplest model consistent with the available information that produced an acceptable fit to the data; acceptable by discretion of the modeler. The model used was an infinite-acting, radial system with a T, wellbore storage, and negative skin. The pumping period consisted of two parts: an initial constant-rate period followed by a shorter, variable-rate period. A gravel pack surrounding the screened portion of the well and localized fracturing likely account for the existence of negative skin. Model transmissivity varied by less than a factor of two about a best fit value of T = 1.228E-07 m^2/s. Storativity, skin conductivity, and skin specific storage estimates ranged over approximately two orders of magnitude.

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NOTE:

1. Depths in feet below ground surface/level unless otherwise noted.
2. Not to scale.
3. Washington, 2009.

Figure 3. H-15R well configuration during testing (Baker 2017).

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3.1.1 Pumping Test Analysis

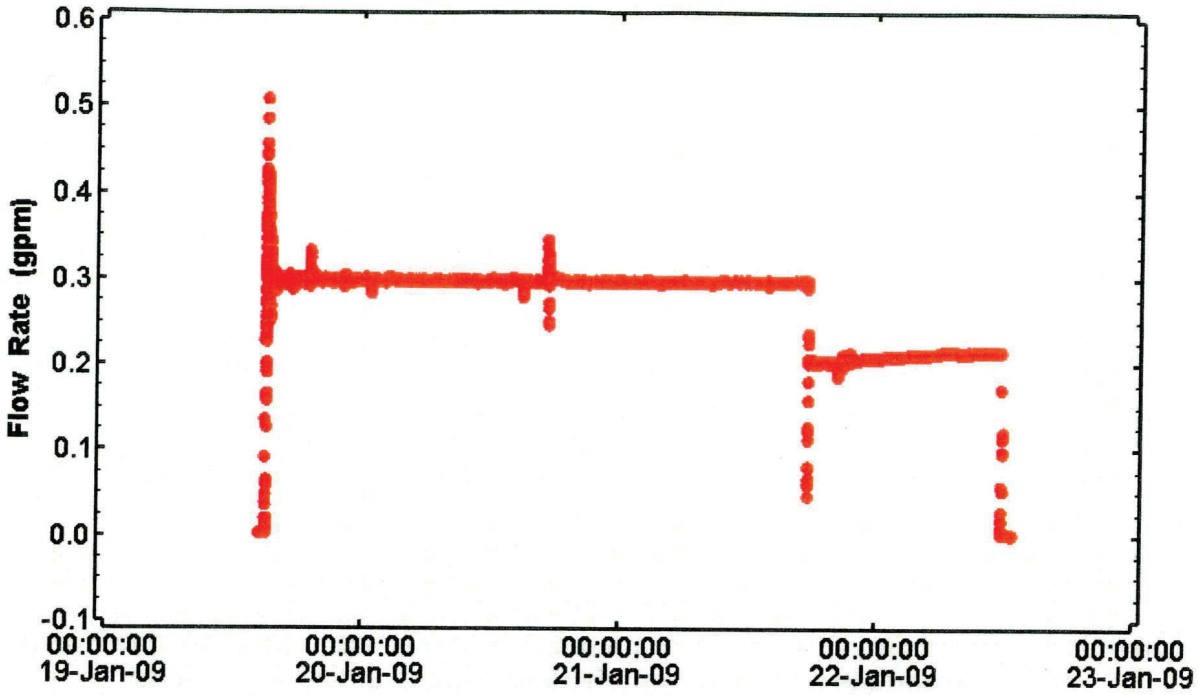


Figure 4. Pumping rates for the final Culebra pumping test in H-15R.

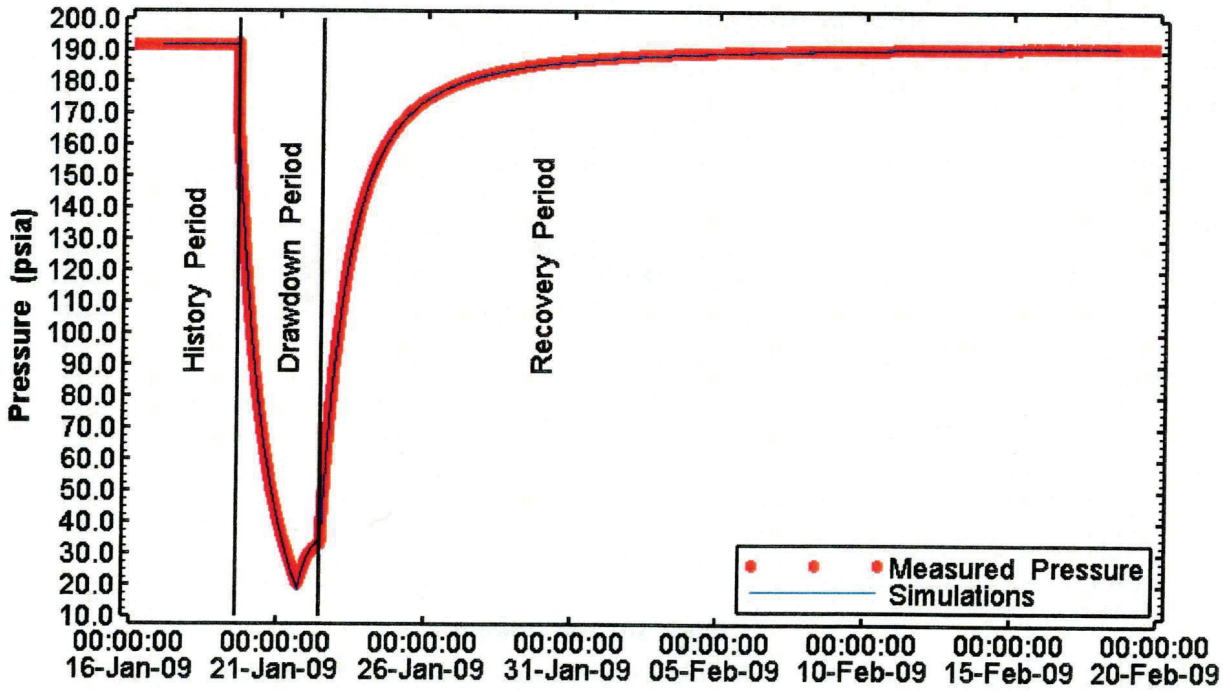


Figure 5. Pressure data and 438 model fits of the final Culebra pumping test in H-15R.

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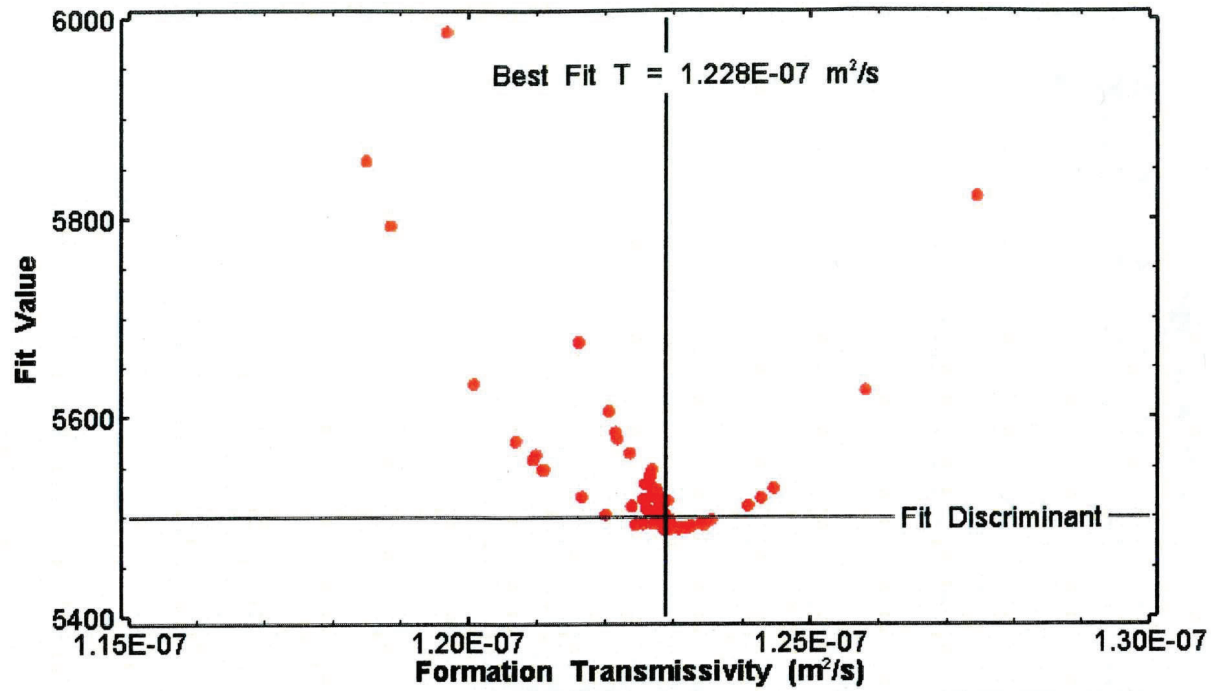


Figure 6. X-Y scatter plot showing the transmissivity parameter space derived from the H-15R perturbation analysis with fit discriminant and best fit values.

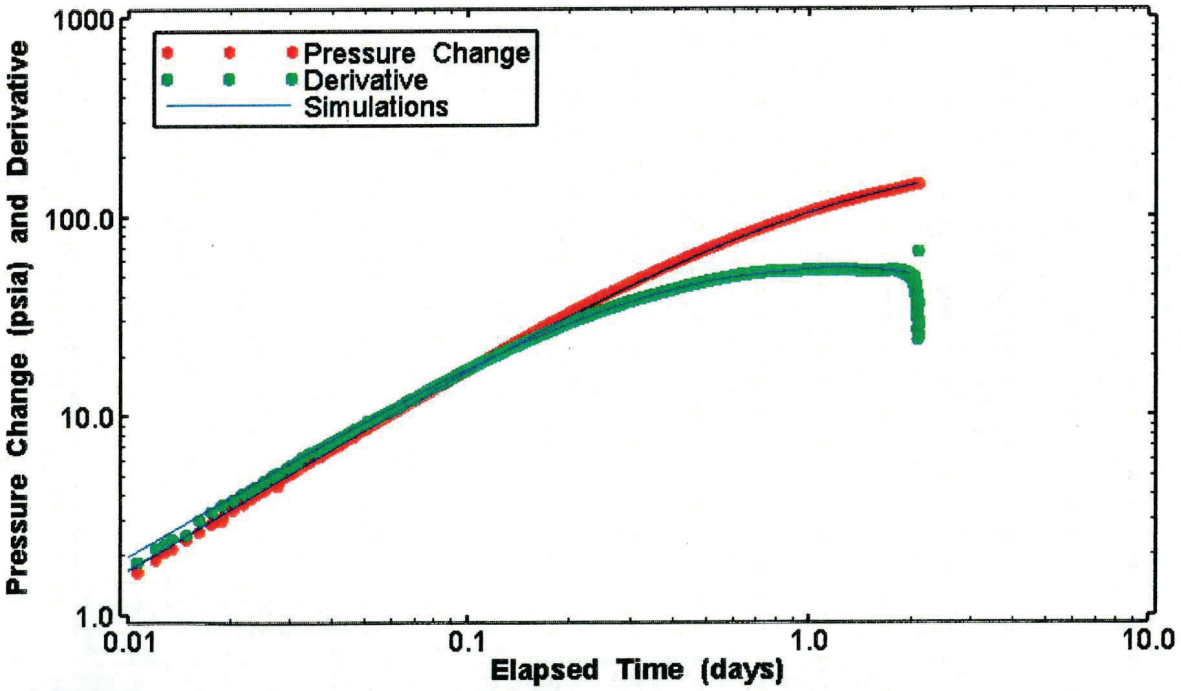


Figure 7. Log-log plot showing 438 simulations of the H-15R drawdown period pressure change and derivative response.

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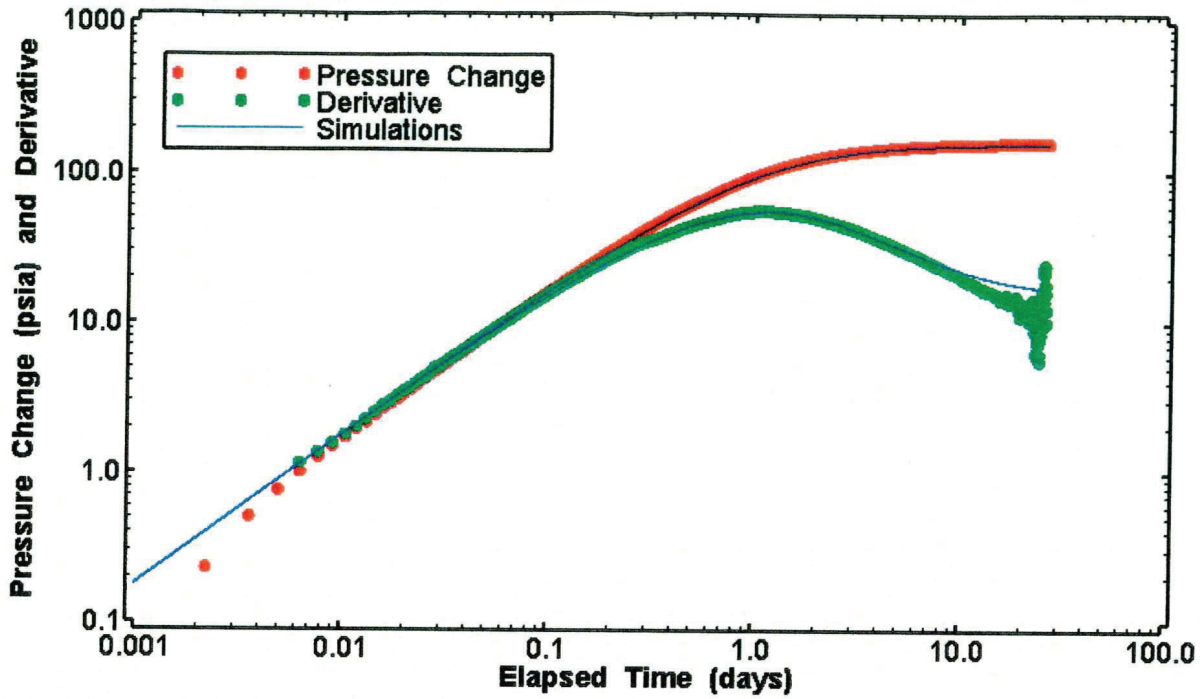


Figure 8. Log-log plot showing 438 simulations of the H-15R recovery period pressure change and Bourdet derivative response.

4. References

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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 – H-15R Hydraulic Test – 1/19/09 to 1/22/09

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-15R	1/19/09 14:26	1/22/09 12:41	1/19/09 14:58	1/22/09 11:42	4.875

Inside Tubing or Casing Diameter (in)	Culebra Interval (ft bgs)	Fluid Density (g/cm^3)	Field Notebook	Data Source Report(s)
2.8	858-882 (24 ft)	1.130	WSWT-13	N/A

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Appendix B – nSIGHTS Listings

```
************
nPre/64 2.50
************

Version date    25 June 2012
Listing date    01 Jul 2019
QA status       non-QA Open Source
Config file     C:\SANDIA_PROJECTS\WIPP_wells\Culebra\H-15R_Pumping Test\H-
15R_Bourdet_trimX.nPre
```

Control Settings

Main Settings

Simulation type	Optimization	
Simulation subtype	Normal	
Phase to simulate	Liquid	
Skin zone ?	yes	
External boundary	Fixed Pressure	

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	193.500	[psi]
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]

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Maximum value	1.00000E-02	[m/sec]
Estimate value	1.68075E-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	1.06992E-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	0.3771241	[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	8.02353E-03	[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	1.72431E-03	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1130.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	2.4	[in]
Tubing string radius	1.4	[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

Information Only

Transmissivity	min/max	
Minimum	7.31520E-10	[m^2/sec]
Maximum	7.31520E-02	[m^2/sec]
Storativity	min/max	
Minimum	7.31520E-08	[]
Maximum	7.31520E-04	[]
Diffusivity	min/max	
Minimum	1.00000E-06	[m^2/sec]
Maximum	1.00000E+06	[m^2/sec]

Skin Zone

Transmissivity	min/max	
Minimum	7.31520E-10	[m^2/sec]
Maximum	7.31520E-02	[m^2/sec]
Storativity	min/max	
Minimum	7.31520E-10	[]
Maximum	7.31520E-02	[]
Diffusivity	min/max	
Minimum	1.00000E-08	[m^2/sec]
Maximum	1.00000E+08	[m^2/sec]
Skin factor	min/max	
Minimum	-1.96657E-03	[]
Maximum	5.28751E+08	[]

Test Zone

Open hole well-bore storage	3.58504E-07	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.05783	[]
Maximum	0.08439	[]
First grid increment	min/max	
Minimum	5.98356E-01	[m]
Maximum	4.48185E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00004	[]
Maximum	0.10791	[]
Skin first grid increment	min/max	
Minimum	2.03885E-06	[m]
Maximum	5.78844E-03	[m]
Skin last grid increment	min/max	
Minimum	2.04278E-06	[m]
Maximum	1.02810E+00	[m]
Increment ratio	min/max	
Minimum	5.82003E-01	[]
Maximum	2.19399E+03	[]

Sequences

Sequence: H_01

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Sequence type	History	
Start time	39830.000000	[day]
Duration	2.631020	[day]
Time step type	Static	
Static time step	0.011574	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	39832.631020	[day]
Duration	2.102310	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-0.2958	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	39834.733330	[day]
Duration	0.754714	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Sequence: F_03

Sequence type	Flow	
Start time	39835.488044	[day]
Duration	27.136956	[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
Curve object to use	Q_Curve

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Curve type	Flow Rate
Start sequence	F_02
End sequence	F_02
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]

OutputFiles

XY Forward Output

Write file ?	yes
C:\SANDIA_PROJECTS\WIPP_wells\Culebra\H-15R_Pumping Test\Post\H-15R.nXYSim	
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
C:\SANDIA_PROJECTS\WIPP_wells\Culebra\H-15R_Pumping Test\Post\H-15R.nOpt	
Run ID	Run#1
If file exists	Overwrite
Write residuals ?	no
Write Jacobian ?	no
Write covariance matrices?	yes

Optimization Setup

Algorithm	Simplex
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	5
Formation conductivity	OK
Skin zone conductivity	OK

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

Fits to Optimize

Cart_DAT_P	OK

Calculated Parameters Included

# of calculated variables included	0

Suite/Range Setup

# of suite/range variables	0

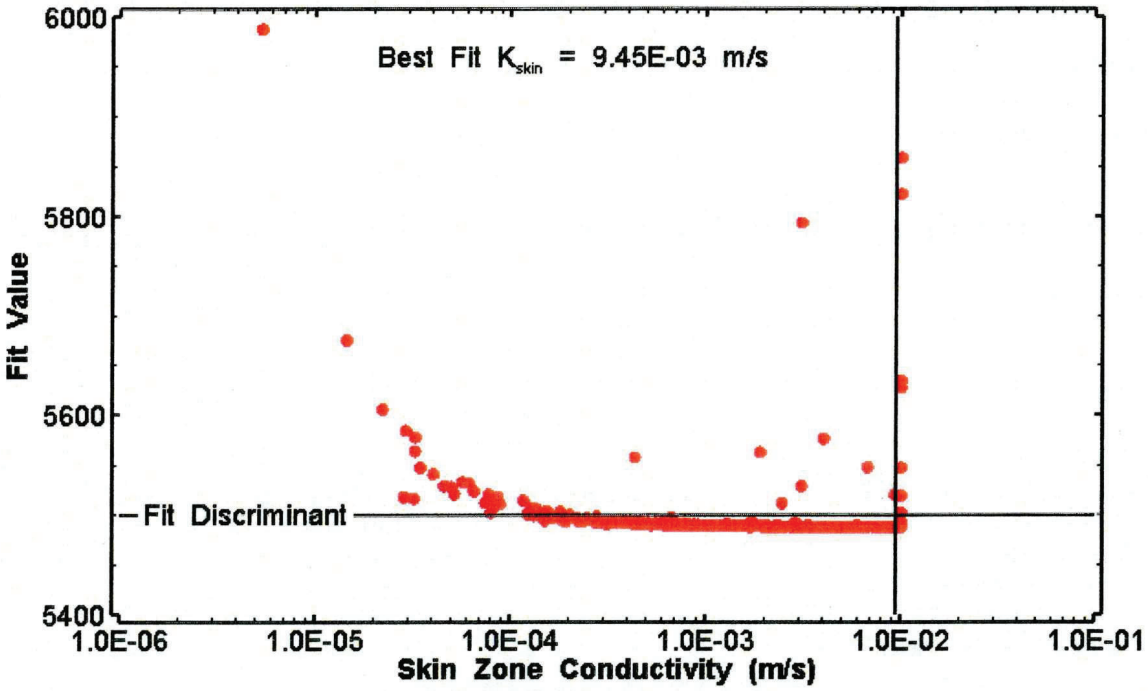


Figure B-1. X-Y scatter plot showing the skin conductivity parameter space for the H-15R perturbation analysis with the fit discriminant and best fit values.

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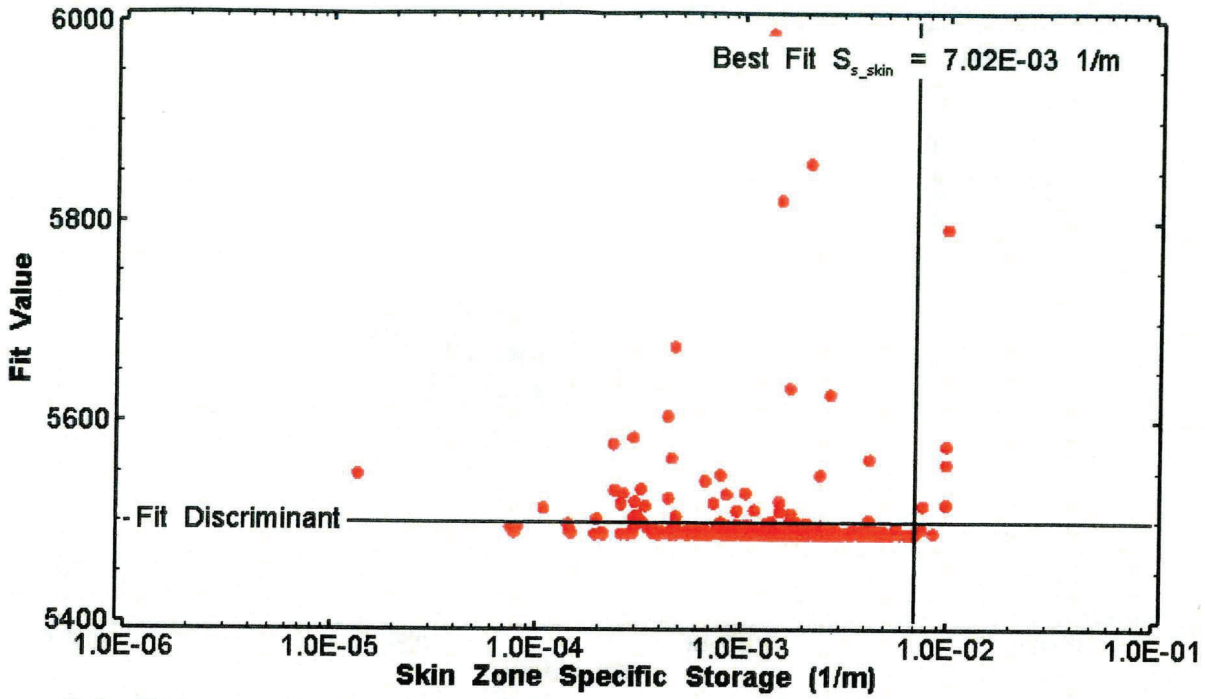


Figure B-2. X-Y scatter plot showing the skin specific storage parameter space for the H-15R perturbation analysis with the fit discriminant and best fit values.

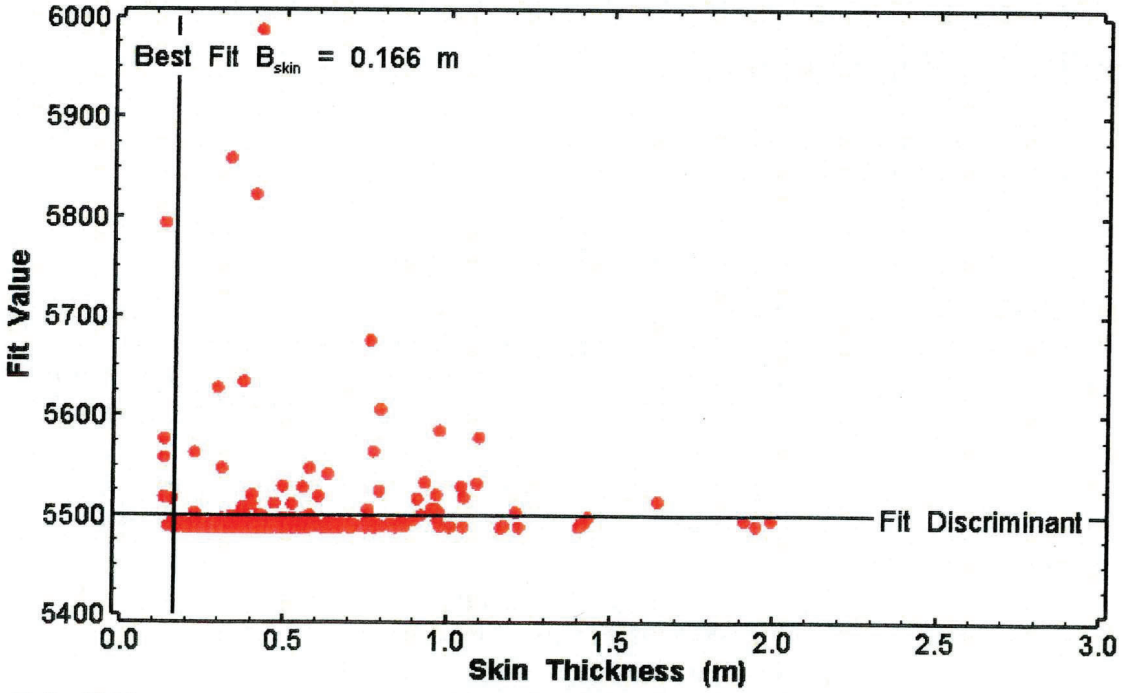


Figure B-3. X-Y scatter plot showing the skin thickness parameter space for the H-15R perturbation analysis with the fit discriminant and best fit values.

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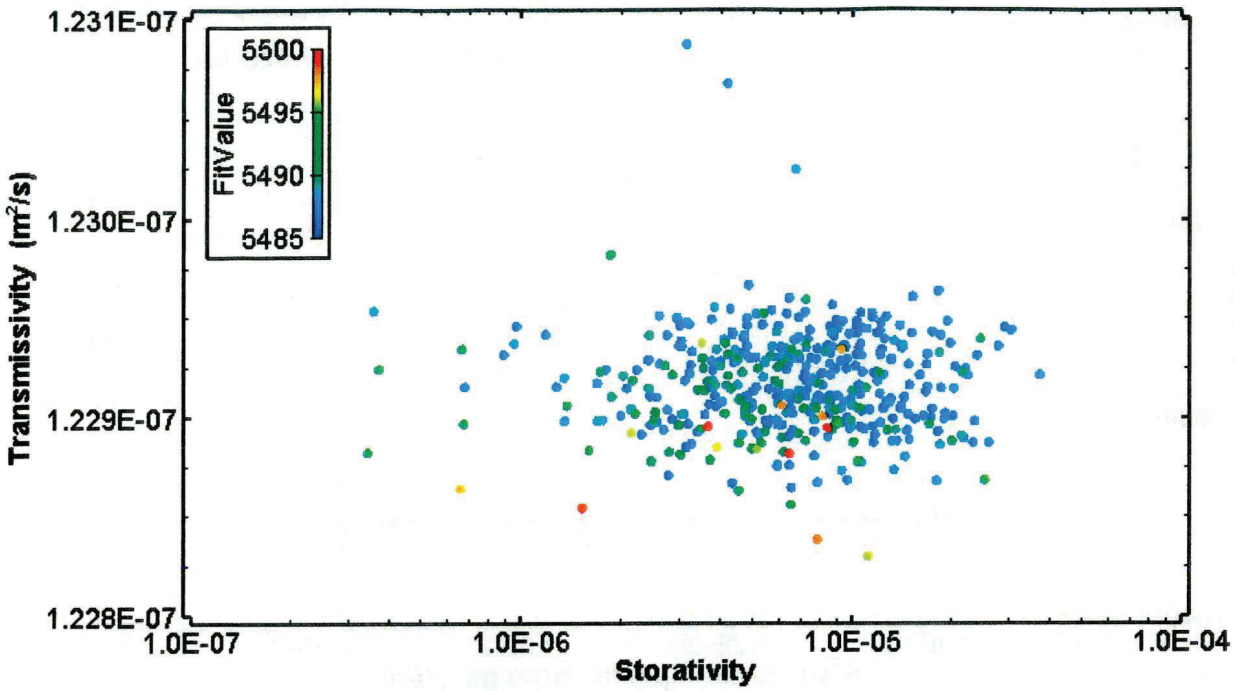


Figure B-4. X-Y scatter plot showing the transmissivity versus storage parameter space for the H-15R perturbation analysis with the fit discriminant and best fit values.

Appendix C – File Directories

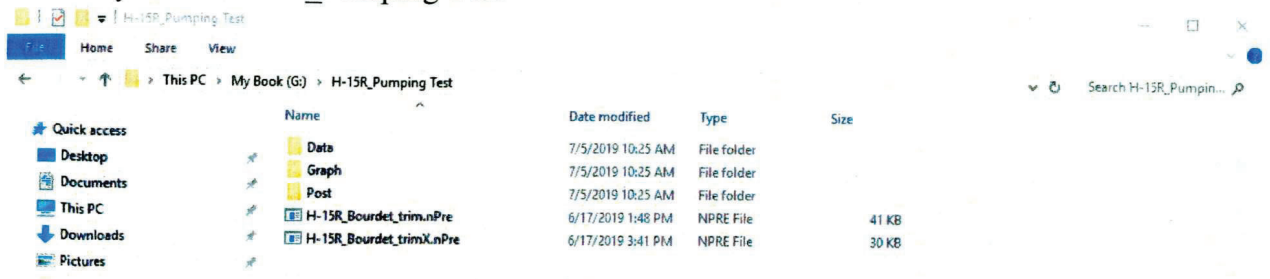
Associated files can be found in the Solaris Directory - /nfs/data/CVSLIB/WIPP_EXTERNAL/AP070.

Table C-1. File descriptions.

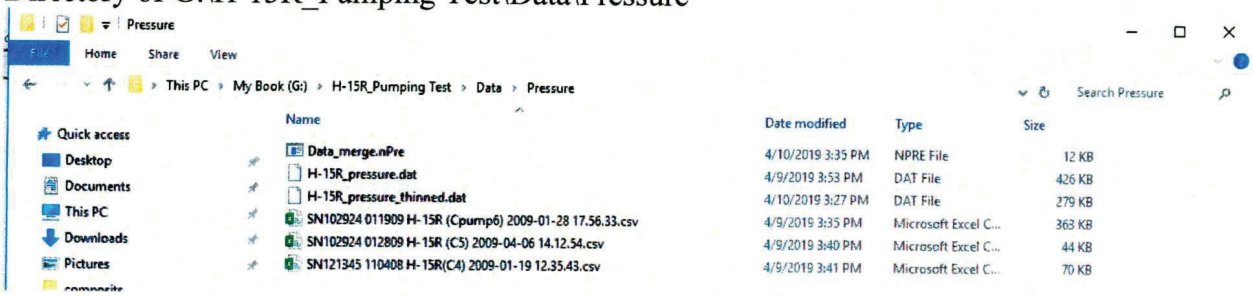
File Extension	Function/Use
<filename>.nPre	Files used for initial well test analysis.
<filename>X.nPre	Files used to generate perturbation analysis of .nPre results.
.nPost	Post-processing files used to visualize .nPre and perturbation analysis.
.nOpt	Optimization data used for post processing in .nPost 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

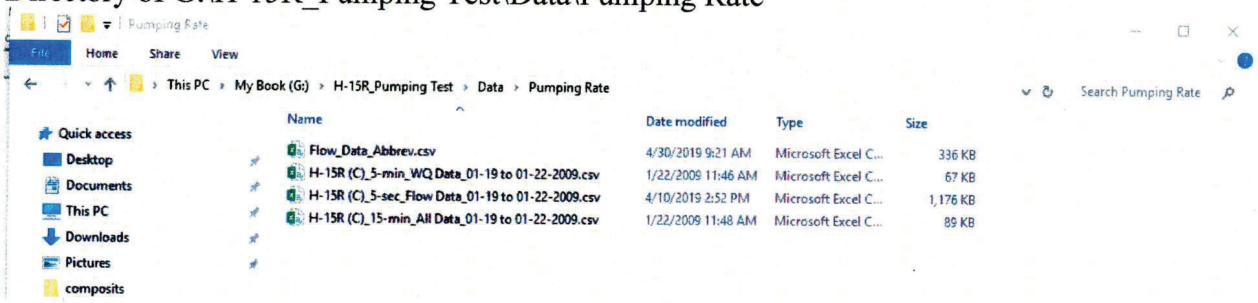
Directory of G:\H-15R_Pumping Test



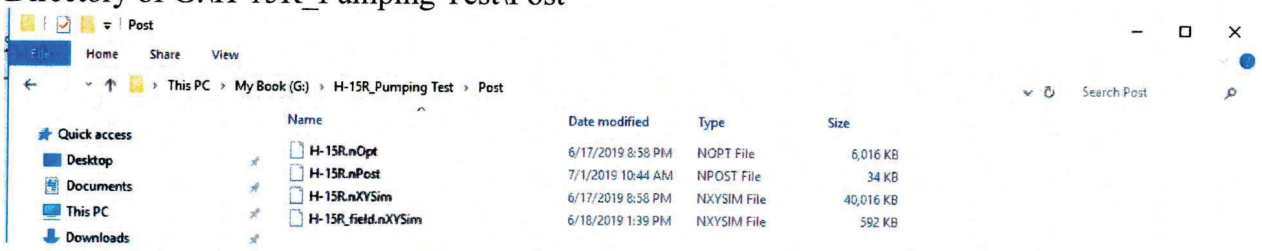
Directory of G:\H-15R_Pumping Test\Data\Pressure



Directory of G:\H-15R_Pumping Test\Data\Pumping Rate

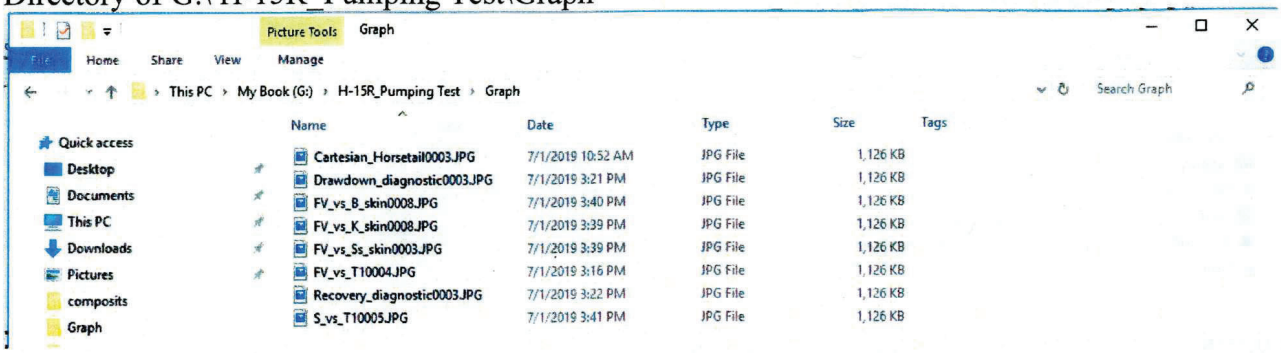


Directory of G:\H-15R_Pumping Test\Post



Information Only

Directory of G:\ H-15R_Pumping Test\Graph



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