Analysis Report for AP-070

Analysis of the H-5bR Slug Test Conducted On 12/7/21

AP-070: Analysis Plan for Hydraulic-Test Interpretations

Task Number 4.4.2.3.1

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Contents

1. Introduction....3
2. Test and Analysis Procedures....4
3. H-5bR Analysis Results....6
3.1. H-5bR....6
4. References....11
Appendix A – H-5bR Slug-Withdrawal Test – 12/07/21....12
Appendix B – nSIGHTS Listings....13
Appendix C – File Directories....17
Associated files can be found in the Solaris Directory -
/nfs/data/CVSLIB/WIPP_EXTERNAL/AP070....17

Tables

Table 1. Culebra Transmissivity and Storativity Estimates....6
Table 2. File descriptions....17

Figures

Figure 1. WIPP stratigraphy....3
Figure 2. Location of the H-5bR Culebra well located on the H-5 wellpad. The H-5bR pumping well is designated by a blue star....5
Figure 3. H-5bR well configuration during testing....8
Figure 4. Pressure data and 389 model fits of the final Culebra slug-withdrawal test in H-5bR....9
Figure 5. X-Y scatter plot showing the transmissivity parameter space derived from the H-5bR perturbation analysis with fit discriminant and best fit values....9
Figure 6. Semilog plot showing 389 simulations of the H-5bR slug-withdrawal Ramey A and derivative response....10
Figure 7. Log-log plot showing 389 simulations of the H-5bR slug-withdrawal Ramey B and derivative response....10

Appendix B Figures

Figure B-1. X-Y scatter plot showing the formation storage parameter space for the H-5bR perturbation analysis with the fit discriminant and best fit values....16
Figure B-2. X-Y scatter plot showing the skin tubing string radius parameter space for the H-5bR perturbation analysis with the fit discriminant and best fit values....16
Figure B-3. X-Y scatter plot showing the transmissivity versus storage parameter space for the H-5bR perturbation analysis....17

Information Only

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-5 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 3 (Bowman, 2020). 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 3. 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. Formation pressure sans anthropogenic events is described as static formation pressure for our model. The data prior to our testing of the well, labeled as history data, allows us to hold this value as a constant. Double porosity effects were also not observed, so fracture-matrix storativity and interporosity flow did not apply to the model.

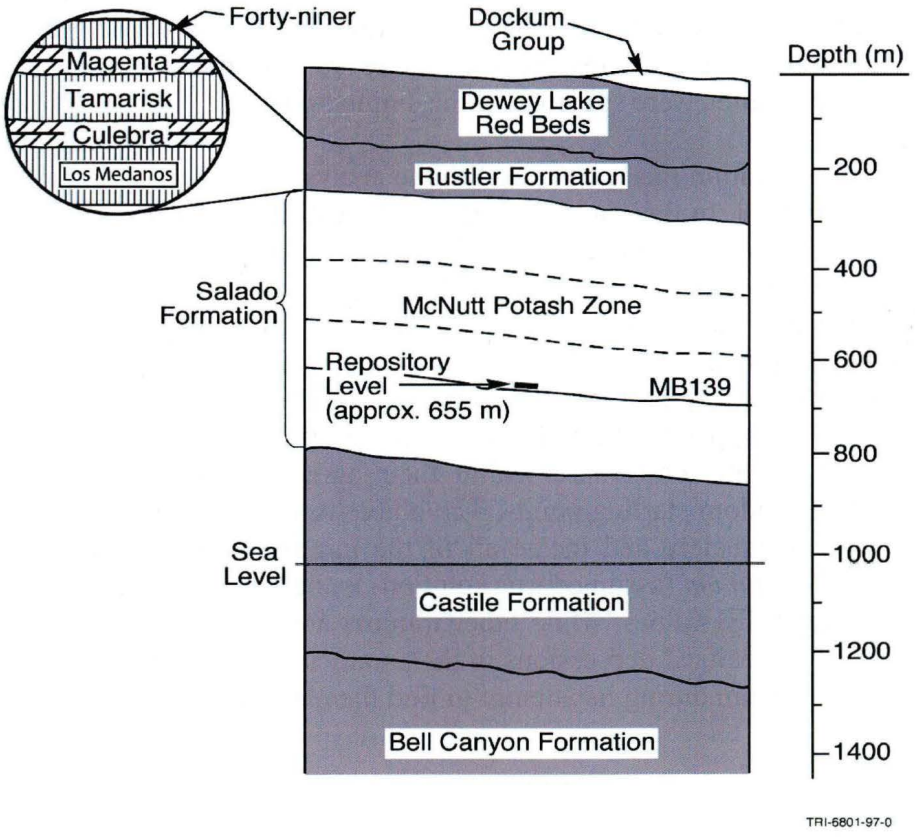

Figure 1. WIPP stratigraphy

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2. Test and Analysis Procedures

Seven purge tests were performed in the H-5bR replacement well between 10/1/20 and 7/27/21 to diagnose aquifer parameters, remove non-formation water, and obtain water quality samples. Water quality samples were gathered during a water quality test of the well that was conducted on 1/18-20/21. Analysis of the second and third purge data indicated that the Culebra at H-5bR was not transmissive enough to sustain a constant-rate pumping test given the standard pumping test approach and typical pumps in use. Subsequently, it was decided to perform a slug-withdrawal test by pumping the well at maximum pump speed to decrease the head of the well by a predetermined length. To evaluate aquifer parameters of the Culebra for the H-5bR monitoring well, slug-withdrawal analysis was performed on the 2021 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-5bR wellpad. The location of the H-5bR well pad in the WIPP well network is shown in Figure 2.

Slug-withdrawal analysis for the H-5bR pressure data included the fitting of simulated well response with wellbore storage in an infinite-acting radial flow system to Cartesian pressure data, derivatives of normalized pressure data (Ramey A and Ramey B). The initial model fit is designated 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, and derivative diagnostics of that data, collected during slug-withdrawal recovery period. 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 parameter-space topography that can trap the inverse regression algorithm during its attempt to find the global minimum.

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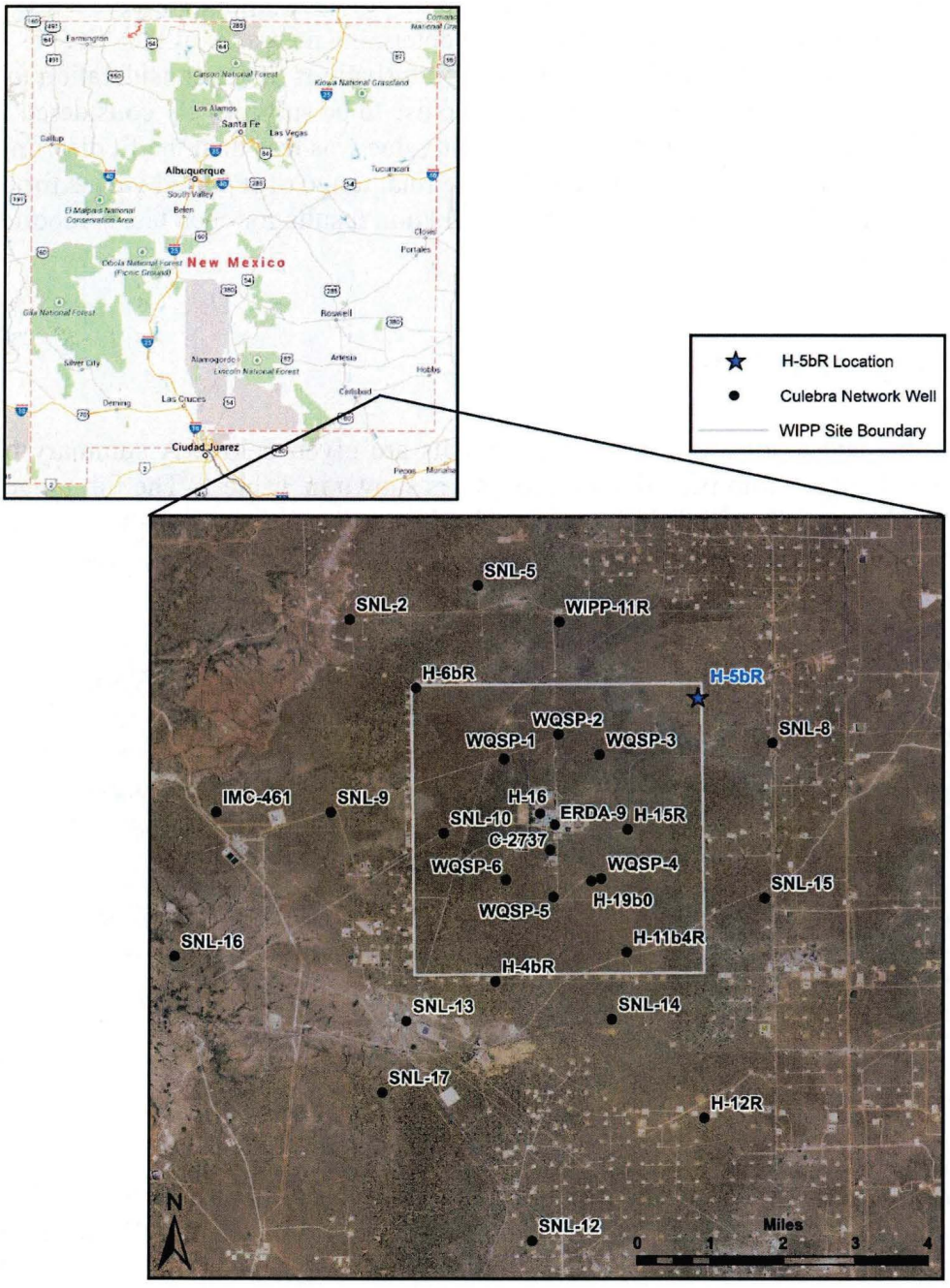

Figure 2. Location of the H-5bR Culebra well located on the H-5 wellpad. The H-5bR pumping well is designated by a blue star.

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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-5bR Analysis Results

Discussions of H-5bR 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-5bR 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 $(m^2/s)^2$
Slug-withdrawal	5.55E-06	6.46E-08	-7.1899	-7.3593	-7.0529	1.22E-18
1978 Shut-in #1	1E-05	2.15E-07	N/A	N/A	N/A	N/A
1978 Slug Injection	1E-05	2.15E-07	N/A	N/A	N/A	N/A
1978 Shut-in #2	1E-05	3.23E-07	N/A	N/A	N/A	N/A

3.1. H-5bR

The Culebra interval of well H-5bR was drilled and completed on 9/13/19 (DOE 2022). The well was drilled to a depth of 944 ft with the Culebra interval screened from 897 ft to 918 ft. At the Culebra, the inner diameter (ID) of the well is 2.375-in and the pump is hanging on 1.4-in ID tubing. The siting and creation of the H-5bR well was based on the need to replace the previous H-5b 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.

Seven purges and low-flow pumping test, designed to sample water quality, were initiated in the Culebra at H-5bR between 10/1/20 and 7/27/21. Analysis of the early purge tests determined that the Culebra was not transmissive enough to support a traditional pumping test, so a slug test was deemed appropriate.

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A ~40 psi slug-withdrawal test was conducted in the Culebra at H-5bR on 12/07/21. The H-5bR nSIGHTS simulation consisted of two sequences: a history period prior to the slug-withdrawal and the slug-withdrawal, itself. The details of each sequence (start/end time, pressure, etc) are listed in Appendix B specified as the H-5bR_Slug.nPre file. The data acquired during the test are shown in Figure 4.

The specified H-5bR 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 and wellbore storage. Skin affects were considered but did not improve the model fit and the skin parameter values were not well constrained. Model transmissivity varied by less than a factor of five about a best fit value of T = 7.80E-08 m^2/s. Storativity ranged over less than an order of magnitude.

Both estimated storativity and transmissivity decrease by an order of magnitude in comparison with previous testing conducted by the USGS in 1978 (USGS 1982). The 1978 analysis consisted of fits to two shut-in tests and a slug-injection test. The shut-in analyses both fit only late-time data. The slug-injection analysis does an adequate job modeling the data, but only looks at what appears to be a Ramey A diagnostic. Cartesian data is not fit by the test. That said, as no observation wells are taken into account for these analyses, a comparison of their diffusivity (D) is more appropriate. The 1978 analysis, D = 3.22E-02 m^2/sec, and the 2022 analysis, D = 1.16E-02 m^2/sec, differ by less than a factor of 3.

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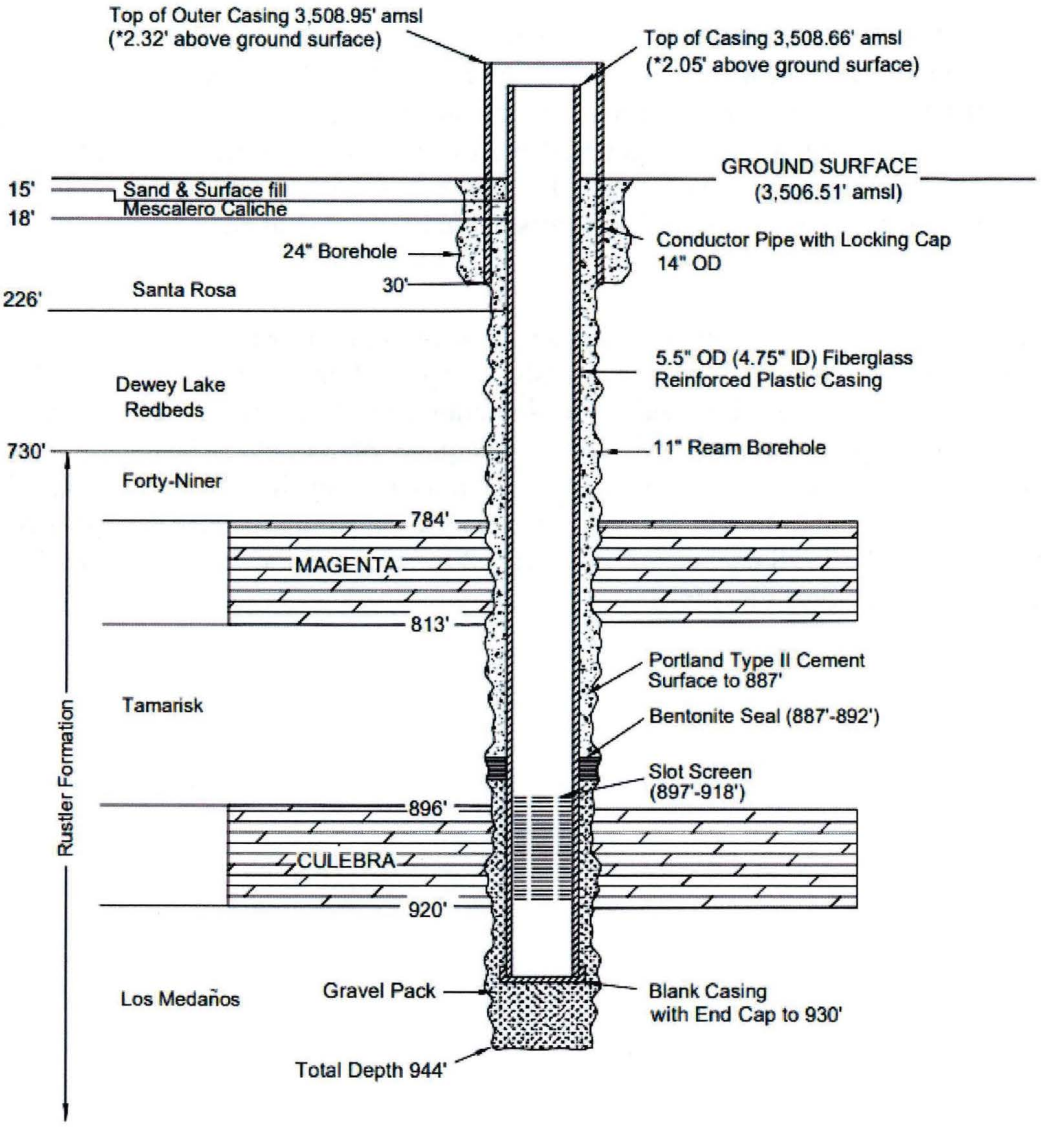
H-5bR



NOTE:
1. Depths in feet below ground surface unless otherwise noted
2. Not to scale
3. Well info references H-5bR's BDR (DOE/WIPP-22-3637, C-2745 POD2 - 05/10/2022)
4. amsl = Above Mean Sea Level
5. * indicates measurements by Orlando Reyna and Cody Franco, 9/14/2020.

Figure 3. H-5bR well configuration during testing.

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3.1.1 Slug Test Analysis

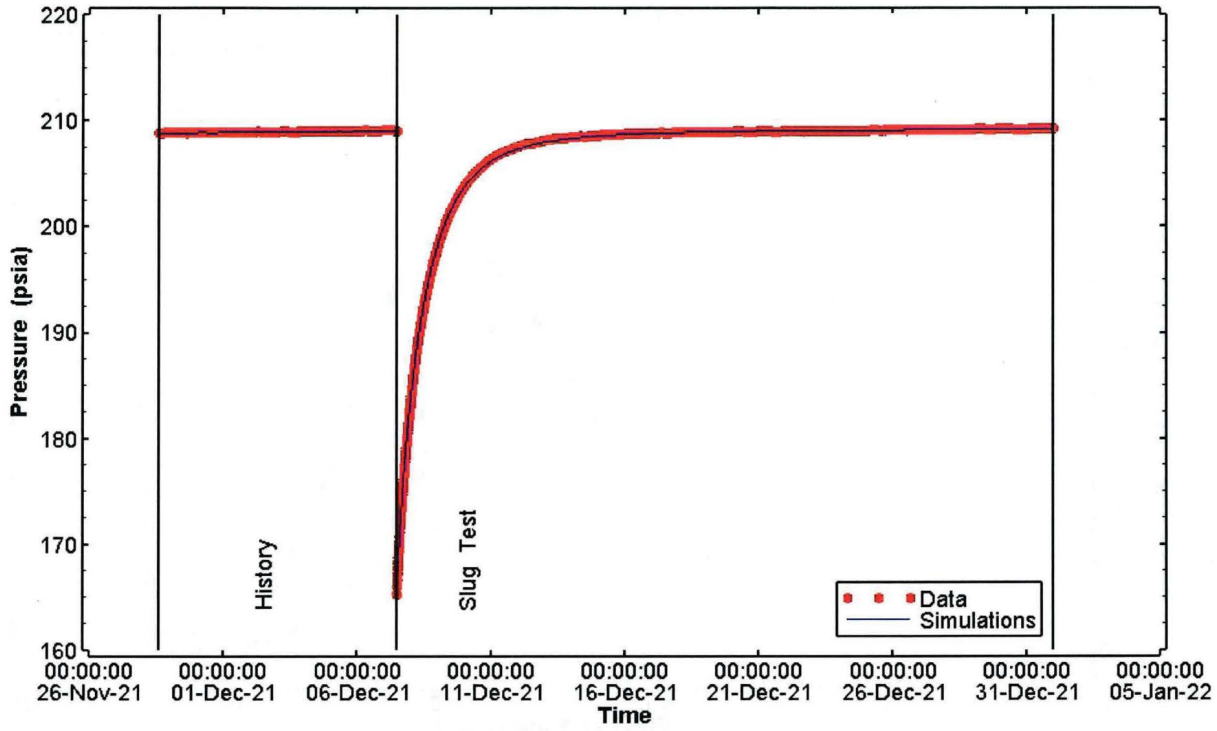

Figure 4. Pressure data and 389 model fits of the final Culebra slug-withdrawal test in H-5bR.

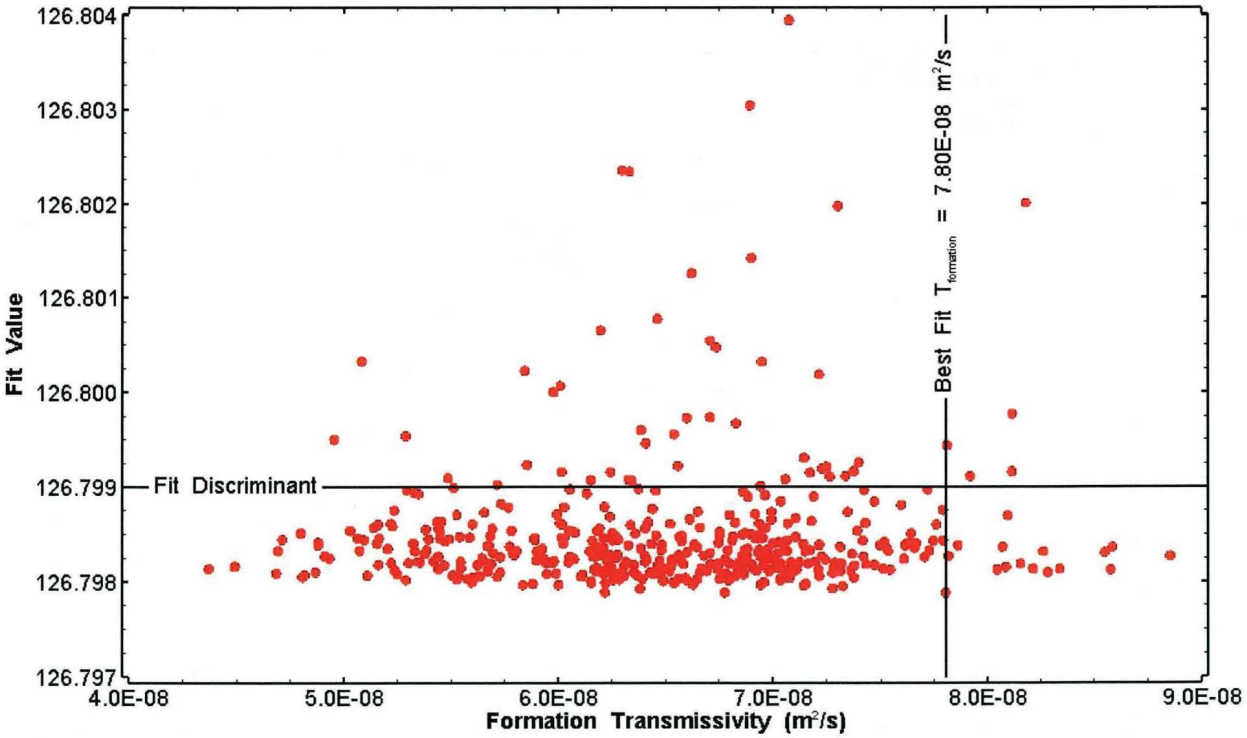

Figure 5. X-Y scatter plot showing the transmissivity parameter space derived from the H-5bR perturbation analysis with fit discriminant and best fit values.

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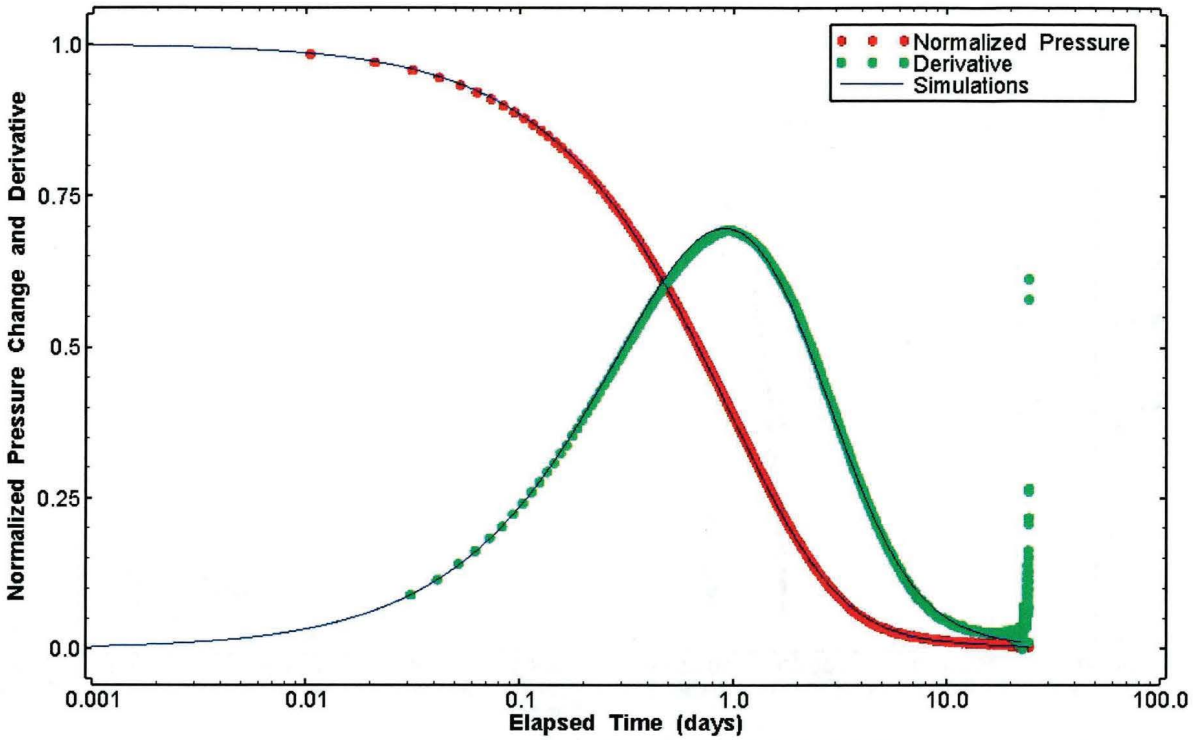

Figure 6. Semilog plot showing 389 simulations of the H-5bR slug-withdrawal Ramey A and derivative response.

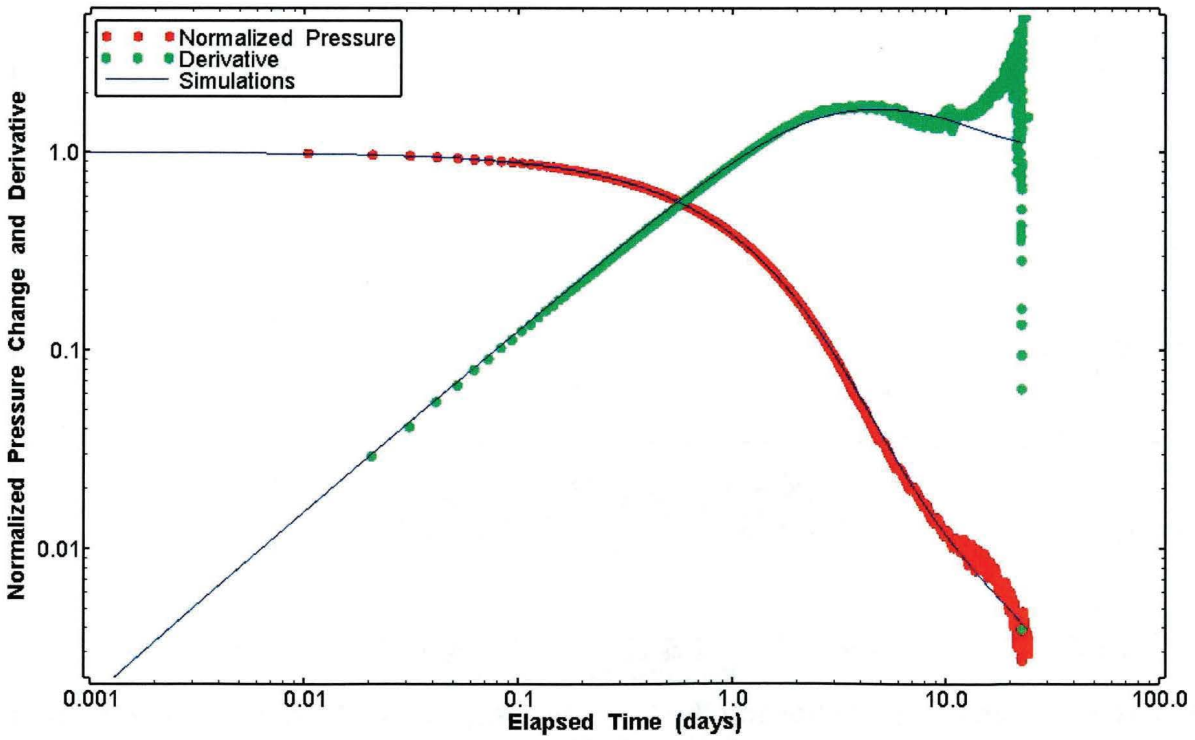

Figure 7. Log-log plot showing 389 simulations of the H-5bR slug-withdrawal Ramey B and derivative response.

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4. References

Bowman, D.O. 2020. Analysis Plan for Hydraulic-Test Interpretations, AP-070, Revision 3. ERMS# 574237. 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.

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U.S. Geological Survey 1982. Results of Hydrologic Tests and Water-Chemistry Analyses, Wells H-5a, H-5b, and H-5c, at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico. USGS/WRI 82-19, Albuquerque, NM.

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Appendix A – H-5bR Slug-Withdrawal Test – 12/07/21

Well	Date and Time Start DAS	Date and Time Start Slug	Date and Time Stop Slug	Date and Time Stop DAS	Borehole Diameter (in)
H-5bR	11/28/21 14:15	12/07/21 11:30	12/07/21 11:45	1/1/22 0:00	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	896-920 (24 ft)	1.105	WSWT-21	N/A

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Appendix B – nSIGHTS Listings

```
************
nPre/32 2.50
************

Version date    25 June 2012
Listing date    25 Jul 2022
QA status       non-QA Open Source
Config file     C:\Users\dobowma\Desktop\Priority_Reports_AH\H-5bR_slug\H-
5bR_Slug.nPre
```

Control Settings

Main Settings

Simulation type	Forward
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	no
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	209.300	[psi]
External boundary radius	1000000	[m]
Formation conductivity	8.30387E-09	[m/sec]
Formation spec. storage	7.14587E-07	[1/m]

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Fluid

Fluid density	1105.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	2.375	[in]
Tubing string radius	1.5792161	[in]

Numeric

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

Calculated Parameters

Formation

Transmissivity	6.07445E-08	[m^2/sec]
Storativity	5.22735E-06	[]
Diffusivity	1.16205E-02	[m^2/sec]

Test Zone

Open hole well-bore storage	4.66484E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.06676	[]
First grid increment	4.16484E-03	[m]

Sequences

Sequence: H_01

Sequence type	History	
Start time	44528.593750	[day]
Duration	8.895830	[day]
Time step type	Static	
Static time step	0.001157	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: S_01

Sequence type	Slug	
Start time	44537.489580	[day]

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Duration	24.510420	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Initial pressure type	Absolute	
Initial pressure	165.247	[psi]

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]

OutputFiles

XY Forward Output

Write file ?	no

Profile Output

Write file ?	no

Suite/Range Setup

# of suite/range variables	0

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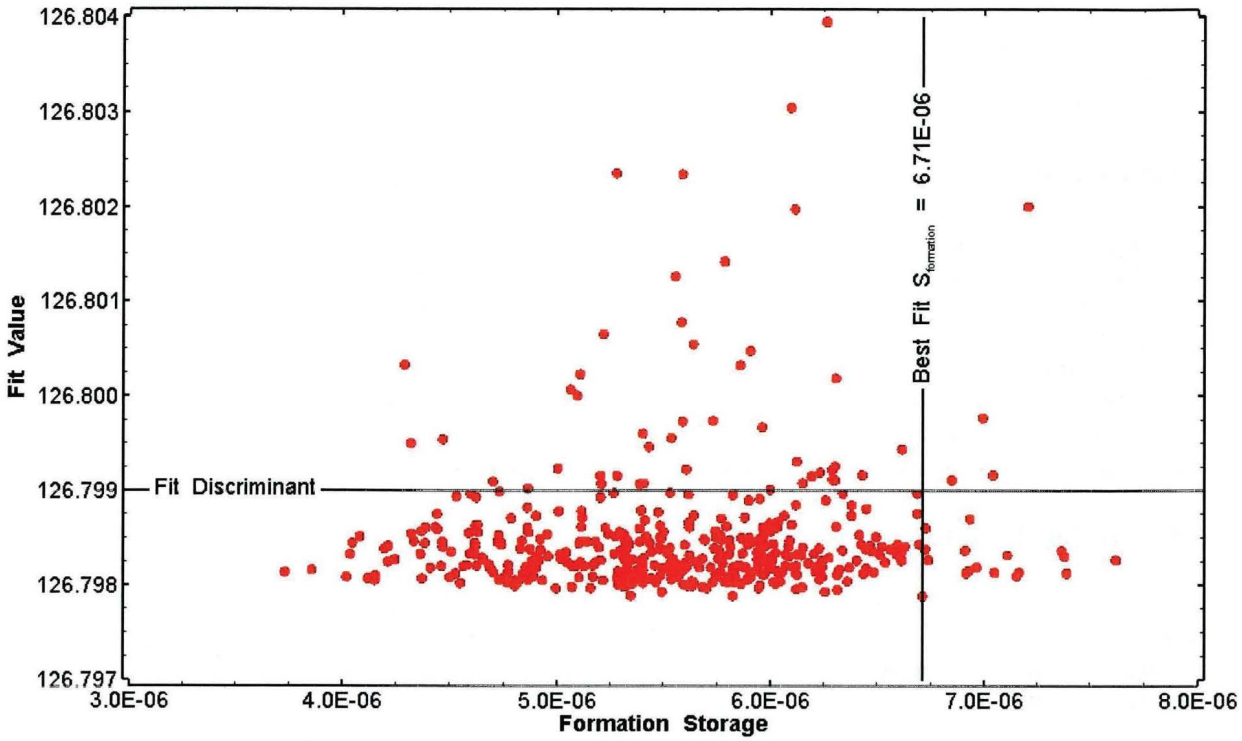

Figure B-1. X-Y scatter plot showing the formation storage parameter space for the H-5bR perturbation analysis with the fit discriminant and best fit values.

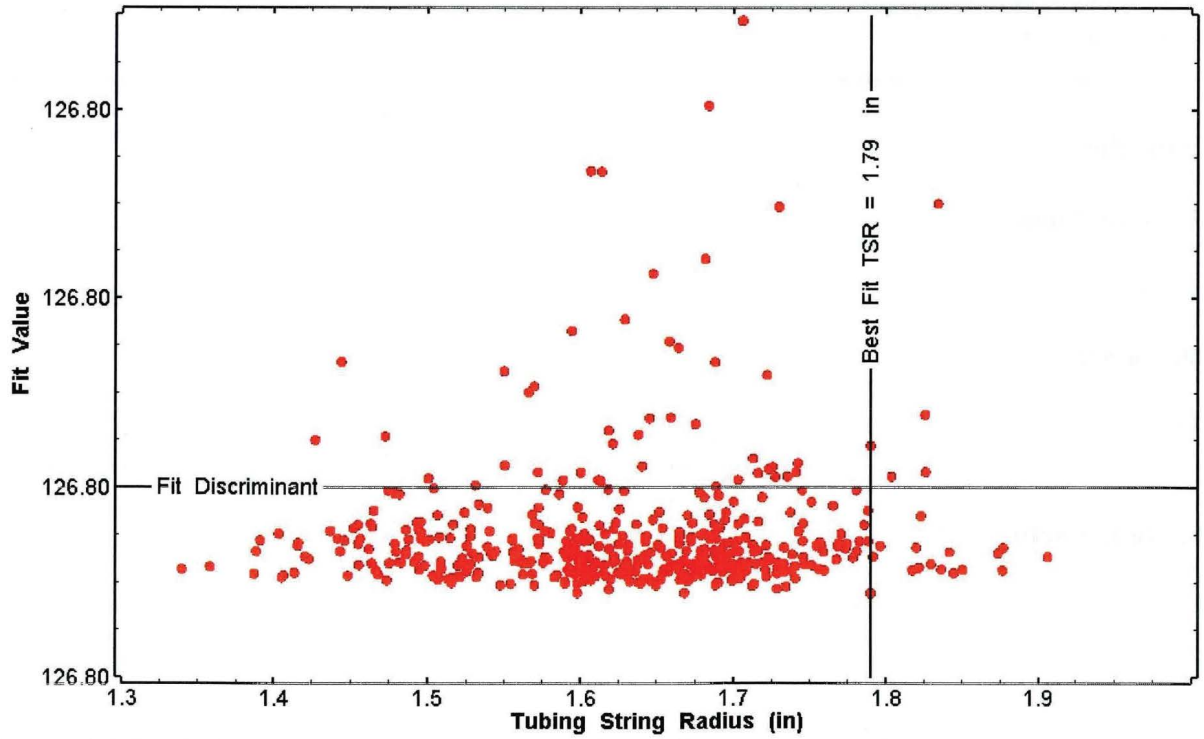

Figure B-2. X-Y scatter plot showing the skin tubing string radius parameter space for the H-5bR perturbation analysis with the fit discriminant and best fit values.

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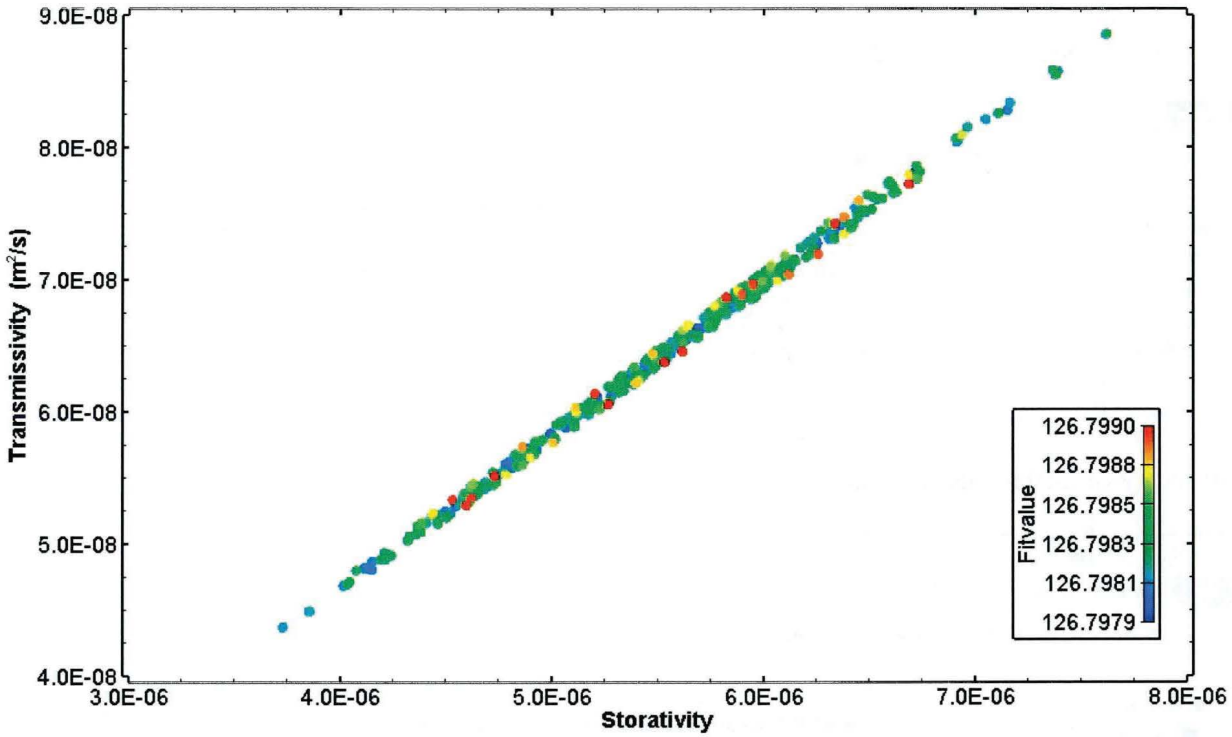

Figure B-3. X-Y scatter plot showing the transmissivity versus storage parameter space for the H-5bR perturbation analysis.

Appendix C – File Directories

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

Table 2. 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.

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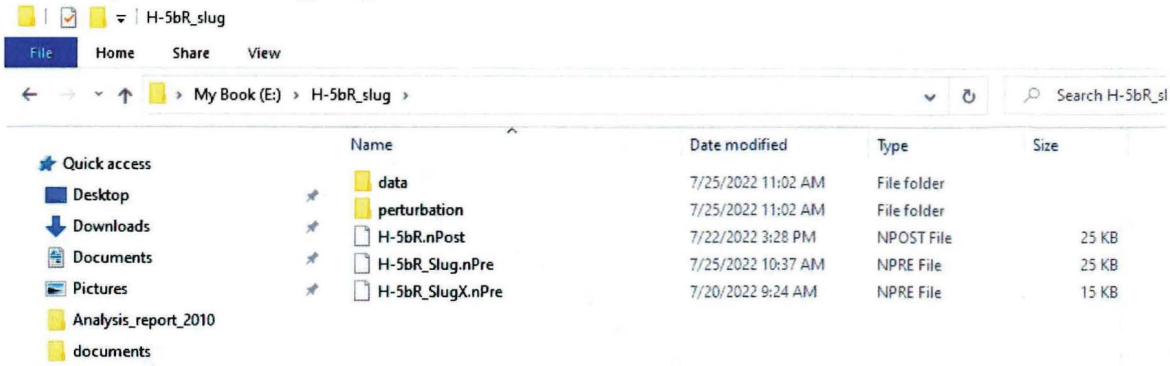
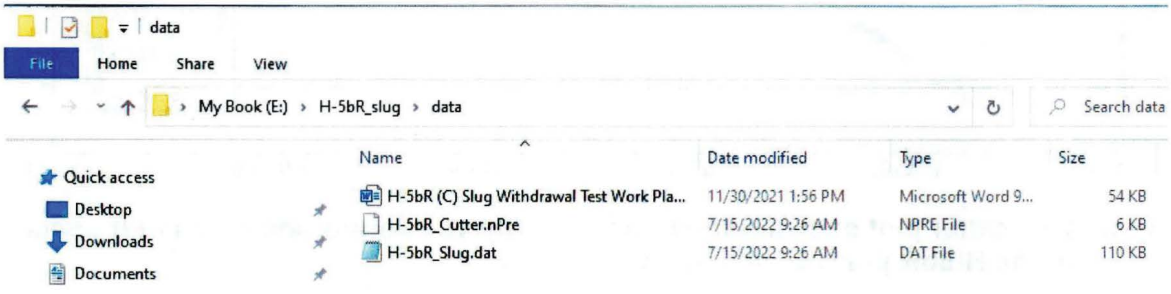
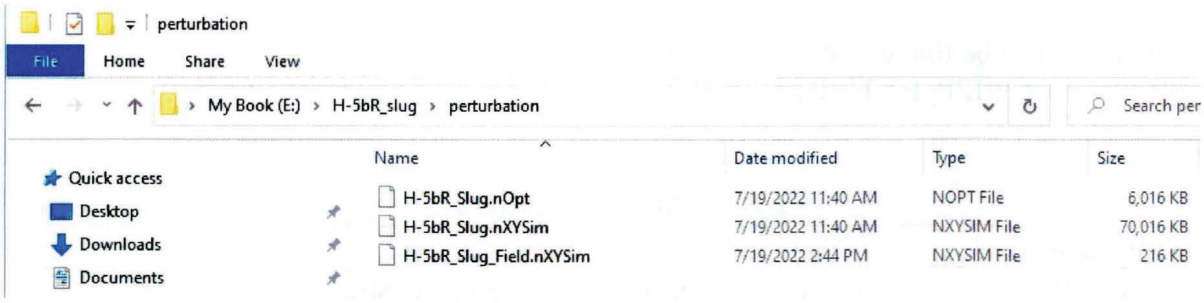
Directory of G:\H-5bR_Slug



Directory of G:\H-5bR_Slug\data



Directory of G:\H-5bR_Slug\perturbation



Acknowledgements

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