Analysis Report for AP-070

Analysis of the H-12R Pumping Test Conducted
From 4/20/15 to 4/22/15

AP-070: Analysis Plan for Hydraulic-Test Interpretations

Task Number 4.4.2.3.1

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Date  
9/18/15  
9/14/15  
9/17/15  
9/18/2015
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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-12 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 2.50. 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.
2. Test and Analysis Procedures

Four purge tests were performed in the H-12R replacement well on 8/28/14, 10/22/14, 12/10/14, and 2/19/15 for the purpose of removing non-formation water and obtaining water quality samples. These purges removed a total of 1014 gal. of water from the H-12R well. Analysis of the first purge indicated that the well could sustain approximately a 0.25 gpm pumping rate for a 48 hour test. 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-12R well pad in the WIPP well network is shown 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).

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 and wellbore skin were also included as fitting parameters 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 the previous Culebra well on the H-12 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
Figure 2. Location of the H-12R Culebra well located on the H-12 wellpad. The H-12R pumping well is designated by a blue star.
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 defined through perturbation analysis. The final number of satisfactory perturbation results for each test is reported in the Section 3 figure captions.

### 3. H-12R Analysis Results

Discussions of H-12R 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>
<thead>
<tr>
<th>H-12R Test</th>
<th>Mean $S$ (fixed values)</th>
<th>Geo. Mean $T$ (m²/s)</th>
<th>Log Geo. Mean $T$ (m²/s)</th>
<th>Log Min. $T$ (m²/s)</th>
<th>Log Max. $T$ (m²/s)</th>
<th>Variance (m²/s)²</th>
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<tbody>
<tr>
<td>Purge 1</td>
<td>7.92E-06</td>
<td>1.11E-07</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>Pumping Test</td>
<td>7.92E-05</td>
<td>1.53E-07</td>
<td>-6.81455</td>
<td>-6.87282</td>
<td>-6.76143</td>
<td>1.02E-18</td>
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### 3.1. H-12R

The Culebra interval of well H-12R was drilled and completed between 7/12/2014 and 7/24/2014. The well was drilled to a depth of 865 ft with the Culebra interval screened from 820 ft to 846 ft. At the Culebra, the inner diameter (ID) of the well is 4.31-in and the pump is hanging on 1.59-in ID tubing. The siting and creation of the H-12R well was based on the need to replace the previous H-12R 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.
Four purge tests and a pumping test were initiated in the Culebra at H-12R between 8/28/14 and 4/22/15. The first purge test was analyzed to gain insight on the hydraulic parameters associated with the replacement well to better frame the pumping rate and duration for the final pumping test. The other purges were designed to reach stabilized water quality parameters. The simulation for the purge test consisted of a history period prior to drawdown and a recovery period once purging concluded. The data and model used in the analysis is shown in Figure 4.

A ~893 gallon pumping test was conducted in the Culebra at H-12R from 4/20/15 to 4/22/15. 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 data acquired for the test is shown in Figure 5.

The H-12R nSIGHTS simulations each consisted of three sequences. The details of each sequence, i.e., start/end time, pressure, etc., are specified in the H-12R.nPre file and are listed in Appendix B.1.

The specified H-12R 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 model used was in infinite-acting, radial systems with a variable $T$, wellbore storage, two image wells, and a negative, time-dependent skin. Storativity and skin specific storage estimates were very poorly constrained so they were held as constants in the final model fit.

A gravel pack surrounding the screened portion of the well and localized fracturing likely account for the existence of negative skin with respect to $T$ estimates. The skin is likely time dependent due to continued physical development of the well, blockage of the well screen, and unknown blockage in the gravel pack by the sealant in the well screen.

The static formation pressure of the well seemingly drops every time a pumping test is conducted in the Culebra. This would indicate pumping in a discreet, rather than a traditionally assumed continuous aquifer. The initial model had a close radial boundary was first attempted to fit the pumping test data with no success. The idea that boundaries were affecting the aquifer response was still sound, but a second method, implementation of no-flow boundaries, produced better model results. To apply this effect, two image wells were implemented in the model which decreased model error (fit value) by orders of magnitude. The range of $T$ values derived from this analysis is shown in Figure 6. The $T$ estimates gained through this analysis are described in the preceding Table 1.
Figure 3. H-12R well configuration during testing.

NOTE:
1. Depths in feet below ground surface unless otherwise noted.
2. Not to scale.
3.1.1 Purge Test Analysis

![Figure 4. Pressure data and model fit of the first Culebra purge test in H-12R.](image)

3.1.2 Pumping Test Analysis

![Figure 5. Pressure data and 184 model fits of the final Culebra pumping test in H-12R.](image)
Figure 6. X-Y scatter plot showing the transmissivity parameter space derived from the H-12R perturbation analysis with fit discriminant and best fit values.

Figure 7. Log-log plot showing 184 simulations of the H-12R drawdown period pressure change and derivative response.
A brief note needed to be added that the data, prior to model fitting was thinned. The purpose of the thinning was to lower the modeling run time while still retaining the pressure-change characteristics of the test. Using the full data set, the perturbation analysis contained in this report would require 52 days of processing time. By thinning the data, the processing time was reduced to approximately 7 hours. Figure 9 displays the original data and the overlying thinned data to demonstrate the reduction and the pressure characteristic retention.
4. References


DeYonge, Wesley. 2015. WIPP Site Well Testing Notebook 16 (WSWT-16), ERMS #563685 Pkg #540244.
DeYonge, Wesley. 2015. WIPP Site Well Testing Notebook 17 (WSWT-17), Pkg #540244.


Appendix A – H-12R Hydraulic Test – 4/20/15 to 4/22/15

<table>
<thead>
<tr>
<th>Well</th>
<th>Date and Time Start DAS</th>
<th>Date and Time Stop DAS</th>
<th>Date and Time Start Test</th>
<th>Date and Time Stop Test</th>
<th>Borehole Diameter (in)</th>
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<td>H-12R</td>
<td>4/20/15 10:35</td>
<td>4/22/15 11:00</td>
<td>4/20/15 11:00</td>
<td>4/22/15 10:52</td>
<td>4.31</td>
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<table>
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<tr>
<th>Inside Tubing or Casing Diameter (in)</th>
<th>Culebra Interval (ft bgs)</th>
<th>Fluid Density (g/cm³)</th>
<th>Field Notebook</th>
<th>Data Source Report(s)</th>
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<tr>
<td>2.155</td>
<td>820-846 (26 ft)</td>
<td>1.104</td>
<td>WSWT-17</td>
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## Appendix B – nSIGHTS Listings

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

Version date   25 June 2012  
Listing date   08 Sep 2015  
QA status       non-QA Open Source  
Config file       C:\SANDIA_PROJECTS\WIPP_wells\Culebra\H-12R\H-12R_RR_X.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: 26.000 [ft]
- Flow dimension: 2.0
- Static formation pressure: Optimization
  - Minimum value: 160.000 [psi]
  - Maximum value: 180.000 [psi]
  - Estimate value: 173.791 [psi]
  - Range type: Linear
  - Sigma: 1.00000E+00
- External boundary radius: 1000000 [m]
- Formation conductivity: Optimization

Information Only
Minimum value                            1.00000E-12     [m/sec]
Maximum value                            1.00000E-02     [m/sec]
Estimate value                           2.12834E-08     [m/sec]
Range type                                       Log
Sigma                                    1.00000E+00
Formation spec. storage                     1.00000E-04     [1/m]

Skin
Radial thickness of skin                  Optimization
  Minimum value                            1.0E-05     [m]
  Maximum value                                    5.0     [m]
  Estimate value                               0.5373267     [m]
  Range type                                    Linear
  Sigma                                    1.00000E+00
Skin zone conductivity                     f(t) point
Skin zone spec. storage                     1.00000E-05     [1/m]

Fluid
Fluid density                                   1104.00     [kg/m^3]
Fluid thermal exp. coeff.                   0.00000E+00     [1/C]

Test-Zone
Well radius                                       2.155     [in]
Tubing string radius                                2.0     [in]

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

f(x) Points Parameters

Skin zone conductivity

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Information Only
Calculated Parameters

**Formation**

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<td>Diffusivity</td>
<td>1.0000E-08</td>
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**Skin Zone**

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**Test Zone**

Open hole well-bore storage 7.48871E-07 [m^3/Pa]

**Grid Properties**

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### Maximum and Minimum Grid Increment Information

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<td>Increment ratio</td>
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<td>2.35119E+04</td>
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### Sequences

#### Sequence: H_01
- **Sequence type**: History
- **Start time**: 42114.416667 [day]
- **Duration**: 0.049303 [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**: 42114.465970 [day]
- **Duration**: 2.485420 [day]
- **Time step type**: Log
- **First log step**: 1.15741E-07 [day]
- **# of time steps**: 250
- **Type**: Fixed
- **Fixed value**: -0.247 [USgpm]
- **Wellbore storage**: Open

#### Sequence: F_02
- **Sequence type**: Flow
- **Start time**: 42116.951390 [day]
- **Duration**: 43.048610 [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

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<td><strong>Output units</strong></td>
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<td><strong>Minimum value</strong></td>
<td>2.0 [m]</td>
</tr>
<tr>
<td><strong>Maximum value</strong></td>
<td>1000 [m]</td>
</tr>
<tr>
<td><strong>Estimate value</strong></td>
<td>67.1701016 [m]</td>
</tr>
<tr>
<td><strong>Range type</strong></td>
<td>Linear</td>
</tr>
<tr>
<td><strong>Sigma</strong></td>
<td>1.00000E+00</td>
</tr>
<tr>
<td><strong>P_S_01[3] operation</strong></td>
<td>- Delta P</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>Optimized</td>
</tr>
<tr>
<td><strong>Optimized radius optimization ID</strong></td>
<td>P_S_01[3]</td>
</tr>
<tr>
<td><strong>Minimum value</strong></td>
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<tr>
<td><strong>Maximum value</strong></td>
<td>1000 [m]</td>
</tr>
<tr>
<td><strong>Estimate value</strong></td>
<td>72.0335999 [m]</td>
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<tr>
<td><strong>Range type</strong></td>
<td>Linear</td>
</tr>
<tr>
<td><strong>Sigma</strong></td>
<td>1.00000E+00</td>
</tr>
<tr>
<td><strong>Output units</strong></td>
<td>[psi]</td>
</tr>
</tbody>
</table>

## OutputFiles

### XY Forward Output

**Write file?** yes  
C:\SANDIA_PROJECTS\WIPP_wells\Culebra\H-12R\Post\H-12R_sim.nXYSim 
**Run ID** Run#1 
**If file exists** Overwrite 
**Output data** AutoSimData

### Optimization Output

**Write file?** yes  
C:\SANDIA_PROJECTS\WIPP_wells\Culebra\H-12R\Post\H-12R_sim.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**
15  
**Formation conductivity**
OK  
**K_s.T[01]**
OK  
**K_s.T[02]**
OK  
**K_s.T[03]**
OK  
**K_s.T[04]**
OK  
**K_s.T[05]**
OK  
**K_s.V[01]**
OK  
**K_s.V[02]**
OK  
**K_s.V[03]**
OK  
**K_s.V[04]**
OK  
**K_s.V[05]**
OK  
**P_S_01[2]**
OK  
**P_S_01[3]**
OK  
**Static formation pressure**
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
Figure B-1. X-Y scatter plot showing the skin conductivity parameter space for the first time span derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Figure B-2. X-Y scatter plot showing the skin conductivity parameter space for the second time span derived from H-12R perturbation analysis with the fit discriminant and best fit values.
Figure B-3. X-Y scatter plot showing the skin conductivity parameter space for the third time span derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Figure B-4. X-Y scatter plot showing the skin conductivity parameter space for the fourth time span derived from H-12R perturbation analysis with the fit discriminant and best fit values.
Figure B-5. X-Y scatter plot showing the skin conductivity parameter space for the fifth time span derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Figure B-6. X-Y scatter plot showing the skin zone thickness parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.
Figure B-7. X-Y scatter plot showing the first time dependent skin time parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Best Fit $t_1 = 42115.36$ days

Figure B-8. X-Y scatter plot showing the second time dependent skin time parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Best Fit $t_2 = 42116.946$ days
Figure B-9. X-Y scatter plot showing the third time dependent skin time parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Figure B-10. X-Y scatter plot showing the fourth dependent skin time parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.
Figure B-11. X-Y scatter plot showing the fifth dependent skin time parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Figure B-12. X-Y scatter plot showing the static formation pressure parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.
Figure B-13. X-Y scatter plot showing the image well #1 distance parameter space derived from H-12R perturbation analysis with the fit discriminant and best fit values.

Figure B-14. X-Y scatter plot showing the image well #2 distance parameter space derived from H-12R 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.

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

Directory of G:\ H-12R
Directory of G:\H-12R\Data

Directory of Directory of E:\H-12R\Post

Information Only
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.