Analysis Report for AP-070

Analysis Report that reviews and re-analyzes pumping tests of the western monitoring network

AP-070: Analysis Plan for Hydraulic-Test Interpretations

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1. Introduction

This report documents the review of pumping test analyses for the western WIPP monitoring network, and the reanalysis of six pumping tests. Twelve pumping tests were reviewed in this report, and the following six pumping tests were reanalyzed: P-14, SNL-2, SNL-5, SNL-9, SNL-19, and WIPP-11. For this report, the previous conceptual model (e.g., flow dimension, the presence or absence of a skin zone, type of porosity, and the wellbore storage) is reviewed. Pumping tests were reanalyzed only when alternative conceptual models were more appropriate. The motivation of this review is presented in Section 2. In Section 3, the methodology and results of the pumping test review are presented. Section 4 focuses on the pumping test reanalysis. Discussion of the results and concluding remarks are presented in Sections 5 and 6, respectively.

2. Study Rationale

Pumping tests are the primary means by which hydraulic parameters such as hydraulic conductivity and storativity are estimated. With proper diagnostic methods, aquifer conditions can also be inferred from pumping tests. The accuracy of inferred aquifer conditions and estimated hydraulic parameters is strongly dependent on the conceptual framework and methods used to analyze pumping tests. Traditional well test analysis, including at WIPP, assumes radial flow. In the case of WIPP, heterogeneity was typically compensated by using models with a transmissivity (T) that varies as a function of radius, $T(r)$, from the pumping well. While this modeling approach is reasonable, it has led to a repeating model pattern in WIPP well test analysis in which the highest modeled $T(r)$ is always at the lowest r value with decreasing modeled T values as r increases. If these models are accurate representations of the geology/hydrology at WIPP, it follows that each of these wells are located independently in the highest T area, which is unlikely.

A more reasonable explanation, from a modeling perspective, is that the flow geometries of these tests are non-radial. Realistically, both geometry and T influence the flow behavior, but it is difficult, if not impossible, to separate these effects. As radial models tend to exclude flow geometries as an affect, models that assume a single T but varied flow geometry, are appropriate to investigate. Flow dimension is the exponent that describes the power law scaling between flow area and the radial distance from the borehole (Barker, 1988):

$$A(r) \sim r^{(n-1)}$$

where A is the flow dimension area, r is the radial distance from the borehole, and n is the flow dimension. Flow dimension can be expressed through Barker's function, or by using the second derivative of log pressure change with respect to log time for pumping test response. Integer flow dimensions (n=1, linear; n=2, radial; n=3, spherical) are easily quantified and have a fairly direct geometric interpretation. In the case of field testing, flow dimension diagnostics are considered relative indicators of flow geometry change unless values stabilize. Figure 1 illustrates the general derivative and flow dimension diagnostics for some integer values of flow dimension.

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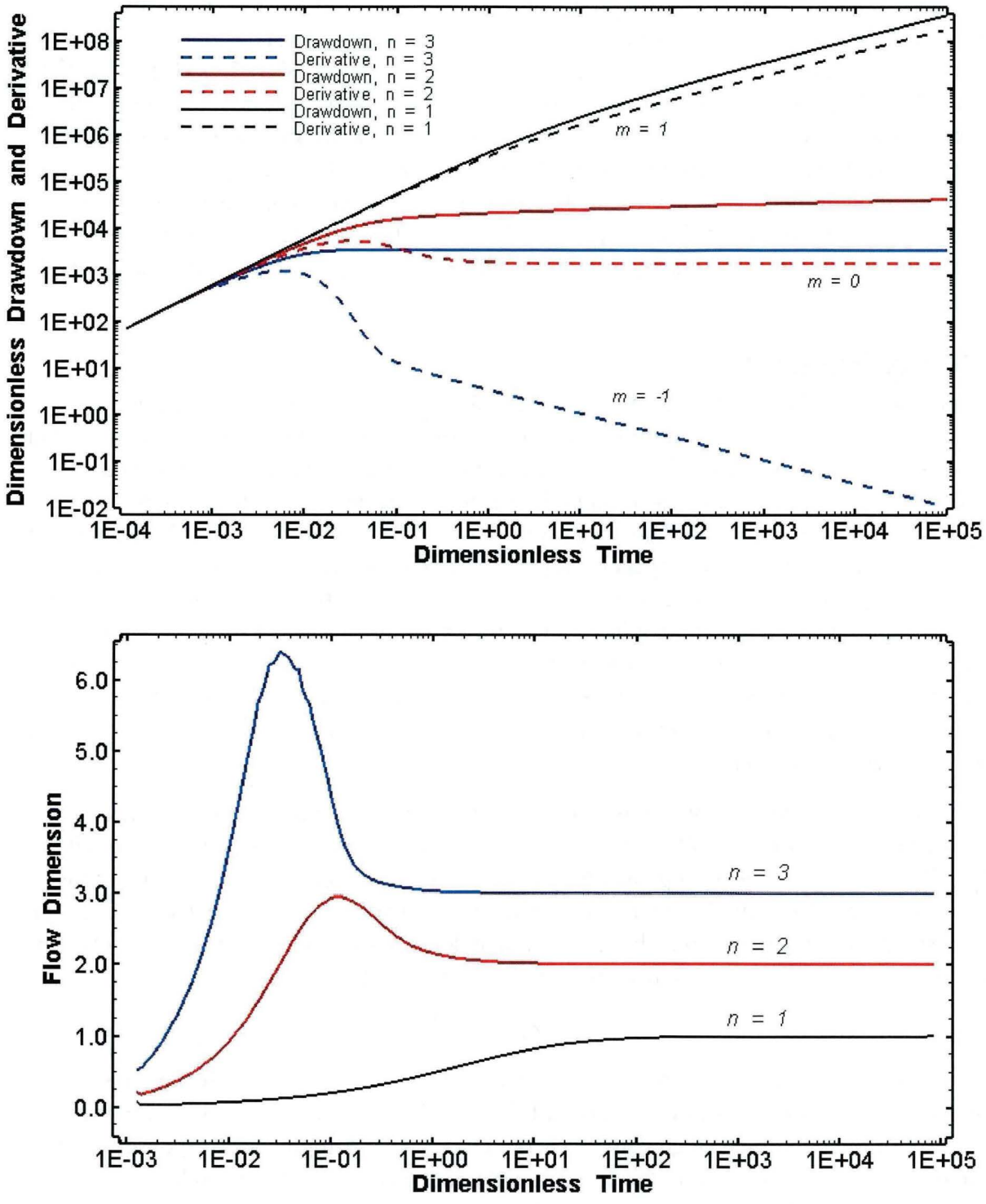


Figure 1: Idealized derivative diagnostics with corresponding flow dimensions (from Bowman et al., 2013)

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One of the common assumptions in pumping test analysis is that flow is cylindrical and radial; this translates to a radial flow dimension of 2. Numerous studies, however, have shown that the "radial flow" assumption may not always be applicable (Audouin et al., 2008, Beauheim et al., 2004, Bowman, 2013, Odling et al., 2013). For example, Ferroud et al. (2018) reviewed 121 pumping tests and found that 69% of these tests have a non-radial signature. Other studies also show that hydraulic parameters values can be significantly under or over-estimated if the correct flow geometry is not used (Beauheim, 1998; Beauheim et al., 2004; Bowman et al., 2013; Garin et al., 2021).

Previous studies at WIPP (Beauheim and Roberts 1998; Roberts, 2006) reported flow dimension values that deviate from the radial flow assumption (e.g., P-14, and WIPP-11). WIPP-11 pressure derivative plot shows a complex pattern of heterogeneity (Figure 2). The plot shows an initial stage where wellbore storage is dominant, followed by two sequences of rising and decreasing pressure derivatives. P-14 pressure derivative shows a similar pattern starting with wellbore storage, followed by radial stabilization and increase in pressure derivative (Figure 3). These two examples indicate the need to explore alternative framework to interpret pumping tests, instead of systematically assuming radial flow.

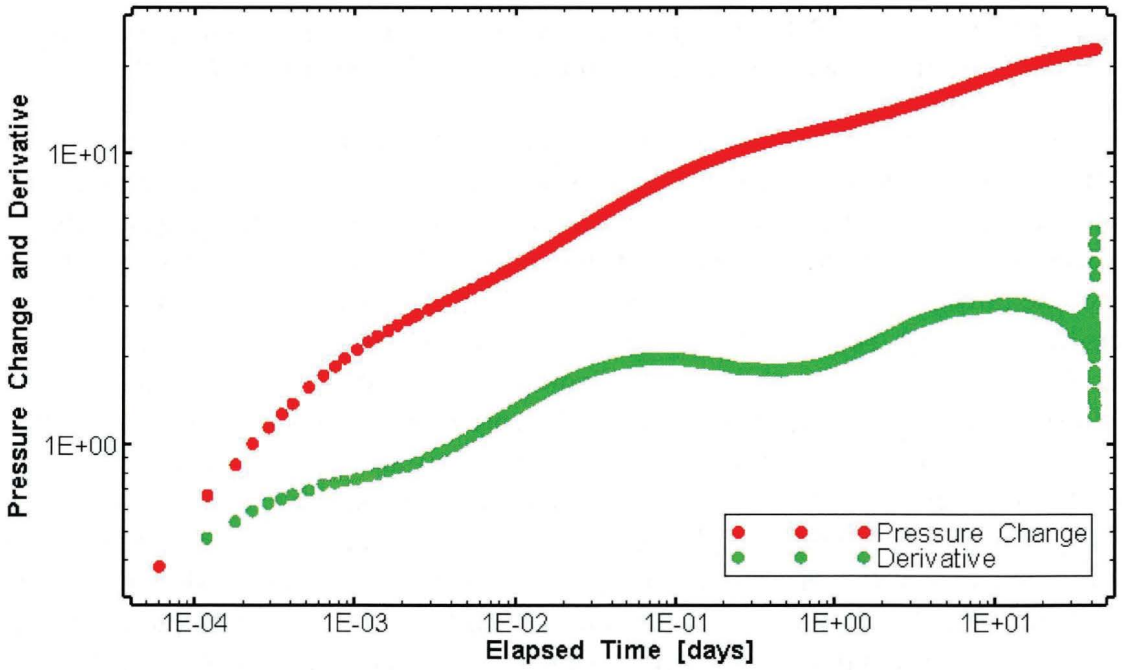


Figure 2: Diagnostic plots of WIPP-11. Plots shows a complex pattern of rising and decreasing pressure derivative.

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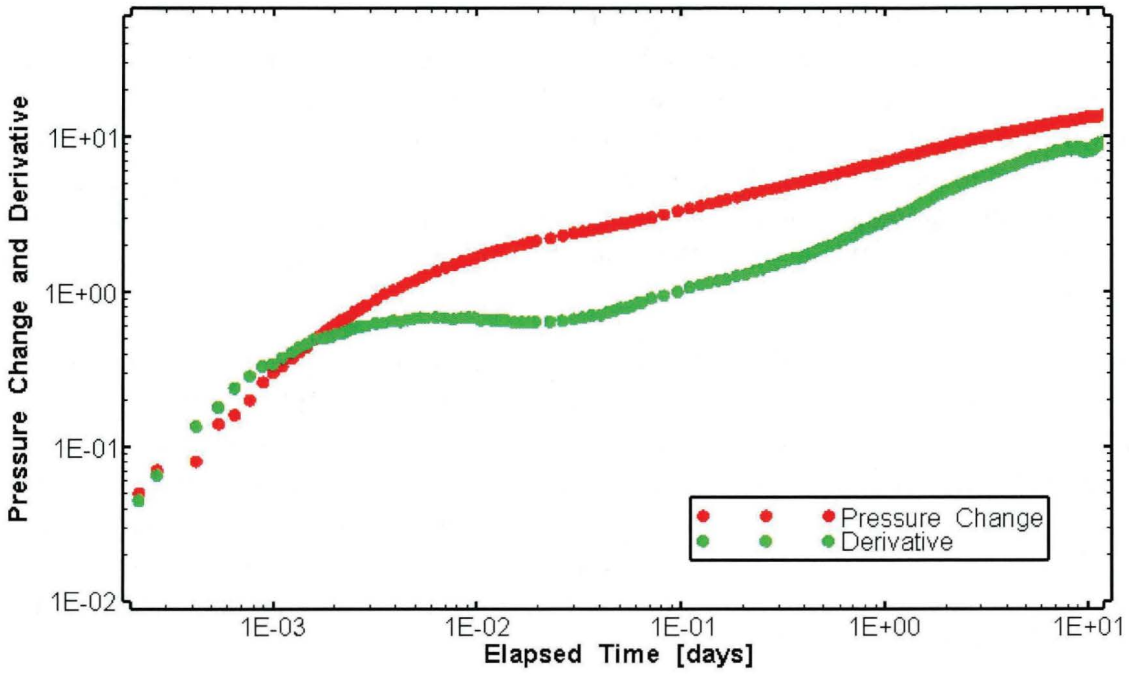


Figure 3: Diagnostic plots of P-14. The pressure derivative curve (green dots) shows an initial wellbore storage followed by radial stabilization (n=2) and rise (n<2) in the derivative.

Although flow dimension variations are readily apparent from pressure derivative plots, interpretation of these variations is less straightforward. The difficulty arises when trying to incorporate these variations into hydraulic parameters estimation. Doe (1991) suggested that flow dimensions could be interpreted in three different ways. The fist approach assumes that the geometry of the flow area is constant, and thus variations in flow dimension reflect the hydraulic parameters heterogeneity. The second approach explains variations in flow dimension by changes in flow area geometry; in this case, the hydraulic parameters are assumed homogeneous. Figure 4 illustrates the first two approaches. The third approach assumes that flow dimension variations are due to some combination of the variation in flow area geometry and hydraulic parameters heterogeneity. The third approach seems the most realistic in natural settings, however, in practice it is difficult to implement. This is because independent knowledge of how hydraulic parameters and flow dimension vary spatially is often not available. Moreover, trying to estimate both hydraulic parameters and flow dimensions based on single-well pumping tests often lead to an ill-inverse problem, and increases the non-uniqueness of the solution.

For some of the wells considered in this report, the previous pumping test analyses (Beauheim, and Roberts, 1998; Roberts 2006, 2007) assumed a radial flow geometry, and thus, variations in flow dimension are only due to changes in transmissivity. This study aims at exploring the alternative approach, where hydraulic parameters are assumed homogeneous and variations in flow dimension are accounted for by changes in the flow area geometry.

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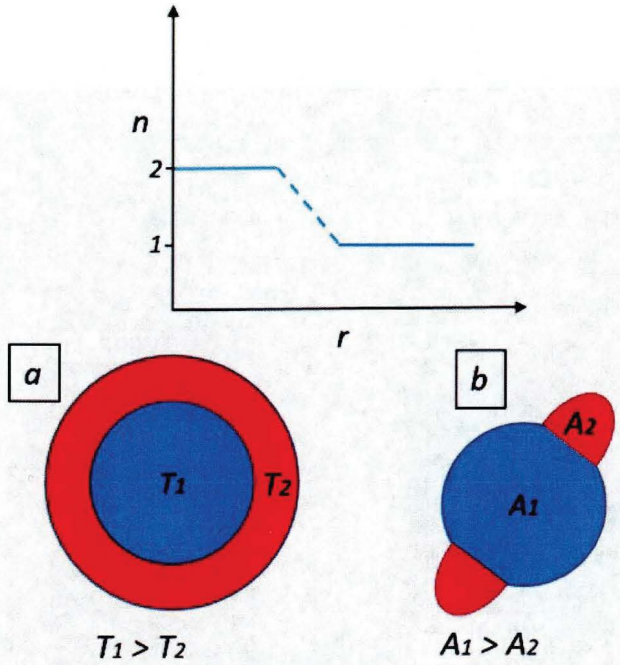


Figure 4: Illustration of two methods for interpreting flow dimensions. a) The flow dimension sequence 2-1 is due to a decrease in transmissivity; b) change in flow dimension 2-1 is due to flow area restriction.

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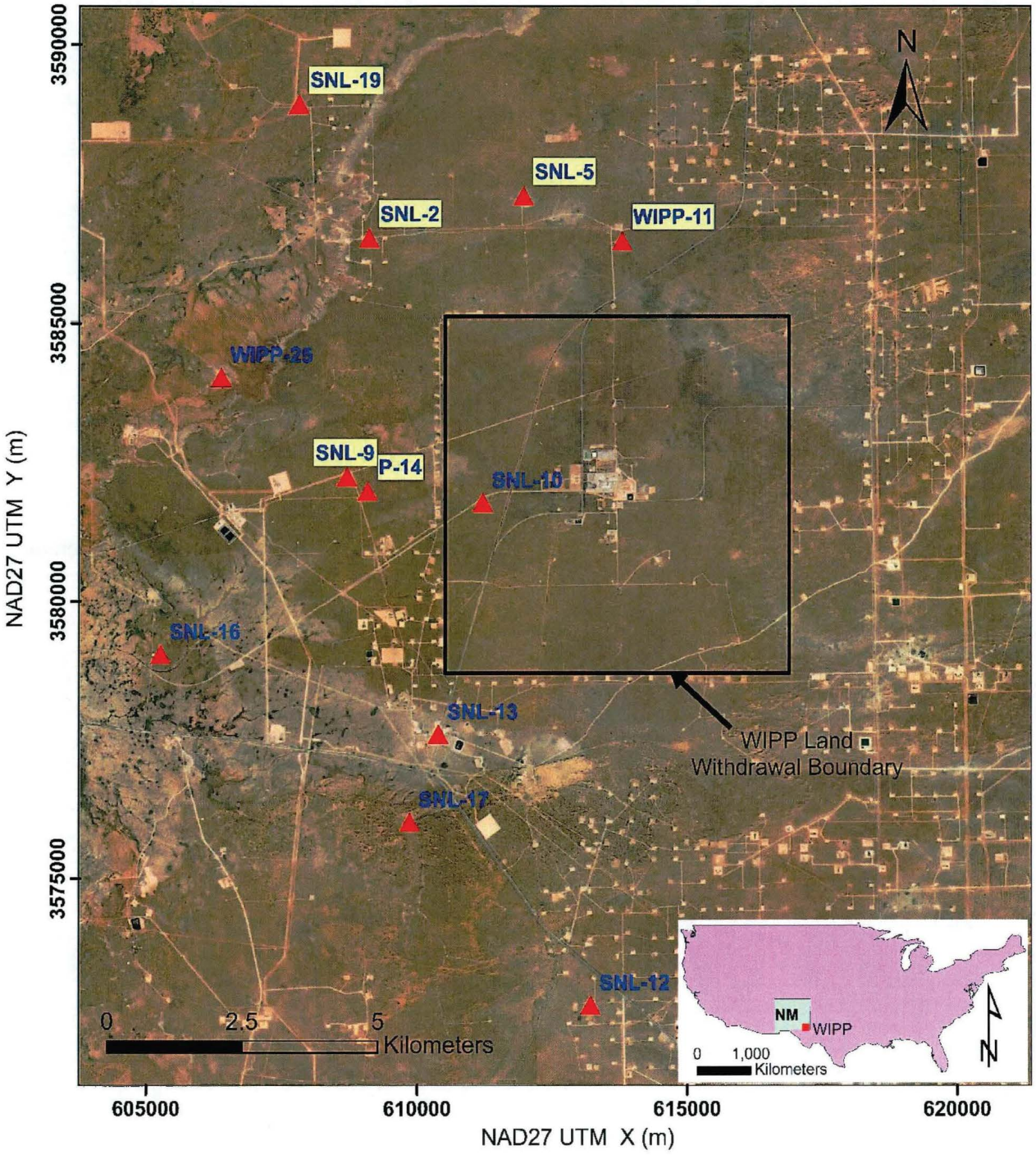


Figure 5: Map of the 12 wells reviewed in this analysis (red triangles). The six wells reanalyzed are highlighted in yellow.

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3. Methodology

3.1. nSIGHTS Overview

The nSIGHTS (n-dimensional Statistical Inverse Graphical Hydraulic Test Simulator) software package was used for the pumping test analysis. nSIGHTS is a well-test analysis code that simulates a single-phase, one- or two- dimensional, radial or non-radial flow regime, with a borehole at the center of the modeled flow system. It consists of two independent applications: nPre.exe and nPost.exe. The nPre application is used to pre-process the pumping test data, define the mathematical model, run the inverse model to estimate hydraulic parameters of interest, and perform the uncertainty quantification. The diagnostic plots, used to infer the flow area geometry and aquifer conditions, are also generated using the nPre application. The nPost allows for statistical analysis and plotting of the nPre results.

3.2. Review of previous pumping test analysis

The conceptual flow model used to estimate hydraulic parameters is often the greatest source of uncertainty. Hence, this review focuses on the conceptual flow model previously used to estimate hydraulic parameters. Figure 5 shows the twelve wells reviewed in this report, and details about these pumping test can be found in Beauheim (1987), Stensrud et al. (1990), and Roberts (2006, 2007). For pumping test analyses, the conceptual flow model specifies the flow dimension (radial vs. non-radial), the type of porosity (single vs. double), the presence or absence of a skin zone, and wellbore storage.

Pumping test diagnostic plots were used to infer the conceptual flow model. At the exception of P-14, all wells reviewed in this study are constant rate tests. Thus, the diagnostic plot was a log-log plot of the pressure change and the derivative of pressure as a function of elapsed time. Note that the pressure derivative is computed with respect to the natural log of time, as described in Bourdet (1989). The variation in pressure derivative was used to specify the conceptual flow geometry near the pumping well. No further action is taken if the previous conceptual flow model is similar to that of this review. However, pumping tests are reanalyzed if an alternative model can be proposed.

Table 1 shows the previous and new conceptual flow models for the twelve wells reviewed. Associated well files will be archived in the /nfs/data/CVSLIB/WIPP_EXTERNAL/AP070 directory. Based on the review results, six wells were selected for reanalysis. For the remaining six wells, the new and previous conceptual models are similar, and thus no need for reanalysis. Several reasons justify the need to reanalyze some of wells. The first reason concerns the use of variable $-T$ and radial flow model to account for variations in the pressure derivative for hydrogeology that has the potential to be non-radial, at SNL-2, SNL-5, SNL-19, and WIPP-11. Second, a dual-porosity and radial flow model is used for SNL-9. A dual-porosity model implies the presence of a fracture system and a matrix system with distinct hydraulic parameters. This approach increases the number of parameters used in a model when the goal is to minimize the number of parameters used. A new model may achieve that goal. Finally, P-14 hydraulic parameters were estimated using a type-curve method described by Theis (1935). Note that the Theis solution is and analytical solution that may not be ideal for the complex hydrogeology of

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the Culebra. As noted in Section 2, these wells can be reanalyzed using a variable -*n* and constant -*T* flow model.

Table 1: Results of the pumping tests review

Wells	Previous Conceptual Model	Reference	New Conceptual Model
*P-14	Theis solution Radial flow	Beauheim, 1987 Stensrud, 1990	Composite -*n* Constant *T*
*SNL-2	Composite -*T* Radial Flow	Roberts, 2006	Composite -*n* Constant *T*
*SNL-5	Composite -*T* Radial Flow	Roberts, 2006	Composite -*n* Constant *T*
*SNL-9	Dual porosity Radial Flow	Roberts, 2006	Single porosity Composite -*n*
SNL-10	Radial Flow	Roberts, 2007	Radial Flow
SNL-12	Dual-porosity Composite -*n*	Roberts, 2006	Composite -*n*
SNL-13	Radial-Flow	Roberts, 2007	Radial Flow
SNL-16	Dual-porosity Radial Flow	Roberts, 2007	Radial Flow
SNL-17	Dual- porosity Composite -*n*	Roberts, 2007	Composite -*n*
*SNL-19	Composite -*T*	Roberts, 2007	Composite -*n* Constant *T*
*WIPP-11	Composite -*T* Radial Flow	Roberts, 2006	Composite -*n* Constant *T*
WIPP-25	Radial Flow	Roberts, 2006	Radial Flow

* Pumping tests that were reanalyzed in this report

3.3. Pumping test reanalysis

The pumping test analysis follows the Analysis Plan AP-070 (Bowman, 2020). Prior to analysis, the pressure data were corrected for barometric and earth-tide effects, using the Specific Procedure SP 9-13 (Bowman, 2021). The barometric data were obtained from the Port-a-camp area at WIPP. For earth tide correction, synthetic earth tides were generated using TSoft Version 2.2.4 (Van Camp and Vauterin, 2005). Once the pumping test data were corrected for barometric and earth-tide effects, nSIGHTS was used to define sequences, calculate diagnostic derivatives, and generate diagnostic plots.

Pumping test analyses consisted of finding values of the fitting parameters that provide the best-simulated matches to the pressure data and diagnostics plots. Of the fitting parameters (transmissivity, flow dimension, static formation pressure, tubing string radius, etc.) considered in this report, transmissivity change and flow dimension were the main parameters of interest.

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Flow dimension and its diagnostic were of interest as they describe the non-radial nature of the model and potentially of the subsurface. Transmissivity values are of importance as they are used in the *T*-fields generation and WIPP performance assessment calculations. The correlation between estimated transmissivity and the other fitting parameters is taken into account when the uncertainty in *T* values is large. The uncertainty in *T* values was often small in this report; hence, the correlation between transmissivity and the other fitting parameters was not considered in this analysis.

For all pumping test analysis, the uncertainty in the estimated transmissivity was quantified using a "perturbation analysis". The first step in the perturbation analysis is to derive an acceptable fit to the pumping test data, given the parameter constraints specified in the nPre configuration file. The set of fitting parameter values estimated in this first step constitutes the baseline solution set. The next step in the perturbation analysis is to define, for each of the baseline fitting parameters, the minimum/maximum that corresponds to the parameter space of interest. Appendix B presents the fitting parameter ranges for all pumping tests. The final step of the perturbation analysis consists in adding random perturbations to the baseline solution set such that the new parameters values are within the predefined parameter range. The new set of parameter values is then optimized. The objective of the perturbation analysis is to sample the parameter space adequately and locate the global minima amongst local minima within the parameter space. The parameter space minimum that provides the smallest sum of squared errors (SSE) is the global minimum. For the purpose of these analyses, a weighted version of SSE, *Fit Value*, is used to describe model error.

For each of the pumping test analysis in this report, 500 perturbations/optimizations were performed. A scatter plot showing transmissivity values and corresponding Fit Values for the 500 simulations is presented. Of all perturbation results, only *T* values that provide a good fit (qualitatively) and fall within the global minimum are used to compute the geometric mean of *T*. The final number of satisfactory perturbation results for each pumping test is presented in Section 4.

4. Pumping Test Analysis Results

4.1. P-14

The pressure data used in this analysis was derived from a 72-hour air-lift pumping test performed at P-14 in 1989. The pumping test was conducted from February 14 through 17, 1989, and recovery was monitored until March 10, 1989. The total volume of water pumped during the 72-hour test was approximately 248,000 gallons, which corresponds to an average pumping rate of 57.5 gpm. The variation of pumping rate as a function of time was included in the analysis. Details (start/end time, porosity type, flow rate, etc…) of the nSIGHTS sequences are specified in the P-14.nPre and listed in Appendix B.1.

P-14 pressure derivative shows an initial stage suggestive of wellbore storage and skin effect. The initial wellbore storage phase is followed by a brief period of radial stabilization, and a sharp rise in pressure derivative (n<2) (Figure 6). Based on these trends, a constant -n (n<2) flow

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system with wellbore storage and skin effect is used to analyze the P-14 pumping test (Figure 7). The geometric mean of *T*, based on the best 350 perturbation analysis results, is 7.18E-03 m^2/s (Figures 6, 8, and 9).

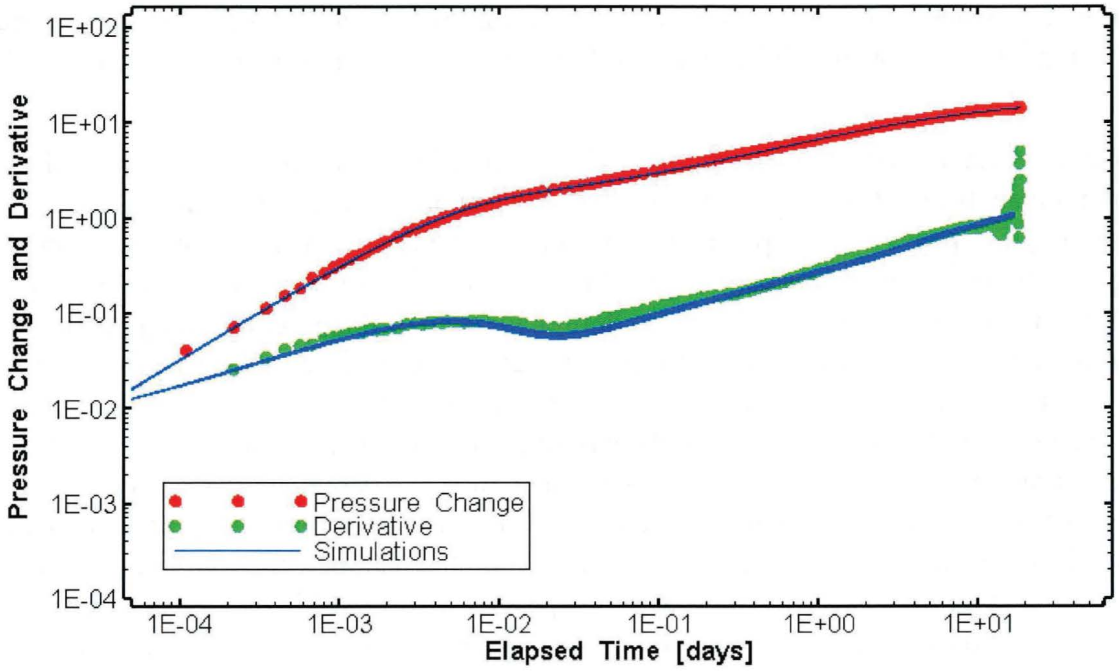
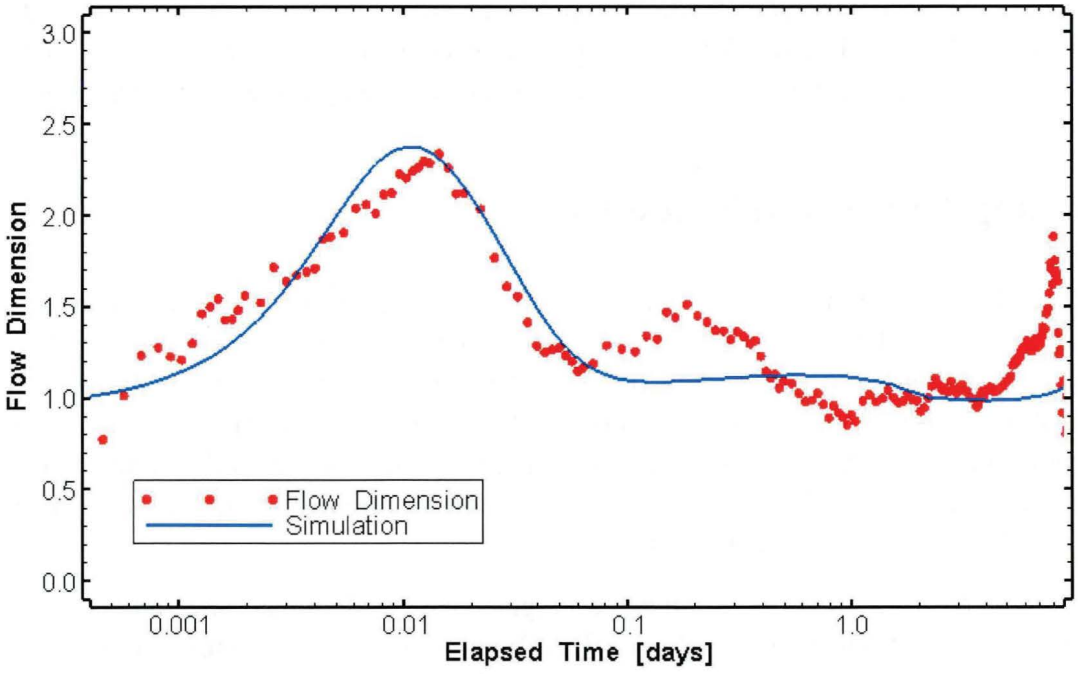


Figure 6: Plot showing the observed pressure change and derivative during P-14 recovery (red and green dots). The blue lines are the best 350 simulations derived from the perturbation analysis.



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Figure 7: Observed and simulated flow dimension for P-14 recovery. Note that the blue line is the baseline fit, prior to the perturbation analysis.

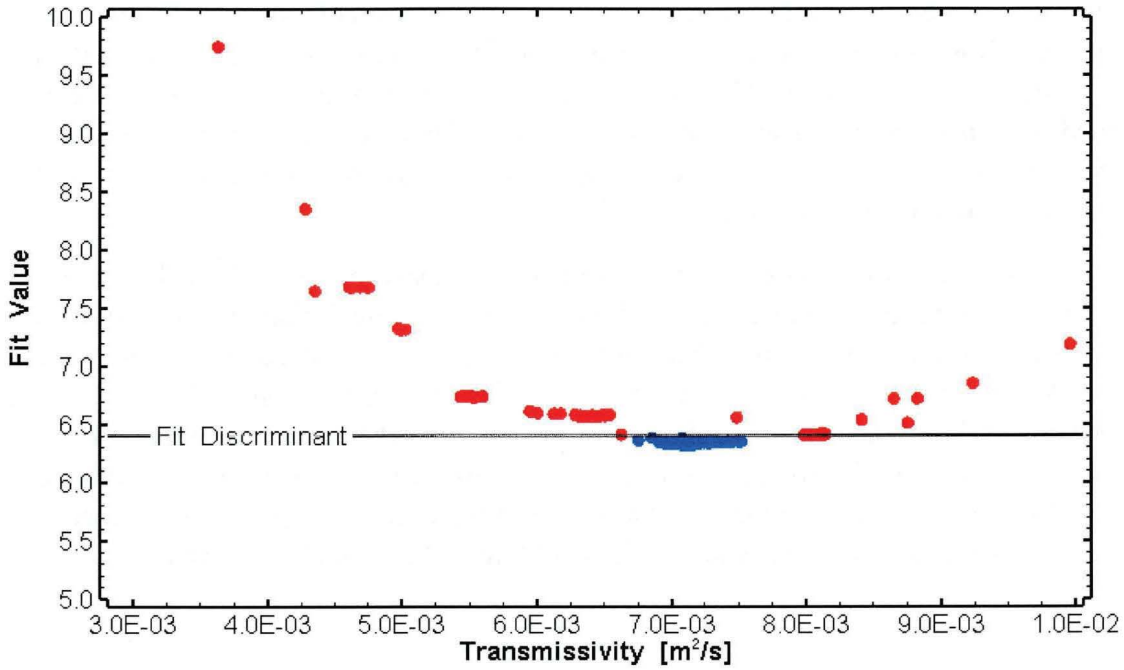
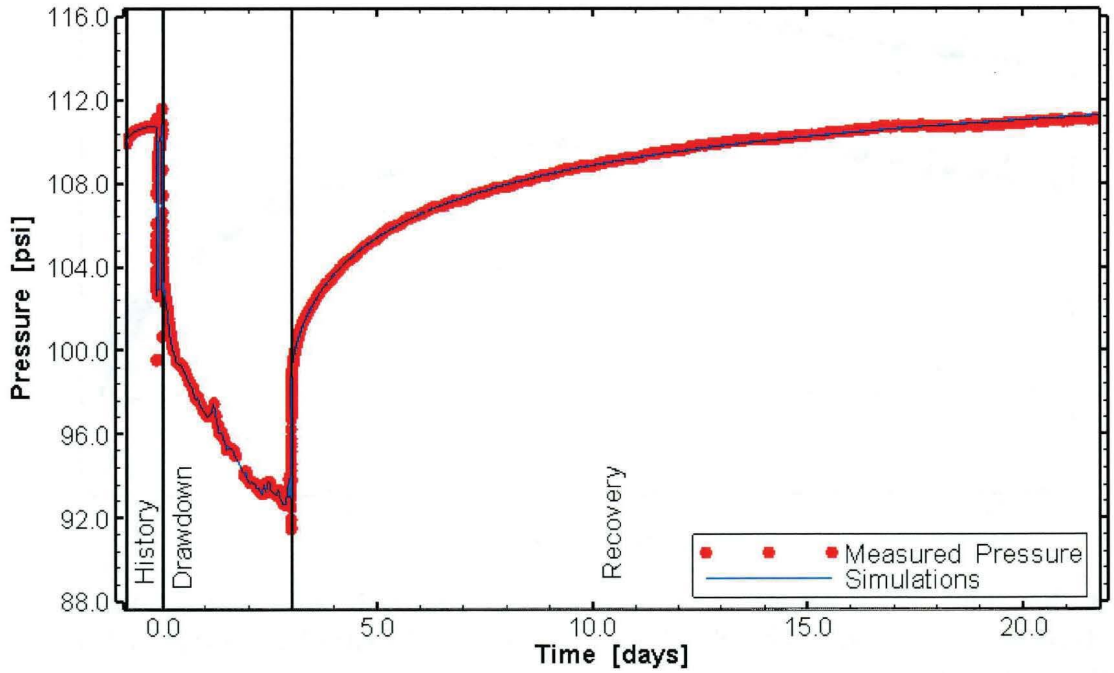


Figure 8: Scatter plot showing P-14 transmissivity values based on the perturbation analysis. Values greater than the fit discriminant are represented by the red dots. Blue dots represent the 350 best fits.



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Figure 9: Plot showing the measured pressure at P-14 (red dots) and the best 350 simulations (blue lines).

4.2. SNL-2

The pumping test at SNL-2 started on January 20, 2005. The test consisted of ~96-hour constant rate pumping followed by recovery. SNL-2 was pumped at a constant rate of 12 gpm. Pressure data from January 20 through 28, 2005 were included in this analysis. The pumping test was subdivided into three nSIGTHS sequences (history, drawdown, and recovery). More information (start/end time, porosity type, flow rate, etc…) about these sequences are presented in the SNL-2.nPre file and listed in Appendix B.2.

The pressure derivative plot was interpreted as a single porosity, constant -T, and composite -n flow system with wellbore storage. Figure 10 and 11 show an initial phase (<60 min) of subtle rise in pressure derivative; this can be interpreted as a sub-radial flow regime (n<2). The pressure derivative declines slightly from ~170 to 600 min, corresponding to a non-radial flow regime (n>2). Beyond 700 min the derivative shows a sharp decline, which can be interpreted as spherical flow regime (n=3). The function describing flow dimension variation is implemented in the nSIGHTS model, using three flow dimension points (Figure 11). The geometric mean of the 422 best fits gives a transmissivity value of 2.50E-03 m^2/s (Figures 10, 12, and 13).

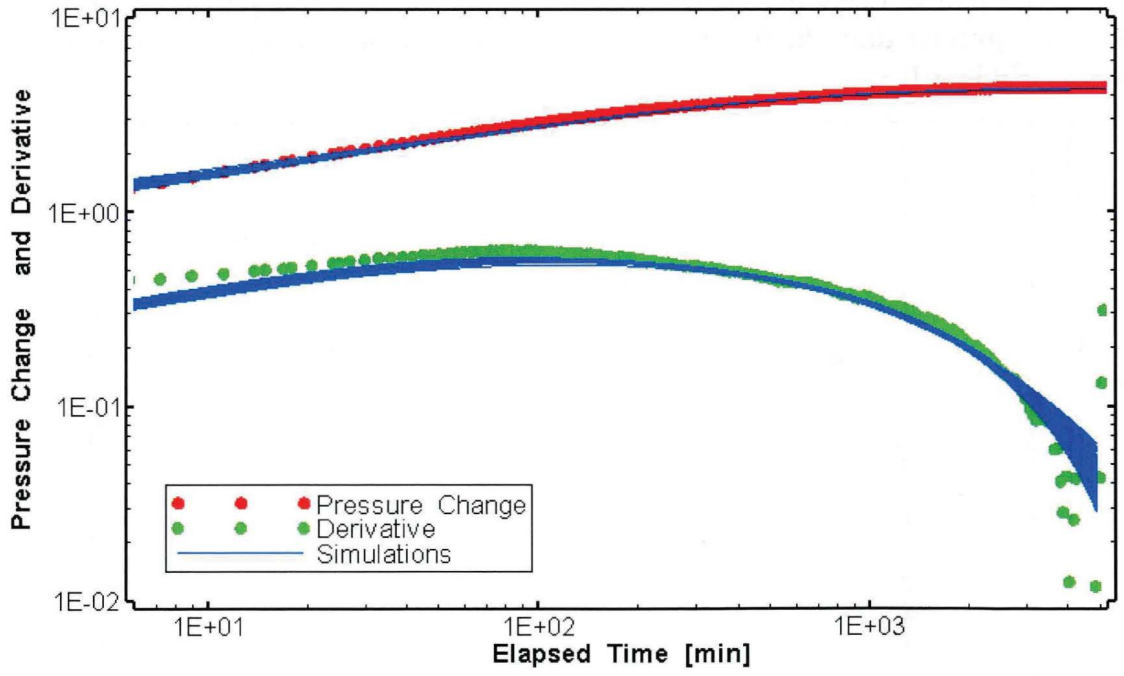


Figure 10: Plot showing the observed pressure change and derivative during SNL-2 recovery (red and green dots). The blue lines are the best 422 simulations derived from the perturbation analysis.

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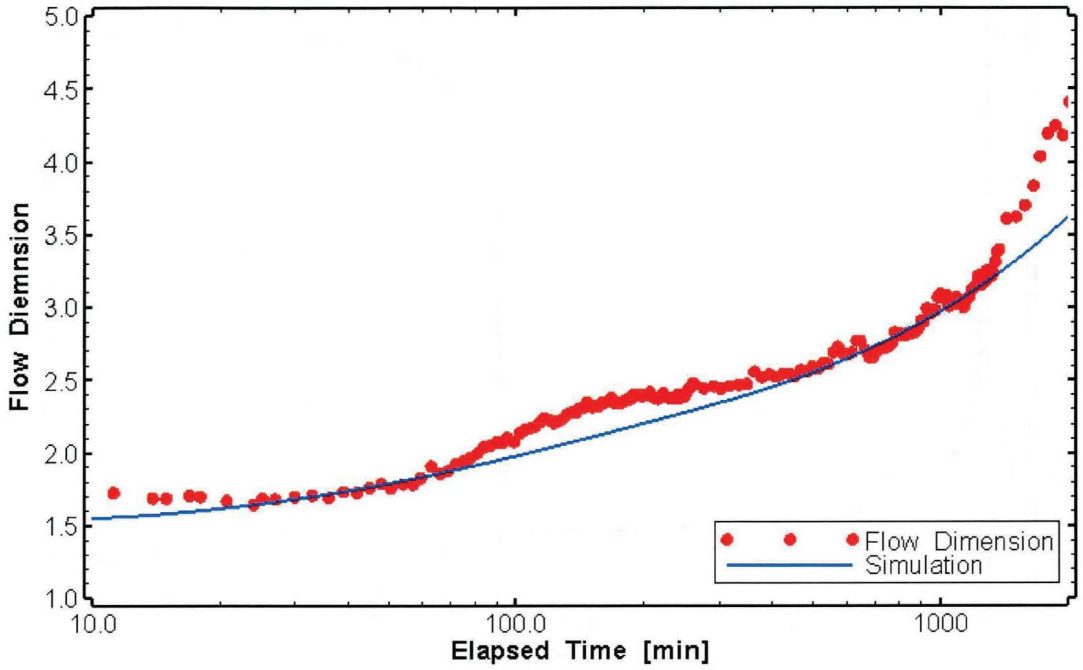


Figure 11: Observed and simulated flow dimension for SNL-2 recovery. Note that the blue line is the baseline fit, prior to the perturbation analysis.

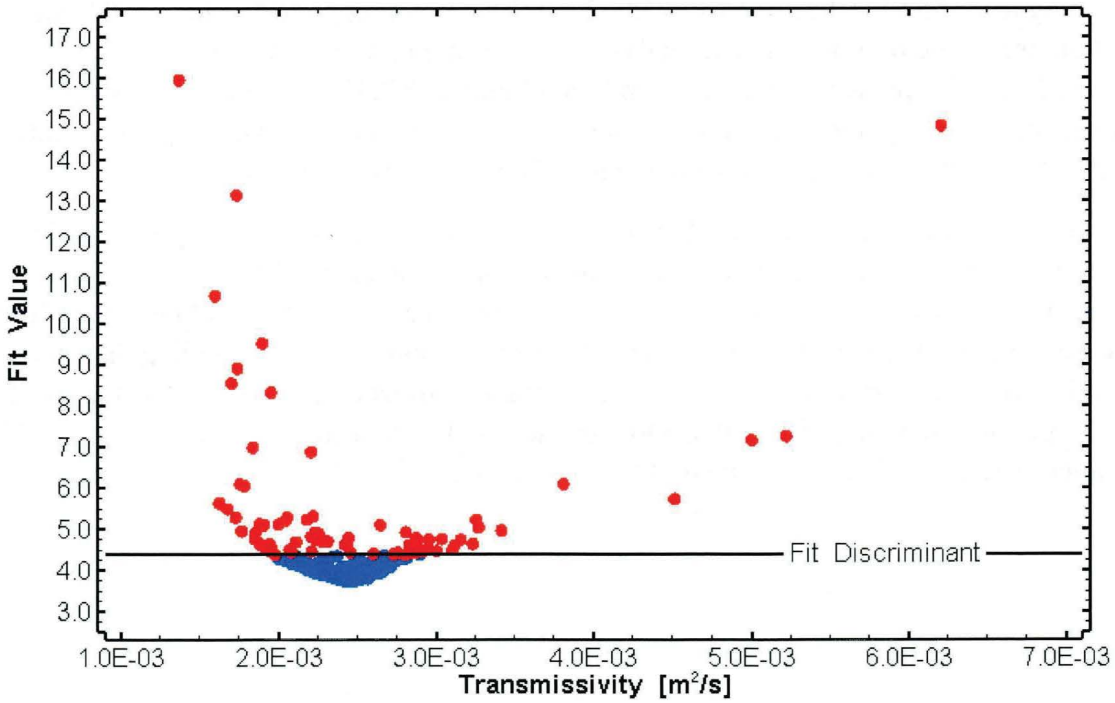


Figure 12: Scatter plot showing SNL-2 transmissivity values based on the perturbation analysis. Values greater than the fit discriminant are represented by the red dots. Blue dots represent the 422 best fits.

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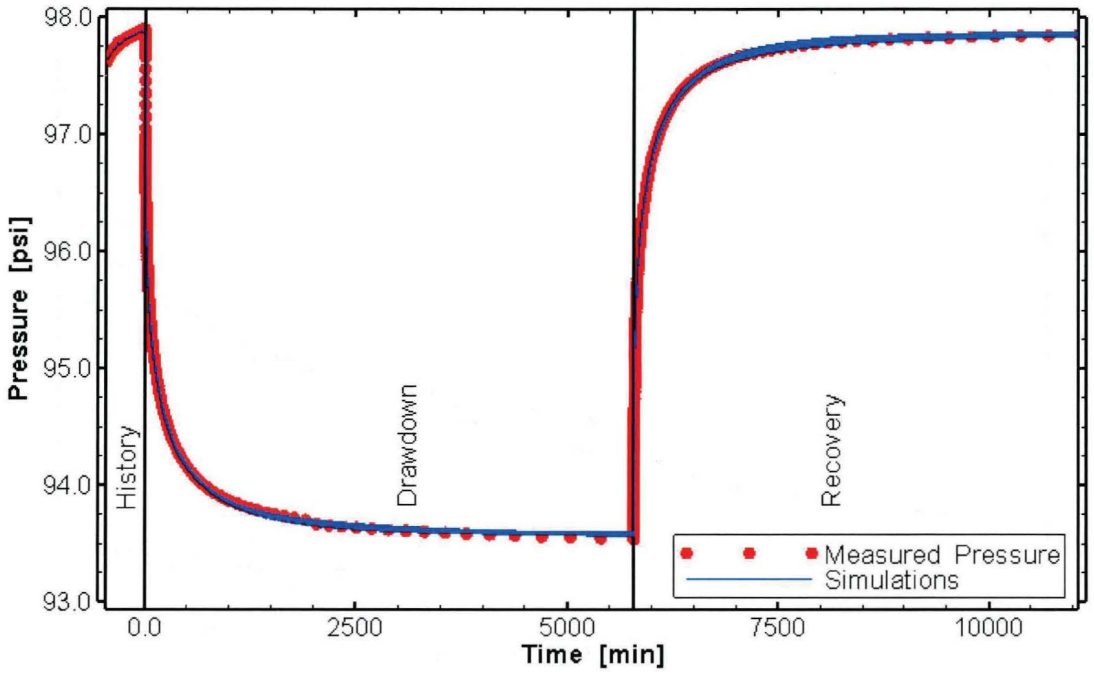


Figure 13: Plot showing the measured pressure at SNL-2 (red dots) and the best 422 simulations (blue lines).

4.3. SNL-5

The pumping test of SNL-5 began on July 20, 2004. The pumping period lasted for 94-hour at a constant pumping rate of 3.5 gpm. The analysis was based on pressure data from July 19 to August 18, 2004. The pressure data were subdivided into 3 nSIGHTS sequences: history, drawdown, and recovery. Details of these sequences (start/end time, porosity type, flow rate, etc…) are presented in the SNL-5.nPre file, which is listed in Appendix B.3.

Based on the pressure derivative of SNL-5 recovery period, a constant -*T*, composite -*n* flow system with wellbore storage and skin effect was used in this analysis (Figure 14). After the initial wellbore storage phase, the pressure derivative shows a continuous decline, which leads to an increase in the flow dimension value. Three flow dimension and corresponding distance were used in this analysis; these values were derived through optimization in nSIGHTS (Figure 15). Of the 500 perturbation analysis results, 440 were selected as best fits (Figures 14, 16, and 17). The geometric mean of *T* based on the 440 fits is 3.22E-05 m^2/s.

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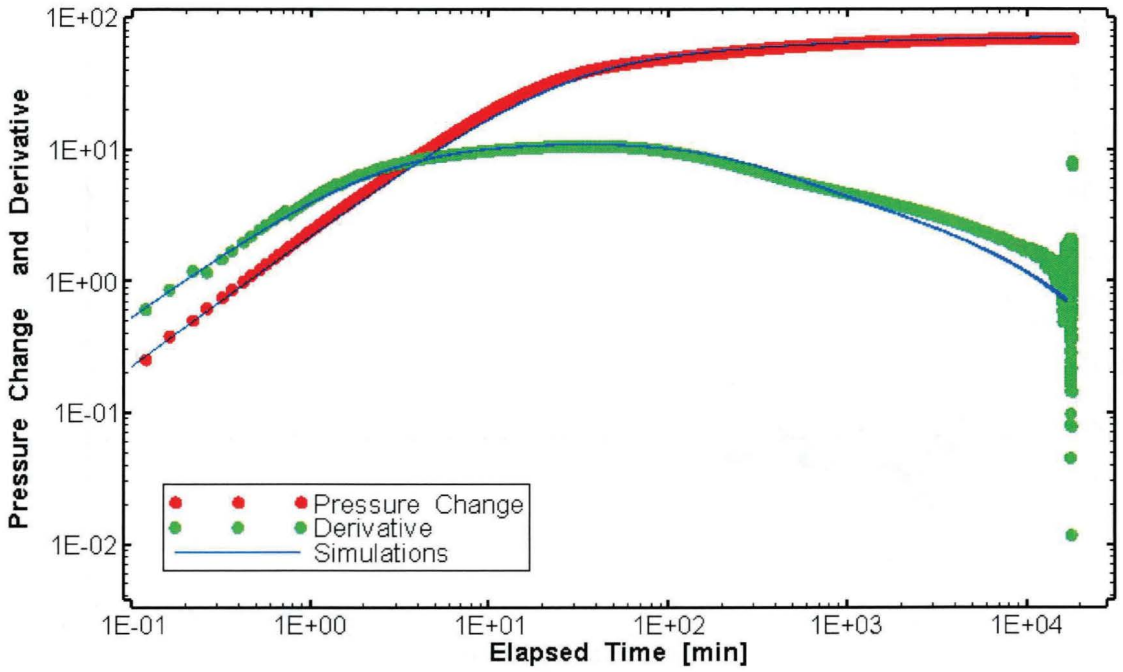


Figure 14: Plot showing the observed pressure change and derivative during SNL-5 recovery (red and green dots). The blue lines are the best 440 simulations derived from the perturbation analysis.

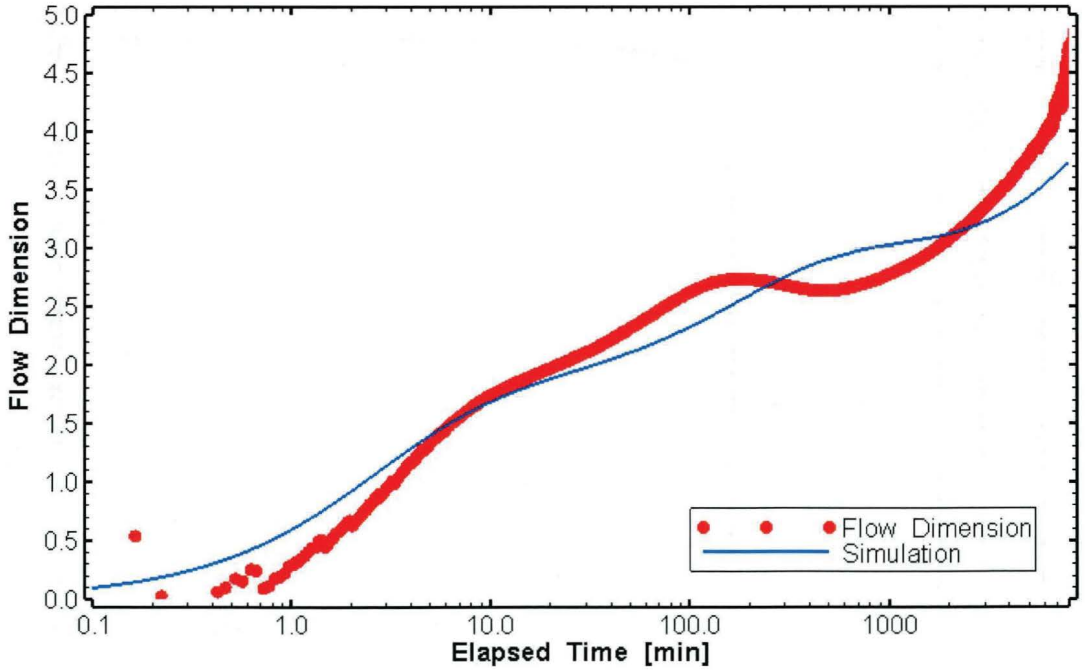


Figure 15: Observed and simulated flow dimension for SNL-5 recovery. Note that the blue line is the baseline fit, prior to the perturbation analysis.

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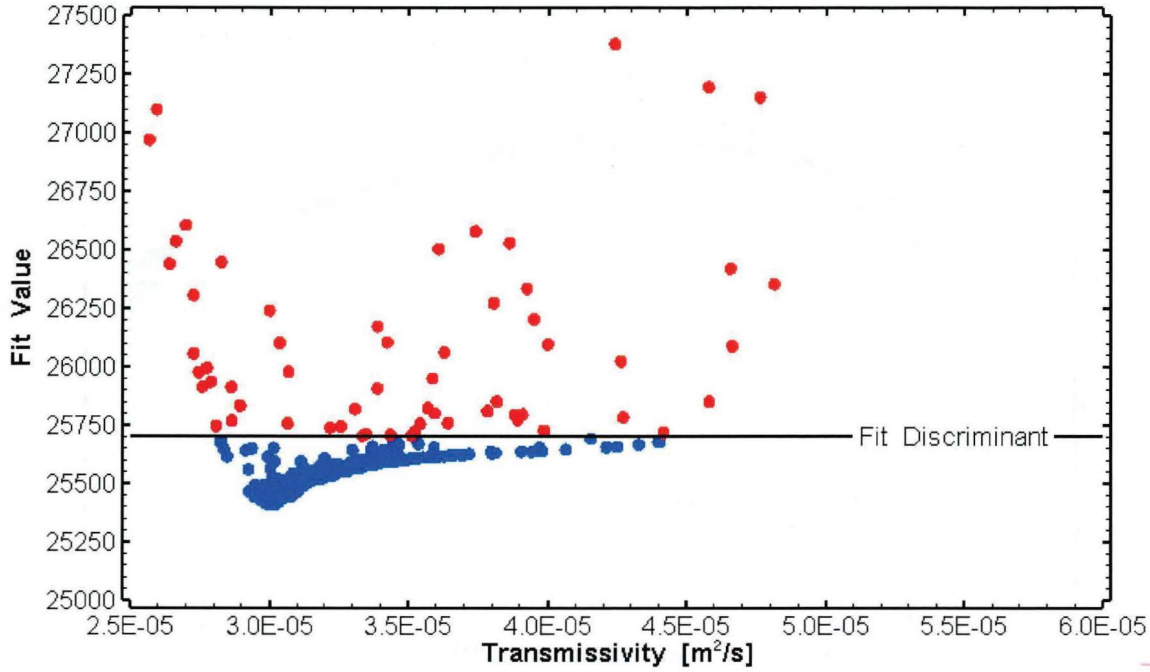


Figure 16: Scatter plot showing SNL-5 transmissivity values based on the perturbation analysis. Values greater than the fit discriminant are represented by the red dots. Blue dots represent the 440 best fits.

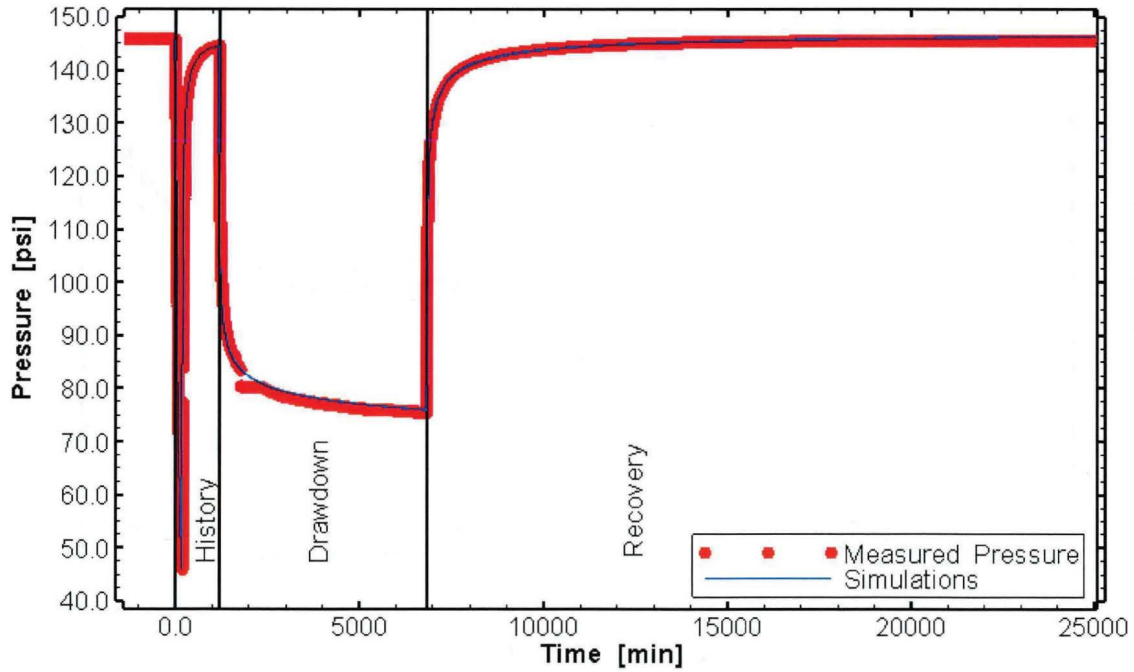


Figure 17: Plot showing the measured pressure at SNL-2 (red dots) and the best 440 simulations (blue lines).

Information Only

4.4. SNL-9

The pumping test started on December 2, 2003. SNL-9 was pumped at a constant rate of 12.5 gpm, for approximately 90.6-hour. The pressure data from December 2 through 17, 2003 were used. The pressure data were subdivided into three nSIGHTS sequences. Details of each sequence (start/end time, porosity type, flow rate, etc…) are presented in the SNL-9.nPre file and listed in Appendix B.4.

The pressure derivative in Figure 18 indicates a dual-porosity system with wellbore storage and time dependent positive skin effect. From 0.1 to ~10 min, the pressure derivative approximates a 45° straight line, which is characteristic of wellbore storage. The wellbore storage phase spans almost two log cycles, which indicates a positive skin effect. Following the wellbore storage phase, the pressure derivative declines sharply, reaches a minimum at ~300 min, and rises until 10000 min. The decline-rise sequence in the pressure derivative is typical of a double-porosity system. In the previous analysis, a dual-porosity with radial flow was used to simulate SNL-9. Thus, the fracture and matrix hydraulic conductivity and specific storage were specified independently. Such an approach increases the number of fitting parameters, which in turn increases the non-uniqueness of the solution. Hence, a single porosity flow system with spatially variable flow dimension was used in this analysis. The function describing flow dimension variation is implemented in the nSIGHTS model, using five flow dimension points (Figure 19). The geometric mean of T, based on the best 135 perturbation analysis results, is 4.16E-06 m^2/s (Figure 18, 20, and 21).

Information Only

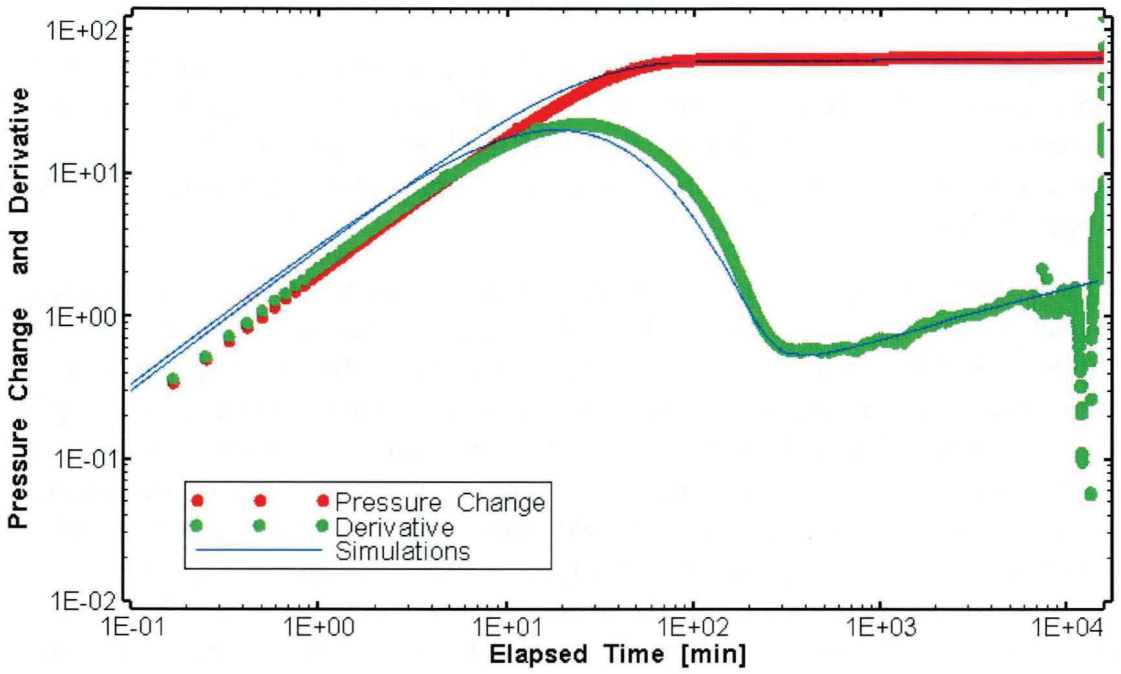


Figure 18: Plot showing the observed pressure change and derivative during SNL-9 recovery (red and green dots). The blue lines are the best 135 simulations derived from the perturbation analysis.

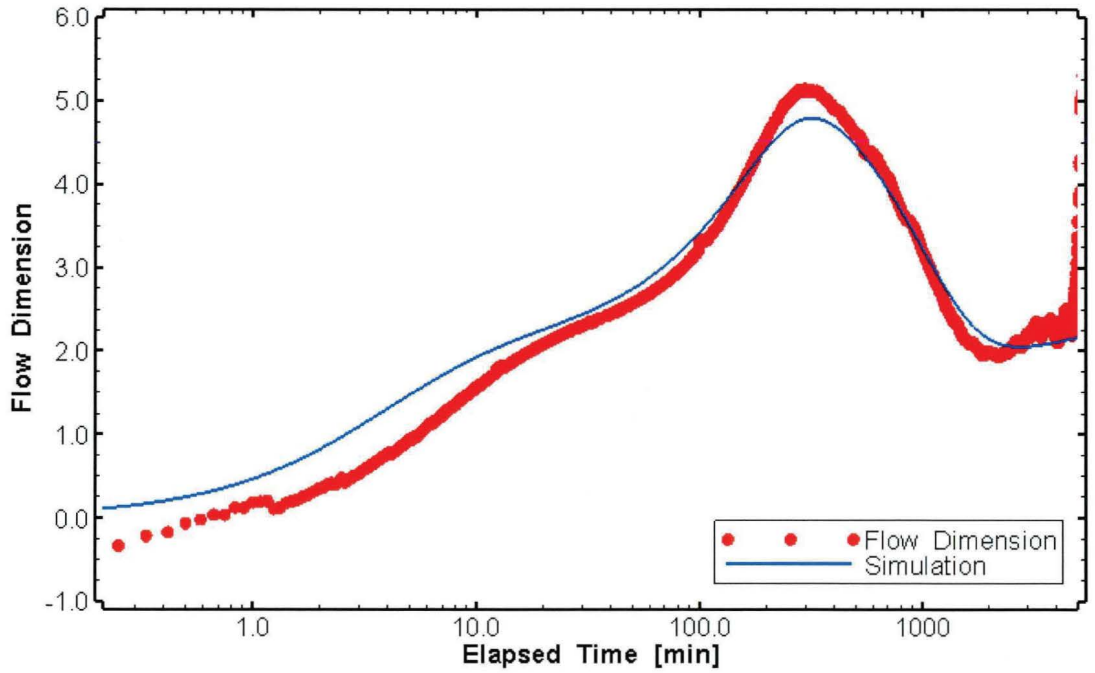


Figure 19: Observed and simulated flow dimension for SNL-9 recovery. Note that the blue line is the baseline fit, prior to the perturbation analysis.

Information Only

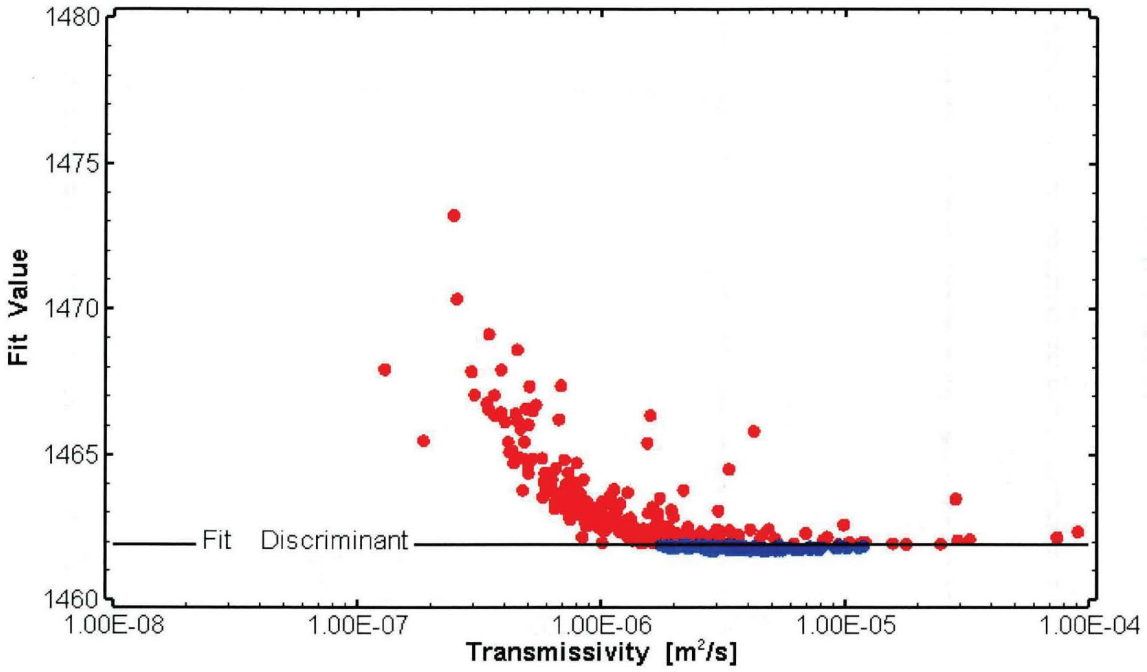


Figure 20: Scatter plot showing SNL-9 transmissivity values based on the perturbation analysis. Values greater than the fit discriminant are represented by the red dots. Blue dots represent the 135 best fits.

Information Only

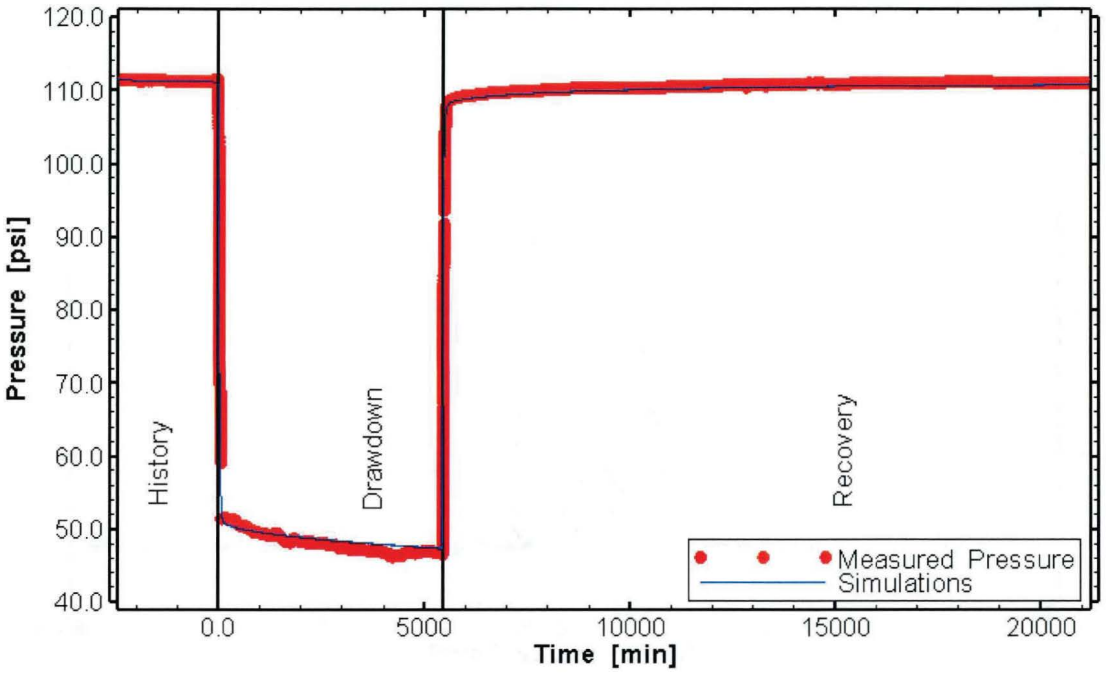


Figure 21: Plot showing the measured pressure at SNL-9 (red dots) and the best 135 simulations (blue lines).

4.5. SNL-19

SNL-19 was pumped at a constant rate of 30 gpm, starting on July 24, 2006. The pumping lasted for four days. Pressure data from July 12 to August 07, 2006 were included in this analysis. Details (start/end time, porosity type, flow rate, etc…) of the nSIGHTS sequences are specified in the SNL-19.nPre and listed in Appendix B.5.

The pressure derivative shows an initial phase (< 1 min) of wellbore storage and skin effect. The initial phase is followed by a transition period where the derivative declines sharply (n>2). Beyond 40 min, a steady decline in pressure derivative is observed. Given the above-mentioned trends, a composite -n flow system with wellbore storage and positive skin effect was used to simulate the SNL-19 pumping test. In nSIGHTS, four pairs of flow dimension (n) and distance (r) values were used to reproduce the variations in pressure derivative (Figure 23). The geometric mean of T, based on the best 134 perturbation analysis results, is 1.79E-04 m^2/s (Figures 22, 24, and 25).

Information Only

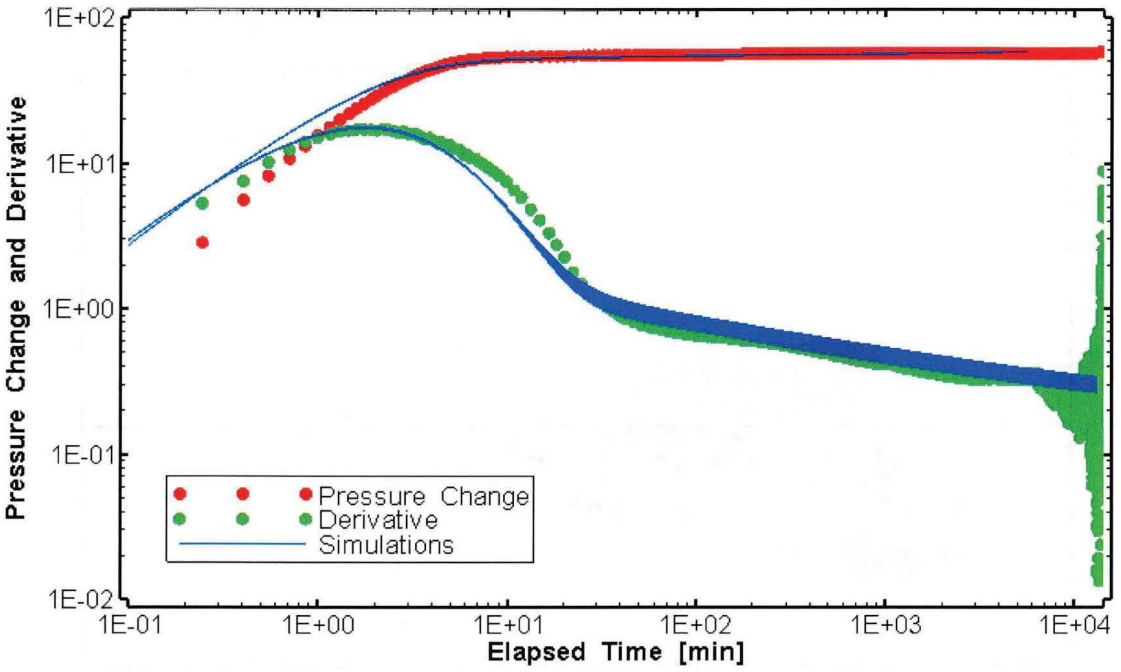


Figure 22: Plot showing the observed pressure change and derivative during SNL-19 recovery (red and green dots). The blue lines are the best 134 simulations derived from the perturbation analysis.

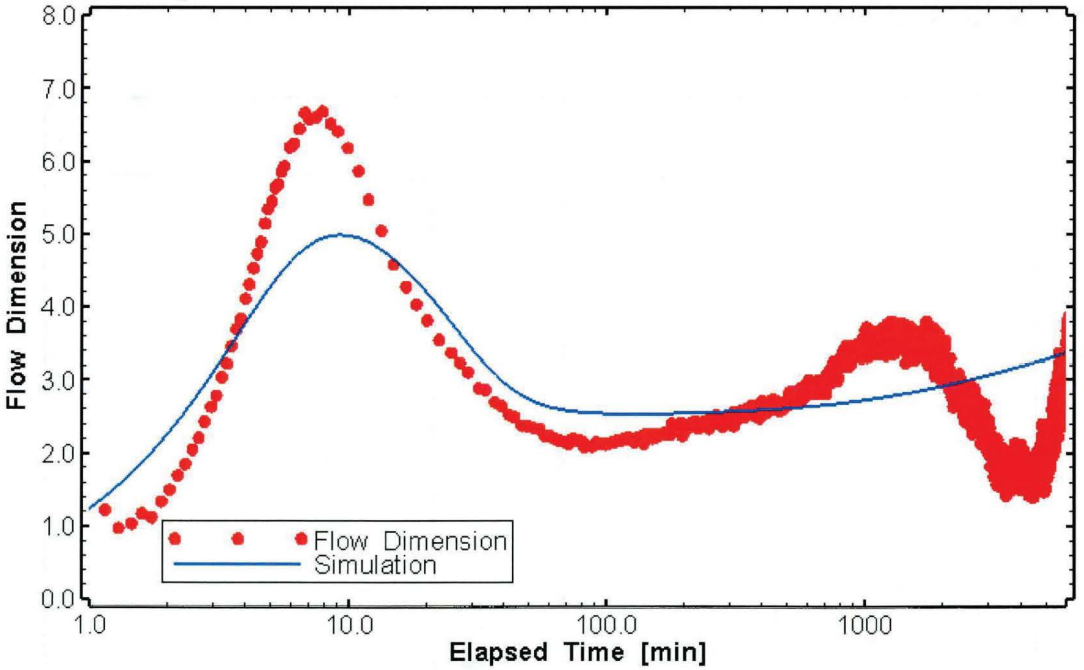


Figure 23: Observed and simulated flow dimension for SNL-19 recovery. Note that the blue line is the baseline fit, prior to the perturbation analysis.

Information Only

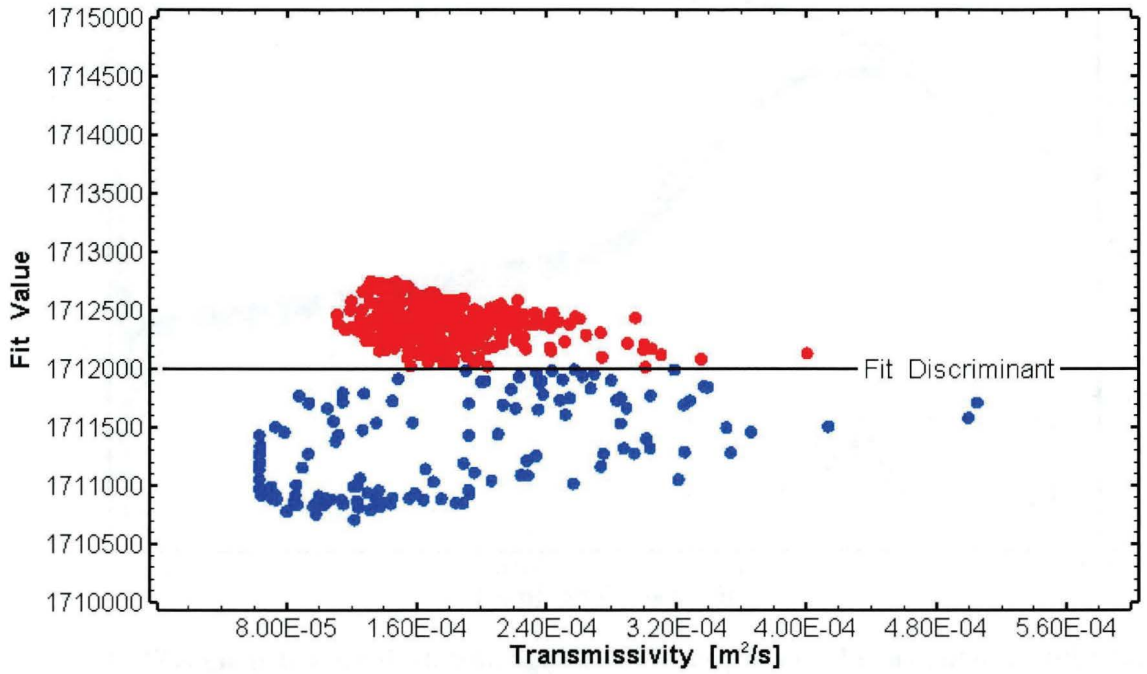


Figure 24: Scatter plot showing SNL-19 transmissivity values based on the perturbation analysis. Values greater than the fit discriminant are represented by the red dots. Blue dots represent the 134 best fits.

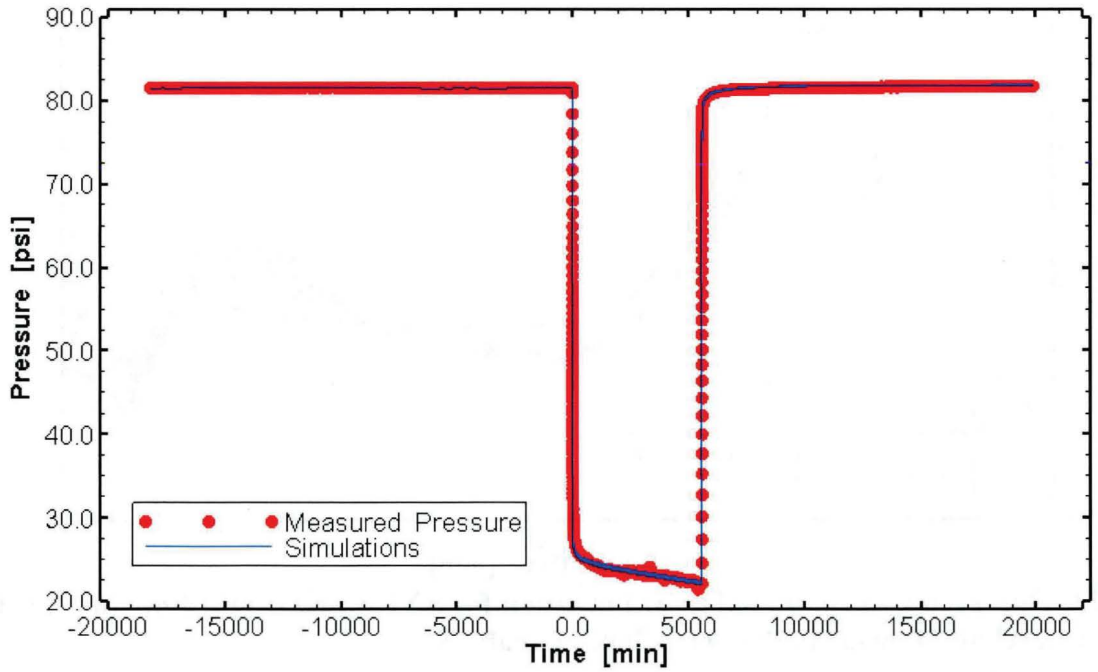


Figure 25: Plot showing the measured pressure at SNL-19 (red dots) and the best 134 simulations (blue lines).

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4.6. WIPP-11

A step-drawdown test was conducted on January 31, 2005, to evaluate the appropriate pumping rate. The pumping test at WIPP-11 started on February 1, 2005, and lasted for 20 days. WIPP-11 was pumped at a rate of 35 gpm. Pressure data from February 1 to April 4, 2005 were subdivided into eight nSIGHTS sequences, which form the basis of this analysis. Details (start/end time, porosity type, flow rate, etc…) of the eight nSIGHTS sequences are specified in the WIPP-11.nPre and listed in Appendix B.6.

WIPP-11 pressure derivative shows an oscillation pattern with rising and declining pressure derivative (Figure 26). Based on these trends, a composite -*n* flow system with wellbore storage and skin effect is used to analyze the P-14 pumping test. Seven pairs of flow dimension and distance values were used to model the complex variation in pressure derivative (Figure 27). The geometric mean of *T*, based on the best 204 perturbation analysis results, is 1.00E-03 m^2/s (Figures 26, 28, and 29).

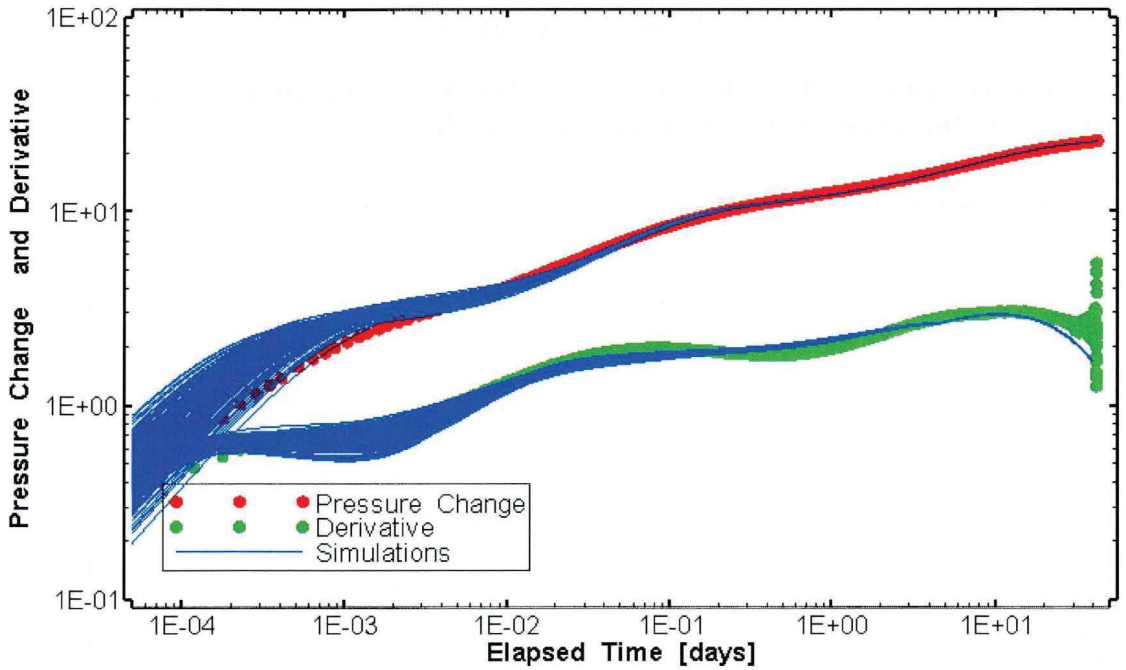


Figure 26: Plot showing the observed pressure change and derivative during WIPP-11 recovery (red and green dots). The blue lines are the best 204 simulations derived from the perturbation analysis.

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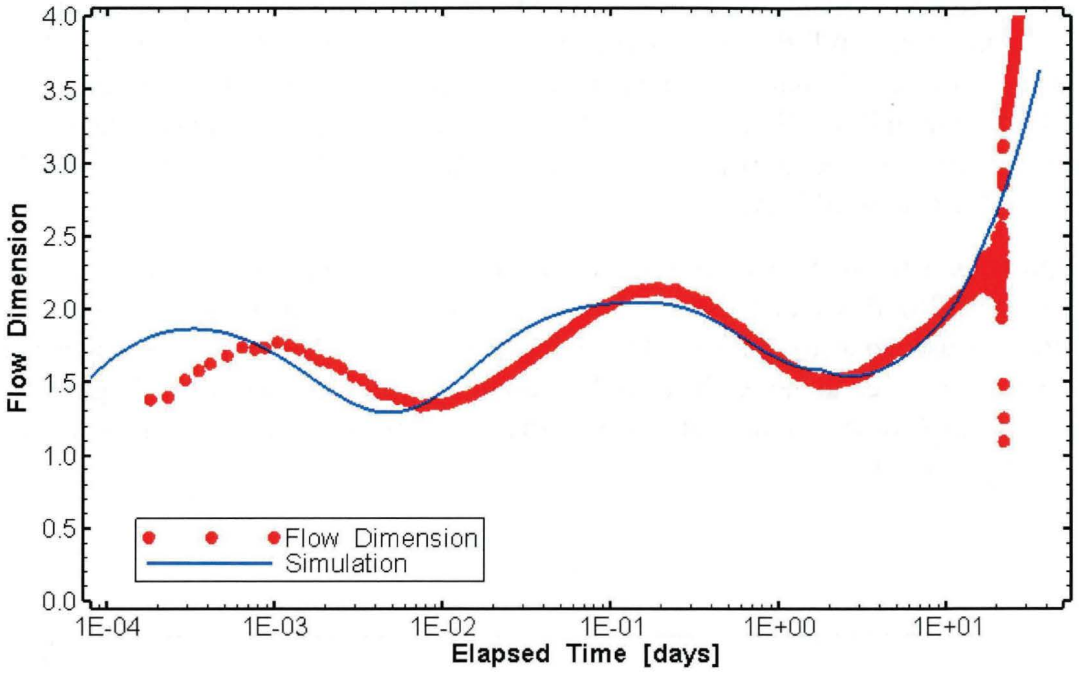


Figure 27: Observed and simulated flow dimension for WIPP-11 recovery. Note that the blue line is the baseline fit, prior to the perturbation analysis.

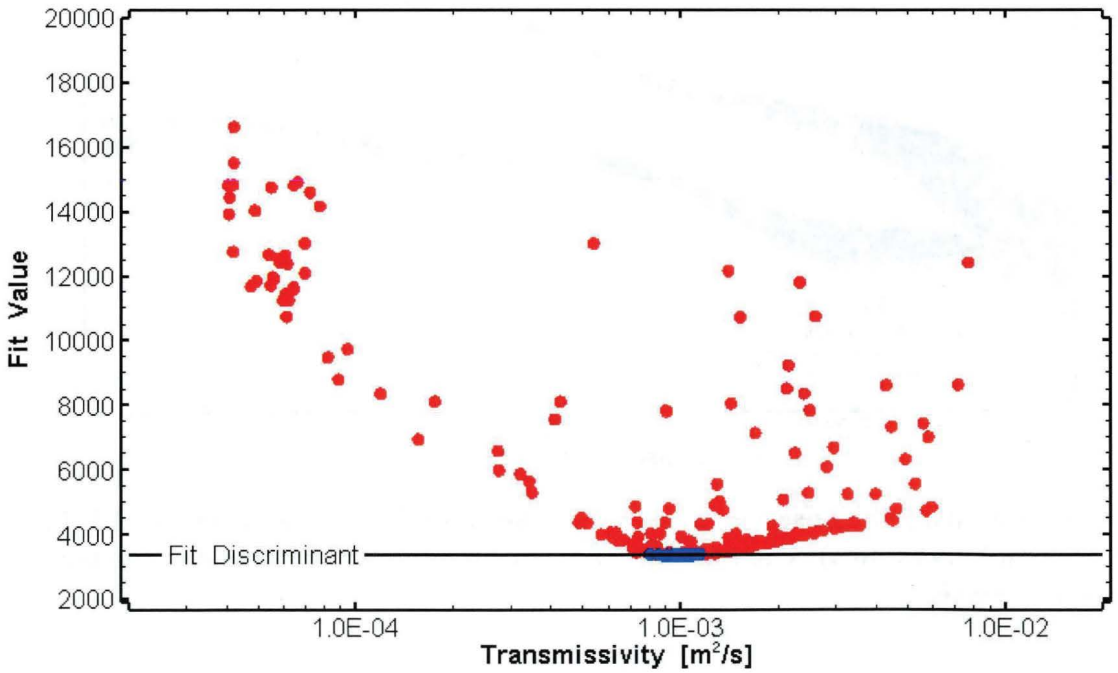


Figure 28: Scatter plot showing WIPP-11 transmissivity values based on the perturbation analysis. Values greater than the fit discriminant are represented by the red dots. Blue dots represent the 204 best fits.

Information Only

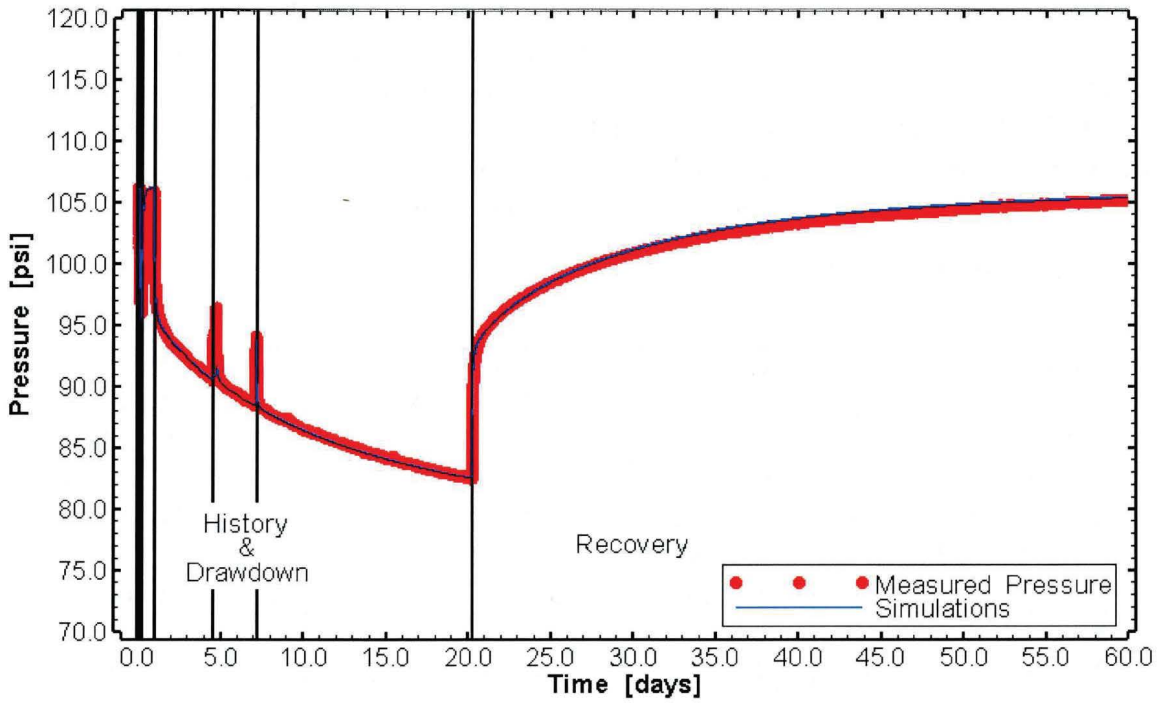


Figure 29: Plot showing the measured pressure at WIPP-11 (red dots) and the best 204 simulations (blue lines).

5. Discussion

The overarching goal of this report was to explore whether a variable flow geometry and constant transmissivity model can provide reasonable fits to pumping test data. Qualitatively, the measured and simulated flow dimensions, of the six wells reanalyzed in this study, are in good agreement. Four out of the six wells show extended period of sub-radial flow regime, which is suggestive of flow channeling. This is consistent with field observations from Holt (1997), who reported the presence of fractures at the WIPP site, especially in the western part. These results suggest that the variable -*n* and constant -*T* model is a reasonable approach to explain the complex derivative trends observed in the western part of WIPP. The diagnostic plots are quite different from one well to the other, which further indicates the highly heterogeneous nature of the subsurface at WIPP.

Table 2 presents the transmissivity values for the six wells reanalyzed in this study. For P-14, SNL-2, SNL-5, and WIPP-11, the new transmissivity values are higher than the previous values. The new transmissivity value for SNL-9 is significantly lower than that of the previous studies. Previous and new *T* values are similar, in the case of SNL-19. Overall, the differences are due to the use of variable and non-radial flow dimension values. Flow was assumed radial (n=2) in the previous analyses. As reported by several studies, assuming radial flow in sub-radial flow system leads to under-estimation of the transmissivity value. Conversely, assuming radial flow in a spherical flow system leads to over-estimation of the transmissivity value. The pressure

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derivative curve for SNL-9 indicates flow dimension values greater than 2, and thus, the new *T* value is lower compared to the previous analysis. For P-14, SNL-2, SNL-5, and WIPP-11, sub-radial ($n<2$) behavior can be observed in the pressure derivative, which explains the increase in *T* values. Similar trends were reported in the literature (e.g., Beauheim, 1998; Ferroud et al., 2018). Ferroud et al. (2018) used a Theis analytical model to estimate hydraulic conductivity under linear and spherical flow regimes, and found that this led to an overestimation and underestimation of the hydraulic conductivity values, respectively.

Table 2: Transmissivity values

Well	Minimum [m^2/s]	Maximum [m^2/s]	Variance	Geometric Mean [m^2/s]	Previous Geometric Mean [m^2/s]
P-14	6.75E-03	7.51E-03	1.29E-08	7.18E-03	3.16E-04
SNL-2	1.99E-03	2.89E-03	1.83E-08	2.50E-03	1.07E-04
SNL-5	2.83E-05	4.40E-05	5.44E-12	3.22E-05	4.86E-06
SNL-9	1.77E-06	1.10E-05	4.02E-12	4.16E-06	3.86E-05
SNL-19	6.34E-05	5.05E-04	9.20E-09	1.79E-04	4.26E-04
WIPP-11	8.07E-04	1.14E-03	2.44E-09	1.00E-03	4.27E-04

6. Conclusion

The conceptual flow models of 12 wells in the western WIPP monitoring network were reviewed. The review indicated that six out of the twelve wells could be reanalyzed using a variable *-n* and constant *T* model. Overall, the new transmissivity values are one order of magnitude higher (P-14, SNL-2, SNL-5, and WIPP-11), or lower (SNL-9) than that of the previous analyses. These noticeable differences result from the use of variable and non-radial flow dimensions. These results show that the variable *-n* and constant *T* model is a reasonable approach to estimate transmissivity; however, the values obtained from such analyses can only be used in combination with a good knowledge of the flow geometry. Hence, the new transmissivity values reported in this study cannot be used without further characterization of the directionality and spatial extent of the heterogeneities. Further studies that explore optimization techniques to better characterize heterogeneities may be required, in order to use these values in WIPP related calculations.

7. References

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Appendix A – Culebra Hydraulic Tests

Well	Date and Time Start Pump	Date and Time Stop Pump	Borehole Diameter (in)	Inside Casing Diameter (in)	Culebra Interval (ft)	Specific Gravity (g/cm^3)	Data Source/ Report(s)	Field Notebook
P-14	02/14/1989 09:00	02/17/1989 12:00	7.86	4.5	573-595	1.000	Stensrud et al., 1990	N/A
SNL-2	1/19/2005 19: 11	1/24/2005 10:25	12.25	4.33	456-481	1.009	SNL-2 (C12pump) 2005-01-19 121756.csv	WIPP Notebook #5
SNL-5	7/19/2004 13:52	7/23/2004 7:50	11	4.33	637-660	1.011	SNL-5 (C1) 2004-06-09 132552.csv SNL-5 (CPump1) 2004-07-19 112609.csv	WIPP Notebook #3 &4
SNL-9	12/2/2003 14:38	12/6/2003 9:16	15.75	8.42	550-573	1.022	SNL9 (C2) 2003-11-19 120134.csv	WIPP Notebook #2
SNL-10	10/30/2006 15:19	11/3/2006 16:37	11	4.85	599-621	1.008	SNL-10 (CPump1) 2006-10-30 130000.csv	WSWT#10
SNL-12	8/9/2004 13: 17	8/14/2004 8:28	12.25	4.33	547-587	1.0044	SNL-12 (C2) 2004-07-13 132021.csv SNL-12 (C3pump) 2004-08-09 101349.csv	WIPP Notebook #4
SNL-13	7/12/2006 12:06	7/17/2006 13:28	11	4.85	388-412	1.016	SN18823 2006-07-25 130000 SNL-13(C11).csv	WSWT#8
SNL-16	6/5/2006 13:51	6/9/2006 14:25	11	4.85	193-217	1.014	SNL-16 (Cpump2) 2006-06-05 130000.csv	WSWT#8
SNL-17	9/11/2006 13:46	9/15/2006 13:55	11	4.85	332-362	1.003	SNL-17 (C2) 2006-08-31 110000.csv SNL-17 (C Pump1) 2006-09-11 124500.csv SNL-17 (C3) 2006-09-15 142733.csv	WSWT#9
SNL-19	7/24/2006 15:00	7/28/2006 12:18	11	4.85	341-362	1.007	SNL-19 (C3) 2006-06-15 140500.csv	WSWT#9

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							SNL-19 (CPump2) 2006-07-24 142000.csv	
WIPP-11	1/31/2005 13:45	2/20/2005 18:53	12.5	8.921	844-867	1.038	WIPP-11 (C9PumpBU1) 2005-01-31 132623.csv WIPP-11 (C7PumpBU2) 2005-02-23 122621.csv	
WIPP-25	9/10/2004 11 :39	9/23/2004 0:25	7.875	4.95	447-472	1.022	SN16771 2004-09-20 135045 WIPP-25(C5Pump1).csv	WIPP Notebook #4

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Appendix B – nSIGHTS Listings

B.1 P-14 nSIGHTS Listings

```
*************
nPre/64 2.41a
*************

Version date    1 April 2011
Listing date    20 Sep 2022
QA status       QA: Approved
Config file     C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-
09\P14\Data\P-14.nPre
```

Control Settings

Test Description

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	22.000	[ft]

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Flow dimension	Optimization	
Minimum value	0.1	[]
Maximum value	3.0	[]
Estimate value	0.798043	[]
Range type	Linear	
Sigma	1.00000E+00	
Static formation pressure	117.298	[psi]
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	8.92177E-04	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	1.00000E-06	[1/m]

Skin

Radial thickness of skin	Optimization	
Minimum value	0.001	[m]
Maximum value	5.0	[m]
Estimate value	0.4956422	[m]
Range type	Linear	
Sigma	1.00000E+00	
Skin zone conductivity	1.02225E-08	[m/sec]
Skin zone spec. storage	6.45408E-06	[1/m]

Fluid

Fluid density	1000.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	0.1	[m]
Volume change from normal	0.0	[m^3]
Test-zone compressibility	1.10395E-08	[1/Pa]

Numeric

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

Calculated Parameters

Formation

Transmissivity	min/max	
Minimum	6.70560E-10	[m^2/sec]

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Maximum	6.70560E-02	[m^2/sec]
Storativity	6.70560E-06	[]
Diffusivity	min/max	
Minimum	1.00000E-04	[m^2/sec]
Maximum	1.00000E+04	[m^2/sec]

Skin Zone

Transmissivity	6.85479E-08	[m^2/sec]
Storativity	4.32785E-05	[]
Diffusivity	1.58388E-03	[m^2/sec]
Skin factor	min/max	
Minimum	-9.85299E-03	[]
Maximum	3.84625E+06	[]

Test Zone

Test-zone volume	0.2106626	[m^3]
Isolated well-bore storage	2.32562E-09	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.06124	[]
Maximum	0.08095	[]
First grid increment	min/max	
Minimum	3.22072E-01	[m]
Maximum	8.51549E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00020	[]
Maximum	0.08024	[]
Skin first grid increment	min/max	
Minimum	2.03089E-05	[m]
Maximum	8.35485E-03	[m]
Skin last grid increment	min/max	
Minimum	2.05078E-05	[m]
Maximum	3.93243E-01	[m]
Increment ratio	min/max	
Minimum	8.19016E-01	[]
Maximum	4.15232E+02	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	-0.833860	[day]
Duration	0.833860	[day]
Time step type	Static	
Static time step	0.005000	[day]
Type	Curve	

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Wellbore storage	Isolated	

Sequence: H_02

Sequence type	History	
Start time	0.000000	[day]
Duration	3.001330	[day]
Time step type	Static	
Static time step	0.001157	[day]
Type	Curve	
Wellbore storage	Isolated	

Sequence: F_01

Sequence type	Flow	
Start time	3.001330	[day]
Duration	18.789460	[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	Isolated	

Test Zone Curves

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

Simulation Results Setup

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

Information Only

Flow rate output type	Well
Output units	[USgpm]

OutputFiles

XY Forward Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\P-14\Data\P14.nXYSim	
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\P-14\Data\P14.nOpt	
Run ID	Run#1
If file exists	Overwrite
Write residuals ?	yes
Write Jacobian ?	yes
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	3
Formation conductivity	OK
Flow dimension	OK
Radial thickness of skin	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK

Information Only

SimRunOutput	OK
# of calculated variables included	8

Suite/Range Setup

# of suite/range variables	0

B.2 SNL-2 nSIGHTS Listings

```
*************
nPre/64 2.41a
*************

Version date   1 April 2011
Listing date   20 Sep 2022
QA status      QA: Approved
Config file    C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-
09\SNL2\Data\SNL-2.nPre
```

Control Settings

Main Settings

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

Liquid Phase Settings

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

Test Zone Settings

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

Parameters

Information Only

Formation

Formation thickness	25.000	[ft]
Flow dimension	f(r) point	
Static formation pressure	97.881	[psi]
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-08	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	2.71282E-04	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	1.18012E-06	[1/m]

Fluid

Fluid density	1009.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	2.165	[in]
Tubing string radius	2.05	[in]

Numeric

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

---

f(x) Points Parameters

Flow dimension

Points type	f(r)	
Radius #1	0.0724803	[m]
Y value#1	1.9217438	[]
Radius #2	Optimized	
Minimum	101.0	[m]
Estimat	107.805483	[m]
Maximum	500.0	[m]
Y value#2	Optimized	
Radius #3	Optimized	
Minimum	501.0	[m]
Estimat	4945.7055463	[m]
Maximum	100000	[m]
Y value#3	Optimized	
X opt range type	Linear	
X opt sigma	1.00000E+00	

Information Only

Y opt minimum value	1.0	[]
Y opt maximum value	5.0	[]
Y opt range type	Linear	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	min/max	
Minimum	7.62000E-08	[m^2/sec]
Maximum	7.62000E-02	[m^2/sec]
Storativity	8.99251E-06	[]
Diffusivity	min/max	
Minimum	8.47371E-03	[m^2/sec]
Maximum	8.47371E+03	[m^2/sec]

Test Zone

Open hole well-bore storage	8.60860E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.06713	[]
First grid increment	3.81844E-03	[m]

Sequences

Sequence: H_01

Sequence type	History	
Start time	-461.878	[min]
Duration	470.160	[min]
Time step type	Static	
Static time step	0.167	[min]
Type	Curve	
Wellbore storage	None	

Sequence: F_01

Sequence type	Flow	
Start time	8.282	[min]
Duration	5781.845	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Fixed	

Information Only

Fixed value	-12.0	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	5790.127	[min]
Duration	5274.374	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# 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	F_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 ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL2\Data\SNL2.nXYSim	
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Information Only

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL2\Data\SNL2.nOpt	
Run ID	Run#1
If file exists	Overwrite
Write residuals ?	yes
Write Jacobian ?	yes
Write covariance matrices?	yes

Optimization Setup

Algorithm	Simplex
Simplex algorithm	Nelder/Mead
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
n.R[02]	OK
n.R[03]	OK
n.V[02]	OK
n.V[03]	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
# of calculated variables included	8

Suite/Range Setup

# of suite/range variables	0

B.3 SNL-5 nSIGHTS Listings

```
*************
nPre/64 2.41a
*************
```


Information Only

```
Version date    1 April 2011
Listing date    16 Sep 2022
QA status       QA: Approved
Config file     C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-
09\SNL5\Data\SNL-5.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	7.0104	[m]
Flow dimension	f(r) point	
Static formation pressure	146.922	[psi]
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-09	[m/sec]
Maximum value	1.00000E-04	[m/sec]
Estimate value	4.38849E-06	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	Optimization	
Minimum value	5.00000E-08	[1/m]

Information Only

Maximum value	9.99000E-06	[1/m]
Estimate value	1.56065E-06	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Skin

Radial thickness of skin	Optimization	
Minimum value	0.001	[m]
Maximum value	0.01	[m]
Estimate value	0.0032172	[m]
Range type	Linear	
Sigma	1.00000E+00	
Skin zone conductivity	4.49342E-08	[m/sec]
Skin zone spec. storage	1.00000E-07	[1/m]

Fluid

Fluid density	1011.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	2.165	[in]
Tubing string radius	2.0402194	[in]

Numeric

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

---

f(x) Points Parameters

Flow dimension

Points type	f(r)	
Radius #1	0.0013971	[m]
Y value#1	1.7126475	[]
Radius #2	29.0417624	[m]
Y value#2	1.8191423	[]
Radius #3	Optimized	
Minimum	200.01	[m]
Estimat	432.0377393	[m]
Maximum	10000	[m]
Y value#3	Optimized	
X opt range type	Linear	
X opt sigma	1.00000E+00	

Information Only

Y opt minimum value	1.5	[]
Y opt maximum value	3.0	[]
Y opt range type	Linear	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	min/max	
Minimum	7.01040E-09	[m^2/sec]
Maximum	7.01040E-04	[m^2/sec]
Storativity	min/max	
Minimum	3.50520E-07	[]
Maximum	7.00339E-05	[]
Diffusivity	min/max	
Minimum	1.00100E-04	[m^2/sec]
Maximum	2.00000E+03	[m^2/sec]

Skin Zone

Transmissivity	3.15007E-07	[m^2/sec]
Storativity	7.01040E-07	[]
Diffusivity	4.49342E-01	[m^2/sec]
Skin factor	min/max	
Minimum	-1.76204E-02	[]
Maximum	3.71664E+02	[]

Test Zone

Open hole well-bore storage	8.50979E-07	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.08316	[]
Maximum	0.08391	[]
First grid increment	min/max	
Minimum	5.63580E-03	[m]
Maximum	4.90094E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00037	[]
Maximum	0.00341	[]
Skin first grid increment	min/max	
Minimum	2.02285E-05	[m]
Maximum	1.87827E-04	[m]
Skin last grid increment	min/max	
Minimum	2.05888E-05	[m]
Maximum	2.21228E-04	[m]

Information Only

Increment ratio	min/max	
Minimum	2.54751E+01	[]
Maximum	2.38039E+02	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	0.000	[min]
Duration	1189.000	[min]
Time step type	Static	
Static time step	0.167	[min]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	1189.000	[min]
Duration	5651.484	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Fixed	
Fixed value	-3.5	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	6840.484	[min]
Duration	18248.521	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	SNL5_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	

Information Only

Simulation Results Setup

Output ID	DAT
Output type	Pressure
Pressure capture type	Test Zone
Output units	[psi]
Output ID	DAT
Output type	Flow Rate
Flow rate output type	Well
Output units	[m^3/sec]

OutputFiles

XY Forward Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL5\Data\SNL5.nXYSim	
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL5\Data\SNL5.nOpt	
Run ID	Run#1
If file exists	Overwrite
Write residuals ?	yes
Write Jacobian ?	yes
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	5
Formation conductivity	OK
n.R[03]	OK
n.V[03]	OK
Formation spec. storage	OK
Radial thickness of skin	OK

Fits to Optimize

Information Only

CompositeFit	OK

Calculated Parameters Included

SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
# of calculated variables included	7

Suite/Range Setup

# of suite/range variables	0

B.4 SNL-9 nSIGHTS Listings

```
*************
nPre/64 2.41a
*************

Version date    1 April 2011
Listing date    29 Sep 2022
QA status       QA: Approved
Config file     C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-
09\SNL9\Data\SNL-9.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

Information Only

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	23.000	[ft]
Flow dimension	f(r) point	
Static formation pressure	111.747	[psi]
External boundary radius	100000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	2.04256E-07	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	1.72336E-08	[1/m]

Skin

Radial thickness of skin	Optimization	
Minimum value	0.01	[m]
Maximum value	5.0	[m]
Estimate value	0.4943026	[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	2.95734E-06	[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	1.26098E-06	[1/m]
Range type	Log	
Sigma	1.00000E+00	

Fluid

Fluid density	1022.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Information Only

Well radius	4.21	[in]
Tubing string radius	Optimization	
Minimum value	2.0	[in]
Maximum value	4.0	[in]
Estimate value	3.1405946	[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

Flow dimension

Points type	f(r)	
Radius #1	Optimized	
Minimum	0.01	[m]
Estimat	0.2876218	[m]
Maximum	1.0	[m]
Y value#1	Optimized	
Radius #2	Optimized	
Minimum	1.01	[m]
Estimat	2.8440454	[m]
Maximum	5.0	[m]
Y value#2	Optimized	
Radius #3	Optimized	
Minimum	5.01	[m]
Estimat	8.3730664	[m]
Maximum	10.0	[m]
Y value#3	Optimized	
Radius #4	Optimized	
Minimum	10.01	[m]
Estimat	18.3683729	[m]
Maximum	50.0	[m]
Y value#4	Optimized	
Radius #5	Optimized	
Minimum	50.01	[m]
Estimat	86.8161747	[m]
Maximum	100.0	[m]
Y value#5	Optimized	
X opt range type	Linear	
X opt sigma	1.00000E+00	
Y opt minimum value	0.1	[]
Y opt maximum value	8.0	[]
Y opt range type	Linear	

Information Only

Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	min/max	
Minimum	7.01040E-10	[m^2/sec]
Maximum	7.01040E-02	[m^2/sec]
Storativity	1.20814E-07	[]
Diffusivity	min/max	
Minimum	5.80262E-03	[m^2/sec]
Maximum	5.80262E+05	[m^2/sec]

Skin Zone

Transmissivity	min/max	
Minimum	7.01040E-10	[m^2/sec]
Maximum	7.01040E-02	[m^2/sec]
Storativity	min/max	
Minimum	7.01040E-10	[]
Maximum	7.01040E-02	[]
Diffusivity	min/max	
Minimum	1.00000E-08	[m^2/sec]
Maximum	1.00000E+08	[m^2/sec]
Skin factor	min/max	
Minimum	-8.93979E-02	[]
Maximum	3.86614E+08	[]

Test Zone

Open hole well-bore storage	min/max	
Minimum	8.08957E-07	[m^3/Pa]
Maximum	3.23583E-06	[m^3/Pa]

Grid Properties

Grid increment delta	min/max	
Minimum	0.04966	[]
Maximum	0.06864	[]
First grid increment	min/max	
Minimum	2.60013E-01	[m]
Maximum	8.30804E-03	[m]
Skin grid increment delta	min/max	
Minimum	0.00182	[]
Maximum	0.07890	[]
Skin first grid increment	min/max	
Minimum	1.95273E-04	[m]
Maximum	8.77897E-03	[m]

Information Only

Skin last grid increment	min/max	
Minimum	2.13145E-04	[m]
Maximum	3.87455E-01	[m]
Increment ratio	min/max	
Minimum	6.71078E-01	[]
Maximum	3.89783E+01	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	-2460.250	[min]
Duration	2460.250	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	0.000	[min]
Duration	5438.598	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Fixed	
Fixed value	-12.5	[USgpm]
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	5438.598	[min]
Duration	15783.199	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# 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

Information Only

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 ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL9\Data\SNL9.nXYSim	
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL9\Data\SNL9.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	15
Formation conductivity	OK
Skin zone conductivity	OK
n.R[01]	OK
n.R[02]	OK

Information Only

n.R[03]	OK
n.R[04]	OK
n.R[05]	OK
n.V[01]	OK
n.V[02]	OK
n.V[03]	OK
n.V[04]	OK
n.V[05]	OK
Tubing string radius	OK
Skin zone spec. storage	OK
Radial thickness of skin	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
# of calculated variables included	6

Suite/Range Setup

# of suite/range variables	0

B.5 SNL-19 nSIGHTS Listings

```
*************
nPre/64 2.41a
*************

Version date   1 April 2011
Listing date   16 Sep 2022
QA status      QA: Approved
Config file    C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-
09\SNL19\Data\SNL-19.nPre
```

Control Settings

Main Settings

Simulation type	Optimization
Simulation subtype	Normal
Phase to simulate	Liquid
Skin zone ?	yes

Information Only

External boundary	Fixed Pressure	
Curve data source	Objects	

Liquid Phase Settings

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

Test Zone Settings

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

Parameters

Formation

Formation thickness	6.4008	[m]
Flow dimension	f(r) point	
Static formation pressure	81.949	[psi]
External boundary radius	100000	[m]
Formation conductivity	Optimization	
Minimum value	9.90000E-06	[m/sec]
Maximum value	1.00000E-03	[m/sec]
Estimate value	2.71475E-05	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	2.46127E-07	[1/m]

Skin

Radial thickness of skin	0.0135104	[m]
Skin zone conductivity	f(t) point	
Skin zone spec. storage	1.00000E-06	[1/m]

Fluid

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

Test-Zone

Well radius	5.5	[in]

Information Only

Tubing string radius	1.8249013	[in]

Numeric

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

f(x) Points Parameters

Flow dimension

Points type	f(r)	
Radius #1	Optimized	
Minimum	1.0E-06	[m]
Estimat	0.0002255	[m]
Maximum	0.0099	[m]
Y value#1	Optimized	
Radius #2	0.8202161	[m]
Y value#2	2.111439	[]
Radius #3	6.6210411	[m]
Y value#3	2.1151603	[]
Radius #4	1288.112679	[m]
Y value#4	2.4279899	[]
X opt range type	Linear	
X opt sigma	1.00000E+00	
Y opt minimum value	1.0	[]
Y opt maximum value	3.0	[]
Y opt range type	Linear	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Skin zone conductivity

Points type	f(t)	
Time #1	34334.496	[min]
Y value#1	2.35934E-07	[m/sec]
Time #2	335894.688	[min]
Y value#2	2.23000E-07	[m/sec]
Parameter curve type	Linear	

Calculated Parameters

Formation

Information Only

Transmissivity	min/max	
Minimum	6.33679E-05	[m^2/sec]
Maximum	6.40080E-03	[m^2/sec]
Storativity	1.57541E-06	[]
Diffusivity	min/max	
Minimum	4.02232E+01	[m^2/sec]
Maximum	4.06295E+03	[m^2/sec]

Skin Zone

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

Test Zone

Open hole well-bore storage	6.83542E-07	[m^3/Pa]

Grid Properties

Grid increment delta	0.06728	[]
First grid increment	1.06628E-02	[m]
Skin grid increment delta	0.00188	[]
Skin first grid increment	2.63439E-04	[m]
Skin last grid increment	2.88373E-04	[m]
Increment ratio	3.69757E+01	[]

Sequences

Sequence: H_01

Sequence type	History	
Start time	-18174.758	[min]
Duration	18174.758	[min]
Time step type	Static	
Static time step	0.001000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_01

Sequence type	Flow	
Start time	0.000	[min]
Duration	5598.345	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Fixed	
Fixed value	-36.0	[USgpm]
Wellbore storage	Open	

Information Only

Sequence: F_02

Sequence type	Flow	
Start time	5598.345	[min]
Duration	14306.905	[min]
Time step type	Log	
First log step	1.66667E-04	[min]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	Create Curve
Curve type	Pressure
Start sequence	H_01
End sequence	F_02
Curve time base	Test
Curve Y data units	[psi]
Curve Y data is log 10	no

Simulation Results Setup

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

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

OutputFiles

XY Forward Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL19\Data\SNL19.nXYSim	
Run ID	Run#1
If file exists	Overwrite
Output data	AutoSimData

Optimization Output

Write file ?	yes
C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-09\SNL19\Data\SNL19.nOpt	
Run ID	Run#1
If file exists	Overwrite

Information Only

Write residuals ?	yes
Write Jacobian ?	yes
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	3
Formation conductivity	OK
n.R[01]	OK
n.V[01]	OK

Fits to Optimize

CompositeFit	OK

Calculated Parameters Included

SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
# of calculated variables included	8

Suite/Range Setup

# of suite/range variables	0

B.6 WIPP-11 nSIGHTS Listings

```
*************
nPre/64 2.41a
*************

Version date   1 April 2011
Listing date   16 Sep 2022
QA status      QA: Approved
Config file    C:\Users\makara\Desktop\FY22 deliverables\HYDRO-22-
09\WIPP11\Data\WIPP-11.nPre
```


Information Only

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	23.000	[ft]
Flow dimension	f(r) point	
Static formation pressure	106.519	[psi]
External boundary radius	1000000	[m]
Formation conductivity	Optimization	
Minimum value	1.00000E-10	[m/sec]
Maximum value	1.00000E-02	[m/sec]
Estimate value	1.82278E-04	[m/sec]
Range type	Log	
Sigma	1.00000E+00	
Formation spec. storage	1.00000E-06	[1/m]

Skin

Radial thickness of skin	0.1305956	[m]
Skin zone conductivity	2.27269E-04	[m/sec]
Skin zone spec. storage	2.78722E-07	[1/m]

Information Only

Fluid

Fluid density	1038.00	[kg/m^3]
Fluid thermal exp. coeff.	0.00000E+00	[1/C]

Test-Zone

Well radius	4.4605	[in]
Tubing string radius	Optimization	
Minimum value	0.75	[in]
Maximum value	6.0	[in]
Estimate value	3.3684641	[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

Flow dimension

Points type	f(r)	
Radius #1	Optimized	
Minimum	100.01	[m]
Estimat	158.6182844	[m]
Maximum	180.0	[m]
Y value#1	Optimized	
Radius #2	Optimized	
Minimum	180.01	[m]
Estimat	198.1841162	[m]
Maximum	400.0	[m]
Y value#2	Optimized	
Radius #3	446.408412	[m]
Y value#3	-1.7674482	[]
Radius #4	724.1359237	[m]
Y value#4	3.4275582	[]
Radius #5	Optimized	
Minimum	1000.01	[m]
Estimat	1289.4575812	[m]
Maximum	1500	[m]
Y value#5	Optimized	
Radius #6	Optimized	
Minimum	1500.01	[m]
Estimat	2575.7085025	[m]
Maximum	3000	[m]
Y value#6	Optimized	
Radius #7	14999.577477	[m]

Information Only

Y value#7	3.1752402	[]
X opt range type	Linear	
X opt sigma	1.00000E+00	
Y opt minimum value	-10.0	[]
Y opt maximum value	10.0	[]
Y opt range type	Linear	
Y opt sigma	1.00000E+00	
Parameter curve type	Linear	

Calculated Parameters

Formation

Transmissivity	min/max	
Minimum	7.01040E-10	[m^2/sec]
Maximum	7.01040E-02	[m^2/sec]
Storativity	7.01040E-06	[]
Diffusivity	min/max	
Minimum	1.00000E-04	[m^2/sec]
Maximum	1.00000E+04	[m^2/sec]

Skin Zone

Transmissivity	1.59325E-03	[m^2/sec]
Storativity	1.95395E-06	[]
Diffusivity	8.15397E+02	[m^2/sec]
Skin factor	min/max	
Minimum	-7.66716E-01	[]
Maximum	3.29693E+01	[]

Test Zone

Open hole well-bore storage	min/max	
Minimum	1.12006E-07	[m^3/Pa]
Maximum	7.16838E-06	[m^3/Pa]

Grid Properties

Grid increment delta	0.07652	[]
First grid increment	1.93940E-02	[m]
Skin grid increment delta	0.01565	[]
Skin first grid increment	1.78673E-03	[m]
Skin last grid increment	3.78655E-03	[m]
Increment ratio	5.12181E+00	[]

Sequences

Information Only

Sequence: H_01

Sequence type	History	
Start time	0.000000	[day]
Duration	0.074990	[day]
Time step type	Static	
Static time step	0.000100	[day]
Type	Curve	
Wellbore storage	None	

Sequence: F_01

Sequence type	Flow	
Start time	0.074990	[day]
Duration	0.147470	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	
Wellbore storage	Open	

Sequence: F_02

Sequence type	Flow	
Start time	0.222460	[day]
Duration	0.742120	[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	

Sequence: H_02

Sequence type	History	
Start time	0.964580	[day]
Duration	0.010410	[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	0.974990	[day]
Duration	3.525010	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Curve	

Information Only

Wellbore storage	Open	

Sequence: H_03

Sequence type	History	
Start time	4.500000	[day]
Duration	2.658910	[day]
Time step type	Static	
Static time step	0.100000	[day]
Type	Curve	
Wellbore storage	Open	

Sequence: F_04

Sequence type	Flow	
Start time	7.158910	[day]
Duration	13.067870	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	-35.0	[USgpm]
Wellbore storage	Open	

Sequence: F_05

Sequence type	Flow	
Start time	20.226780	[day]
Duration	42.573220	[day]
Time step type	Log	
First log step	1.15741E-07	[day]
# of time steps	250	
Type	Fixed	
Fixed value	0.0	[USgpm]
Wellbore storage	Open	

Test Zone Curves

Curve object to use	P_Curve	
Curve type	Pressure	
Start sequence	H_01	
End sequence	H_03	
Curve time base	Test	
Curve Y data units	[psi]	
Curve Y data is log 10	no	
Curve object to use	Q_Curve	
Curve type	Flow Rate	
Start sequence	F_01	
End sequence	F_03	
Curve time base	Test	
Curve Y data units	[USgpm]	
Curve Y data is log 10	no	

Information Only

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

Optimization Output

Write file ?	no

Optimization Setup

Algorithm	Simplex
Simplex algorithm	Nelder/Mead
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
Formation conductivity	OK
n.R[01]	OK
n.R[02]	OK
n.R[05]	OK
n.R[06]	OK
n.V[01]	OK
n.V[02]	OK
n.V[05]	OK
n.V[06]	OK
Tubing string radius	OK

Fits to Optimize

CompositeFit	OK

Information Only

Calculated Parameters Included

SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
SimRunOutput	OK
# of calculated variables included	8

Suite/Range Setup

# of suite/range variables	0

Information Only