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SWIFT GREAT MIAMI AQUIFER MODEL SUMMARY OF IMPROVEMENTS REPORT VOLUME 1 DRAFT FINAL REVISION B APRIL 1994

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SWIFT Great Miami Aquifer Model Summary of Improvements Report

Volume I

Fernald Environmental Management Project
April 1994
Draft Final Revision B

Submitted by:
U.S. Department of Energy
Fernald Office
P.O. Box 398705
Cincinnati, Ohio 45239-8705

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SWIFT Great Miami Aquifer Model Summary of Improvements Report

Volume I

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SWIFT Great Miami Aquifer Model
Summary of Improvements Report

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LIST OF ACRONYMS AND ABBREVIATIONS

AWWT	Advanced Wastewater Treatment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRARE	Comprehensive Response Action Risk Evaluation
CRT	Constant Rate Pumping Test
CRU	CERCLA/RCRA Unit
DMEPP	Design Monitoring Evaluation Program Plan
DOE	United States Department of Energy
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
FS	Feasibility Study
ft	feet
ft^2	square feet
GMA	Great Miami Aquifer
gpm	gallons per minute
HELP	Hydrologic Evaluation of Landfill Performance
MB	Megabytes
mgd	million gallons per day
MSL	Mean Sea Level
Ohio EPA	Ohio Environmental Protection Agency
OU	Operable Unit
ppb	parts per billion
psi	pounds per square inch
QA	Quality Assurance
QC	Quality Control
RAM	Random Access Memory
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
SDT	Step-Drawdown Pumping Test
SOWC	Southwestern Ohio Water Company
SPRW	South Plume Recovery Wells
SSOD	Storm Sewer Outfall Ditch
SWIFT	Sandia Waste Isolation Flow and Transport
TO/TA	Task Objective/Technical Approach
US EPA	United States Environmental Protection Agency

SECTION 1

INTRODUCTION

A three dimensional finite difference groundwater model simulating flow and transport conditions in the Great Miami Aquifer (GMA) was developed using the Sandia Waste Isolation Flow and Transport (SWIFT) III code by the United States Department of Energy (DOE) in 1988 to support Remedial Investigations (RI), Feasibility Studies (FS), and Remedial Design activities at the Fernald Environmental Management Project (FEMP) site (DOE 1993a). The United States and Ohio Environmental Protection Agencies (US EPA and Ohio EPA) had concerns about the accuracy and appropriate use of the SWIFT GMA model. The DOE conducted a review of the model and concluded that the conceptual model represented a reasonable hypothesis of the natural system but that uncertainties did exist in the models construction and calibration. In 1993, the plan was issued which outlined a program for addressing these concerns and uncertainties. The SWIFT GMA model would be improved by conducting both short term and long term model improvement tasks (DOE 1993b). Short term improvement activities outlined in this plan included grid expansion to the east and north; addition of a model layer; transient flow, steady state flow, and solute transport calibration; uncertainty and sensitivity analysis; capture zone analysis of area pumping wells; a more formal and sophisticated quality assurance program; and a post-audit program.

This present summary report completes the short-term model improvement tasks by presenting the approach and the results of each of these tasks. Figure 1-1 shows a flow chart of the overall model improvement program with the present report highlighted. This report has been divided into two volumes. Volume I contains text and appendices and Volume II contains figures and tables.

During the fall of 1993 and winter of 1994 the US EPA and Ohio EPA worked closely with the DOE to facilitate an interactive approach to model improvement. A series of meetings were held and interim document submittals for various improvement tasks (which are incorporated into this report) were presented and reviewed. This forum provided an opportunity for DOE to communicate early responses to US EPA comments and questions. Task Objectives/Technical Approach (TO/TA) documents defined the scope of each particular improvement task and Summary Letter Reports outlined the results of the work. The following interim deliverables were created, reviewed, and discussed during this time period.

1) Model Design Task Objective and Technical Approach Document (DOE 1993c)

2) Model Design Summary Letter Report (DOE 1993d)

3) Geostatistical Analysis Summary Letter Report (DOE 1993e)

4) Model Calibration Task Objective and Technical Approach Document (DOE 1993f)

5) Model Uncertainty Analysis Task Objective and Technical Approach Document (DOE 1993g)

6) Model Zonation and Values of Geochemical Parameters Task Objective and Technical Approach Document (DOE 1993k)

1.1 Contents of Summary of Improvements Report

The groundwater model improvement program consisted of several tasks. The approach and results of these tasks are contained in sections within this document. These tasks included:

1) Conducting geostatistical analyses to understand and correlate the spatial distribution of key data sets. These data sets include the water elevation data and the uranium analytical data from the 2000, 3000, and 4000 series monitoring wells. Calculations included the sample semivariogram, and kriging and cokriging estimators along with their estimation variance. This work was used to help determine calibration criteria and to identify areas of the site where lower confidence existed in the analyzed data sets (see Section 2).

2) Expanding the model grid for steady-state flow and solute transport. The previous solute transport grid of 78 cells by 102 cells was enlarged by adding a band of approximately 5,250 feet width along the eastern side and a band of approximately 1,250 feet width along the northern side. The new grid contains 120 by 112 cells, each 125 feet square. The layering of the model also has been refined. The five layers of the original model have been replaced with six layers to better match existing well screen elevations. This allowed field data to be more accurately depicted and provided better vertical control over contaminant dispersion (see Section 3).

3) Calibrating transient flow using the South Plume Pumping Test results. Parameter values for horizontal and vertical hydraulic conductivity, porosity and rock compressibility were developed from this calibration. Because of the scale and orientation of the pumping test wells, a telescoped grid (25 foot cell size) was created in the south plume area to effectively simulate the results of the pumping test (see Subsection 4.2).

4) Calibrating steady-state flow using the expanded and reconstructed steady-state grid. Steady-state heads were matched to the established calibration criteria. This recalibrated steady-state model is the primary model used for flow and solute transport simulations (see Subsection 4.3).

5) Recalibrating the solute transport model to determine reasonable values of distribution coefficient (K_d) (for uranium) and dispersivity for a representative source loading. The range of acceptable uranium K_d values has been established by reviewing site data related to K_d and by reviewing

sensitivity runs of previously utilized K_d values corresponding to retardation factors of 9 and 12. After selection of K_d and dispersivity, the historical source loading terms were decoupled from the model. Monitoring data are used to define initial (current) conditions of uranium concentrations. Results from the glacial overburden and Paddys Run models are used to define future loading terms (see Subsection 4.4).

6) Analyzing sensitivity on horizontal hydraulic conductivity (K_h), ratio between horizontal hydraulic conductivity and vertical hydraulic conductivity (K_h/K_v), porosity, uranium K_d, and dispersivity (α) to understand the effect of variation of these parameters on the maximum concentration and transport of a normalized plume (see Section 5).

7) Conducting particle tracking and capture zone analysis to understand flow patterns within the model grid (see Section 6).

8) Defining Quality Assurance/Quality Control (QA/QC) control procedures for future modeling to control and confirm the quality of the modeling effort (see Section 7).

9) Creating a post-audit program to continue to check the accuracy of the model (see Section 8).

A summary/conclusion of the model improvement program is given in Section 9. References are listed in Section 10. Appendices are provided at the back of Volume I while figures and tables are contained by section in Volume II.

1.2 Objective of the Model Improvement Program

The objective of the model improvement program is to create a reasonable and defensible groundwater model that is acceptable to the US and Ohio EPAs for designated applications at the FEMP. This revised model will incorporate the latest available data.

The applications of the improved model will be:

1) Performing CERCLA/RCRA Unit 5 (CRU-5) RI fate and transport modeling
2) Supporting Feasibility Studies for the FEMP CRUs
3) Supporting relevant preliminary design efforts
4) Conducting performance modeling during detailed design
5) Supporting clean-up operations

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New data sets have been used in the construction and calibration of the model (see Table 1.2-1). In summary, new data sets reflect:

1) Monitoring data from the 1990 to 1993 period

2) Monitoring data from new wells installed since original calibration

3) Results of additional aquifer analysis to define K_d

4) Geostatistical analysis of data sets

5) Results from the South Plume Pumping Test

6) Results from construction and operation of the South Plume Recovery System

7) Output from additional models (glacial overburden, Paddys Run) to define hydraulic and solute loading terms

1.3 Background on the Overall Groundwater Modeling Approach

Figure 1.3-1 shows the current groundwater fate and transport modeling domain for the FEMP. The fate and transport model defines the transport of contaminants from the source through the applicable pathways to the theoretical receptors. The conceptual model consists of three primary processes:

1) Source term definition
2) Vadose zone transport
3) Saturated zone transport

Figure 1.3-2 shows the modeling process with more detail on the current methodology for modeling and the proposed CRU-5 improvements. The source term development process will be the same for CRUs 1, 2, 4, and 5. For input terms for vadose zone transport, the current process uses the Hydrologic Evaluation of Landfill Performance (HELP) model to define infiltration rate and EQ3/6 to determine leachate concentration. The proposed CRU-5 modeling process will use a new glacial till model for verifying infiltration rate and will rely on direct leachate or Toxicity Characteristic Leaching Procedure data for leachate term definition. For vadose zone transport, the one-dimensional codes ST1D and One-Dimensional Analytical Solute Transport (ODAST) will be supplemented by a more sophisticated glacial till model. SWIFT input will be improved by using a surface water model of Paddys Run to define loading rates. Finally, saturated zone transport will be refined by improving the present SWIFT model (i.e., the subject of this report).

Figure 1.3-3 presents the approach that will be taken to complete the fate and transport modeling for CRU-5. Over the last several months, groundwater modeling and risk assessment issues have been reviewed and integrated. Based upon this review, three primary categories of activities have been identified:

1) Development of new models
2) Additional fieldwork
3) Global model improvement

With these new models, additional field data, and the improved SWIFT GMA model, the fate and transport modeling for the CRU-5 risk assessment can be successfully completed.

The global model improvement program is being undertaken to refine the present SWIFT GMA model so that future applications will be accepted by review agencies. Figure 1.0-1 shows a flow chart of the overall model improvement program with the present report highlighted. This figure shows two parallel activities, preparing a stand-alone groundwater modeling report (DOE 1993b - extracted from the former Groundwater Report [DOE 1990a]) and performing an evaluation of the existing model culminating with a model improvement plan (DOE 1993b). After review by the US and Ohio EPAs, defined improvement activities have been implemented and a "final" groundwater model has been developed (the basis of this report). The "final" model will be refined on a continuing basis by long-term improvement activities, including post audits.

1.4 Background on the SWIFT GMA Model

The FEMP's GMA model uses the SWIFT numeric code for simulating flow and transport. The SWIFT GMA model is used for simulating three-dimensional contaminant transport in the GMA.

The SWIFT code is a fully coupled, transient, three-dimensional, finite-difference model for groundwater flow and transport through both porous and fractured media. The mass transport equations contained in the code include terms for convection, dispersion, retardation by sorption, and decay or degradation of the contaminant. The SWIFT code, originally developed by Sandia National Laboratory in the late 1970s for the DOE High Level Waste Program, has been revised several times to increase its capability and to change computer platforms. These revisions include the addition of fractured media, a free water surface, extended boundary conditions, conversion to Fortran 77, extended options for matrix solutions, and post processing. GEOTRANS (1991) has converted SWIFT for use on 386 and 486 personal computers and made additional changes to improve user friendliness, and input and output control. The most recent version of the SWIFT code is 2.54 (GEOTRANS 1993).

SWIFT was selected from among several codes for use in developing a flow and transport model of the GMA in the vicinity of the FEMP. Subsequent to selection of the code, the SWIFT III code was

specifically verified for use at the FEMP (IT 1990). A model of the GMA (using SWIFT) was originally developed and calibrated from 1988 through 1990 (DOE 1993a). This model building effort consisted of:

1) Development and calibration of two-dimensional and three-dimensional regional flow models

2) Development and calibration of a telescoped, three-dimensional flow model with a more refined grid on the FEMP and its adjacent areas

3) Development and calibration of two-dimensional and three-dimensional solute transport models on the more refined grid

The original model consisted of five layers. The two uppermost layers represent the upper and lower parts of the upper GMA. The middle layer includes a clay interbed that is present beneath the FEMP site and the lower two layers represent the lower GMA. The layers extend laterally into bedrock at the edges of the buried valley that contains the aquifer. This original FEMP steady-state flow model was calibrated to 1986 water elevation data. This model has been used to support RIs in CRUs 1, 2, and 4.

SECTION 2

GEOSTATISTICAL ANALYSIS

2.1 Introduction

Geostatistical analysis has been conducted to correlate the spatial and temporal distribution and to define the uncertainties of the water level and uranium concentration data sets in the GMA in the vicinity of the FEMP. Geostatistical analysis provides a comprehensive method to interpolate between and beyond spatially and temporally varying data sets and to obtain a spatially varying uncertainty value for these data sets. These analyzed data sets also define the calibration criteria for the steady state flow and solute transport model calibrations.

The geostatistical analysis is part of the Model Uncertainty Analysis Task of the Model Improvement Program (see the Groundwater Modeling Evaluation Report and Improvement Plan [DOE 1993b]). The approach to conducting the geostatistical analysis and the results are described in the following sections.

2.1.1 Background and Approach to Kriging Analysis

Kriging is a statistical interpolation method for analyzing spatially and temporally varying data. It is used to estimate hydraulic head (or any other important parameter) on a dense grid of spatial and temporal locations covering the region of interest. At each location, two values are calculated with the kriging procedure: the estimate of hydraulic head (in feet), and the precision of the estimate (also in feet). The precision can be interpreted as the half-width of a 95 percent confidence interval for the estimated head.

The kriging approach includes two primary analytical steps:

1) Estimate and model temporal and spatial correlations in the available monitoring data using a semivariogram analysis.

2) Use the resulting semivariogram model and the available monitoring data to interpolate (i.e., estimate) parameter values at unsampled times and locations; calculate the statistical precision associated with each estimated value.

Background on the analytical methods and the specific approach used in this study are discussed in the following sections.

2.1.2 Spatial Correlation Analysis

The objective of the spatial correlation analysis is to statistically determine the extent to which measurements taken at different locations and/or times are similar or different. This section is written in terms of hydraulic head measurements; however, the analytical approach is similar for any measured parameter of interest. Generally, the degree to which head measurements taken at two locations are different is a function of the distance between the two sampling locations. Also, for the same separation distance between two sampling locations, the spatial correlation may vary as a function of the direction between the sampling locations. For example, head values measured at each of two locations, a certain distance apart, are often more similar when the locations are at the same depth, than when they are at the same distance apart but at very different depths.

Spatial/temporal correlation is statistically assessed with the semivariogram function, $\gamma(\underline{h})$, which is defined as follows (Journel and Huijbregts 1981):

$$2\gamma(\underline{h}) = E\,\{[Z(\underline{x}) - Z(\underline{x}+\underline{h})]^2\}$$

where $Z(\underline{x})$ is the hydraulic head measured at location $\underline{x}$, $\underline{h}$ is the vector of separation between locations $\underline{x}$ and $\underline{x}+\underline{h}$, and E represents the expected value or average over the region of interest. Note that the location $\underline{x}$ might be defined by an easting, northing, and depth coordinate, or for joint spatial/temporal data by an easting, northing, and time coordinate. Similarly, the vector of separation might be defined as a three-dimensional shift in space, or for joint spatial/temporal data as a shift in both space and time. The semivariogram is a measure of spatial differences so that small semivariogram values correspond to high spatial correlation and large semivariogram values correspond to low correlation.

As an initial hypothesis, it is assumed that the strength of spatial correlation is a function of both distance and direction between the sampling locations. When the spatial correlation is found to depend on both separation distance and direction it is said to be anisotropic. In contrast, when the spatial correlation is the same in all directions, and therefore depends only on separation distance, it is said to be isotropic.

The spatial correlation analysis is conducted in the following steps using all available measured head data:

1) Experimental semivariogram curves are generated by organizing all pairs of data locations into various separation distance and direction classes (e.g., all pairs separated by 500-1,500 feet in the east-west direction $\pm$ 22.5 degrees), and then calculating within each class the average squared-difference between the measurements taken at each pair of locations. The results of these calculations are plotted against separation distance and by separation direction.

2) A variety of experimental semivariogram curves are generated by subsetting the data into discrete zones, such as different depth horizons or time periods. If significant differences are found in

the semivariograms they are modeled separately; if not, the data are pooled together into a single semivariogram.

3) After the data have been pooled or subsetted accordingly and the associated experimental semivariograms have been calculated and plotted, a positive-definite analytical model is fitted to the experimental curve(s). The fitted semivariogram model is then used as the spatial correlation structure input for the subsequent kriging interpolation.

In this study, the computer software used to perform the geostatistical calculations was the GSLIB software written by the Department of Applied Earth Sciences at Stanford University, and documented and released by Prof. Andre Journel and Dr. Clayton Deutsch (Deutsch and Journel 1992). Some computational details concerning the calculation of semivariograms are as follows:

1) The primary subroutine used to calculate experimental semivariograms was GAMV3, which is used for three-dimensional, irregularly spaced data.

2) For three-dimensional spatial analyses, horizontal separation distance classes were defined in increments of 1,000 feet with a tolerance of 500 feet, while vertical distances were defined in increments of 20 feet with a tolerance of 10 feet. Horizontal separation directions were defined in the four primary directions of north, northeast, east, and southeast with a tolerance of 22.5 degrees.

4) For the joint spatial/temporal analysis, spatial separation distances and directions were defined in the same way as described immediately above, although there was no vertical direction associated with this analysis. For the temporal portion of this analysis, separation distance classes were defined in increments of 30 days with a tolerance of 15 days.

2.1.3 Interpolation Using Ordinary Kriging

Ordinary kriging is a linear geostatistical estimation method which uses the semivariogram function to determine the estimated head values and the precision associated with the estimates (Journel and Huijbregts 1981). In a sense, kriging is no different from other classical interpolation and contouring algorithms. However, kriging differs in that it produces statistically optimal estimates and associated precision measures.

The kriging analysis was conducted in this study using the GSLIB computer software (subroutine KTB3D). The primary steps involved in this analysis were as follows:

1) A three-dimensional grid was defined, specifying the locations at which estimated head values are required. The horizontal origin of this grid (southernmost point) was at Ohio State Planar

Coordinates 469,197.58 feet north and 1,379,948.62 feet east. The network included 112 blocks in the northern direction (rotated 30 degrees west of North) and 120 blocks in the eastern direction. All blocks were 125 feet square. For three-dimensional spatial kriging, the vertical origin was at 390 feet above sea level, and the network included 30 vertical blocks each 5 feet thick. For joint spatial/temporal kriging, the network included 43 monthly blocks in increments of 30 days, starting at January 20, 1990.

This grid was set to match the latest SWIFT groundwater flow and transport model grid in the XY dimension to facilitate the defining of model boundary conditions and model calibration criteria. Vertical discretization of the kriging output could not match the SWIFT layering in the improved model because the SWIFT model layers were being revised concurrent with the geostatistical analysis. However, the resulting vertical discretization can be easily translated to the model layers of the improved model.

2) At each block in the grid, the average hydraulic head across the block was estimated using all measured data found within a pre-defined search radius. For three-dimensional spatial kriging, the search radius was 6,000 feet in all directions. For joint spatial/temporal kriging, the search radius was anisotropic and extended 6,000 feet in space and 72 days in time.

3) After the available data were identified for each grid block, the appropriate data weighting, estimated head value, and estimation precision were calculated using the appropriate semivariogram model.

4) Output from the kriging process was post processed using a Fortran routine to create vertical values of head (or concentration) that represent the centroid of each model block. Since SWIFT model layers 1, 3, and 6 represent 2000, 3000, and 4000 series wells, these model layers will provide estimates of head (or concentration) that portray these well screen levels.

5) Output from the kriging process was typically displayed in the form of contour maps, to represent spatial variations, and time-series graphs to represent temporal variations.

2.2 Analysis of GMA Water Levels

Steady-state water levels in the GMA were needed for calibration of the steady-state groundwater flow model. A two-step data analysis approach was used to estimate the steady-state water levels.

1) A joint spatial-temporal kriging analysis was performed to estimate monthly water level changes in 2000 series wells and to select a single month that is representative of steady-state conditions.

2) A three-dimensional spatial kriging analysis was performed with data from the selected month in the 2000, 3000, and 4000 series wells to estimate steady-state hydraulic heads.

2.2.1 Joint Spatial-Temporal Analysis

The joint spatial-temporal kriging analysis was performed using monthly water level measurements collected during the period from January 1990 through July 1993 in one-hundred, seventy-seven 2000 series wells. As shown in Table 2.2-1 there were a total of 3,791 such measurements. The semivariogram curves, quantifying spatial and temporal correlation in these data, are shown in Figures 2.2-1 and 2.2-2. The spatial semivariograms in Figure 2.2-1 were calculated for four standard directions (relative to the groundwater model grid system) denoted 0 degrees (north), 45 degrees (northeast), 90 degrees (east), and 135 degrees (southeast). These semivariograms show clear anisotropy with the highest variabilities directed north 180 degrees to the predominant flow direction, and the lowest variabilities directed east perpendicular to the predominant flow direction. The corresponding temporal semivariogram for the 2000 series monthly water levels is shown in Figure 2.2-2. Note that the units for separation distances between data locations are in days in Figure 2.2-2 and in feet in Figure 2.2-1. The semivariograms in Figures 2.2-1 and 2.2-2 were modeled with an anisotropic mathematical model containing three nested variance structures. The parameters of the model are listed in Table 2.2-2. Note in this table that three types of semivariogram models were used in various parts of these analyses: spherical, gaussian, and linear models. These models are fully described by Journel and Huijbregts (1981).

The monthly 2000 series well water levels were used along with the semivariogram model to estimate monthly changes in water levels across the entire groundwater modeling grid. The time period for this kriging analysis was taken as every 30 days starting January 20, 1990 and ending July 2, 1993. The monthly water levels (in feet above mean sea level) are depicted in Figure 2.2-3 for six locations uniformly spaced across the groundwater modeling grid. This figure shows that water levels during this period were relatively high in 1990, decreased in 1991, were relatively low in 1992, and are increasing in 1993. Spatial variability across the grid is depicted in Figure 2.2-4 for April 1991 water levels (in feet). As expected, this figure shows a general trend of decreasing hydraulic heads to the south associated with the predominant flow direction south and to the east to the Great Miami River. Figure 2.2-5 presents the statistical uncertainty (in feet) associated with the water level estimates in Figure 2.2-4. These uncertainties can be interpreted as half-widths of a 95 percent confidence interval for the estimates. That is, the confidence interval for the April 1991 water level at any location in the grid is

$$\text{HEAD} \pm \text{PREC}$$

where HEAD is the estimated water level from Figure 2.2-4 and PREC is the estimation uncertainty from Figure 2.2-5. Note in Figure 2.2-5 that in this case most of the estimation uncertainties are from 2 to 4 feet.

2.2.2 Three-Dimensional Spatial Analysis for Steady State Heads

The primary reason for performing the joint spatial-temporal analysis is to select for the steady-state analysis, a single month which is representative of average water levels during the 1990-1993 period. Examining the results in Figure 2.2-3, it appears that 3 months can be considered representative: January 1990; November 1991; and June 1993 (represented as months 1, 23, and 41 in Figure 2.2-3). Water levels in each of these 3 months appear to be approximately equal to the average water level across the entire 1990-1993 time period. However, several new wells were installed in the area in 1993, particularly in the southeastern part of the modeling grid. Therefore, a significantly greater number of water level measurements were available for June 1993 in comparison with January 1990 and November 1991. As a result, June 1993 was selected as the month to represent steady-state conditions.

As shown in Table 2.2-1, water level measurements for June 1993 were available for the steady-state kriging analysis in 202 wells at the 2000, 3000, and 4000 series depths. The three-dimensional spatial semivariograms for these data are shown in Figures 2.2-6 and 2.2-7. As in the joint spatial-temporal analysis (Figure 2.2-1), horizontal semivariograms in Figure 2.2-6 were calculated in four primary directions. In addition, the semivariogram in Figure 2.2-7 was calculated in the vertical direction. Note in Figure 2.2-7 that, except for one point at a separation distance of about 75 feet, the vertical variability among the June 1993 water levels is quite low. This same result is further indicated by Figure 2.2-8 which plots water level differences as a function of vertical separation for pairs of spatially clustered wells. Note in Figure 2.2-8 that these differences are almost always less than 1 or 2 feet. Two outlier cases are shown for well couplets 2066/3066 and 2018/3018. These wells represent unusual conditions in the aquifer. According to site personnel, the 3000 series wells at these locations may be screened within the clay interbed.

A kriging analysis was performed with the June 1993 data and the semivariogram model shown in Figures 2.2-6 and 2.2-7, as well as Table 2.2-2. This analysis estimated steady-state water heads across the groundwater modeling grid at regular 5 feet vertical intervals from 390 to 540 feet above sea level. The horizontal variability in steady-state water heads for the 2000, 3000, and 4000 series well layers are shown in Figures 2.2-9, 10, and 11. These figures show a southerly direction of flow on the western and southern part of the grid and an easterly direction of flow (with a flat gradient) across the site toward the Great Miami River. One significant feature in these figures is the major water level depression caused by the three production wells in the eastern portion of the grid. Similar patterns are exhibited in the three well screen zones indicating strong vertical continuity of water levels and predominantly horizontal flow. Local differences in the heads between the three levels can also be noted. Figures 2.2-12, 13, and 14, which present the statistical uncertainty associated with the estimates in Figures 2.2-9, 10, and 11, show that the steady-state water levels are generally estimated to within 1 or 2 feet, although the southeast corner showed higher values (greater than 5 feet) due to the lack of data in this area of the grid.

2.3 Analysis of GMA Uranium Concentrations

Estimated GMA uranium levels are needed for calibration of the groundwater solute transport model. Separate three-dimensional spatial kriging analyses, similar to that for steady-state water levels, were performed using uranium levels measured during 1990, 1991, 1992, and 1993. One important difference between these uranium analyses and the water level analysis was that a logarithmic transformation of the uranium data was performed prior to the semivariogram and kriging analyses. This transformation was required to reduce the extreme variability seen in the uranium concentrations. After the kriging step, the estimates and statistical uncertainties were back-transformed with an inverse-logarithmic transformation. As a result of this procedure, the 95 percent confidence intervals for uranium concentrations are multiplicative, rather than additive, in format. That is, the confidence interval at any location in the grid is

[CONC/PREC, CONC*PREC]

where CONC is the back-transformed estimated uranium concentration and PREC is the back-transformed estimation uncertainty.

2.3.1 1990 Uranium Concentrations

The spatial kriging analysis was performed using average uranium concentrations (μg/L) measured during 1990 in 169 wells at the 2000, 3000, and 4000 series depths. As shown in Table 2.2-1, the mean of these measurements was 29.3 μg/L, although the maximum concentration (691 μg/L) was considerably higher. The overall variability in the uranium data, as measured by the coefficient of variation, was also relatively high (2.90), particularly in comparison with that of the water level data (0.01).

Horizontal semivariograms were calculated in the four primary directions (Figure 2.3-1), and indicated no significant anisotropy; that is, all four directional curves exhibit the same shape and variability. The vertical semivariogram (Figure 2.3-2) was found to plateau at the same overall variance [3.0 (μg/L)^2] as the horizontal semivariograms. However, the vertical semivariogram reaches a plateau at a separation distance of about 120 feet while the horizontal semivariograms reach a plateau at a separation distance of about 3,000 feet. As a result, a geometric anisotropic semivariogram model was fitted to these curves, as shown in Figures 2.3-1 and 2.3-2. The details of these models are summarized in Table 2.2-2.

A three-dimensional kriging analysis was performed using the 1990 average uranium concentrations and the semivariogram model discussed above. The resulting estimated spatial distribution of the uranium concentrations is depicted for the 2000 and 3000 well levels in Figures 2.3-3 and 2.3-4, respectively. The most significant uranium concentrations, those above 70 μg/L, occur in a northeast oriented area extending about 2,500 feet by 900 feet horizontally, and about 40 feet vertically. A surrounding area,

about five to 10 times larger, contains lower uranium concentrations between 10 and 70 μg/L. The uranium plume in the southern area (South Plume) is more elongated at the 2000 series level than the 3000 (as defined by the 10 μg/L contour). Based on an inspection of the output file, the maximum uranium concentration in the 4000 series level is 8.2 μg/L and the mean concentration is 1.57 μg/L, thus the uranium concentrations are not contoured for the 4000 series well.

A sample vertical section cut along the long axis of the plume is shown in Figure 2.3-5. This figure shows the vertical trace of contamination covering both the 2000 and 3000 well series levels, but not extending to the 4000 level. Figures 2.3-6 and 2.3-7, which present the statistical uncertainty associated with the estimates in Figures 2.3-3 and 2.3-4, indicate the uranium concentrations are typically estimated to within a multiplicative factor of 10; that is, the true concentrations could be 10 times higher or lower.

2.3.2 1991 Uranium Concentrations

The 1991 uranium spatial kriging analysis was performed in the same way as that for 1990 uranium levels. As shown in Table 2.2-1, 163 average 1991 uranium concentrations were analyzed, with a mean concentration of 35.1 μg/L and a maximum concentration of 1,572.5 μg/L. The broader range of 1991 uranium concentrations in comparison with 1990 levels is also reflected in the coefficients of variation (4.62 for 1991 data versus 2.90 for 1990 data).

Figures 2.3-8 and 2.3-9 show horizontal and vertical semivariograms which were calculated with the log-transformed 1991 uranium data. These figures show a very similar structure to those for the 1990 uranium data (Figures 2.3-1 and 2.3-2), although the overall variance for the 1991 data [3.8 $(\mu g/L)^2$] is higher than that for the 1990 data [3.0 $(\mu g/L)^2$]. As a result, a similar geometric anisotropic semivariogram model was fitted for the 1991 uranium data, as shown in Figures 2.3-8 and 2.3-9, and Table 2.2-2.

A three-dimensional kriging analysis was performed with the 1991 uranium data. The resulting estimated spatial distribution of the uranium concentrations is depicted for the 2000 and 3000 levels in Figures 2.3-10 and 2.3-11, respectively. Qualitatively, the results were quite similar to those for the 1990 uranium levels. Like 1990, the most significant uranium concentrations, those above 70 μg/L, occur in a northeast oriented area about 40 feet vertically. A surrounding area, about five to ten times larger, contains lower uranium concentrations between 10 and 70 μg/L. The uranium plume in the southern area (South Plume) is similar at the 2000 series level and the 3000 (as defined by the 10 μg/L contour), although the 10 μg/L contour at the 2000 level extends further north. Based on an analysis of the output file, the maximum uranium concentration in the 4000 series level is 18.9 μg/L and the mean concentration is 1.75 μg/L, thus the uranium concentrations are not contoured for the 4000 series well level. Comparing the 1991 and 1990 uranium levels (Figures 2.3-10, 2.3-11, 2.3-3, and 2.3-4) indicates that the magnitude and extent of the most significant concentrations were still approximately the same. However, because of the marginally higher variability in 1991 uranium concentrations versus those in 1990, the statistical

uncertainty of the 1991 uranium estimates (Figures 2.3-12 and 2.3-13) is somewhat higher (approximately 25 percent higher) than that of the 1990 estimates (Figures 2.3-6 and 2.3-7).

2.3.3 1992 Uranium Concentrations

The kriging analysis for 1992 uranium concentrations was performed in a similar manner to the analyses of 1990 and 1991 uranium levels. However, the 1992 uranium data were found to be quite different. As shown in Table 2.2-1, 153 average 1992 uranium concentrations were analyzed. The 1992 mean concentration (6.7 μg/L) was found to be substantially lower than those in 1990 (29.3 μg/L) and 1991 (35.1 μg/L). Likewise, the coefficient of variation for the 1992 data (2.28) was lower than those in 1990 (2.90) and 1991 (4.62). It appears that the primary reason for these differences is that while many of the same wells were sampled for uranium in 1990 and 1991, a large number of different wells were sampled in 1992.

Horizontal and vertical semivariograms for the log-transformed 1992 uranium data are presented in Figures 2.3-14 and 2.3-15. In general, these figures show a similar structure to those for the 1990 and 1991 uranium data (Figures 2.3-3, 2.3-4, 2.3-10, and 2.3-11). However, the overall variance for the 1992 data is lower, although it appears that the very short scale variability (i.e., for separation distances less than 700 feet) may be larger for the 1992 data. Because of this latter possibility, two different semivariogram models were considered (see Figures 2.3-14 and 2.3-15). Kriging of the solid line model, showing larger short scale variability, resulted in excessive spatial smoothing of the estimated uranium concentrations with a tendency to "average out" and mask potential high concentration areas. In contrast, use of the dotted-line model (see Table 2.2-2) tends to accentuate potential high concentration areas and thus provide conservative worst-case estimates. For this reason, it was decided to use the dotted-line semivariogram model in the subsequent kriging step.

A three-dimensional kriging analysis was performed with the 1992 uranium data. The resulting estimated spatial distribution of the uranium concentrations is illustrated for the 2000 and 3000 levels in Figures 2.3-16 and 2.3-17, respectively. Qualitatively, the pattern of the results are similar to those for the 1990 and 1991 uranium levels. Like 1990 and 1991, the most significant uranium concentrations occur in an area near Willey Road with a maximum value of 40 μg/L. A surrounding area, about five to 10 times larger, contains lower uranium concentrations (less than 10 μg/L). The 10 μg/L contour stretches along Paddys Run from the waste pits to south of Willey Road. The 3000 level results only show three small areas greater than 10 μg/L (Figure 2.3-17). The 1992 results show considerably less uranium than the 1990 and 1991 results. Based on an analysis of the output file, the maximum uranium concentration in the 4000 series level is 3.6 μg/L and the mean concentration is 0.81 μg/L, thus the uranium concentrations are not contoured for the 4000 series well level. Figures 2.3-18 and 2.3-19 show the contour plots of the statistical uncertainty. The statistical uncertainty of the 1992 uranium estimates (Figures 2.3-18 and 2.3-19) is similar to the 1991 estimates (Figures 2.3-12 and 2.3-13).

2.3.4 1993 Uranium Concentrations

In an attempt to determine whether uranium concentrations measured in 1990-1992 were similar to those present in 1993, data available from a "snapshot" survey in 1993 were analyzed with a kriging approach similar to that already described. While the general trends observed in 1990-1992 data persist in the 1993 data, one important difference in these data should be noted. That is, while the 1990-1992 data for a given well represent the average uranium concentration by year across multiple monitoring measurements collected during each year, the 1993 datum for each well represents a single uranium measurement taken at a single "snapshot" time. As a result, the short-scale spatial variability of the 1990-1992 data is reduced by the averaging step, leading to significantly different semivariograms and smoother 1993 kriging estimates (i.e., estimates showing less spatial variability).

As shown in Table 2.2-1, 209 1993 uranium measurements were available with a mean concentration of 35.5 $\mu g/\ell$, a maximum concentration of 2097.9 $\mu g/\ell$, and a coefficient variation of 4.92. Horizontal and vertical semivariograms calculated with the log-transformed 1993 uranium data are shown in Figures 2.3-20 and 2.3-21. Because of the lack of averaging in the 1993 data, these semivariograms are quite different from those shown earlier for the 1990-1992 data (Figures 2.3-1, 2.3-2, 2.3-8, 2.3-9, 2.3-14, and 2.3-15). In particular, as detailed in Table 2.2-2, the nugget variance for the 1993 data is relatively short (i.e., 2,000 feet), and there is no evidence of a geometric anisotropy (i.e., an isotropic model fit both the horizontal and vertical semivariograms). In simple terms, these differences in the semivariograms mean that there is greater short-scale spatial variability in the 1993 snapshot uranium concentrations as compared with the 1990-1992 average uranium concentrations.

These differences in the semivariograms lead to resulting differences in the kriging estimated uranium concentrations. The most significant difference, as noted above, is that the 1993 estimated concentrations are spatially smoother than the 1990-1992 estimates. In fact, this smoothing effect was so pronounced that a shorter vertical data search radius of 20 feet was required for the 1993 kriging so that higher uranium concentrations measured at the 2000 level would not be unrealistically extended to lower levels. (A vertical search radius of 150 feet was used for the 1990-1992 krigings.)

The estimated spatial distributions of 1993 uranium concentrations for the 2000 and 3000 levels are shown in Figures 2.3-22 and 2.3-23, respectively. Although the highest concentrations still appear in the same general locations as with the 1990-1992 data (see Figures 2.3-3, 2.3-4, 2.3-10, 2.3-11, 2.3-16, and 2.3-17), the 1993 estimated concentrations are generally lower than those in 1990-1992. This difference is directly related to the spatial smoothing effect discussed above and does not represent a dilution of uranium in the groundwater between 1992 and 1993. The statistical uncertainty associated with the estimates is depicted in Figures 2.3-24 and 2.3-25. The greater short-scale spatial variability in the 1993 uranium measurements leads to greater estimation uncertainty. Whereas the 1990-1992 uranium levels were generally estimated to within a multiplicative factor of about 10 (see Figures 2.3-6, 2.3-7, 2.3-12, 2.3-13, 2.3-18, and 2.3-19), the 1993 uranium levels are generally estimated to with a factor of about 15.

SECTION 3

MODEL DESIGN

3.1 Task Objective

The model grid design task objective was to increase the areal coverage and vertical resolution of the SWIFT GMA groundwater model. The previous GMA model grid, consisting of 78 by 102 blocks, was expanded to the east by 5,250 feet and to the north by 1,250 feet as shown in Figure 3.1-1. The new model grid consists of 120 blocks by 112 blocks, each block measuring 125 by 125 feet. This expansion allows important regional hydrologic features (a portion of the GMA and the Southwestern Ohio Water Company [SOWC] production wells) to be within the model's domain.

The vertical resolution of the model was increased from five layers to six to provide:

1) Better vertical control for contaminant transport modeling

2) A thinner layer at the top of the model to more accurately represent the mixing depth in the aquifer

3) A closer match between model layers and monitoring well screen elevations to facilitate the calibration process

3.2 Development of SWIFT GMA Model Layers

The GMA model grid is referenced to screen elevations in the 2000, 3000, and 4000 series monitoring wells and structure on the base of glacial overburden and bedrock. The kriging algorithm contained in Golden Software's SURFER™ package was used to define grid-cell centroid elevations from input structure maps. Since the model grid area extends beyond the monitoring well network, model interfaces are assumed flat in areas where there is no structural control. The basis for each of these surfaces is described below.

The top of model layer 1 was defined using the "Base of Glacial Overburden" structure map (IT 1993) and the topographic surface in Paddys Run channel where overburden has been removed completely by erosion. The resulting map is shown in Figure 3.2-1. The top of model layer 1 is essentially flat east of the FEMP site at an elevation of 570 feet above mean sea level (MSL) and drops to 535 feet above MSL just southwest of the FEMP site.

The top of model layer 2 is referenced to the base of well screens contained in the 2000 series monitoring well network, shown in Figure 3.2-2. This surface ranges in depth from 510 feet above MSL in the northwest quarter of the model grid area to 495 feet above MSL in the southwest quarter of the model gird area. The 2000 series wells used to construct the map shown in Figure 3.2-2 are listed in Table 3.2-1.

The top of model layer 3 is referenced to the top of well screens contained in the 3000 series monitoring well network, Figure 3.2-3. This surface ranges in depth from 502.8 feet above MSL on the northern side of the FEMP site to 453.3 feet above MSL just east of the site. The 3000 series wells used to make the map shown in Figure 3.2-3 are listed in Table 3.2-2.

The top of model layer 4, top of the blue clay interbed, is defined by using Figure 2-13, "Clay Interbed Topographic Surface" from the "Groundwater Report - Summary of Model Development" (DOE 1993a). The map is reproduced in Figure 3.2-4 for reference.

The top of model layer 5, base of the blue clay interbed, is derived from model layer 4 and Figure 2-12, "Clay Interbed Isopach" (DOE 1993a). The resulting map is shown in Figure 3.2-5. Since the blue clay interbed exists only in the northwestern part of the grid area, the material properties assigned to layer 4 (porosity, vertical and horizontal hydraulic conductivity) were set to match the properties of model layer 3 in areas where the clay interbed is not present. A vertical thickness of 2 feet was used for blocks in layer 4 where the clay interbed is not present to facilitate internal bookkeeping by the SWIFT code.

The top of model layer 6 is referenced to the top of well screens contained in the 4000 series monitoring well network, Figure 3.2-6. The surface ranges from 429.5 feet above MSL at well 4125 to 388.3 feet above MSL at well 4013. The wells used to make the map shown in Figure 3.2-6 are listed in Table 3.2-3.

The bottom of model layer 6, the GMA to bedrock interface, is defined as in the previous GMA model by the basement contour map from the seismic refraction study by Watkins and Spieker in 1971. The structure map, updated by the 4000 series monitoring wells which tagged bedrock (Table 3.2-4) is shown in Figure 3.2-7. Two of the wells shown in Table 3.2-4, 2754 and 3679, encountered bedrock even though they are screened at the 2000 and 3000 elevations respectively.

3.2.1 Creation of a Revised SWIFT Input File

Once the model layer interfaces were defined as described above, the six model layers were constructed by isopaching the model layer interface maps. Since all the model interface maps contain centroid elevations at each of the cells, a Fortran routine was used to read the layer top and bottom elevations and to write the 3-D model cell centroid and thickness values in the SWIFT data entry format.

After the SWIFT data entry file was completed, the data in the file were checked to see that model geometry was accurately represented. A Fortran program was used to read model cell centroid elevations and thickness values from the file and post them to a series of maps. These maps were visually checked against the input maps to see that the model layer interfaces were correct. The thickness values for each model layer were then posted and contoured, and the resulting model layer isopach maps are shown in Figures 3.2-8 through 3.2-13. As the thickness values were being read from the SWIFT R1-21 file, the following statistics were compiled:

Figure Model Number	Layer	Maximum Thickness (ft)	Minimum Thickness (ft)
3.2-8	1	69.3	15.6
3.2-9	2	59.2	9.27
3.2-10	3	47.9	6.54
3.2-11	4	22.9	2.00
3.2-12	5	57.7	16.5
3.2-13	6	36.7	2.00

Model layers 2 to 6 are fully saturated so the saturated thickness of these layers is equal to the total layer thicknesses. Since the GMA groundwater table intersects the 2000 series well screens in the long-term steady-state groundwater flow model, the saturated thickness of model layer 1 is less than the total layer thickness as listed above. Typically, the saturated thickness of model layer 1 is less than 15 feet in the immediate vicinity of the FEMP.

Two model cross sections were constructed. These cross sections and their locations on the model grid are shown in Figures 3.2-14, 15, and 16. Figure 3.2-15, Cross Section A-A', was drawn so as to terminate against bedrock illustrating that each model layer is bounded by the bedrock surface. This section has also been reproduced as part of the key in Figures 3.2-8 through 13.

SECTION 4

MODEL CALIBRATION

The groundwater flow and solute transport model of the GMA, constructed for the FEMP remediation program, was recalibrated based on the most recent data sets. This three-dimensional, finite-difference groundwater model utilizes the SWIFT numeric code for simulating flow and transport. This model was originally constructed and calibrated before 1990 (DOE 1993a) and, based on identified issues and the availability of new data collected over the last several years, the model calibration has been revised.

4.1 Technical Approach

The calibration process, defined in the Model Calibration TO/TA (DOE 1993f) consisted of transient flow, steady-state flow, and solute transport calibration steps. The overall approach to calibration of the model is defined in Figure 4.1-1. These steps are summarized below:

1) A transient flow calibration was performed using the South Plume Pumping Test results. Values for horizontal hydraulic conductivity, vertical hydraulic conductivity, porosity, and rock compressibility were defined from this calibration. Because of the scale and orientation of the pumping test wells, a telescoped grid (25 by 25 foot cell size) was created in the South Plume area to effectively simulate the results of the pumping test.

2) A steady-state flow calibration was conducted using the expanded and reconstructed steady-state grid (Figure 4.1-2). Steady-state heads were matched to criteria consisting of geostatistical analysis of water level data and other data. This recalibrated steady-state model is the primary model used for flow and solute transport simulations.

3) The solute transport model was recalibrated to determine reasonable values of K_d (for uranium) and dispersivity for a representative source loading. The range of acceptable uranium K_d values was established by reviewing site data related to K_d and by reviewing sensitivity runs of previously utilized K_d values corresponding to retardation factors of 9 and 12. Dissolved and adsorbed mass of uranium were calculated from the geostatistical depiction of dissolved plumes in the GMA and these established K_d values. Mass loading to the GMA was scaled to these calculated mass numbers and cases were reviewed to select the most appropriate K_d and dispersivity values.

4.1.1 Calibration Criteria

Calibration criteria was developed prior to commencement of the calibration of the transient flow, steady-state flow, and solute transport models (DOE 1993f). The success of the calibration was determined based upon satisfying this previously defined calibration criteria. Geostatistical analysis, conducted to understand and correlate the spatial distribution of water level and uranium data from monitoring wells, was used to determine water level and uranium targets for each block and to identify areas of the site where lower confidence exists in the analyzed data sets. Confidence interval information was used to weight the calibration targets. The geostatistical analysis of data sets is described in Section 2.

Calibration criteria included quantitative measures (comparing model output to field data), qualitative measures (inspecting reasonableness of the simulation), and relative measures (comparing the different calibration simulations). Quantitative criteria included the definition of both target cell locations and statistical parameters (and acceptable ranges of these parameters) for model calibration. Qualitative measures included the evaluation of the correspondence among model simulations and the physical structures of the hydrogeological system (i.e., pattern of heads and concentrations). The sum of weighted residuals (weighted with the geostatistically determined uncertainty parameter) was also calculated to determine the overall precision of the simulation relative to other simulations. The best simulation with the minimum summed weighted residual was selected.

The calibration criteria are presented for the transient flow, steady-state flow, and solute transport modeling in the discussions of each models calibration effort below.

4.2 Transient Flow Calibration and Validation

A calibration of the localized SWIFT transient flow model was performed using the South Plume Pumping Test results. The purpose of the calibration was to determine the most appropriate model parameters under transient conditions. Parameter values for horizontal and vertical hydraulic conductivity, porosity, water compressibility, and well index were modified during the calibration to develop the most appropriate transient model. The parameter values determined with the transient calibration were used in the calibration of the steady-state flow model.

Figure 4.2-1 shows the approach used for the calibration task. Transient flow calibration and validation of the SWIFT model consisted of six main steps (DOE 1993f):

1) Establishment of calibration criteria for both steady-state and transient flow calibration efforts.

2) Development of a new localized model grid which provided the necessary resolution for the transient flow calibration.

3) Development and calibration of a steady-state model to simulate conditions just prior to the Constant Rate Pumping Test (CRT) using the measured well heads and the calibration criteria.

4) Processing CRT results into a format which could be used for transient flow calibration.

5) Performing pumping test simulations and comparing the modeled and measured CRT results. Appropriate transient model parameters were adjusted and simulations were continued until agreement between the modeled and measured CRT results was within the calibration criteria.

6) Confirming the transient results with the step drawdown test results. The calibrated transient model was used to simulate the step-drawdown pumping test results. The objective of the validation was to see if the calibrated model adequately predicted the other set of data without any additional calibration.

Each of these steps are described in the following subsections.

4.2.1 Calibration Criteria

Two sets of calibration criteria were necessary for the transient calibration task. These criteria included one set for the initial steady-state calibration and a second set for the transient calibration.

The steady-state calibration criteria required that the modeled water table match the field measured water table within 1 foot (DOE 1993f). If this criterion was not met, then boundary conditions and/or model parameters were to be modified until agreement was reached.

For the transient flow calibration, a more detailed set of criteria was used. A summary of the transient flow calibration criteria developed prior to the calibration is presented in Table 4.2-1 (DOE 1993f). Also shown in Table 4.2-1 are the predetermined ranges for each of the model parameters for which calibration was performed. These parameter ranges were determined from field investigations (DOE 1993j and Haliburton NUS 1993) and literature values.

4.2.2 Model Grid Development

Because of the spacing and orientation of the pumping test wells, a telescoped grid (25 foot by 25 foot cell size) was created in the south plume area to effectively simulate the results of the pumping test. The new model grid was aligned at an angle of inclination from north of 21.3042 degrees so that the pumping test piezometers would fall at grid block centers. This alignment approximates a groundwater flow pattern across the grid in a north to south direction. The origin of the grid had a Northing Coordinate of 472,648.92 feet and an Easting Coordinate of 1,379,778.48 feet. The grid consisted of 115 by 115 cell blocks and covered a 2,875 foot by 2,875 foot area.

The size of the grid was selected by using the previously developed solute transport SWIFT model (see Section 3) to determine the approximate extent of the steady-state cone of depression due to a pumping rate of 425 gallons per minute (gpm). Figure 4.2-2 shows the cone of depression within the selected model area. Once the area was determined, a square grid encompassing the area was selected. The square grid size was selected so that there was no significant simulated drawdown along the grid boundary with the pumping well located directly in the center of the grid. While Figure 4.2-2 shows the 0.05-foot contour passing through the eastern and southern boundaries, this value is within measurement errors and will not significantly affect results. Figure 4.2-3 shows the model grid which was developed and used for transient model calibration.

After determining the areal extent of the model, the vertical extent of the grid was then determined. Seven model layers were chosen for the grid. Model layers were selected so that a well or piezometer screen would be in only one layer and a buffer layer would be between each screened layer. There was one exception, Well No. 3927 (RW-4), which was the pumping well, had a screen interval of 40 feet and spanned two layers with no buffer layer in between. Figure 4.2-4 shows the layering structure and the appropriate well and piezometers which are screened in each layer.

Boundary Conditions

For the transient model grid, constant head boundary conditions were selected for the four sides of the model grid. The constant head boundary conditions were determined using contoured head measurements and the assumption that the pressure along the boundary was hydrostatic (i.e., no vertical gradient). Surface infiltration through the top of the model grid (ground surface and Paddys Run) was assumed to be zero for the steady-state and transient simulations based upon the insignificant infiltration that occurred during the pumping test. Figure 4.2-5 shows the boundary conditions used for the model.

The contoured head measurements used to determine the constant head boundary conditions were developed using measurements taken just prior to the CRT. The measurements were taken at 28 wells within the model grid. These measurements are summarized in Table 4.2-2. The measurements were then imported into SURFER and its kriging routine was used to develop a grid-wide head distribution. Figure 4.2-6 shows the grid-wide head distribution. After this was fixed, constant head boundaries were determined for the SWIFT model.

By reviewing Figure 4.2-6 it can be seen that there is an irregular flow pattern along the northwestern side of the grid. Wells 2624 and 3624 show a measured head of 519.95 feet, while wells 2125 and 3125 show a measured head of approximately 520.9 feet. Wells 2125 and 3125 are very close to a bend in Paddys Run and may be influenced by recharge from the stream. Also, the water table depth in this area is shallow, approximately 10 to 13 feet, and Paddys Run Road separates the two well clusters and may affect the groundwater flow pattern. These reasons were not very decisive and could not be quantified.

Additional research was conducted to find any other reasons to better explain the flow pattern. A review of all of the available data for the wells in that vicinity showed that the four elevations taken prior to the CRT may be anomalies. Figures 4.2-7 and 4.2-8 show a time series of data from 1988 to 1993 for wells 2095, 2125, and 2624, and 3095, 3125, and 3624, respectively (see Figure 4.2-2 for well locations). From the figures it can be seen that the trend is for wells 2095 and 3095 to be upgradient of wells 2624 and 3624, while wells 2125 and 3125 are downgradient. This trend agrees with the expected general flow pattern to the south of the model grid. Therefore, since the times series show the expected trend it is believed that the four data points used to determine the measured flow pattern in Figure 4.2-6 are anomalies.

4.2.3 Steady-State Calibration of Transient Grid

Once the model grid and boundary conditions were finalized, an initial steady-state SWIFT input file was created. The contoured steady-state modeled solution is shown in Figure 4.2-9. The model was run with initial hydraulic parameters in the model equal to the previously developed solute transport model's parameters (DOE 1993a) and the results were compared with the head measurements (Figure 4.2-6). Also during the initial runs the number of iterations taken by the model to develop a solution were increased until the model gave consistent results. After the comparison it was determined that the horizontal hydraulic conductivities needed to be zoned into two regions, north and south for Layers 1 and 2. The zones were approximately equal in size. The values used for horizontal hydraulic conductivity were 600 and 400 feet per day (ft/day) for the north and south zones, respectively. The hydraulic conductivity value used for the lower 5 layers was 600 ft/day.

The zonation of hydraulic conductivity was warranted because after inspection of Figure 4.2-6 it was noticeable that the northern part of the model area showed a low hydraulic gradient which usually corresponds to a higher hydraulic conductivity, while the southern part of the model area showed a high hydraulic gradient which corresponds to a lower hydraulic conductivity. By making this zonation, the modeled head conditions were in better agreement with the contoured head conditions and were within the model calibration criteria.

Besides modifying hydraulic conductivity, other parameters such as infiltration and boundary conditions could have been modified to help achieve calibration of the model. However, as stated earlier no significant rainfall events occurred during the pumping test so use of this parameter during calibration would not be defendable. Likewise, the boundary conditions which were set for the model were measured only hours before the pumping test and were the best starting conditions available for the model.

The first step to calibrating the local model was to calibrate the initial steady-state model. The criteria for this calibration was simple, the modeled water table must match the field measured table within 1 foot. Figure 4.2-10 shows a plot of the residuals between field measured results and the steady-state

solution. As can be seen from the figure, the maximum residual was approximately 0.90 feet, which is below the calibration criteria of 1 foot.

These results were then used as the starting conditions for the transient flow simulations. Model parameters were subsequently modified during transient model calibration with more detailed zonation resulting. The final steady-state results were compared against the calibration criteria after transient calibration was complete as a final check. Figure 4.2-9 shows the final results of the steady-state solution.

4.2.4 CRT Data Preparation

Data which was collected during the CRT was summarized in the "South Plume Removal Action Pumping Test Report" (DOE 1993j). During the CRT test, both Hermit data loggers and hand measurements were used to collect data. The redundant measurements were taken so that a cross-check of the data could be made. Also, measurements were taken at wells outside the pumping test influence area to determine background trends in the groundwater table.

After all of the data was collected and reviewed, it was deemed necessary to make several corrections to the data including corrections for background trends, transducer cable slippage, and data logger time inconsistency. These corrections are all discussed in the Pump Test Report (DOE 1993j).

After the previously mentioned problems were corrected in the data, a cross-check of the data showed that the hand measurements did not always agree with the data logger measurements. Under the assumption that the hand measurements were more reliable, the data logger measurements were adjusted to match the hand measurements for all of the wells. The resulting data, an example of which is summarized in Appendix A-1 for Well 3927 (RW-4), was then used for transient model calibration.

For the calibration of the transient model, nine wells were selected to be modeled; 3927, 3910, 3911, 3916, 3918, 3921, 3922, 3923, and 2002. These wells were previously designated as RW-4, SPPZ-1, SPPZ-2A, SPPZ-2C, SPPZ-2E, SPPZ-3, SPPZ-4, SPPZ-5, and 2002, respectively. Figures 4.2-6 and 4.2-4 show the areal and vertical locations, respectively, of these wells. These wells were selected because they gave the maximum areal and vertical coverage of the pumping test. By using these wells the homogeneity and anisotropy of the aquifer could be investigated. Wells 3922 and 2002 were both approximately 200 feet from the well with 2002 being north of the 3927 and 3922 being south of 3927. Wells 3911, 3916, and 3918 were from the same well cluster but screened in different layers with 3911 being the shallowest at an elevation of 479.11 feet and 3918 being the deepest at an elevation of 438.8 feet.

Ten drawdown data points and 10 recovery data points were selected for each well to represent the drawdown and recovery portion of the pumping test. The selected points and plots of each of the data

sets are included in Appendix A-2. The points were selected at various times to ensure adequate coverage of each portion of the test and to capture any change in pumping test conditions. For instance, the times of 3986 and 4005 minutes were selected due to the stop and subsequent restart in pumping which occurred during this time period. In addition the 10,431 minute time was selected since this was approximately the end of the drawdown phase of the pumping test; likewise, the 15,032 minute time was selected since it was very near the end of the recovery phase of the pump test.

4.2.5 Transient Calibration

Once the steady-state model was initially calibrated and the measured CRT data corrected and selected, a transient flow portion was added to the model to simulate the CRT results. Both drawdown and recovery were simulated for the transient model calibration. The details of the calibration are discussed in the following sections.

Simulated Drawdown

Calibration of the transient model began with the initially calibrated steady-state flow model. The model was modified to simulate a pumping test with a pumping rate of 425 gpm and a duration of approximately 7 days. The transient model was created to write results at the same 10 times as the measured data.

To start transient calibration, a baseline run was completed to determine how well the model simulated the measured results with the same parameters as the steady-state flow model. As part of this step, several runs were made to ensure an appropriate amount of time steps and iterations were made by the model to limit numerical dispersion and divergence. Once these parameters were fixed, model results were compared to the measured data. Although the initial results showed some agreement with the measured data, several wells were not within the calibration criteria so additional calibration was warranted. The model required approximately 8 hours of run time to simulate the transient drawdown solution using a 486/50 computer with 96 Megabytes (MB) of Random Access Memory (RAM).

Model parameters which were modified during the calibration included horizontal and vertical hydraulic conductivities, porosity, water compressibility, and well index. Rock compressibility was found to have a limited effect on calibration and was, therefore, not modified for this calibration. During calibration, model parameters were modified within the range of field measurements if available or literature values when no measurements were available. Field measurements of vertical and horizontal hydraulic conductivity were taken from the Pumping Test Report (DOE 1993j) and the South Plume Piezometer Slug Test Report (Haliburton NUS 1993).

A total of 15 model runs were completed during the calibration task. A list summarizing the model runs and the corresponding parameters which were modified for each run are included in Appendix A-3. As can be seen from the list, the zonation of the horizontal and vertical hydraulic conductivity was modified

during calibration with the zonation becoming more complicated with successive runs to help achieve better results. Final values of horizontal hydraulic conductivity ranged from 638 to 200 ft/day, while vertical hydraulic conductivity values ranged from 51 to 22.4 ft/day. In addition, the porosity was increased from 0.25 (i.e., the value used in the original model) to 0.30 to achieve better agreement between modeled and measured results. Water compressibility was increased from the original value of 6.38×10^{-14} 1/pounds per square inch (psi) to an appropriate literature value of 3.00×10^{-6} 1/psi (Domenico and Schwartz 1990). The original water compressibility value was not a realistic value since it suggested that water compressibility was less than that of rock compressibility. Rock compressibility was assigned a value of 1.45×10^{-12} 1/psi which was the same as was used in the previous model.

The well index parameter used in the SWIFT model was also modified during the calibration to account for the well efficiency of the pumping well. It was determined that two values of the well index were necessary to simulate the pumping test, one for times prior to the accidental stop in pumping and one after the accidental stop/restart in pumping. A value of 5074 square feet per day (ft^2/day) was used for all simulations prior to the stop and 5922 ft^2/day after the stop/restart of the pumping. This conclusion was reached after reviewing the data which showed the final drawdown prior to the stop in pumping was greater than the final drawdown after the stop in pumping. Data such as this suggests that the well efficiency may have increased after the stop in pumping.

Initially, model results were compared against the measured results by visually inspecting the resulting drawdown curves. Over the course of the calibration the model became more realistic and visual comparisons could no longer be made. To confirm that modifications in model parameters were properly affecting the model calibration and to be in conformance with the calibration criteria, statistical analyses were conducted on the modeled and measured results. Several sets of the results are included in Appendix A-4 for review. They show the effects of model parameter changes for each of the model runs.

The final results of the calibration of the SWIFT model against measured drawdown data are presented in Appendix A-4 and A-5. Included in Appendix A-4 are the final curves showing measured versus modeled drawdown results. The statistical results for the final run (tranw114) are included in Appendix A-5. As can be seen the modeled results are in good agreement with the measured results. Final model parameters are summarized in Subsection 4.2.7. The final run included the following characteristics:

1) Vertical and areal zonation of the horizontal hydraulic conductivity
2) Vertical zonation of the vertical hydraulic conductivity
3) Uniform porosity value for the entire model grid
4) Two well index values were used for the duration of the pumping test

Simulated Recovery

The recovery portion of the pumping test was simulated using the SWIFT model after the drawdown portion was calibrated. This calibration method was more time efficient than simulating both drawdown and recovery for all calibration runs. The assumption for this technique was that if the drawdown portion of the pumping test results were adequately matched, then the recovery portion would also reasonably match.

To simulate recovery results, the final SWIFT model for drawdown was modified to also include a recovery phase. For the recovery phase, the pumping rate for Well 3927 (RW-4) was 0 gpm. The total recovery time simulated was approximately 3 days. An additional 10 recovery times were simulated by the model so that output could be obtained to compare with measured recovery data. Total model run time, including drawdown and recovery solutions, was approximately 14 hours using a 486/50 computer with 96 MB of RAM.

The results of the initial run for the recovery phase showed good agreement with the measured data, therefore, no further calibration was required. The final model results are shown in Appendix A-6 and A-7. The information includes the final curves for each well showing drawdown and recovery (Appendix A-6) and statistical results for the combined drawdown and recovery modeling (Appendix A-7). A discussion of the final results is presented in Subsection 4.2.7.

As mentioned in Subsection 4.2.3, the steady-state conditions were also verified with the final calibrated model. The final simulated steady-state water table was previously presented in Figure 4.2-9.

Calibration Results

Once the steady-state model was calibrated, transient model calibration commenced. For calibration of the model, the individual run's drawdown results were tabulated and statistical analyses were performed. The results were compared on an interim basis to the calibration criteria, the appropriate model parameters modified, and the model rerun until the most reasonable match with the calibration criteria was obtained. Afterwards, the final model, which included drawdown and recovery, was used to simulate the CRT and the results were compared to the calibration criteria. This final simulation's results show the best overall comparison between modeled and measured results since both drawdown and recovery were simulated, and will therefore be presented here for the comparison between model results and the calibration criteria. For the CRT a majority of the model results were within the calibration criteria. The individual wells statistical results are summarized in Appendix A-7. The calibration criteria for individual well points was that the maximum residual of individual drawdown or recovery modeled data points versus measured data points would be $< \pm 15$ percent. From the table in Appendix A-7 it can be seen that many of the individual data point's percent difference was below the criteria and some data points were outside the criteria. The percent differences ranged from -259 percent to 130 percent. A

majority of the major differences occurred at the beginning of the drawdown curve and at the end of the recovery curve.

Another set of criteria to be met during the calibration was that the average residual for modeled individual wells (approximately 20 total data points) had to be $< \pm 10$ percent. Table 4.2-3 shows the highlights of the statistical results from all of the wells. As can be seen from the table, all of the wells except for 3921 (SPPZ-3) met the calibration criteria. Well 3921 had a time-weighted residual of -15.69 percent which is only slightly above the criteria. The other wells' percent differences ranged from -9.958 percent to 9.790 percent.

The criteria for average residual for all wells was that it should be $< \pm 10$ percent. Table 4.2-3 shows that the average time-weighted residual for all wells was -4.676 percent, which is within the criteria, while the average time-weighted absolute residual for all wells was 12.180 percent, which is slightly above the criteria.

The variance of the residuals for all wells was to be ≤ 0.20 square feet (ft^2). As can be seen in Table 4.2-3 the time-weighted residual variance was 0.008 ft^2 which is below the calibration criteria.

According to the Model Calibration TO/TA, the time of change in curvature of the modeled drawdown and recovery curves was to match within 10 percent of the measured curves' time. It was determined that a check on the time of change in curvature could be done by a visual inspection of the curves. The final CRT drawdown and recovery curves are shown in Appendix A-6. From the curves it can be seen that almost all wells have the same time of change in curvature. The only noticeable exception is the curve for Well 3921 (SPPZ-3). Since only one out of the nine wells showed any significant difference, the results were considered acceptable.

As a check to see that the model grid was selected large enough so that boundary conditions did not influence drawdown within the model, the final cone of depression due to the CRT pumping was created using the appropriate SWIFT model results and the SURFER plotting program. The CRT cone of depression plot is shown in Figure 4.2-11. The figure shows that there was minimal drawdown occurring at or near the boundary and, therefore, the areal extent of the boundary was appropriate and the boundary conditions were not influencing the modeled drawdown.

4.2.6 Model Validation

For model validation the calibrated transient model was used to simulate the step-drawdown pumping test results. The objective of the validation was to see if the calibrated model adequately predicted the other set of data without any additional calibration. If the outcome was positive, no further calibration was necessary, however, if the outcome was negative, additional calibration and revalidation would be necessary.

Step-drawdown Model Development

To create a SWIFT model that would simulate the step-drawdown pumping test (SDT), the SWIFT CRT model was modified in two ways: (1) the model was modified so that the results could be obtained at the times when the pumping rates changed during the SDT and (2) the pumping rates were modified to correspond to those used for the SDT. No other changes were made to the model parameters, grid, or boundary conditions. A well index of 5074 ft^2/day was used in the model. The use of this value was reasonable since the SDT was completed prior to the CRT so the initial well index of the CRT test would be more appropriate than the final value. The data used for the SDT were taken from the South Plume Pumping Test Report (DOE 1993j).

Boundary conditions were not modified for the SDT test since the conditions prior to the SDT test were very similar to the CRT test. A change in boundary conditions would have created only sightly different initial steady-state conditions and very little, if any, change in the transient results. Table 4.2-4 shows a comparison of the initial conditions taken prior to the CRT and the SDT.

For the SDT the same nine wells were simulated by the model as in the CRT. Six pumping rates were used in the model and six sets of time-dependent results were output from the model. No recovery phase was simulated by the model since no recovery data was measured for the test. The SDT pumping rates and selected measured drawdown data are summarized in Table 4.2-5. The total length of time of the SDT was 574 minutes (0.40 days) which is much shorter than the total length of time of the CRT which was 15,032 minutes (10.4 days).

Validation Results

The SDT modeling results are summarized in Appendix A-8 and A-9, and Table 4.2-6. Included in the two appendices are the modeled versus measured drawdown curves for each of the nine wells and the statistical results of the SDT run, respectively. Table 4.2-6 shows a summary of the results of the SDT statistical analyses.

The total model run time for the validation model was approximately 4 hours using a 486/50 computer with 96 MB of RAM. This simulation time seems consistent with the CRT modeling results, which required 14 hours to simulate 20 time steps while the SDT results required 4 hours to simulate 6 time steps.

Discussion of Validation Results

No criteria was outlined in the Calibration TO/TA (DOE 1993f) for the evaluation of the validation results. However, the results were evaluated in two different ways to determine if the validation results

were reasonable: (1) a visual inspection of the drawdown curves was made to see if the modeled curves reasonably matched the measured curves; and (2) statistical analyses were completed for the model run.

After a visual inspection of the SDT results in Table 4.2-6 and Appendix A-8 and A-9, it can be seen that the model adequately predicted the SDT test at a majority of the wells. There were several wells, Wells 3911 (SPPZ-A), 3918 (SPPZ-2E), 3922 (SPPZ-4), and 2002 for which the model did not predict the SDT results for very well. The reason for Wells 3911 and 3918 poor agreement is due to each well's development. If a well reacts the same while the same pumping rate was occurring but at a different time then the well could be said to be completely developed and will not change with time. However, if the same well does not react the same under the same pumping conditions then the well is being developed with time. For these two wells, the drawdown which occurred at the wells during the CRT and at a comparable pumping rate and time for the SDT, were compared and showed that the wells did not react the same under the two test conditions. The comparison of the two wells results are summarized in Table 4.2-7. Therefore, the deviations between the predicted SDT results and the measured SDT results are probably due to the changing well conditions.

The major reason for the statistics showing a large percent deviation of modeled and measured results for Wells 3922 and 2002 is that the drawdown at these two wells are very small (i.e., approximately 0.2 feet) and a small deviation in modeled versus measured drawdown creates a large percent difference. The measured versus modeled drawdown curves for these wells show similar patterns and it is believed that the validation results for these two wells are adequate.

As a check to see that the model grid was selected large enough so that boundary conditions did not influence drawdown within the model, the final cone of depression due to the SDT pumping was created using the appropriate SWIFT model results and the SURFER plotting program. The SDT cone of depression plot is shown in Figure 4.2-12. The figure shows that there was minimal drawdown occurring at or near the boundary and, therefore, the areal extent of the boundary was appropriate and the boundary conditions were not influencing the modeled drawdown.

Even though several wells showed limited agreement, the results of the validation seemed to be acceptable. For instance, for many of the wells the shape of the modeled curve was very similar to that of the measured curve. This agreement in curves generally means that the appropriate porosity and hydraulic conductivity are being used in the model. In addition, many of the modeled total drawdowns at the wells are close to the measured total drawdowns and total drawdown is related to the proper hydraulic conductivity. The statistical analyses showed that model predicted the SDT results within an average error of approximately 36 percent (Table 4.2-6). Therefore, since the validation results are acceptable no additional calibration was necessary.

4.2.7 Summary of Model Parameters

The final model parameters determined during calibration are summarized below.

1) Horizontal Hydraulic Conductivity - Final horizontal hydraulic conductivity values are presented in Figure 4.2-13. The figure shows the conductivity values on a layer by layer basis. The values ranged from 638 to 200 ft/day.

2) Vertical Hydraulic Conductivity - Final vertical hydraulic conductivity values are also presented in Figure 4.2-13. The figure shows the conductivity values on a layer by layer basis. The values ranged from 22.4 to 51 ft/day.

3) Porosity - A final porosity of 0.30 was determined from calibration.

4) Water and Rock Compressibility - A final water compressibility value of 3.00×10^{-6} 1/psi (Domenico and Schwartz 1990) was used for the model. Rock compressibility was assigned a value of 1.45×10^{-12} 1/psi which was the same as was used in the previous model.

5) Well Index - Two well index values were used in the final calibrated model. The two well indices were 5074 and 5922 ft^2/day. The first value was for all times prior to the accidental shut off of the pump and the second value was for all times after the accidental shut off.

6) Layer Allocation of Pumping Rate - The final pumping rate used for model calibration was 425 gpm. Since the pumping well RW-4 (3927) was screened in two of the model layers, an appropriate amount of the pumping rate had to be allocated to each layer. This allocation was done based on the length of screen which was in each of the model layers. Approximately 32.7 feet of screen was in model layer 1 and 7.3 feet of screen was in layer 2. Therefore, the layer allocation factors used in the model were 81.75 percent for layer 1 and 18.25 percent for layer 2.

4.3 Steady-State Flow Model Calibration

The previous FEMP steady-state flow model was calibrated to 1986 water elevation data (DOE 1993a). Since that time, additional data were collected, new wells were installed, and a large scale pumping test (South Plume Pumping Test) was conducted. In addition, a transient calibration of the model using the results of the South Plume Pumping Test (see Subsection 4.2) defined values for certain aquifer properties. The steady-state flow model was recalibrated to incorporate these additional data. Once recalibrated, the model was tested by performing the solute transport runs (Subsection 4.4), performing sensitivity analysis (Section 5), and performing particle tracking analysis (Section 6).

The steady-state flow calibration was conducted using the expanded and reconstructed steady-state model grid (see Section 3). Updated data sets (e.g., bedrock surface elevations or clay layer thickness) were used in defining the structural parameters of the new model. A new SWIFT input file corresponding to the new structure of the model was created.

The steady-state calibration criteria and modeling approach is defined in the Model Calibration TO/TA (DOE 1993f). The overall approach to calibrating the steady-state model is shown on Figure 4.3-1. The steady-state flow calibration of the SWIFT model followed six main steps:

1) Establish steady-state calibration criteria

2) Define target heads

3) Define boundary conditions

4) Define zones and flow properties

5) Simulate and compare predicted and target heads and vary certain parameters until a reasonable agreement is achieved and the criteria are satisfied

6) Perform analysis on the final run to compare it to quantitative and qualitative calibration criteria.

While the process is described in this sequence, the actual calibration is an iterative process with boundary conditions, zones and flow properties adjusted during the calibration. The following text discusses each of these steps.

4.3.1 Steady-State Calibration Criteria

Calibration criteria were developed for the steady-state flow model in the Model Calibration TO/TA (DOE 1993f). The calibration criteria consisted of quantitative measures to compare cells with wells, qualitative measures for overall inspection of the simulation, relative measures to compare the accuracy of different calibration runs, and suggested ranges for varying parameters.

Geostatistical analysis of the piezometric head from monitoring wells was used to determine head for each block and to identify areas of the site where lower confidence exists in the analyzed data sets (see Section 2). This confidence determination was used to weight the heads determined during the model calibration thus allowing qualitative comparison of the heads predicted at locations not supported by field data.

Table 4.3-1 shows the measures that were used to assess quantitatively the calibration at blocks with well control. Quantitative criteria for the flow model included measures of mean residual, mean of absolute

residuals, maximum residual, regression coefficient, and water mass balances. These measures were only applied at blocks which contain field data and compared the target value (determined at the block centroid with geostatistical analysis) and the model simulation results.

The calibration was also evaluated with qualitative measures. These measures include:

1) Contours of head were plotted, inspected, and compared to target contour plots to identify trends of differences in the model output versus targets. This measure determined if there is any clustering of residuals

2) Model velocity vector output was evaluated and compared to observed and postulated conditions

3) Results in the vicinity of the SOWC collector wells were evaluated since there are large gradients in this area

A relative measure was used to compare the accuracy of different calibration simulations. The relative measure summed weighted residuals at every active model block (weighted with the geostatistically determined uncertainty parameters) to determine the overall "accuracy" of a particular simulation for comparison with other simulations. These results were used to select the "best simulation" (i.e., the simulation with the minimum summed weighted residual).

Table 4.3-2 summarizes the criteria for the adjustment of the model parameters. As shown on this table, it was expected that several of these parameters would be refined based upon the transient flow calibration results. Constant head boundary conditions and head calibration targets were to be set based upon geostatistical analysis of water elevations.

4.3.2 Target Heads

The geostatistical analyses used water levels from June 1993 to define the steady-state heads for the calibration targets (see Section 2). These heads are shown on Table 4.3-3. Table 4.3-3 also shows the model block location for each well and the precision value for each block. These blocks form the list of "blocks with well control" to which the more rigorous calibration criteria is applied. These data do not represent actual well data, but rather are the well data geostatistically analyzed and transposed to the actual model block center. Therefore, these values may be used for comparison with model output with out the common finite difference problem of target data not being block centered.

Data were obtained from several monitoring wells in the vicinity of the SOWC collector wells. However, there were insufficient measurements to determine boundary heads and overall drawdown patterns; therefore, boundary heads and overall drawdown patterns were set with Dove (1961) and June 1993 river

data (see discussion below). The actual measurements in the vicinity of the SOWC collector wells were used for the evaluation to the calibration criteria.

4.3.3 Boundary Conditions

The steady-state flow model used two kinds of boundary conditions: specified heads (water levels) and specified fluxes (flow rates). Boundary conditions for the SWIFT input file included:

1) Specified heads around the active vertical boundaries of the SWIFT grid

2) Specified heads for surface blocks along the centerline of the Great Miami River

3) Specified fluxes for major pumping wells

4) Specified fluxes for vertical recharge to simulate infiltration through surface blocks Paddys Run and SSOD

5) Specified fluxes (0 flux or "no flow") along bedrock interfaces

Boundary Heads

Geostatistical analyses of the water levels (see Section 2), head contours from Dove (1961, Figure 47), and current Great Miami River heads defined the heads around the active vertical boundaries of the SWIFT grid. The geostatistical analyses included 3-D kriging (time as the third dimension) on the 2000-series water levels collected from 1990 through 1993. A few regional wells that were continuously monitored in the GMA area and periodic measurements of the river and adjacent wells by the SOWC provided some additional data.

Steady-state target heads may be defined with time averaged data or, alternatively, by selecting a single time that is representative of steady state. The latter approach was selected since the RI process was still ongoing during the period 1990 to 1993 and additional monitoring wells continued to be installed. To select the appropriate time, water levels from representative locations around the geostatistical analysis grid were graphed over time. These graphs indicated that the month of June 1993 would effectively represent "steady-state" conditions (see Figure 2.2-3). June 1993 was selected because, by being the latest possible date approximately representing steady-state conditions, the most comprehensive set of well data was available.

However, a lack of well control generally exists in the eastern part of the site because it lies outside of the routine data collection area of the FEMP. This lack of well control caused the geostatistical analyses to extrapolate unreasonable heads in the eastern part of the grid near the Great Miami River. Figures

4.3-2 through 4.3-4 (for model layers 1, 3 and 6 corresponding to the 2000, 3000, and 4000 series well levels) show that the geostatistical analyses overpredicted drawdown at the river near the SOWC production wells. The geostatistical analysis was not constrained by river elevations. In contrast, these figures also show that the analyses predicted increasing rather than decreasing heads where the Great Miami River left the SWIFT grid. Regional depictions of flow patterns in this area show a gradient sloping toward this grid boundary (DOE 1993a). Again the geostatistical analysis was not constrained in this area since there were no monitoring wells.

To compensate for the lack of well control in the eastern part of the site, data available from Dove (1961, Figure 47) defined heads on the eastern vertical boundaries of the SWIFT grid. Coincidentally, GMA regional groundwater levels and the Great Miami River stage are similar for these time periods. These data replaced the heads predicted by the geostatistical analyses. The pumping rates from Dove (1961, Page 64) were about 17 million gallons per day (mgd) versus the somewhat higher June 1993 rates of about 21 mgd. Along the south eastern boundary of the SWIFT grid, the stage elevations from the Great Miami River on June 8, 1993 were used to define boundary heads (see discussion below). These data were combined and used to create an overall head distribution for the site on June 8, 1993.

Figure 4.3-5 shows the contours and boundary conditions derived from the combined geostatistical, Dove (1961, Figure 47), and river stage elevation data sets. This figure forms the basis of both the boundary heads and the target heads for flow model calibration. The transition between the two data sets is fairly smooth, although some small differences exist between these data sets. Merging the two data sets and creating combined target heads (Figure 4.3-5) provided a method of defining a reasonable eastern and south eastern boundary condition and gave a pattern of heads to try to match while varying river and pumping conditions. This approach provided a practical solution to not having comprehensive data in the river region. As described above, these idealized contours were not used for quantitative assessment of the calibration, but rather were used to derive boundary conditions and served as a guide to developing the correct flow patterns (i.e., actual geostatistically transposed well levels were used to quantitatively assess the calibration).

Simulation of the Great Miami River

To simulate the Great Miami River, the steady-state flow model imposed heads corresponding to the water surface profile or stage elevations along the river centerline. Dove (1961, Pg. 67) indicates that the effects of silting on the river bottom are probably confined to short periods of low-velocity flow. In addition, DOE (1987, Table 5.4.3 and Figure 5.1-1) describes bottom sediments as having little or no silt over the river area encompassed by the SWIFT grid. Furthermore, DOE (1987, Figures 2.1-5 through 2.1-10) show that the Great Miami River cuts directly through the sand and gravel of the main aquifer. Therefore, the Great Miami River directly contacts the GMA for most of its reach within the model grid. These data confirm that the steady-state flow model should use the aquifer hydraulic conductivity of the GMA and that no leakage term be imposed on the river bottom. Geotrans (1985, Pg.

31) similarly modeled the Great Miami River as a constant head boundary and assumed a total hydraulic connection of each river block with the GMA. In contrast, DOE (1993a) used a river leakage factor of 0.5 to model a low hydraulic conductivity zone along the bottom of the river. DOE (1993a) assumed vertical gradient of 1 and a vertical hydraulic conductivity of 0.001 times the aquifer hydraulic conductivity. While the DOE (1993a) approach gave seemingly reasonable results, the current approach is simpler and more rational given the lack of evidence of low hydraulic conductivity sediments along the bottom of the Great Miami River and the possible transient nature of these sediment locations (if they do exist).

The actual heads that were used in the model calibration were obtained from a combination of two sources. One source provided a single value along the appropriate reach at the correct time while the second data source provided an entire river profile but at a different time. Daily measurements were made along the Big Bend of the Great Miami River during June of 1993 (the calibration period) at approximately River Station 24.35 (see Figure 4.3-6) (FERMCO 1993b). For June 8, 1993, a river elevation at this station of 521.83 was measured. For the June period, this was the only location in the immediate vicinity where the river was measured. However, a water level survey of the Great Miami River was conducted in October 1991 covering a reach of the river from New Baltimore to Hamilton (see Figure 4.3-7) (PARSONS 1993). The results of this survey cover the reach of the Great Miami River that is included in the model. The water levels used in the model were corrected upward by a factor of 2.5 feet which was the difference between the measurement at River Station 24.25 on June 8, 1993 and the corresponding October 1991 measurement (see Figure 4.3-7). While this linear interpolation of river stage is not strictly valid, nevertheless, over the relatively small difference in stage (less than 3 feet) this forms a good approximation. Appropriate head values from this corrected profile were defined for the appropriate model blocks defining the constant head river.

Simulation of Major Pumping Major Wells

A review of site and regional data showed that three wells in the model domain are pumped sufficiently to have an impact on the flow patterns in the GMA. These wells are the SOWC Collector 1, SOWC Collector 2, and the FEMP Production Well. The earlier flow model also included production wells for industries south of the site in the Paddys Run Road and Fernald areas. These wells are no longer pumped as these locations have been supplied with an alternate water supply. The South Plume Recovery Wells, first operated in August 1993, were not included in the calibration because they were not operating during the time period being used for calibration (June 1993).

Table 4.3-4 shows the historical record of pumping rates for all three SOWC collectors through 1992. These pumping rates vary annually based primarily upon seasonal domestic water demand, new development, and industrial usage rate. This table shows in general an increasing trend from 1952 to 1967 from an annual average of 9.77 to 17.89 mgd. Since that time no steady growth pattern or declining pattern is evident. Over this period the maximum pumping rate was 18.94 mgd in 1987 while

the minimum was 16.04 mgd in 1976. The 5 and 10 year rolling averages calculated from this historical data of pumpage smooth the variation and show some small trend of increasing pumpage. The maximums for the 5 and 10 year rolling averages are 18.13 mgd in 1988 and 17.80 mgd in 1992 respectively.

Table 4.3-5 shows daily totals for the month of June 1993 for Collectors 1 and 2. Collector 3 is not being used. The totals for June 7, 8, and 9 in Table 4.3-5 were averaged for use in the steady-state calibration to correspond to the time during which measurements of the Great Miami River and adjacent wells were available. Collectors 1 and 2 had daily averages of about 11 and 10 mgd, respectively. Dove (1961, Pg. 26-28) showed that the SOWC wells were radial collector wells set in the lower GMA with an effective radius of nearly 200 feet. So, to accurately simulate the drawdown around each collector well, the model used several blocks with individual pumping rates. The pumping rates for each block were proportioned directly against the total pumping rate according to the percentage of radial well screen found within each block.

The pumping rate of the FEMP production well was set based upon recent operating data to 350,000 gallons per day (PARSONS 1994). Based on well construction information, pumping from this well was simulated to occur in model layer 5.

Simulation of Surface Recharge and Paddys Run/SSOD

Recharge was simulated following a similar approach as the original model (DOE 1993a), only with updated surface geology maps (IT 1993) and a more sophisticated approach to defining fluxes through Paddys Run and the Storm Sewer Outfall Ditch (SSOD) based upon recent surface water modeling efforts (DOE 1993n). Figure 4.3-8 shows the basis for the zonation of recharge for the steady-state model. Zones were defined based on surface material properties and flux through the seasonal surface water bodies (Paddys Run and SSOD). The two geologic units with different properties affecting infiltration are the fine grained glacial overburden units (till) and the surface-exposed GMA or the GMA covered with river alluvium. These units were defined as separate zones for recharge and following the earlier modeling efforts (DOE 1993a), values of 6 in/yr and 14 in/yr were assigned for the till and GMA/alluvium respectively. The areas with exposed bedrock had zero recharge specified.

Fluxes for vertical recharge through portions of Paddys Run and the SSOD were also defined. For the reaches of Paddys Run and the SSOD which flow on top of the glacial overburden (till), infiltration is considered the same as the till value (6 in/yr). Increased vertical recharge occurs where the stream channels of Paddys Run and the SSOD have cut through the glacial overburden into the outwash deposits of the GMA (see Figure 4.3-8). The water table elevation in the GMA in and around the site generally lies below the stream bed. Hence, an unsaturated (vadose) zone forms between the water table and the stream bed. Significant amounts of water can infiltrate from the stream to the unsaturated glacial outwash deposits and then enter the GMA. When Paddys Run cuts deep enough into the glacial outwash deposits

so that the streambed elevation matches the water table elevation, additional infiltration becomes negligible and stream values are assigned the same value as the adjacent alluvium.

The approach to zoning Paddys Run and the SSOD followed the surface water modeling effort (DOE 1993n) which is summarized below. The United States Geological Survey's VS2DT code (Lappola et al. 1987) was used to calculate the appropriate vertical recharge to use with the SWIFT model for Paddys Run and the SSOD. Drainage areas for reaches of the SSOD and Paddys Run were defined and average physical parameters at these reaches were calculated. From these parameters, the HEC-1 model simulated runoff into Paddys Run and its tributaries and the SSOD. When the surficial runoff and streambed discharges reached where Paddys Run and the SSOD have cut through the glacial overburden, infiltration occurred. The infiltration rates generally started high and decreased as the infiltrating water saturated the glacial outwash deposits between the streambed and the groundwater table and as the depth of flow in the stream channel cross section decreased. The VS2DT results showed that only 29 percent of the total runoff generated by a 1-year, 24-hour storm event infiltrated through the streambeds of Paddys Run and the SSOD. These results gave annual infiltration rates through the stream bottom of 255, 112, 12, and 140 in/yr, for Reaches CC-DD, DD-EE, EE-FF, and II-KK, respectively (see DOE 1994). However, because the 1-year 24-hour storm only accounts for a small percentage (less than 6 percent) of the annual rainfall, it was decided to multiply all infiltration rates by a factor of 4. The factor of 4 was chosen as a balance between accounting for a larger percentage of the annual rainfall and the realization that only relatively large rainfall events contribute significantly to Paddys Run flow. When the percentages of each SWIFT block covered by the streambeds are considered, the infiltration loadings became 176, 84, 14, and 50 in/year for each cell in Reaches CC-DD, DD-EE, EE-FF, and II-KK, respectively.

Figure 4.3-9 shows the infiltration rates used in the calibrated model and Table 4.3-6 summarizes the parameters used in the calculation of recharge in these streams.

4.3.4 Zones and Flow Properties

Figures 4.3-10 through 4.3-12 give the three zonal configurations for horizontal hydraulic conductivity used in the flow calibration and the ratio of vertical to horizontal hydraulic conductivity. These three zone configurations were developed based on the following:

1) A least seven pumping tests have been conducted in the Great Miami Aquifer within 15 miles of the site. These pump tests have calculated hydraulic conductivities ranging between 120 ft/day to 720 ft/day (see Subsection 5.2 for listing). Of these pumping tests, five have been performed within the model grid including one within the FEMP site in the production area (Spieker et al. 1962), three at the SOWC collector wells (Dove 1961, Kazman 1950, and Lewis 1968), and one south of the site in the South Plume area (DOE 1993j). The locations and results of these pumping tests were utilized in the zoning of hydraulic conductivity.

2) The transient calibration of the South Plume pumping test was used to set Zones III and IV (see Figures 4.3-10 through 4.3-12) north and south of the recovery wells (see Subsection 4.2).

3) In general, boring logs have included reasonably consistent descriptions of the sands and gravel of the GMA. One exception to this consistency is reports of greater fine grained content north of the FEMP up the Shandon Trough. This information was used to create Zone VI (see Figure 4.3-12) zone in the north part of the grid.

4) Consideration was given to the location of the center of the bedrock trough in creation of zones. It is theorized that glacial outwash streams deposited a greater percentage of the higher velocity (coarser and more conductive) sediments in the middle of the channel versus the outer edges. The outer edges would be more likely to have finer floodplain-type sediments.

5) Consideration was given to other geologic features such as the location of the glacial overburden (see Figure 4.3-8) and the blue clay layer within the aquifer. These features may indicate similar deposition of finer grained sediments at much smaller scales within similar locations.

These zones also allowed the flow properties within the model to change from spatially simple to more complex zonation. Each zone had six layers.

4.3.5 Flow Model Calibration

The calibration of the flow model basically involved an iterative adjustment and/or correction of various hydraulic parameters. These parameters included hydraulic conductivity and defined zones, the ratios of vertical to horizontal conductivities, recharge rates, pumping rates, and eastern boundary conditions. Table 4.3-7 summarizes these parameters for each of the calibration runs. Runs 3DM1 through 3DM7 (not shown in Table 4.3-7) involved seven previous cases. These seven runs developed and tested the new grid, new material properties and layering, and new types of boundary conditions (e.g., river and configuration of pumping wells). For runs 3DM8 through 3DM20, the flow model calibration generally followed the steps outlined below:

1) The SWIFT input file is created with the defined conditions for the calibration run.

2) The calibration run is simulated to steady-state conditions.

3) The output is post processed
   (1) Heads are contoured.
   (2) Residuals between simulated results and targets are contoured.

(3) Simple statistics (for example average residual) are calculated to determine whether the simulation is closer to the calibration criteria than previous simulations. The later runs in the calibration had all the statistical measures calculated.

4) The output is assessed. Based on this assessment, the conditions for the subsequent runs are defined.

5) The previous steps are repeated until modeled and target heads agree reasonably well.

6) Calibration criteria are formally checked against modeled heads once they satisfy the steady-state flow criteria. This more detailed check may lead to further refinement of model parameters.

Initially, the residual head contour plots were inspected to screen out unrepresentative estimates of the various parameters. Once the residual head contour plots showed general agreement, statistical measures were calculated and compared to the established criteria.

Refinement of model parameters started with simple configurations and progressed to more complex ones by changing the spatial variation or actual values of various parameters. For example, reviews of the literature and data from the transient flow calibration (see Subsection 4.2) suggested several possible zones of hydraulic conductivity (Figures 4.3-10 through 4.3-12). Run 3DM8 applied the Zonal Configuration A given in Figure 4.3-10 to only two zones by using the same hydraulic conductivities for Zones I and IV and Zones II and III, respectively. Table 4.3-7 gives the vertical distribution of hydraulic conductivity by each zone. Run 3DM9 increased the spatial complexity slightly by changing the hydraulic conductivities used in Zone I to 350 ft/day as shown in Table 4.3-7. Changes in later runs also included corrections to the pumping rates, eastern boundary heads, recharge rates, and ratio of vertical to horizontal hydraulic conductivity. Ultimately, Run 3DM19B gave the best overall representation of the flow system with the lowest statistical deviations from the target calibration heads. Figure 4.3-13 shows the hydraulic conductivity distribution for the selected run.

4.3.6 Analysis of Calibrated Model

Figures 4.3-14 through 4.3-19 give the predicted head contours for the steady-state flow model. The steady-state heads conform to the conceptual model of groundwater entering the FEMP area (see DOE 1993a) through buried channels on the west (New Haven Inlet), north (Shandon Trough), and east (New Baltimore Outlet). Under natural conditions, the groundwater would flow primarily across the site to the south. However, the large collector wells of the SOWC east of the FEMP in the Big Bend area of the Great Miami River create a large cone of depression. This cone of depression causes flow at the FEMP to have easterly, southeasterly, and southerly components. Infiltration from the Great Miami River clearly reduces the drawdown cone near the collector wells, especially in Layer 1 as shown in Figure 4.3-14. In contrast, Layers 5 and 6, Figures 4.3-18 and 19, respectively, show less recharge from the river

because they have larger drawdowns. The larger drawdowns result in part because these layers contain the collector well screens, which are farther away than other layers from the river bed, and have more encroachment by the bedrock. Figures 4.3-20 and 4.3-21 show the effects of river infiltration and the SOWC collector wells in terms of contours of the head differences between Layers 1 and 3 and Layers 1 and 6, respectively. The maximum head difference occurs between Layers 1 and 6 and indicates less vertical infiltration at depth than in the higher layers and greater drawdown near the well screens of the pumping wells.

These calibration runs showed that spatial variations in the hydraulic conductivity and eastern boundary conditions strongly affected the calculated heads. The final steady-state flow model has six zones of hydraulic conductivity (see Figure 4.3-13). The sixth zone corresponds to low hydraulic conductivities near the Shandon trough. In contrast, changes in the vertical recharge rates through Paddys Run and the SSOD and the pumping rates at the collector wells showed a much smaller effect on the calculated heads. Similarly, vertical changes in the horizontal hydraulic conductivity because of layering did not to have a major effect on the calculated heads. In Run 3DM19B, only Zones II and III continued to have a vertical variation in the horizontal hydraulic conductivity.

Table 4.3-8 shows the target geostatistic heads and uncertainties, the calculated heads from the calibrated run, the absolute residuals and the residuals corrected for the uncertainty factor. Table 4.3-9 shows the results compared to the calibration criteria. All of the criteria were met except for the requirement of the maximum residual falling within the kriged confidence interval. In this case only 12.5 percent of the blocks with well control fell within this interval. Since the confidence interval is set based on the spatial density of data and blocks with well control, by definition, have nearby data, this confidence interval produced by the geostatistical analysis was very small (typically 0.30 feet or less). The maximum residual was 2.36 feet at well 2018. With the measure of the mean of the absolute residuals of 2 feet and the standard deviation of the head differences of 3 feet; a maximum residual could have been at least 3 feet. This provision requiring all of the residuals for each model block with well control was unnecessary to control the accuracy of the calibration. For blocks without well control, a higher percentage (67.8 percent) of the model blocks fell within the confidence interval.

Table 4.3-10 shows the projected and actual range of the steady-state flow model calibration parameters. Several of these parameters were determined with the transient calibration including horizontal and vertical conductivity, porosity and rock compressibility. The horizontal and vertical hydraulic conductivity determined with the transient calibration and then used in the steady-state calibration fell slightly out of the projected range. The eastern boundary conditions and targets were modified based on other data sets due to the scarcity of data in this area as discussed above.

Figures 4.3-22 through 4.3-27 show the spatial distribution of residuals (calculated heads minus target heads) for Run 19B for the six model layers. In general, the calculated heads match the target heads quite well. For layer 1, a large portion of the FEMP and east of the FEMP has residuals less than 1 foot

and the majority of the model domain has residuals less than 2 feet. Areas with residuals greater than +/-2 feet are southwest of the production area adjacent to Paddys Run, northwest of the production area and adjacent to the Great Miami River. The high residual at the area adjacent to Paddys Run is caused by the local high occurring there in the geostatistical data set (see Figure 4.3-5). This high could not be matched even with increased infiltration (up to 176 in/yr) along Paddys Run. The steep gradient along the northern boundary in the target contours (see Figure 4.3-5) could not be matched with the model even with the 120 feet/day hydraulic conductivity used in Zone 6. This zone possibly could have been increased in size; however, based upon the scarcity of data in this area, it was felt that this was not justified. For the river residual, further adjustment was not deemed acceptable based both the scarcity of data and the steep and transient effects of river and high volume pumping. The remaining five layers show similar locations of residuals.

Figures 4.3-28 through 4.3-33 show the velocity vectors for the six model layers. These vectors show the groundwater velocity direction and relative magnitude. As discussed above, groundwater flows from the north boundaries from the Shandon and New Haven Troughs to the south and to the east through the Paddys Run Outlet, to the SOWC collector wells, and through the New Baltimore Outlet. Velocities are highest in the Paddys Run outlet and adjacent to the SOWC collector wells while velocities are the lowest just east of the FEMP. Directions of flow and velocity distribution are similar in all layers except; the FEMP production well effects flow in layers 5 and 6 and velocities are less in the lower layers south of the FEMP due to the lower hydraulic conductivities in those zones in the lower layers.

4.4 Solute Transport Model Calibration

The solute transport model was recalibrated because additional data have been collected and new monitoring wells have been installed and sampled since the original calibration in 1990. These data show that the southern extent of the south plume does not extend as far south as was believed during the original calibration. In addition, the vertical distribution of concentrations do not compare well with monitoring data with a much greater percentage of mass at lower depths in the original model than is shown in monitoring wells. This has created uncertainty in the selection of the solute transport parameters (source loadings, partition coefficient, and dispersivity) used in the original calibration of the model. Another reason for recalibration of the solute transport model is that the flow model has been recalibrated (see Subsection 4.3) since the final selection of flow model parameters (e.g., hydraulic conductivity and porosity) which also affects solute transport in the model.

4.4.1 Background on Original Calibration

The original calibration (DOE 1993a), using an estimated retardation factor (R) of 9, resulted in a reasonable match to the monitoring data (except for the southern extent of the South Plume as described above) with most of the contamination in the top model layers. Based on the results of a geochemical

study (DOE 1993a, Appendix A), the retardation factor was revised upward to 12. The calibration using R of 12 resulted in more uranium modeled at depth (which does not match new monitoring data) and a much larger historical mass loading to the aquifer. The retardation factor was miscalculated in the geochemical study by using a grain density instead of a bulk density in the retardation equation. In fact, geochemical studies indicate a range of retardation factors from approximately 8 to 33, indicating that the original calibration with a retardation factor equal to 9 was within the range.

4.4.2 Approach to Solute Transport Calibration and Modeling

Figure 4.4-1 shows the steps and logic in the calibration process. The calibration of the solute transport model is an exercise primarily to define reasonable values of the solute transport parameters. Because of the uncertainty of both the location and strength of historical source loading terms and their time distribution, these terms can only be approximated. Ultimately, the calibration of partition coefficient (K_d) and dispersivity is linked to these source terms. Therefore, the calibration exercise is primarily a plume matching activity to define a reasonable K_d and dispersivity within established ranges based on these approximated loadings.

However, although there are the inherent limitations described above, the real issues for model applications are the present uranium concentrations, the present and future loading terms to the GMA, partition coefficient in the GMA, and dispersivity in the GMA. The approach to obtaining reasonable values for each of these is:

1) Present Uranium Concentrations - Monitoring data from wells located within the GMA are used for defining the initial conditions in the GMA, not continuous loading from source loading blocks like the approach used in the previous version of the model (DOE 1993a). These data have been geostatistically analyzed for depiction of values for each model block (see Section 2). By using these values, more accurate depiction of initial conditions can be achieved than would be possible with historical source loadings.

2) Present and Future Loading Terms - Present loading terms to the GMA are defined with more detailed modeling efforts performed as part of each operable units baseline risk assessment. These efforts included calibration of these loading terms to approximate monitoring well concentrations near waste unit boundaries. Loading terms from contaminated source materials were based on sampling data. This more detailed approach for each operable unit is more sophisticated than the original solute transport calibration and considers variables and unit specific data. The original 1990 solute transport calibration more globally defined loading terms. Unlike the original model, the revised model has the benefit of the completion of the operable unit remedial investigations. Future loading terms will be based on the RI's for the baseline case or the remediation scenario for options being evaluated or designed.

3) Partition Coefficient in the GMA - The K_d is estimated from literature reviews (DOE 1993k), site specific testing and information (DOE 1993k), and through solute transport calibration. The literature and site data analysis establish ranges for K_d. The solute transport calibration match existing plumes with 40 years of solute loading to select a K_d value within the established range.

4) Dispersivity in the GMA - The dispersivity is estimated from literature reviews (see Section 5), and through solute transport calibration. The literature analysis establish ranges for dispersivity. The solute transport calibration match existing plumes with 40 years of solute loading to select a dispersivity value within the established range.

To meet the objectives outlined above, the solute transport calibration consisted of the following steps:

1) Definition of calibration criteria.

2) Development of a uranium plume configuration to be used as a target for the calibration. Calculation of dissolved mass based on this plume configuration and calculation of sorbed mass based on the dissolved mass and the selected values of K_d.

3) Performance of calibration simulations. Simulation of the two K_d cases (equivalent to R=9 and R=12) with the scaled loading terms. Scaling of the original loading terms to inject the appropriate quantity of mass into the GMA for each R case. Analysis of the output from these simulations and selection of the "best" case for further analysis. Performance of additional simulations seeking further refinement of the selected case by fine tuning of the loading terms and adjustment of the longitudinal and transverse dispersivity. Analysis of these simulations and selection of final simulation.

4) Performance of more detailed analysis of this final simulation including detailed statistical analyses to check the results versus the calibration criteria.

5) Decoupling of the source loading terms used in the calibration. Definition of initial conditions based upon most conservative (highest concentration) case of waste unit modeling and GMA monitoring data.

Each of these steps is discussed in the following subsections.

4.4.3 Summary of Solute Transport Calibration Criteria

For the solute transport model, quantitative and qualitative criteria were established for matching model results to target concentrations. Quantitative criteria include the definition of both target locations and statistical parameters (and acceptable ranges of these parameters) for calibration of the transport models.

In addition, qualitative comparisons between monitoring data and model predictions were defined. Both quantitative and qualitative assessments of the calibration were performed; nevertheless, solute transport calibration is a more qualitative process than flow calibration because of the complexities of multiple sources and spatially varying transport parameters. Therefore, quantitative measures are less rigorous than for the flow calibration. In general, an attempt was made to balance two primary calibration targets: (1) concentrations at particular blocks representing locations of measured data, and (2) total mass of contaminant in the aquifer.

Table 4.4-1 defines goals for the quantitative criteria for the solute transport calibration. These measures were applied only at blocks which contain wells and compared the target value (determined at the block centroid with geostatistical analysis) and the model simulation results. The calibration attempted to meet these goals, however, allowance was made for instances in which the goal could not be met. In these cases, an appropriate explanation would be provided.

In addition, a relative measure was used to compare the accuracy of different calibration simulations. The relative measure summed weighted residuals at every active model block (weighted with the geostatistically determined uncertainty parameters) to determine the relative accuracy of a particular simulation for comparison with other simulations.

4.4.4 Selection of Uranium Plume Targets and Calculation of Uranium Mass

Since additional data have become available through monitoring and additional well installation, data from 1990 to the present were compiled and evaluated to redefine the solute transport calibration targets for uranium. Geostatistical analysis of the spatial distribution of uranium analytical data from the 2000, 3000, and 4000 series monitoring wells was performed on averaged annual uranium data sets from years 1990, 1991 and 1992 (see Section 2). This analysis was used to determine uranium targets for each block and to identify areas of the site where lower confidence exists in the analyzed data sets. Based upon these depictions and the most recent analytical data, the 1990 plume was selected as most conservative and representative for the calibration effort. Data mean and confidence interval of mean from the 1990 analysis were defined for each block with well control and served as the calibration targets.

The retardation factor, R, which is changed in SWIFT by varying the distribution factor, K_d, is a major factor for controlling the quantity of the historical loading to the aquifer. The equilibrium assumption that is used in the modeling automatically causes the aquifer loading ratio (material sorbed/material dissolved) to be (R-1) so that the total historical loading to the aquifer must equal R times the quantity of material dissolved. The quantity of uranium in the aquifer was calculated by adding the quantity in each cell based on the geostatistically determined (see Section 2) 1990 concentration for each cell. The quantity in the aquifer includes the sorbed material so that this quantity is strongly dependent on R.

Figure 4.4-2 shows the four zones created on the 1990 geostatistical plume for mass calculation. Areas were divided into the entire South Plume (Zone I), the Operable Unit 1 (OU-1) and OU-4 area (Zone II), the Stormwater Retention area (Zone III), and South Field (Zone IV). Table 4.4-2 shows the dissolved mass for each model layer for each of these zones. Table 4.4-3 shows the total dissolved mass (independently calculated since the four zones overlap and do not add up to the total) and calculates adsorbed mass and total mass for each model layer for the R=9 and R=12 cases. The total mass for the R=12 case was 5,550 lbs versus 4,210 lbs for the R=9 case. The majority of the mass (98.76 percent for R=9 and 98.72 percent for R=12) is calculated as being in the upper GMA or model layers 1, 2, and 3. In contrast, the original model showed 51 percent in the upper GMA and 49 percent in the lower GMA (DOE 1993a).

4.4.5 Calibration Simulations

SWIFT runs for the calibration were conducted as shown by Table 4.4-4. The location and sequence of loading given in the Groundwater Model Report (DOE 1993a) was assumed to be representative. The total mass loading for the previously calibrated model with Rd = 12 (DOE 1993a) was 19,218 lbs. Each loading term was scaled downward to correspond to the loadings (5550 and 4210 lb) determined above for Runs 1 and 2.

Based on an inspection of results from Runs 1 and 2, it was concluded that R=12 gave a better overall representation of results. The South Plume is too widespread with R=9 and the predicted plumes leading edge has moved beyond that shown with the monitoring data. The R=12 case showed a much closer XY depiction of the plume. Therefore, further simulations focused on refining the R=12 case.

However, it was found that Run 1 had lower layers containing too high a percentage of the mass compared to the uranium target plumes. Therefore in order to reduce vertical dispersion, α_v was reduced from 10 to 0.1 ft for Run 3. Additional loading terms for OU-1, OU-2, and OU-3 determined by RI activities were also included. Results from Run 3 showed that the lower vertical dispersivity was indeed effective in reducing contaminant concentrations in the lower model layers. Differences still existed, however, in the XY depiction of the plume especially in the South Field and SSOD areas.

For Run 4, the mass was redistributed somewhat to give a better fit with the geostatistically determined data in these areas. A final SWIFT run was conducted (Run 5, 3ds19cs5.dat) in which all parameters were the same as with Run 4 except finalized OU-1 and OU-2 loading terms were used. Thus, it was concluded that the values for R, α_h, and α_v of 12, 100 ft, and 0.1 ft respectively provide the best fit. The value of α_v of 0.1 ft is lower than expected for a field application with α_h of 100 ft. However, numerical dispersion in finite difference computations will cause vertical transport even if α_v were zero. Thus, a lower value of α_v is required to effectively reproduce results found from monitoring data.

4.4.6 Analysis of Selected Simulation

Table 4.4-5 illustrates the comparison of the quantitative criteria goals with the results achieved with Run 5. The results in Table 4.4-5 generally fall outside the criteria goals. However, the goals were perhaps too stringent considering the uncertainties involved in both solute transport modeling and the determination of the target concentrations. In addition, for the reasons stated in Subsection 4.4.2, further fine-tuning would likely require changes in the source loading terms which would not result in a better prediction of K_d and dispersivity.

The results are examined in more detail to provide a better understanding of the correlation between predictions and goals. The SWIFT model grid consists of 6 layers in a 120 by 112 mesh. Of these 80,640 blocks, 60,666 were determined to possibly contain contamination or be within the "plume." Of these 60,666 blocks, 59,972 or 99 percent were modeled within the uncertainty interval. The average of the weighted residuals (weighted by concentration) for the 60,666 blocks is 4.62 percent and the average of the absolute weighted residuals is 7.18 percent. Table 4.4-6 gives a block-by-block correlation for the 166 blocks well control. The data have been sorted to bring the 14 blocks that failed to the top. The table shows well number, grid location (X,Y,Z), 1990 target concentration [C(GST)], uncertainty ratio (UNC)for C(GST), 1990 predicted concentration C(SWIFT), the ratio of C(SWIFT)/C(GST), uncertainty ratio in the prediction (PREDICTED UNC), i.e, C(SWIFT)/C(GST) if C(SWIFT) is greater than C(GST) and the reciprocal if C(GST) is greater than C(SWIFT), and a pass fail notation (OK/FAIL). If the PREDICTED UNC is larger than the UNC, the block has failed to be predicted within the uncertainty interval. Note that the results have been sorted according to descending PREDICTED UNC. The predictions for blocks listed near the end of the table are very close to the target values. Nearly 1/2 of the blocks with well control (78) have PREDICTED UNCs of 2.00 or less.

No attempt to improve the correlation by removing outliers was made. For example, if Well 2045 is removed, the results given in Table 4.4-5 change to those given in Table 4.4-7. The improvement is significant.

Predicted concentration contours for each of the six SWIFT layers are given in Figures 4.4-3 through 4.4-8. These contours are reasonable approximations to the 1990 dissolved concentration levels in the aquifer. Table 4.4-8 shows the distribution of mass in the model layers. The model predicts over 90 percent of the mass in the top three layers.

Further effort of fine tuning of loading terms locations and strengths which could have resulted in a closer match were deemed unnecessary since the objective of setting reasonable K_d and dispersivity values had been met. As stated above, the actual initial concentrations used in solute transport simulations will be set based on conservative depictions of monitoring and modeling results (i.e., these results will not be used for future simulations). The results illustrated in Table 4.4-8 and Figures 4.4-3 to 4.4-8 do provide confidence that SWIFT modeling does include most important phenomena.

4.4.7 Decoupling of Source Loading and Creation of Initial Conditions

For applications of the model beginning with the OU-5 RI, historical source loading terms were decoupled from the model. Initial aquifer concentrations were set based on a most conservative case of monitoring data and specific OU-5 RI model results. By decoupling the historical source term and using the monitoring data directly as initial conditions, the model has become more modular and flexible. In addition, this method of setting initial conditions can be more easily applied to other constituents of concern.

Initial conditions are defined for the GMA model and modeling runs use a defined time equal to 0 as 1994. Forty year model runs from 1954 were performed for uranium with the applicable loading from Operable Unit 1, 2, and 4 to define present day modeled conditions. In addition, monitoring well data for uranium were contoured for 2000, 3000, and 4000 series wells. These monitoring well plume data were superimposed on the model grid and concentrations were assigned for each appropriate grid block. Since these three well levels correspond to revised SWIFT model layers 1, 3, and 6, averaged values between these layer values were assigned for the intervening layers. As the final step, initial conditions were delineated in the SWIFT GMA model as the highest concentration for a particular block from the 40 year model runs with loading from the OUs 1, 2, and 4 and the gridded monitoring data.

Figure 4.4-9 shows the initial GMA model conditions used in the SWIFT GMA model runs for uranium. This plot only shows the GMA model Layer 1 initial concentrations; however, initial conditions were input for all six model layers using the process described above.

SECTION 5

UNCERTAINTY ANALYSIS

5.1 Technical Approach

The objective of the uncertainty analysis is to quantify the uncertainty of the output from the improved GMA groundwater model. For this evaluation, model uncertainty analysis is focused upon the definition of the statistical distribution of specific performance measures used in risk assessments (the current application of the model). These performance measures include the maximum concentration in the aquifer and the travel time to a receptor (e.g., the property line). With the uncertainty defined for these performance measures, the model applications for risk assessments can include ranges rather than a single value and the model can be more appropriately used as a prediction tool. The ECTran and SWIFT models were used in a complementary fashion to perform the uncertainty analysis. ECTran was utilized to perform Monte Carlo analysis using defined ranges of input values of several model parameters. However, since certain simplifications are necessary when using the analytical ECTran model, SWIFT simulations were performed to confirm the ECTran results with the more sophisticated, three-dimensional, numeric model that is actually used in the risk assessments.

Three activities were conducted for the uncertainty analysis.

1) Site and literature data were reviewed to estimate reasonable ranges of the selected model input parameters. Distributions were established for input parameters including horizontal hydraulic conductivity (K_h), horizontal to vertical hydraulic conductivity ratio (K_h/K_v), hydraulic gradient (I), porosity (n), uranium partition coefficient (K_d), dispersivity (α), mixing depth (d_m), and travel distance to a receptor (L). The range of input parameter values was established by compiling site-specific data or literature values. Geostatistical analysis of 2000 series wells water elevations was used to define the range of hydraulic gradient (I) and range of direction of flow (which will be used to define travel distance [L]).

2) Using the estimated ranges and distributions defined in activity 1, Monte Carlo simulations were performed using the ECTran model to provide an analysis of uncertainty of the performance measures. These simulations included input distributions of K_h, K_d, α, I, n, d_m, and L. The ECTran Monte Carlo simulations were utilized to statistically quantify the combined impacts of uncertainties of all the major model parameters on exposure concentrations and time of travel.

3) Sensitivity analysis with the improved SWIFT groundwater model was performed to confirm the results of the ECTran modeling, to include the effect of K_h/K_v (which ECTran is unable to assess), and to assess the impact in a three-dimensional context. The SWIFT model sensitivity

analyses focused on quantifying the ranges of model outputs based on the extreme values of individual or combined model parameters to which the exposure concentrations or contaminant travel times are most sensitive. This analysis included simulations that vary these parameters to designate a case of maximum concentration and a case of minimum time of travel to a receptor or property line. This analysis also defined the sensitivity derivative of each parameter to quantify the relative impact of each parameter on the performance measures. This analysis was performed by varying one parameter at a time and holding the other parameters at their calibrated values. Finally, this analysis compared the results of the calibrated original and revised models to understand the effects the model changes have had on predicted plume transport.

The approach and the results of these three activities are described in greater detail in the following sections.

5.2 Input Parameter Estimation

Site and literature data were reviewed for each of the parameters defined above to establish reasonable ranges of the selected model input parameters. The derivation of these ranges for each parameter are described below:

Horizontal Hydraulic Conductivity (K_h)

Table 5.2-1 shows values of K_h from pump tests conducted in the GMA in the vicinity of the FEMP site. This table shows for 11 tests conducted since 1948, an average K_h of 386 ft/day with a minimum of 120 ft/day and a maximum of 774 ft/day. Figure 5.2-1 shows the locations of these tests.

The improved model has several zones for hydraulic conductivity (see Section 4). For the sensitivity runs, it is necessary to maintain the same ratio between these K_h zones to create similar patterns of hydraulic gradients and groundwater velocities. Therefore, a method to select the zone for setting the minimum and maximum regional values was defined. Review of these data showed that the minimum zone (designated as "B" on Figure 5.2-1) is adjacent to the Great Miami River. Therefore, the zone adjacent to the Great Miami River in the improved model was set to the 120 minimum value and other zones were lowered by the ratio between this 120 minimum value and 375 (the calibrated value - see Section 4) or 0.32 for the minimum case. The maximum value (designated as "H" on Figure 5.2-1) is beneath the edge of an area which is covered with till. In a similar manner, the zone beneath the till in the improved model was set to the 774 maximum value and other zones were raised by the ratio between the 774 and 270 (the calibrated value (see Section 4) or 2.87 for the maximum case.

Horizontal/Vertical Hydraulic Conductivity Ratio (K_h/K_v)

Typically horizontal hydraulic conductivity of unconsolidated materials is greater than vertical hydraulic conductivity due to the anisotropic effects caused by horizontal bedding planes. Higher ratios occur with greater stratification especially with the presence of finer grained layers. Typical factors reported for glacial outwash range from ratios of 5 to 200. The South Plume Pump Test determined ratios of approximately 5 to 15 (DOE 1993j). The early calibrations of the groundwater model used a value of 10 (DOE 1993a) while the recent, revised calibration used values that ranged from 5 to 20 (see Subsection 4.3)

For this sensitivity study, ratios of 5 to 100 were used. The lower number represents a measured value while the upper sets a reasonable upper limit (see GeoTrans 1985).

Effective Porosity (n)

Effective porosity is the porosity available for fluid flow. By definition, effective porosity is some percentage of total porosity based on material properties. Fetter (1988) states that for sediments with interconnected pores (like sand and gravel) effective porosity is essentially the same as total porosity. Therefore, the total porosity is used as the basis for defining effective porosity for this study. Freeze and Cherry (1979) report total porosity values for sand of gravel ranging from 25 percent to 50 percent. Fetter (1988) defines a range for well sorted sediments based upon theoretical cubic and rhombohedral packing between 26 percent to 48 percent, with total porosity lowered with a mixture of grain sizes and shapes. He reports mixed sand and gravel to have ranges from 20 percent to 35 percent. A third source (Driscoll 1986) reports sand with total porosities of 25 percent to 40 percent and mixed sand and gravel as 15 to 25 percent. Boring logs and sieve analysis show both well sorted and less sorted sand and gravel (DOE 1984).

The original site flow model used an effective porosity of 25 percent. The transient calibration of the South Plume Pump Test resulted in an effective porosity of 30 percent. Based upon this review, a range of porosity from 15 percent to 50 percent is assigned for this sensitivity study.

Partition Coefficient (K_d)

Table 5.2-2 shows ranges of uranium K_d values for different units and materials from tests conducted on site-specific samples in the vicinity of the site. This table summarizes results from waste materials, the glacial overburden, the unsaturated sand and gravel, and the saturated sand and gravel of the GMA. These results show GMA values ranging from a minimum of 0.76 L/kg and a maximum of 68.2 L/kg. The lower values are in the South Plume area, the intermediate values in the Southfield, and the highest values are in the Waste Pit Area. There appears to be a trend of decreasing K_d from north to south. The original calibration of the solute transport model used a value of K_d equal to 1.37 L/kg (corresponding

to a retardation factor of 12) while an earlier preliminary calibration used a K_d value of 1.00 L/kg (corresponding to a retardation of factor of 9) (DOE 1993k).

While the higher K_d are within the range of the literature, they do not seem to be representative of the site based on plume transport to date. These high values also provide a less conservative depiction of contaminant transport. Following the recommendations of the DOE (DOE 1993a, Appendix A), a range of K_d values from 0.96 to 3.80 L/kg were selected for use in this study.

Longitudinal Dispersivity (α)

The literature generally reports values of dispersivity within a range of 40 to 300 feet (see Walton 1991, Freeze and Cherry 1978, and Fetter 1988). The literature also states that dispersivity is typically scale-dependent related to the transport path. A typical reported value is 1/10 the transport path (Fetter 1988). This method is reported to be only valid up to some maximum distance, for example, 3,000 feet corresponding to a maximum dispersivity of 300 feet (Walton 1991). Transport distances in the South Plume (based upon estimating distance from Paddys Run to the edge of the plume to the south and southeast) range from 1,500 feet to 2,400 feet. Using the 1/10 ratio, these values would translate to dispersivity values of 150 to 240 feet.

For this sensitivity study, dispersivity has been assigned a range of values from 62.5 feet to 250 feet. The 62.5 foot value was chosen because it represents a minimum related to cell size (125 feet) caused by numeric issues in SWIFT. The 250 foot maximum was chosen based upon the transport distance in the South Plume. Experience with the model has shown that values as high as 250 feet portray extreme cases of plume expansion due to dispersion and, therefore, represent an upper limit.

Hydraulic Gradient (I) and Transport Distance (L)

Geostatistical analysis of 2000 series wells water elevations was used to define the range of hydraulic gradient (I) and range of direction of flow (which will be used to define travel distance [L]). Contour plots were produced at four seasonal values from 1992. Inspection of time versus water level graphs at selected locations (see Figure 2.2-3) showed the 1992 calendar year generally included the maximum and minimum water levels for each location over the entire 1990 to 1993 time period; therefore, analysis of the 1992 seasonal values provided a reasonable depiction of variation in gradient and distance to property line. The locations of the two hypothetical sources used in the SWIFT sensitivity analysis (see Subsection 5.4) were set to determine these variations in gradients and travel distances.

These four seasonal contour plots are shown on Figures 5.2-2 through 5.2-5 and results are summarized in Table 5.2-3. Using hypothetical sources at the production areas and Southfield, gradient is shown to vary from approximately 0.00067 ft/ft to 0.00033 ft/ft and 0.001 ft/ft to 0.0008 ft/ft, respectively for the two areas. Direction of flow based on these contours shows a variation of 30 degrees for the two areas

over these four seasons. Based upon these possible directions of flow, travel distance to the property line from the hypothetical production area source could vary from 2,875 to 3,000 feet and from the hypothetical Southfield source from 4,150 to 4,250 feet (see Table 5.2-3).

Mixing Depth (d_m)

Mixing depth is the portion/thickness of saturated aquifer where the vertical contaminant loading from the overburden is well mixed with the groundwater before leaving the loading area. A theoretical equation described in the ECTran model report (DOE 1993l) was developed for estimating the mixing depth based on the vertical seepage velocity, groundwater flow velocity, and vertical dispersivity. Preliminary calculations for Operable Unit 2 subunits during the preliminary remediation goal development show that the range of mixing depth is normally between 5 to 15 feet at the FEMP. Therefore, a range of 5 to 15 feet was assigned for the mixing depth in the sensitivity analysis.

Infiltration Rate

The downgradient infiltration rate affects property line concentration by providing a variable quantity of clean water that will dilute and potentially "sink" the plume. HELP modeling simulations have determined infiltration rates for the clay-rich glacial overburden ranging from approximately 4 to 8 inches per year. Other regional and local studies have also estimated the infiltration rate to be within this range. Therefore, a range of 4 to 8 inches per year was assigned for the infiltration rate in the sensitivity analysis.

Summary of Parameter Values

Table 5.2-4 summarizes the estimated values of the parameters that will be used in the ECTran and SWIFT simulations based upon the discussion above. Theoretical distributions are also defined on Table 5.2-4 for the ECTran Monte Carlo simulations. Lognormal and uniform distributions have been selected for these parameters based upon available distributions of values and experience with these parameters. Lognormal mean has been calculated based upon a simple log average between the assigned maximum and minimum.

5.3 ECTran Monte Carlo Sensitivity Analysis

The ECTran model (DOE 1993l) was used to perform Monte Carlo simulations as a part of the sensitivity analysis of the model performance measure (i.e., exposure point concentrations) on major hydraulic and geochemical parameters required in the GMA contaminant fate and transport model. Results of these simulations supplement the simple-band SWIFT model sensitivity analysis (described in Subsection 5.4) by presenting the complete range of potential combinations of parameter values and corresponding exposure point concentrations using a probabilistic approach. ECTran model runs were set up

corresponding to the three contaminant loading scenarios used in the SWIFT model sensitivity analysis. Identical values of model parameters as used in corresponding SWIFT model runs for the baseline conditions are assigned in the ECTran model whenever possible. Overall, two on-site point sources and one off-site initial plume source of uranium in the GMA were simulated.

To assess the combined effects and relative importance of horizontal hydraulic conductivity, porosity, horizontal gradient, transport distance, partition coefficient, dispersivity, mixing depth, and surface infiltration rate on the exposure point concentration, these input parameters were assigned best estimates as the baseline values and probability distributions based on the ranges of measured or estimated values. Given the limited number of measurements of each parameter and the purpose of this study, common probability distribution functions were used to describe the possible values of these parameters without conducting intensive statistical procedures for justifying these distribution functions. Some distributions, which were described to ECTran with a mean and a multiplicative standard are specified as lognormal. Deviation and other parameters were given uniform probability distributions with maximum and minimum values provided to ECTran. It was determined that these assumptions are sufficient for providing a general understanding of the sensitivity of the GMA model predictions to these tested parameters. The input parameters which were assigned as independent variables and their respective probability distributions are given at the end of each ECTran sensitivity report. The reports are included in Appendix B.

The following subsections summarize the three loading scenarios studied and the results from the ECTran Monte Carlo simulations. The simulation results of each case include the range and distribution of the performance measure and its relative sensitivities to the parameters tested. Table 5.3-1 summarizes the ECTran results.

5.3.1 Case 1

The ECTran simulation labeled Case 1 corresponds to the loading of uranium in the area surrounding well 2055 in the former production area (GMA model grid block 55,83,1). It assesses the model sensitivity to the various input parameters by looking at the simulated fenceline concentration. The fenceline is assumed to vary from 2,000 feet to 3,000 feet as measured from the well location based on seasonal groundwater flow patterns to the FEMP fenceline on the east and south. The area which bounds this range of travel distances from well 2055 to the FEMP fenceline is shown in Figure 5.3-1. The Case 1 ECTran model run includes hypothetical uranium loading of 50 lbs/day for 100 years. This point loading of 50 lbs/day was simulated by assigning a 3.57×10^4 mg/L uranium concentration to the .522 feet/year infiltration over a 125-foot by 125-foot area (i.e., the size of a SWIFT model block). To simulate the loading of contaminants directly to the GMA, as simulated in the SWIFT model, the two ECTran model source layers were set up to be the unsaturated and saturated GMA, respectively. The thickness of the vadose zone was set at .01 feet so as to neglect travel time and attenuation through this layer.

As evidenced by the sensitivity chart in the ECTran report based on 1,000 simulations, the maximum fenceline concentration is most sensitive to the partition coefficient (K_d) with the concentration at the fenceline increasing as K_d decreases. The next most sensitive parameters in the order of importance to the fenceline concentration were effective porosity, mixing depth, downgradient infiltration rate, horizontal hydraulic conductivity, distance to the fenceline, horizontal dispersivity, and horizontal gradient.

The range of predicted maximum source area concentrations is less than two orders of magnitude (i.e., 1.46×10^5 to 1.21×10^7 μg/L) while the predicted maximum fenceline concentrations cover four orders of magnitude (i.e., 12.8 to 2.73×10^5 μg/L). However, the baseline maximum GMA concentrations in the source area (2.25×10^6 μg/L) and at the fenceline (7.74×10^4 μg/L) are very close to or higher than the mean values of all the corresponding predictions (i.e., 2.58×10^6 μg/L and 4.09×10^4 μg/L) from the Monte Carlo simulation. Because the predicted concentrations have a lognormal type of distribution which skews toward the lower values, 54 percent and 86 percent of the predicted concentrations are less than the baseline values in the source area and at the fenceline, respectively. The highest predicted values are only about five and four times higher than the corresponding baseline values in the source area and at the fenceline, respectively. These differences between the baseline values and potential highest values of the maximum GMA exposure point concentrations from the Monte Carlo simulation are considered insignificant in the overall risk assessment which usually has order-of-magnitude type of accuracies.

5.3.2 Case 2

Case 2 corresponds to the loading of uranium contaminant in the area surrounding well 2046 in the South Field (GMA model grid block 32,64,1). It assesses the model sensitivity to the various input parameters by looking at the simulated fenceline concentration. The fenceline is assumed to vary from 1,200 feet to 4,000 feet as measured from the well location based on seasonal groundwater flow patterns to the FEMP fenceline on the south and east. The area which bounds this range of travel distances from well 2055 to the FEMP fenceline is also shown in Figure 5.3-1. The mass loading scenario and other model parameters in Case 2 are the same as used in Case 1.

As shown in the sensitivity report for Case 2, based on 1,000 simulations, changing the range of distances to the fenceline from 2,000 feet to 3,000 feet in Case 1 to 1,200 feet to 4,000 feet in Case 2 made the fenceline distance the most sensitive parameter in the Case 2 run. Dispersivity and gradient also switched positions. Other than these differences, the relative sensitivity of the other input parameters remains unchanged from their rankings in Case 1.

The range of predicted maximum source area concentrations is less than two orders of magnitude (i.e., 2.03×10^5 to 1.54×10^7 μg/L). Due to the increased range of travel distance in Case 2, the predicted maximum fenceline concentrations had a wider range (i.e., 5.83×10^{-2} to 3.83×10^5 μg/L) than Case 1. However, the baseline maximum GMA concentrations in the source area (2.25×10^6 μg/L) and at the

fenceline (7.74×10^4 μg/L) are still very close to or higher than the mean values of the corresponding predictions (i.e., 2.50×10^6 μg/L and 4.55×10^4 μg/L) from the Monte Carlo simulation.

Because the predicted concentrations have a lognormal type of distribution which skews toward the lower values as in Case 1, 58 percent and 81 percent of the predicted concentrations are less than the baseline values in the source area and at the fenceline, respectively. The highest predicted values are only about 68 and five times higher than the corresponding baseline values in the source area and at the fenceline, respectively. These differences between the baseline values and potential highest values of the maximum GMA exposure point concentrations from the Monte Carlo simulation are considered insignificant in the overall risk assessment which usually has order-of-magnitude type of accuracies.

5.3.3 Case 3

Case 3 corresponds to the pre-existing uranium concentration in the aquifer as modeled in the SWIFT simulations. The uranium plume was assumed to be 1,000 feet by 1,600 feet with an average concentration of 90.5 μg/L as assigned in the SWIFT modeling runs and an age of 40 years in the current South Plume area. This initial plume is shown in Figure 5.3-2. The concentration at a potential receptor 4,000 feet downgradient (i.e., well 2127) was examined to assess the model sensitivity to the input parameters. The age of the initial plume allows the current concentration at the receptor to be considered at the beginning of the simulation. As shown in the sensitivity report for Case 3, based on 1,000 simulations, the partition coefficient appeared to be the most sensitive model parameter in determining the downgradient concentration at 4,000 feet. The other model parameters ranked from most sensitive to least sensitive were the horizontal hydraulic conductivity, the effective porosity, the horizontal gradient, the downgradient infiltration rate, the mixing depth, and the horizontal dispersivity.

The range of predicted maximum receptor concentrations is about four orders of magnitude (i.e., 5.96×10^{-3} to 5.38×10^1 μg/L). However, the baseline maximum receptor concentration (1.48×10^1 μg/L) is higher than the mean values of all the corresponding predictions (i.e., 1.21×10^1 μg/L) from the Monte Carlo simulation. Because the predicted concentrations have a lognormal type of distribution which skews toward the lower values, 58 percent of the predicted receptor concentrations are less than the baseline value. The highest predicted values are only about four times higher than the baseline value. This difference between the baseline value and potential highest value of the maximum GMA exposure point concentration from the Monte Carlo simulation is considered insignificant in the overall risk assessment which usually has order-of-magnitude type of accuracies.

5.4 SWIFT Sensitivity Analysis

5.4.1 Approach

For this sensitivity study, hypothetical uranium sources were defined at selected SWIFT GMA model blocks, and K_h, K_h/K_v, n, K_d, and α were varied (based upon parameter values described above). Hypothetical plume and loading cells were defined for three locations (see Figure 5.4-1). These plumes and loading cells were defined as follows:

1) Mass was directly loaded into block 55,83,1 for 100 years at a rate of 50 lbs/day to represent loading at well 2055 (production area). Transport occurred to the east from this point.

2) Mass was directly loaded into block 32,64,1 for 100 years at a rate of 50 lbs/day to represent loading at well 2064 (South Field). Transport occurred to the south from this point.

3) Model cells in the South Plume area south of Willey Road were set with initial conditions matching the uranium concentrations based on 1993 monitoring data and 40-year model runs (see Figure 5.4-1).

A total of 17 sensitivity runs were performed. As discussed above, the purpose of these simulations was to assess each parameter individually in the revised model, to create maximum risk cases of the performance measures in the revised model by selecting appropriate extreme values of each parameter, and to compare the original and revised models. Because of an interference of plumes during many of the simulations greater than 100 years, the South Field loading and the South Plume initial conditions could not occur in the same simulation. With these plumes intermingling, usable information could not be extracted. Therefore, two different solute loading scenarios were run. For this reason, these sensitivity simulations were divided into four types:

1) Three simulations were performed (including a baseline case) for the two on-site loading cases to estimate the maximum concentration in the aquifer and the minimum travel time to the property line.

2) Three simulations were performed (including a baseline case) to assess the minimum and maximum travel time cases using the conditions approximating the south plume initial conditions.

3) Ten simulations were performed (two extreme cases for each of the five varied parameters) for the two on-site loading cases to assess the sensitivity of the two performance measures to changes in each of the selected dependent parameters. Three simulations are available for each parameter

since the baseline case in 1 above is also the baseline case for each of these parameter simulations.

4) One simulation was performed with the original calibrated model to assess the differences on simulated solute transport between the original and revised models. The baseline case of the revised model will be used for comparison purposes.

Table 5.4-1 shows the simulations conducted for the sensitivity study. These simulations make use of the ranges described in Table 5.2-4 for K_d, K_h, K_h/K_v, n, and α. Other parameters were held at the calibrated values (see Table 5.2-4) or, in some cases, constant ratios to the sensitivity parameters.

These SWIFT simulations provide a large amount of data for analysis and, by necessity, data reduction requires the selection of certain portions of these data for evaluation. For this study, the data analysis approach has included the following steps:

1) Each of the prescribed simulations on Table 5.4-1 were run using SWIFT for 1,000 years. Output was written to file every 20 years.

2) For each simulation, a processing routine defined time, location, and value of grid maximum concentration and fenceline maximum concentration.

3) For each simulation, two model cells were defined at the property lines through which the centerline of each plume migrated (see Figure 5.4-1). For the South Plume cases (Cases 14 - 16), a model cell at New Haven Road was used for this purpose since the plume was already off site. For these cells, the time and value of maximum concentration were defined. A graph of concentration versus time was plotted for each model layer at each of these designated cells.

4) For each simulation of the on-site loading cases, contours at 100 years were plotted for model layers 1 and 3. This time was chosen since it represented the maximum time for many (although not all) of the simulations. By fixing this time as 100 years, these contour plots may be compared with each other to discern the degree of transport under the various scenarios. In a similar manner, 20 years was used for the South Plume cases.

5) For each group of simulations that evaluate a particular parameter, a graph of concentration versus time was created for layer 1 at the eastern property line. This allows a simple comparison of breakthrough curves for the related cases. These related simulations are:
   (1) Maximum Concentration, Minimum Travel Time - Cases 1, 2, 3
   (2) Horizontal Hydraulic Conductivity - Cases 1, 4, 5
   (3) Horizontal/Vertical Hydraulic Conductivity Ratio - Cases 1, 6, 7
   (4) Partition Coefficient - Cases 1, 8, 9

(5) Dispersivity - Cases 1, 10, 11

(6) Porosity - Cases 1, 12, 13

(7) Maximum/Minimum South Plume Travel Time - Cases 14, 15, 16

(8) Calibrated original versus revised models - Cases 1, 17

Following a discussion of baseline results, each of these groups of cases are discussed in the following subsections.

5.4.2 Baseline Results

Figures 5.4-2 and 5.4-3 show the results of the baseline on-site loading scenario (Case 1) at 100 years for model layers 1 and 3, respectively. These two figures show plumes in both model layers crossing the eastern and southern property lines. The southern plume is thinner than the eastern plume because of the steeper gradient and because the bedrock channel is thinner, not allowing lateral expansion of the plume. The concentrations in Layer 1 are considerably higher than Layer 3, although considerable mass has migrated to Layer 3.

Figure 5.4-4 shows the concentration over time for all six model layers at the two property line cells (70,66 - eastern property line and 34,47 - southern property line). The different shape of the curves crossing the two property lines are apparently a function of the hydraulic conductivity zonation (see Subsection 4.3) and the travel distance. The Layer 1 plume (Layer 1 has higher hydraulic conductivity) moves faster through the boundaries than the other layers as evidenced by the more vertical down slope of the curve. The different model layers peak concentrations shift further out in time for both south and east travel. Also evident from this figure is that the plume has dispersed more vertically in the eastern property line case versus the southern property case. This greater vertical dispersion to the east may be caused by the pumping at depth to the east for the SOWC production wells and the lower gradient.

5.4.3 Maximum Concentration and Minimum Travel time Cases

The first set of cases (Cases 2 and 3) vary the parameters to create simulations that will minimize travel time and maximize GMA concentration. For the minimum travel time case, extreme parameter values (see Subsection 5.2) were selected to increase the velocity of contaminant transport in layer 1; that is, the K_h was maximized, the K_h/K_v was maximized, the K_d was minimized, the dispersivity was maximized and the porosity was minimized. For the maximum concentration case, parameter values were selected to maximize the concentration (typically at the model cell that is loaded with contaminant); that is, the K_h was minimized, the K_h/K_v was maximized, the K_d was minimized, the dispersivity was minimized, and the porosity was minimized. Of note is the fact that three of these parameters, K_d, K_h/K_v, and n were the same for these two cases and only K_h and dispersivity were varied (i.e, these are not opposite cases).

Figures 5.4-5 through 5.4-7 show contours and graphs of the results of the minimum travel time case. Clearly the transport has been increased at 100 years when compared to the baseline case (Figures 5.4-2 and 5.4-3) as the plume has extended beyond the Great Miami River in 100 years. Figure 5.4-7 exhibits the trend over time at the property line. The travel time has been reduced with first arrivals at the east and south property lines at 20 and less than 20 years respectively versus 60 and 20 years in the baseline case. The low concentrations shown of Figure 5.4-7 when compared to the baseline case are probably caused by extreme lateral dispersion.

Figures 5.4-8 through 5.4-10 show contours and graphs of the results of the maximum concentration case. The concentration was maximized at the loaded cell (see Table 5.4-2) with the maximum concentration 220 percent of the baseline case. Figure 5.4-10 exhibits the trend over time at the property lines. Compared to the baseline case, these curves are steeper. A higher property line maximum than the baseline case occurs at the eastern property line while a lower than baseline case occurs at the southern property line. This is probably due to the zonation of hydraulic conductivity.

Figure 5.4-11 shows the concentration over time in layer 1 of Cases 1, 2, and 3 at the eastern property line (Cell 70,66). This figure shows that the minimum travel time case comes through faster than the baseline but at a lower concentration. The maximum concentration plume passes the property line before the baseline case and at a higher concentration.

5.4.4 Horizontal Hydraulic Conductivity Variation

Cases 4 and 5 varied horizontal hydraulic conductivity. The recalibrated model had six K_h zones (see Subsection 4.3). For this analysis, the K_h was varied by ratios according to the location of the model zone based on the minimum and maximum regional values (see Subsection 5.2). These ratios ranged from 0.32 to 2.87.

Figures 5.4-12 through 5.4-14 show contours and graphs of the results of the minimum K_h case. The plumes shown on these figures have not expanded as much as the baseline case (Figures 5.4-2 and 5.4-3) with the 100 parts per billion (ppb) contour barely crossing the property line at 100 years. Figure 5.4-14 exhibits the trend over time at the property line. The curve for Case 4 at the eastern property line, when compared to the baseline case, reaches a maximum at a later date, comes to a lower maximum, and extends over a longer time period. The plume first appears at this point at approximately 120 years versus 60 years for the baseline case. This is the expected effect from decreasing the hydraulic conductivity and thus the velocity. Transport is slower and dispersion has a longer time to flatten the curve. The curve for the Case 4 southern property line (Figure 5.4-14) actually reaches a higher maximum (although at a later time) than the baseline case. A more compressed plume appears to cause this effect.

Figures 5.4-15 through 5.4-17 show contours and graphs of the results of the maximum K_h case. The plumes shown on these figures have expanded further than the baseline case (Figures 5.4-2 and 5.4-3) with the leading edge of the plume (20 ppb contour) almost 2,000 feet further east at 100 years. Figure 5.4-17 exhibits the trend over time at the property line. As expected, the plumes in Case 5 reach the property line sooner than the baseline case. The curve for Case 4 at the eastern property line, when compared to the baseline case, reaches a maximum at an earlier date, comes to a lower maximum, and extends over a shorter time period. Processes that tend to expand and dilute the plume (dispersion, recharge, adsorption/desorption) cause this lower maximum since the plume seems to expand in width as well as in length causing this fixed point in the center line to see lower concentrations. The southern property line case shows a flat top effect in the plume depiction over time. The hydraulic conductivity dominates the system over this relatively short travel distance and, therefore, there is not the characteristic bell-shaped curve that a typical conduction-dispersion dominated system would exhibit.

Figure 5.4-18 shows the relationship of these three K_h cases in layer 1 at the eastern property line. As expected, the lower conductivity case moves slower and is more dispersed than the baseline while the higher conductivity case moves faster and is less dispersed.

5.4.5 Horizontal/Vertical Hydraulic Conductivity Ratio

Cases 6 and 7 varied horizontal/vertical hydraulic conductivity ratio. For this analysis, the K_h/K_v ratios were set as a constant value over all model hydraulic conductivity zones. The calibrated model varied this vertical conductivity layer by layer for some of the zones (see Subsection 4.3).

Figures 5.4-19 through 5.4-21 show contours and graphs of the results of the minimum K_h/K_v case. This minimum K_h/K_v case should allow more vertical transport by raising the vertical conductivity. The plumes shown on these figures are quite similar to the baseline case (Figures 5.4-2 and 5.4-3) although they have not expanded as much as the baseline case at 100 years. Figure 5.4-21 exhibits the trend over time at the property line. The curve for Case 6 at the eastern property line, when compared to the baseline case, is quite similar in shape although it reaches a maximum 20 years later and comes to a slightly lower maximum. Conceptually, this is expected since more vertical transport is allowed. The south property line curves are quite similar (Figure 5.4-4 versus 5.4-21).

Figures 5.4-22 through 5.4-24 show contours and graphs of the results of the maximum K_h/K_v case. This maximum K_h/K_v case should allow less vertical transport by lowering the vertical conductivity. The effect of the maximum value is more pronounced than the minimum case. The layer 1 plume has expanded an additional 2,100 feet in Case 6 versus the baseline case while the layer 3 plume has expanded 2,000 feet. In the south property line case, the plume centerline appears to show more easterly transport than the baseline case. Figure 5.4-24 exhibits the trend over time at the property line. The curve for Case 7 eastern property line, when compared to the baseline case, is quite similar in shape and peak

concentration although it reaches a maximum 40 years earlier. With less vertical transport, the plume is able to move faster.

Figure 5.4-25 shows the relationship of these three K_h/K_v cases at the eastern property line. As expected, the lower K_h/K_v conductivity case moves slower and is more dispersed than the baseline while the higher K_h/K_v conductivity case moves faster and is less dispersed.

5.4.6 Partition Coefficient Variation

Cases 8 and 9 varied partition coefficient (K_d). For this analysis, the K_d was varied as a constant value for all layers of the model domain.

Figures 5.4-26 through 5.4-28 show contours and graphs of the results of the minimum K_d case. The plumes shown on these figures have expanded further than the baseline case (Figures 5.4-2 and 5.4-3) with the leading edge of the plume (20 ppb contour) almost 2,100 feet further east in both model layers at 100 years. As expected, the plumes in Case 8 reach the property line sooner than the baseline case (see Figure 5.4-28). The curve for Case 8 at the eastern property line, when compared to the baseline case, reaches a maximum 40 years earlier and exhibits a higher maximum and a steeper curve. The southern property line case shows a similar representation over time but reaches a maximum earlier and exhibits a flat-topped effect. Like the hydraulic conductivity case above, the advective processes apparently dominate the system over this relatively short travel distance and, therefore, there is not the characteristic bell- shaped curve that a typical conduction-dispersion dominated system would exhibit.

Figures 5.4-29 through 5.4-31 show contours and graphs of the results of the maximum K_d case. The plumes shown on these figures have expanded less than the baseline case (Figures 5.4-2 and 5.4-3) with the leading edge barely reaching the eastern property line. This is the only case where the plumes have not merged (see Figure 5.4-30). Figure 5.4-31 exhibits the trend over time at the property line. As expected, the higher K_d shows a plume crossing the property line delayed in time, with a much lower maximum concentration and much more extended time horizon (flatter) when compared to the baseline case. The maximum is not reached at the eastern property line until 280 years compared to 180 years in the baseline case. The southern property line case graph is only delayed by 20 years (compared to the baseline case) and shows slightly lower concentration. The difference in the eastern and southern case is again apparently a function of the increased gradient.

Figure 5.4-32 shows the relationship of these three K_d cases at the eastern property line. As expected, the lower K_d plume moves faster and is less dispersed than the baseline while the higher K_d case moves slower and is more dispersed.

5.4.7 Dispersivity Variation

Cases 10 and 11 varied dispersivity. For this analysis, the longitudinal dispersivity was varied as a constant value for all layers of the model domain. The transverse dispersivity was maintained at the same ratio to the longitudinal dispersivity as the calibrated model or 100 to 0.1.

Figures 5.4-33 through 5.4-35 show contours and graphs of the results of the minimum dispersivity case. The plumes shown on these figures look quite similar to the baseline case (Figures 5.4-2 and 5.4-3). However, the Layer 1 maximum concentration at both the eastern and southern property lines is much higher (see Figure 5.4-35) while more variation between the model layers is evident. Apparently the model is quite sensitive to the lower transverse dispersivity caused by rationing the values down. In SWIFT, the transverse dispersivity controls vertical dispersivity.

Figures 5.4-36 through 5.4-38 show contours and graphs of the results of the maximum dispersivity case. The plumes shown on these figures are similar to the baseline case (Figures 5.4-2 and 5.4-3) but are larger. The plume reached the property line with a similar type of curve; however, the Layer 1 maximum concentration at both the eastern and southern property lines are significantly lower (see Figure 5.4-38) while less variation between the model layers is evident.

Figure 5.4-39 shows the relationship of these three dispersivity cases at the eastern property line in Layer 1. The three plumes cross the property line with a similar distribution in time, however, the peak concentrations are dramatically different.

5.4.8 Porosity Variation

Cases 12 and 13 varied porosity. For this analysis, the porosity was varied as a constant value for all layers of the model domain. Changes in porosity are more complex than the other parameters. Porosity affects transport in three ways. First, porosity is in the advective velocity equation, with an inverse relationship to velocity. Second, porosity is used in the calculation of R from K_d, with higher porosity resulting in higher R. Higher R will "retard" plume transport. Finally, increased porosity results in more contaminant dilution since there is more water available. These three effects of porosity changes have a tendency to counteract each other.

Figures 5.4-40 through 5.4-42 show contours and graphs of the results of the minimum porosity case. The plumes shown on these figures look quite similar to the baseline case (Figures 5.4-2 and 5.4-3) with slightly less transport after 100 years. The layer maximum concentrations at the eastern property line is a little lower than the baseline case (see Figure 5.4-42) while the layer maximums at the southern boundary are very similar.

Figures 5.4-43 through 5.4-45 show contours and graphs of the results of the maximum porosity case. The plumes shown on these figures are similar to the baseline case (Figures 5.4-2 and 5.4-3) but are larger with greater plume expansion to the east and south. The Layer 1 maximum concentration at both the eastern and southern property lines are slightly higher (see Figure 5.4-38) with similar looking curves.

Figure 5.4-46 shows the relationship of these three porosity cases at the eastern property line in Layer 1. This figure shows that the higher porosity case resulted in an earlier peak and a slightly higher peak than the baseline case.

5.4.9 Existing Plume Transport

Three simulations (Cases 14 through 16) were performed to assess the minimum and maximum travel time cases using the conditions approximating the South Plume initial conditions (see Table 5.4-1). Case 14 was a baseline case which included a plume just south of Willey Road that approximated a portion of the South Plume. This baseline case was simulated with the calibrated model parameters. Case 15 sought to minimize travel time (or maximize plume transport velocity) by varying appropriate parameters while Case 16 sought to maximize travel time. A time of 40 years was selected to present representative plumes. In a similar manner as the above analysis, cell 21,14 at New Haven Road was selected to analyze the plume passing over time. In addition, cell 20, 43 approximated the center of the plume and time versus concentration was analyzed at this point. These cases provide slightly different conditions than the loading cases (Cases 1 to 13) by only having an initial plume without any additional loading.

Figures 5.4-47 through 5.4-49 show the contours and graphed results of the baseline case. The plume has migrated south from the initial conditions in the 20 years. Layers 1 and 3 show similar plume configurations.

The maximum occurs at 20 years for the center of plume cell and at 60 years for the New Haven Road cell. In both cases concentrations drop off fairly rapidly.

Figures 5.4-50 through 5.4-52 show the contours and graphed results of the minimum travel time case. The plume is mostly gone with only low concentrations (less than 0.2 ppb) remaining at 40 years. Figure 5.4-52 likewise shows a quick drop off at both the center of the plume and New Haven Road cells.

Figures 5.4-53 through 5.4-55 show the contours and graphed results of the maximum travel time case. The plume is still significant at 40 years with a maximum contour of 20 ppb at both layers 1 and 3. Dispersion appears to be dominating the plume transport in these low velocity cases with transport occurring north as well as south. Figure 5.4-55 shows a gradual decline of concentration at the plume center. At the New Haven Road cell, peaks are reached for the different layers from 260 to 320 years. The lower layers show higher concentrations at this point, although the values are all pretty low (less than 5 ppb).

5.4.10 Comparison of Original and Improved Models

Case 17 simulated the two on-site sources on the original calibrated model. A comparison of the baseline improved model run (Figures 5.4-2 through 5.4-4) with Case 17 (Figures 5.4-56 through 5.4-58) depicts plume transport differences between the old and new models. The original model grid was smaller than the improved model and the edges of the original model are shown on Figures 5.4-56 and 5.4-57. Since the model layers are different in the two models, the comparison is somewhat qualitative. Layers 1 and 2 are analyzed in the original model since Layer 3 is the clay layer.

The patterns exhibited by the plumes at 100 years are quite similar in the two models. The original model shows the center line of the plume from the production area source to be more north than the revised model. The South Field source also apparently initially moves more easterly, although it appears quite similar south of the site. The 20 ppb contour has moved further at 100 years in the original model versus the revised model.

The eastern property line cell (Figure 5.4-58 compared to Figure 5.4-4) shows time of maximum arriving earlier for the original model (140 versus 180 years) although the revised model shows higher concentrations (11000 versus 7500 ppbs). The shape of the curves are similar although the lowest concentration curve in the original model is in Layer 1. The differences in the southern property line time concentration curves are more striking (Figure 5.4-58 compared to Figure 5.4-4). The maximum value in the new model is roughly four times the original model. Concentration decreases from the top to the bottom layers in the new model while all layers are essentially the same in the original model. As previously discussed (see Subsection 4.4), this was one of the criticisms of the original solute transport model. The time of maximum is earlier in the original model (100 versus 140 years).

5.4.11 Summary of Sensitivity Results

Table 5.4-2 shows the time, location, and value of grid maximum concentration and fenceline maximum concentration for each simulation case. This table was generated by searching each simulation output file to determine the model block with the highest concentration anywhere (grid maximum) and at a series of blocks that touch the fenceline (fenceline maximum). The grid maximum corresponds to the performance measure of the maximum concentration in the aquifer and always occurred at 100 years (the end of the loading period). Also shown on this table is a comparison of the concentration produced by each case versus the baseline case expressed as a percentage. This percentage varied from 22 percent for Case 2 (the minimum travel time case) to 220 percent for Case 3 (the maximum concentration case). Variation of K_d (Cases 8 and 9) and porosity (Cases 12 and 13) affected this maximum concentration only to a very small degree. Table 5.4-2 also compares fenceline maximum times and concentrations. The time of maximums varied from 100 to 140 years. These fenceline maximum concentrations varied from 28 percent for Case 2 (the minimum travel time case) to 143 percent for Case 10 (the minimum dispersivity case).

Table 5.4-3 shows the time of arrival, time of maximum, and maximum concentration for two identified blocks in the centerline of the plume at the property line (see Figure 5.4-1). In this case, the maximum is selected from all values generated for these model blocks. A comparison of Tables 5.4-2 and 5.4-3 shows that many of the southern property line values were the maximum anywhere. This is because the South Field loading term is closer to the property line and is influenced by a steeper gradient and the lateral bedrock wall which decreases the effect of plume dispersion. For the east migrating case, the baseline plume first arrived at 60 years and reached a peak at 160 years. Plumes arrived at this point as early as <20 years for Case 2 (the minimum travel time case) to 100 years for Cases 4 and 9 (minimum K_h and maximum K_d). Time of maximums at this location varied from 100 years to 280 years. Maximum concentrations expressed as a percentage of the baseline case varied from 42 percent to 141 percent. The south property line had quicker arrival times and time of maximums, and similar concentration ratios as the eastern property line.

Figures 5.4-59 to 5.4-62 show the sensitivity derivatives for each of the dependent parameters (K_h, K_h/K_v, K_d, dispersivity, porosity) for the performance measures of maximum concentration, maximum concentration at the property line, time of first arrival at the eastern property line, and time of maximum concentration at the eastern property line. Each of the individual graphs on each figure uses the same "y" axis scale of either concentration or years with an "x" axis covering the range of the particular parameter. Therefore, the slope of each line represents the sensitivity of the particular measure to the defined parameter (i.e., greater slope means greater sensitivity).

For the maximum concentration case (Figure 5.4-59), the most sensitive parameter is K_h which is inversely proportional to concentration. Higher K_h results in higher velocities which allow more mass to escape from the loading cell. Both K_h/K_v and Dispersivity are moderately sensitive. Again, both are inversely proportional with lower values of these parameters leading to higher concentrations. Finally, maximum concentration is insensitive to both K_d and porosity. For K_d, with constant mass loading, the dissolved concentration remains essentially equal although the adsorbed concentration will increase with higher K_d.

For the maximum concentration at the eastern property line case (Figure 5.4-60), the most sensitive parameters are dispersivity and K_d. Porosity and K_h/K_v are relatively insensitive. K_h exhibited a more complicated relationship with the maximum occurring with the baseline and lower values at both extreme values. K_h changes both affected the flow model and velocities. Competing changes may account for this distribution.

For the arrival time and time of maximum cases (Figures 5.4-61 and 5.4-62), similar slopes are seen for each parameter for these two cases. The most sensitive parameters are K_h and K_d. For these parameters, times of arrivals varied by 80 years, and time of maximums varied up to 140 years. K_h/K_d and porosity are less sensitive, while dispersivity is insensitive.

Finally, the comparison of the original and revised models (Figures 5.4-2 through 5.4-4 and Figures 5.4-56 through 5.4-58) showed the revised model to be more conservative in maximum concentration both on site and at the fenceline. Table 5.4-2 shows that the grid maximum and the fenceline maximum of the original model are 33 percent and 46 percent, respectively, of the same measures in the revised model.

5.5 Conclusions

The uncertainty analysis task included the performance of complementary ECTran and SWIFT simulations with estimated ranges of input parameters and hypothetical aquifer loading to define model output range or uncertainty. By understanding the uncertainty, the model accuracy limitations may be defined and the model applications can appropriately account for the uncertainty. The risk assessment performance measures of maximum on-site and fenceline concentrations were specifically evaluated to quantitatively define ranges of output for these measures for use in risk assessments.

The ECTran results showed that, while there was wide range of possible results (up to six orders of magnitude using the Monte Carlo technique), the majority (55 percent to 80 percent) of the concentration values were lower than the baseline case. Actually, there was only four to six times variation between the baseline case and the extreme maximum.

The SWIFT sensitivity results, following a simple band approach, showed the grid maximum concentration varying from 22 percent to 220 percent of the baseline case. For the fenceline maximum, the variation was tempered somewhat from 28 percent to 143 percent. These fenceline maximums occurred at the southern site boundary and were caused by the hypothetical South Field loading. The eastern property line had time of maximums from 100 years to 280 years. Maximum concentrations at the property line compared to the baseline case varied from 42 percent to 141 percent. For the grid concentration maximum, the most sensitive parameters are hydraulic conductivity and dispersivity, while for the property line maximum concentration the most sensitive parameters are partition coefficient and dispersivity. The baseline model output is reasonably conservative with the calibrated results closer to the maximum case rather than the minimum case.

A simulation with the original calibrated model (prior to improvements) was performed which resulted in lower grid and fenceline maximum concentrations by factors of 3 and 2 respectively than the revised model. Greater and apparently unrealistic concentrations of contaminant had reached the lower layers in the original model showing the positive results of the model improvements.

Both the ECTran and SWIFT results show that, while the model will produce a reasonably wide range of output based on ranges of input parameters, nevertheless, the baseline model output is within an order of magnitude of the maximum cases based upon both the ECTran Monte Carlo and SWIFT Sensitivity results. The ECTran results showed possible higher concentration values by four to six times than the

baseline case. SWIFT results indicate a tighter range of concentrations; typically less than a factor of 2.5 for the maximum grid concentration and 2 for the fenceline maximum. Since other portions of risk assessments contain typically several orders of magnitude of uncertainty, the uncertainty attributable to the model is relatively minor. Based on a comparison with the original model, the revised SWIFT GMA model presents a more conservative depiction of on-site and property line predicted concentrations than the original model. The improved model predicted a moderately conservative, but realistic depiction of plume transport based on the estimated ranges of model input.

SECTION 6

PARTICLE TRACKING ANALYSIS

Particle tracking was performed with the improved SWIFT GMA model using the STLINE code to analyze the capture zone of pumping wells and to establish flow patterns. Particle tracks represent water, not contamination. In fact, chemical constituents typically move much slower than water as defined by their retardation factor. The capture zone analysis of significant pumping well systems defines the time of travel (no retardation) and direction of travel over discrete flow lines by reverse tracking. By defining a certain time frame of interest, this analysis defines a theoretical water capture zone extending upgradient from the pumping wells. In addition, forward particle tracking was performed to define flow lines from potential on-site sources and from the model boundaries.

This analysis considered pumping at three locations:

1) The SOWC wells located east of the FEMP adjacent to the Great Miami River (C1 and C2)

2) The FEMP production well located beneath the former production area (P1)

3) The recently installed South Plume Recovery Wells (SPRW) located south of the FEMP and south of Willey Road

"Baseline" and "pumping" cases were considered in this analysis. The baseline case includes pumping at the SOWC wells and the FEMP production well while the pumping case includes pumping at all three of the locations. The SOWC and the FEMP production wells were pumped during the baseline case because they have been operating prior to the release of contamination sources and thus, their pumping needs to be considered when assessing historical flow and contaminant transport.

6.1 Technical Approach

Particle tracking analysis consisted of the following steps:

1) Site documentation was reviewed to determine average pumping rates for the different pumping locations.

2) The recalibrated model was used to determine steady-state pressure fields for both baseline and pumping conditions. The SWIFT velocity output files were used as input to the particle tracking runs.

3) Forward tracking was conducted to define flow lines from model boundaries. Particles were seeded in both model layers 1 and 5 to show trajectory differences in the upper and lower GMA.

4) Forward tracking was conducted to define flow lines from on-site sources. This forward tracking considered cases of both pumping and not pumping the SPRW.

5) Capture zones were defined by seeding particles in a small diameter circle around the well screen of the pumping wells and running the particle tracker in reverse. Reverse tracking simulations were performed for 5-, 10-, and 100-year periods. Based upon these analyses, time discrete capture zones were defined in the XY plane.

Each of these steps is discussed in the following sections.

6.2 Pumping Rates

The pumping rates considered in the analysis are summarized on Table 6.2-1. These pumping data were obtained from the Miami Conservancy and FEMP site information. The initial SPRW pumping rate was 2,000 gpm total or 400 gpm for each of the five wells. However, based on monitoring data and evaluation, these rates were decreased at the beginning of 1994 to 1,500 gpm or 300 gpm per well. The FEMP production well pumps at approximately 240 gpm from the lower GMA. For the SOWC collector wells (C1 and C2), Subsection 4.3.3 describes the pumping rate history and the basis for these modeled pumping rates (see Tables 4.3-2 and 4.3-3). A slightly conservative value of 21 mgd total for C1 and C2 was used for the particle tracking analysis.

6.3 Steady-State Simulations

As discussed above, steady-state simulations were run with SWIFT for both the baseline and pumping cases. Pumping rates as defined in Subsection 6.2 were used in these simulations. Other model parameters were set based on the calibrated model (see Section 4).

Head contours from these simulations from model layer 1 are shown on Figures 6.3-1 and 6.3-2 respectively. The baseline case results (Figure 6.3-1) are the same as the calibrated model predicted results. Figure 6.3-2 gives predicted steady state heads after turning on the five SPRW at 300 gpm each. The difference between these contour plots (i.e., the predicted steady-state drawdown) is depicted in Figure 6.3-3. The 1 foot drawdown contour extends out from the recovery wells up to 3,000 feet. By comparing Figures 6.3-1 and 6.3-2, the impact to the flow system can be seen. For example the 520 contour in the pumping case has moved further to the north than the no-pumping case and is indicating greater flow to the south toward the SPRW. P1 has no apparent effect on Layer 1 heads because pumping occurs in Layer 5.

6.4 Forward Tracking from Model Boundary

Forward tracking was conducted for a period of 100 years to define flow lines from model boundaries to potential receptors. Particles were seeded in model cells along eastern, northern, and western model grid boundaries in model layers 1 and 5. Model layers 1 and 5 were both seeded to show transport differences at these two portions of the aquifer.

Figures 6.4-1 and 6.4-2 show the results of this forward tracking for layers 1 and 5 for the pumping case. Prominent features of Figure 6.4-1 include capture of most particles flowing beneath the FEMP site by the well systems except:

1) A group of particles from the north boundary flowed east of the SPRW

2) A single particle from the northern boundary flowed east of the bedrock high to the south border and missed SOWC C1.

It is also of note that there is no significant capture by the FEMP production well in layer 1 (Figure 6.4-1) when compared to Layer 5 (Figure 6.4-2). Figure 6.4-2 also shows a particle crossing the Great Miami River to C1 and does not show a particle going out the southern boundary like Figure 6.4-1. There are fewer particle paths for Layer 5 because of the greater infringement of bedrock at depth.

6.5 Forward Tracking from Source Areas

Forward tracking was conducted for a period of 100 years to depict water transport patterns from on-site sources to points of termination. This forward tracking considered cases of both pumping and not pumping the SPRW. Particles were seeded in model layer 1 (corresponding to 2000 series well screens) beneath the Waste Pits, Silos, Plant 2/3, Plant 6, South Field, Paddys Run, and the SSOD (where contact with the GMA occurs).

Figures 6.5-1 and 6.5-2 show the particle tracks for these two cases. The capture by the SOWC wells C1 and C2 is significantly reduced in the pumping case (Figure 6.5-2) compared to the non-pumping case (Figure 6.5-1). SOWC well capture in the non-pumping case comes largely from underneath the Waste Pits. This simulation also shows that the FEMP production well does not significantly capture any of these first layer particles. The flow divide occurring at the southeast corner of the FEMP site (Figure 6.5-1) shifts eastward approximately 1,300 feet in the pumping case (Figure 6.5-2). This indicates that significantly more of the flow is pulled westward for the SPRW.

Figure 6.5-2 shows significant capture of particles by the SPRW seeded along Paddys Run, SSOD, and the South Field. The western-most wells capture from the reach of Paddys Run adjacent to Paddys Run

Road and south of Willey Road. Particles seeded at the northern part of Paddys Run, the silos, the waste pits, and the production area are not captured by the SPRW.

6.6 Capture Zone Analysis

Capture zones were defined by seeding particles in a small diameter circle around the middle of the well screen, immediately above the well screen, and immediately below the screen, and running the particle tracker in reverse. Reverse tracking simulations were performed for 5, 10, and 100 years. Based upon these analyses, time discrete capture zones were defined in the XY plane.

Figure 6.6-1 shows the results of the reverse tracking. Note that not all of the particles seeded in this manner were captured. For example, particles whose flow paths are not curved approaching the southeast side of the FEMP production well (P1) are not captured. However, all of the particles around the SOWC collectors (C1 and C2) appear to be captured as no flow paths extend through the circles. These collectors are efficient in capturing particles because of the large pumping rate of these wells. Most of the particles in the 100-year case actually originate outside the model grid, and thus, the 100-year particles terminate at the model boundaries. The 5- and 10-year zone particles mostly originate on the grid with many of the 5-year particles originating on-site. Note that much of the capture by the SOWC collectors, especially Collector 1, originates from the river for all three zones. This indicates that, according to the model, the river supplies much of the water for the SOWC collectors C1 and C2.

SECTION 7

MODELING QUALITY ASSURANCE/QUALITY CONTROL

Modeling QA/QC guidelines have been developed to outline general QA/QC requirements for groundwater fate and transport modeling at the FEMP. The purpose of these guidelines is to supplement the general guidelines set forth in the "Quality Assurance Program Description" (FERMCO 1993a) by providing minimum acceptable standards for Fernald Environmental Restoration Management Corporation (FERMCO) and FERMCO subcontractors in the performance of and reporting on groundwater fate and transport modeling activities at the FEMP.

These guidelines cover the following elements of the modeling process:

1) Control of Work and Necessary Documentation
2) Characterization of Model Domain
3) Conceptual Model Design
4) Mathematical Model Design
5) Model Code Selection
6) Hardware Selection
7) Model Code Verification
8) Model Grid Design and Input File Preparations
9) Model Calibration
10) Model Validation (or Performance Evaluation)
11) Model Applications
12) Uncertainty and Sensitivity Analyses
13) Performance Assessment
14) Model Documentation, Reporting, and Record Keeping

These guidelines are included in Appendix C.

SECTION 8

POST-AUDIT PROGRAM

A long-term, post-audit program for the assessment of model performance is required to ensure that aquifer remediation systems are operating efficiently. The groundwater fate and transport model is used to help design and predict the performance of remedial systems. If designs and predictions made using the model are not correct, the efficiency and effectiveness of a remedial system could be affected. This section describes the general requirements and procedures of a post-audit program which will be conducted to assess the performance of the fate and transport model.

8.1 Objective of the Post-Audit Program

The objective of the post-audit program is to routinely assess the performance of the GMA fate and transport model and use the model to improve the efficiency of aquifer remediation systems.

With the implementation of remediation activities at the FEMP, the aquifer will be subjected to stresses and conditions different than those used to calibrate the model, as described in Section 4. The accuracy of modeled predictions, both water level elevations and contaminant concentrations, will be assessed by comparing the predictions to field data collected through the various groundwater monitoring programs associated with each remediation system.

As shown in Figure 8.1-1, each aquifer remediation system will be monitored in conformance with a Design Monitoring Evaluation Program Plan (DMEPP). Each DMEPP is designed specifically for a remediation system. For example, the South Plume Recovery System, currently in operation, is monitored in conformance with the *South Plume Groundwater Recovery System Design, Monitoring, and Evaluation Program Plan* (DOE 1993m), which establishes a monitoring and operational assessment strategy for that system. Integration of the model improvement post-audit program and the south plume DMEPP is shown in Figure 8.1-2 as an example.

8.2 Post-Audit Program Procedures

As shown in Figure 8.2-1, modeled concentration versus time predictions fall within a window of uncertainty and establish operational criteria for remediation systems. Aquifer remediation systems are designed with sufficient operational flexibility to account for the expected uncertainty of the modeling results.

As additional aquifer remediation systems are brought on line, with associated monitoring programs, groundwater elevations and contaminant concentrations will be measured and compared to model

predictions. As long as those measurements are within the uncertainty or "validity" window established by the model uncertainty analysis and system design flexibility, no changes in the operations of the aquifer remediation system and the model will be necessary. However, should the field data reveal that current conditions are outside the validity window of the modeled predictions, model recalibration and new predictions will be necessary. The operational parameters of the aquifer remediation system will be adjusted accordingly to maintain optimal remediation system performance.

The validity window and engineering flexibility associated with each aquifer remediation system are case-specific and will be defined within a DMEPP specific to that system. The fate and transport model utilized in the design of the aquifer remediation systems will be audited with the procedure outlined in Figure 8.2-2 at least once a year. Audits could be more frequent if the performance of a particular remediation system warrants it.

SECTION 9

SUMMARY AND CONCLUSIONS

The short-term SWIFT GMA model improvement program tasks have been implemented. These improvement tasks have resulted in a more up-to-date and "improved" model, a better understanding of model performance, and a more sophisticated modeling program. Specifically, the model has been enhanced to include:

1) The latest data and geostatistical preprocessing of the data
2) A larger domain with more vertical layers
3) The results of a major pumping test and subsequent transient calibration
4) Calibration to the latest head and uranium target data.

The performance of the model and its dependence on key variables is evaluated through the performance of uncertainty analysis. Particle tracking has helped understand the flow regime and the impact of area pumping wells. A modeling QA/QC program has been developed to control and enhance future applications of the model. Finally, a Post Audit Program has been defined which allows for the continual evaluation of model results versus field data. With these model and modeling program improvements, the SWIFT GMA model will be more capable of supporting the remediation at the FEMP. Specifically, OU-1 and OU-2 have used this improved model for their FSs and OU-5 has used the improved model for both their RI and FS.

Since the RI/FS program at the FEMP has continued during the model improvement process and the original and revised model have both been used for site applications, the impact of these revisions to these previous applications needs to be considered. The original model has been applied to two basic types of modeling:

1) Risk Assessments - OU-1, OU-2, and OU-4 baseline RI risk assessments, OU-4 FS risk assessments, and OU-4 Comprehensive Response Action Risk Evaluation (CRARE).

2) Simulation of Pump and Treat Systems - OU-5 South Plume Engineering Evaluation/Cost Analysis and South Plume Modeling Report. Preliminary design of the Advanced Wastewater Treatment (AWWT).

Each of these are discussed below:

Risk Assessments - Groundwater modeling supports risk assessment by the simulation of the transport of contaminants within the saturated zone of the GMA. Other models are also used to transport contaminants within the vadose zone and as runoff through the surface water system.

Both the original and revised models contain uncertainties. Two issues need to be considered regarding these uncertainties: (1) are the relative responses of the original and revised models different to changes in variables, and (2) are there absolute differences between results of the two models that could affect risk assessment results significantly? These two issues are assessed below.

The relative response of the models is similar. The analysis of model uncertainty (in the revised model) showed that defining key variables at extreme values impacts risk assessment performance measures (maximum concentration and maximum concentration at the property line) in general, less than an order of magnitude. Typically, there is a time shift for the maximum concentration at the property line and some change in the maximum concentration values at both the maximum exposure location and the property line. Because of the improvement program, it is considered that overall model uncertainties have been reduced. However, since the basis of the uncertainty in results is parameter estimation, it is expected that the old model would have performed in a similar manner to the variation of these parameters. The flow and contaminant transport parameter in the original and revised model fall within the parameter uncertainty ranges and there is no apparent reason that the response of the old model would be significantly different.

Based on a comparison simulation, the absolute concentrations from the original model were typically less by a factor of 2 to 4 than the revised model (i.e., the revised model is more conservative). The primary parameters that affect maximum concentration values are the model layer 1 thickness and the transverse dispersivity. The original model divided the upper GMA into two layers each approximately 30 feet thick while the revised model has a 10- to 15-foot thick saturated layer 1 corresponding to the 2000 series well levels. Based on the simple dilution ratio, loading concentrations entering the GMA from the vadose zone model or surface water model could have concentrations up to three times higher than the original model. As evidenced by the comparison run results, more vertical dispersion occurred with the original model, further lowering concentrations. Since risk assessments operate on several orders of magnitude, uncertainty basis and, by design, contain many conservative assumptions, it is considered that this difference would not have affected decision making within the previous baseline RI, feasibility study, or CRARE risk assessments.

Simulation of Pump and Treat Systems - The model has been used to simulate pump and treat systems in the South Plume area and on site. The South Plume process was aware of possible model limitations (especially the solute transport model) so the flow model was stressed in the design and conservatism was included in the design. The system is presently operating and there is an ongoing evaluation program (of system and model) as part of the operation. The on-site evaluation to size the expansion of the AWWT again used only the flow model and particle tracking. In addition, this effort is being performed

in more detail as part of the OU-5 FS with the revised model. Therefore, the revision of the model has no effect on these previous efforts.

SECTION 10

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APPENDIX A

TRANSIENT FLOW CALIBRATION SUPPORTING DATA

APPENDIX A1

SUMMARY TABLE OF CORRECTED TIME AND DRAWDOWN DATA FROM CRT

```
"RW4",0.000000,"LGR",517.19,517.19000000
"RW4",0.000006,"LGR",520.76,520.76000009
"RW4",0.000012,"LGR",520.05,520.05000018
"RW4",0.000017,"LGR",517.23,517.23000026
"RW4",0.000023,"LGR",516.66,516.66000035
"RW4",0.000029,"LGR",516.76,516.76000044
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"RW4",0.000040,"LGR",514.99,514.99000060
"RW4",0.000046,"LGR",514.65,514.65000069
"RW4",0.000052,"LGR",514.11,514.11000078
"RW4",0.000057,"LGR",513.59,513.59000086
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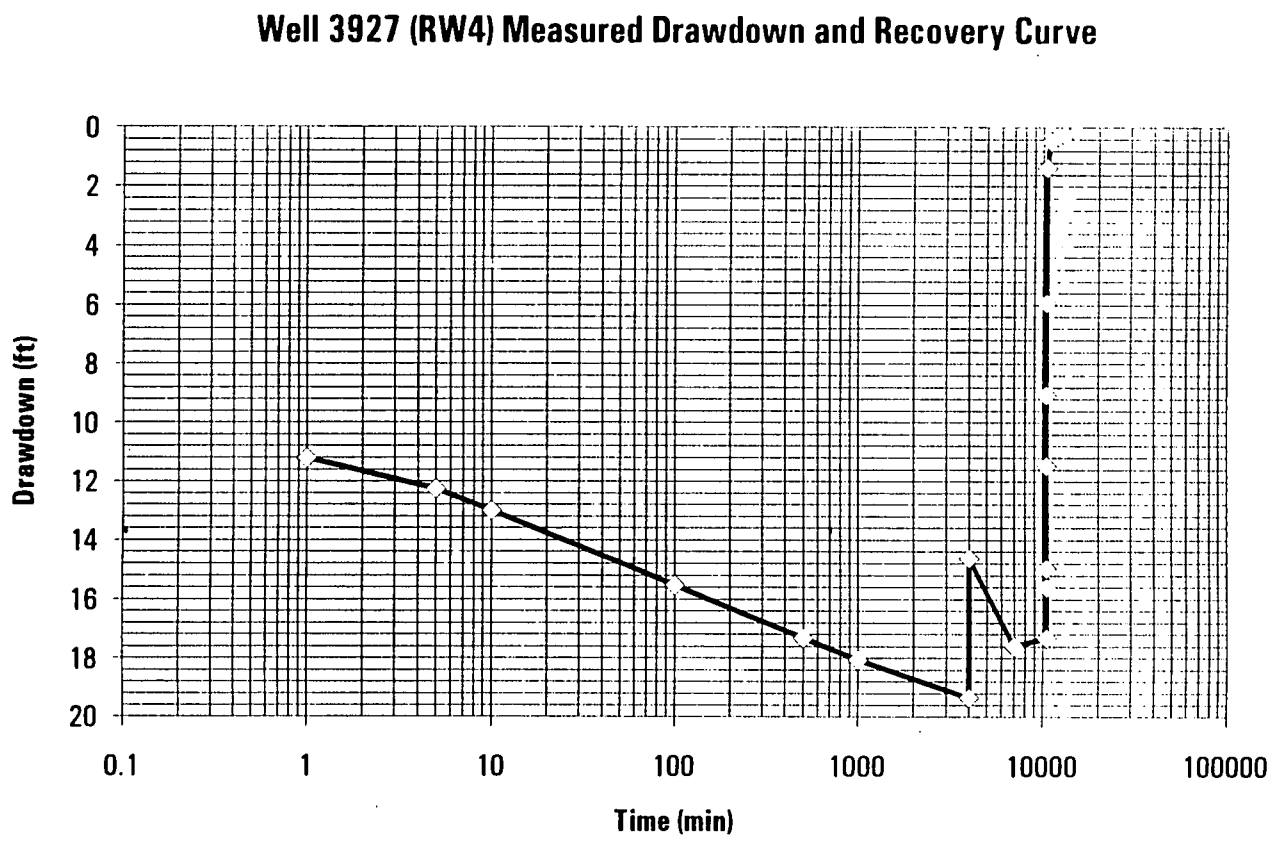
APPENDIX A2

SUMMARY TABLES AND FIGURES FOR SELECTED WELL DRAWDOWN AND RECOVERY POINTS

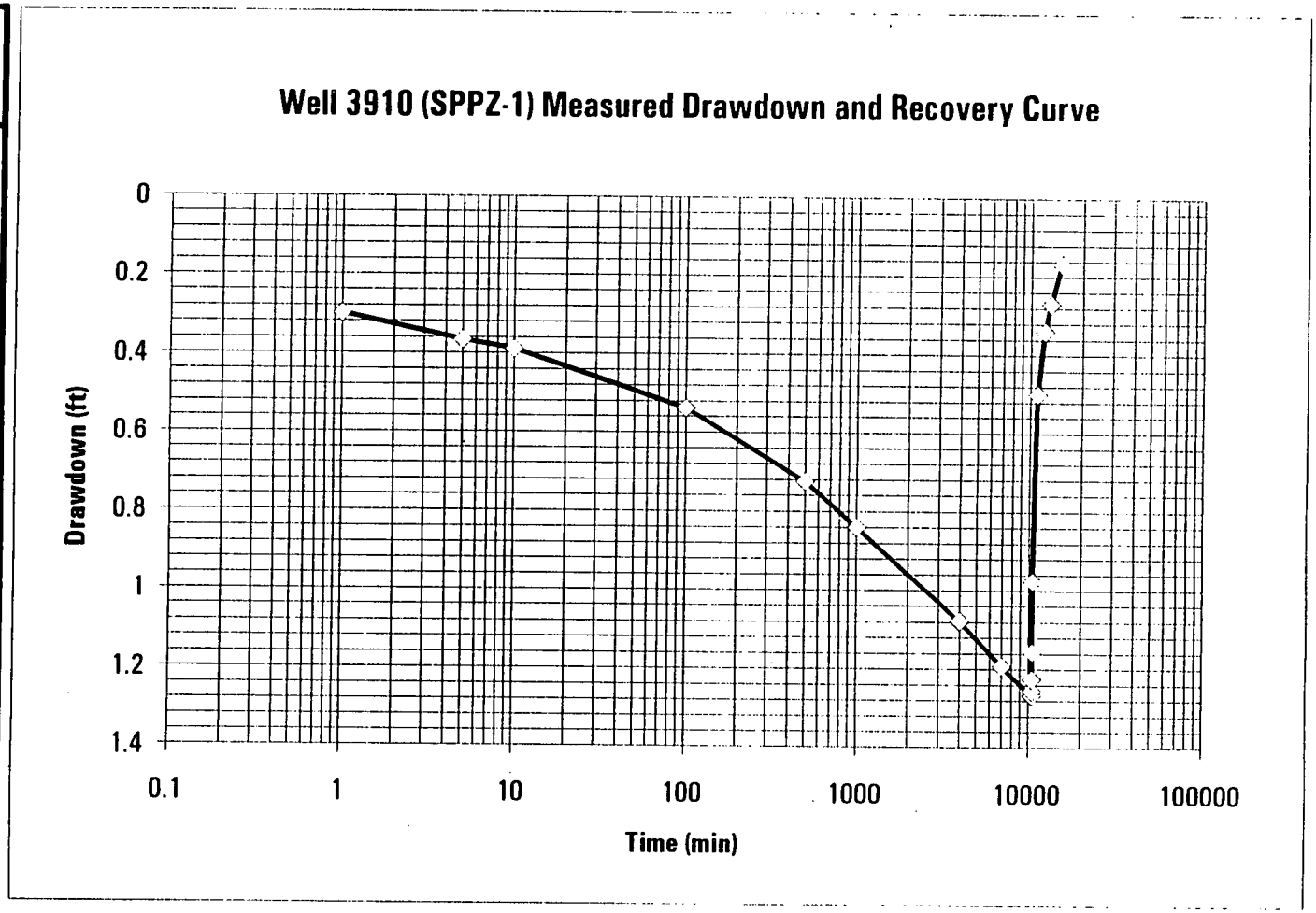
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3927 Drawdown (ft)
1.00	11.233
5.00	12.268
10.00	13.023
100.00	15.533
500.00	17.333
1000.00	18.063
3986.00	19.352
4005.00	14.631
7000.00	17.600
10431.27	17.324
10470.97	15.604
10471.02	14.984
10471.12	11.484
10471.22	9.074
10471.43	5.954
10472.32	1.384
11006.38	0.468
12037.61	0.308
13009.34	0.248
15032.14	0.146



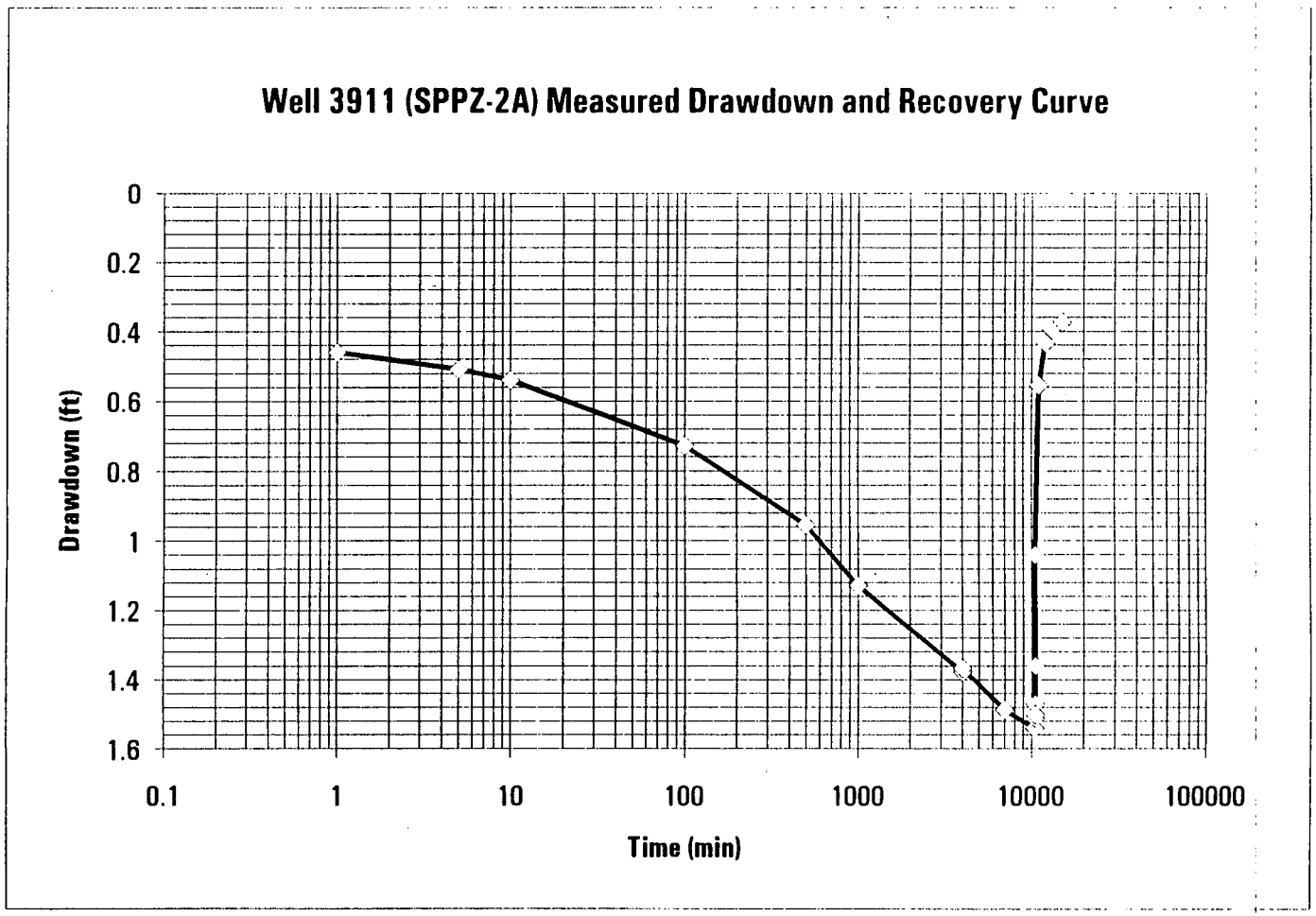
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3910 Drawdown (ft)
1.00	0.300
5.00	0.367
10.00	0.390
100.00	0.539
500.00	0.725
1000.00	0.840
3986.00	1.079
4005.00	1.078
7000.00	1.192
10431.27	1.266
10470.97	1.266
10471.02	1.266
10471.12	1.256
10471.22	1.226
10471.43	1.156
10472.32	0.976
11006.38	0.500
12037.61	0.340
13009.34	0.269
15032.14	0.168



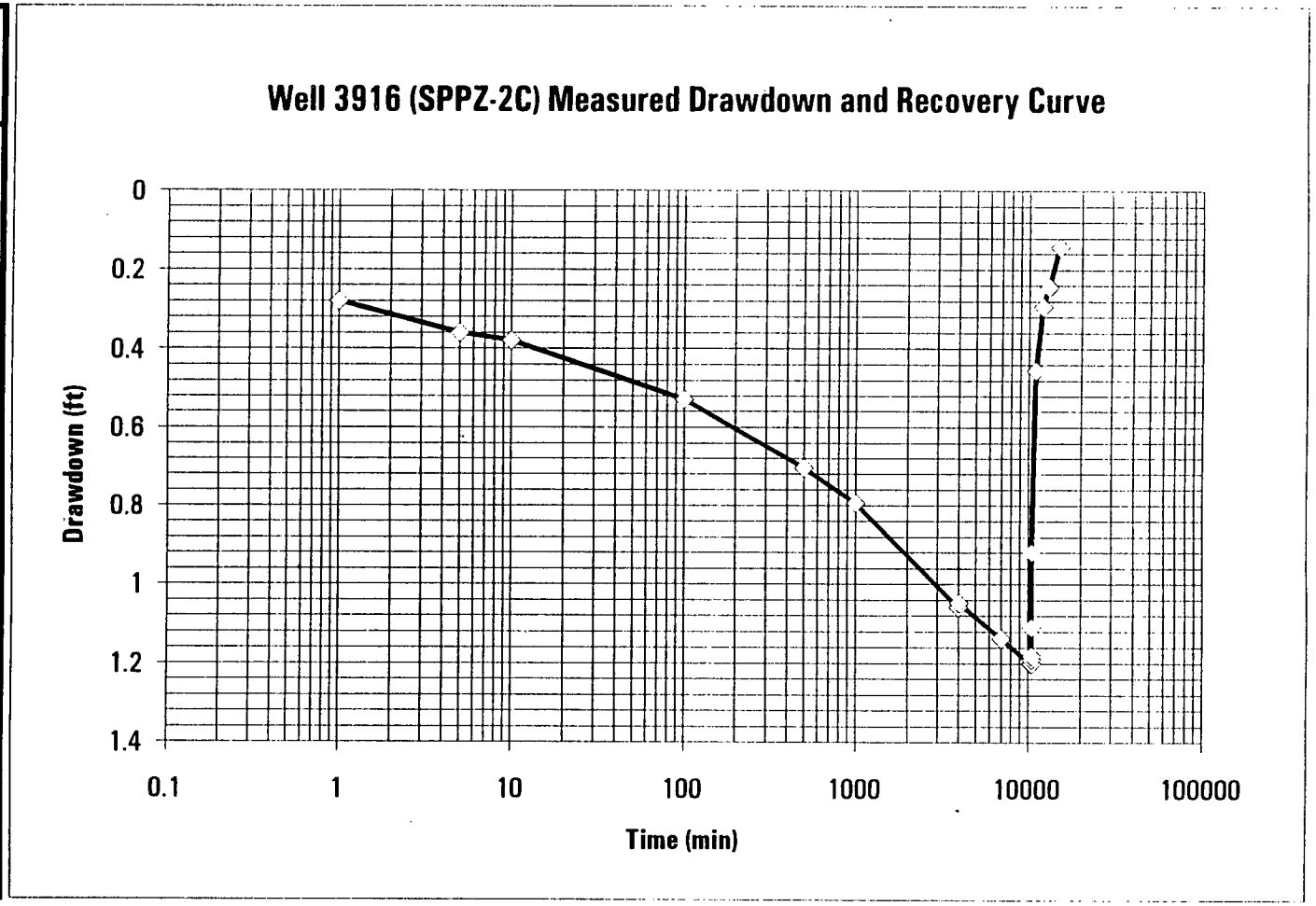
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3911 Drawdown (ft)
1.00	0.460
5.00	0.510
10.00	0.540
100.00	0.729
500.00	0.955
1000.00	1.130
3986.00	1.378
4005.00	1.368
7000.00	1.487
10431.27	1.541
10470.97	1.471
10471.02	1.501
10471.12	1.511
10471.22	1.501
10471.43	1.361
10472.32	1.041
11006.38	0.555
12037.61	0.435
13009.34	0.394
15032.14	0.373



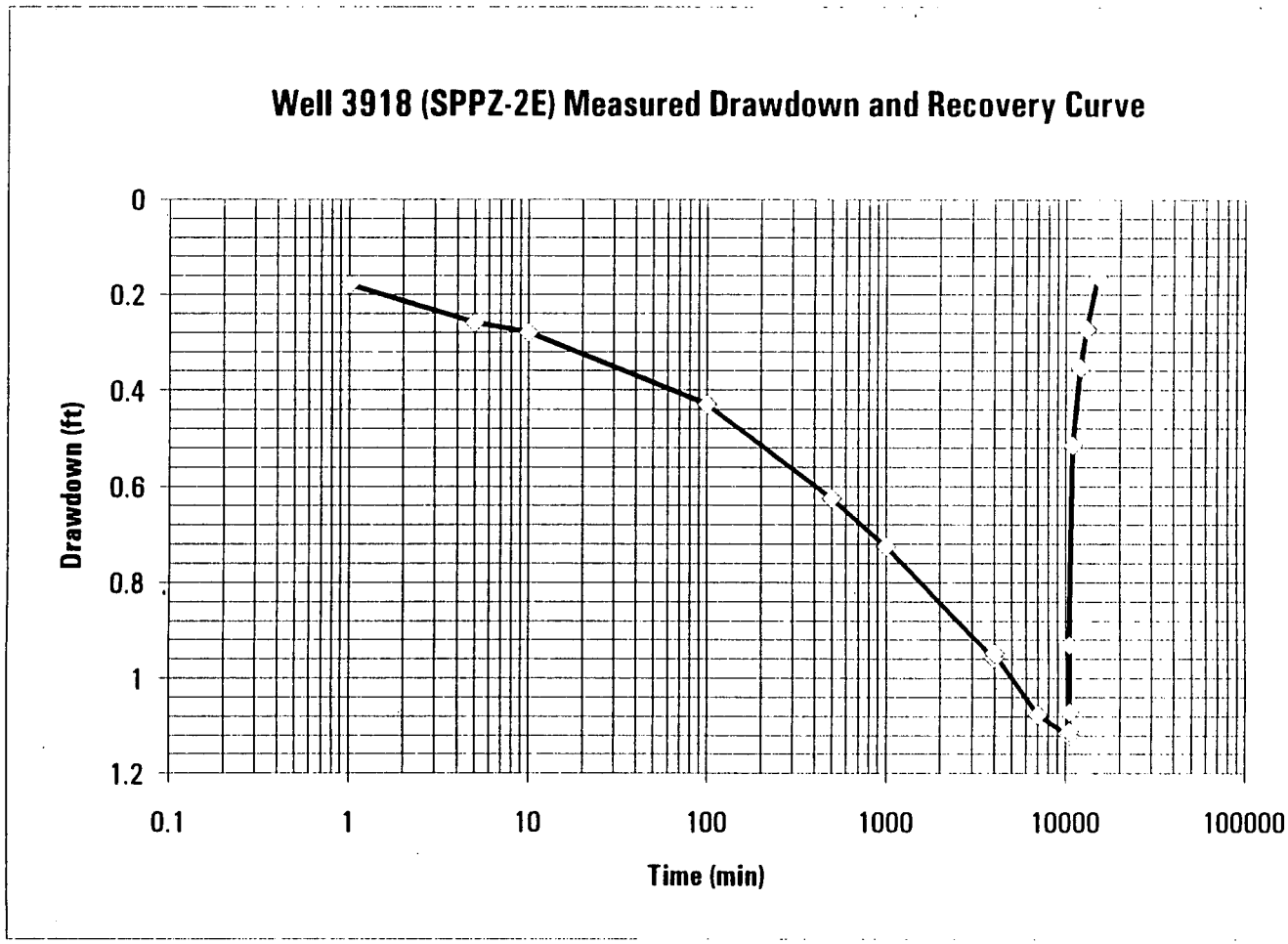
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3916 Drawdown (ft)
1.00	0.280
5.00	0.360
10.00	0.380
100.00	0.529
500.00	0.705
1000.00	0.795
3986.00	1.059
4005.00	1.048
7000.00	1.137
10431.27	1.201
10470.97	1.201
10471.02	1.201
10471.12	1.191
10471.22	1.181
10471.43	1.111
10472.32	0.921
11006.38	0.455
12037.61	0.295
13009.34	0.244
15032.14	0.143



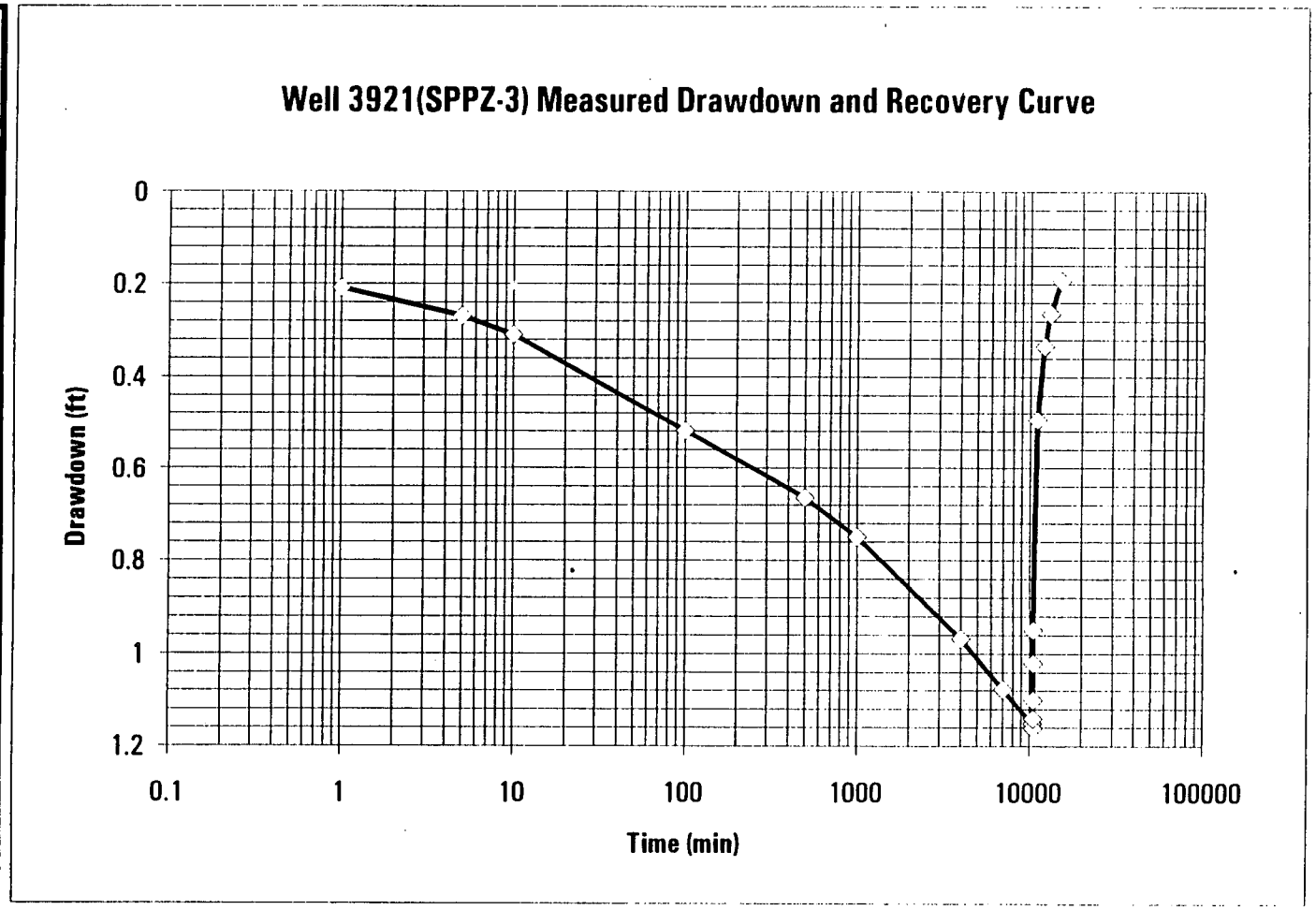
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3918 Drawdown (ft)
1.00	0.180
5.00	0.260
10.00	0.280
100.00	0.429
500.00	0.625
1000.00	0.725
3986.00	0.958
4005.00	0.948
7000.00	1.077
10431.27	1.121
10470.97	1.121
10471.02	1.121
10471.12	1.121
10471.22	1.111
10471.43	1.071
10472.32	0.931
11006.38	0.515
12037.61	0.355
13009.34	0.274
15032.14	0.163



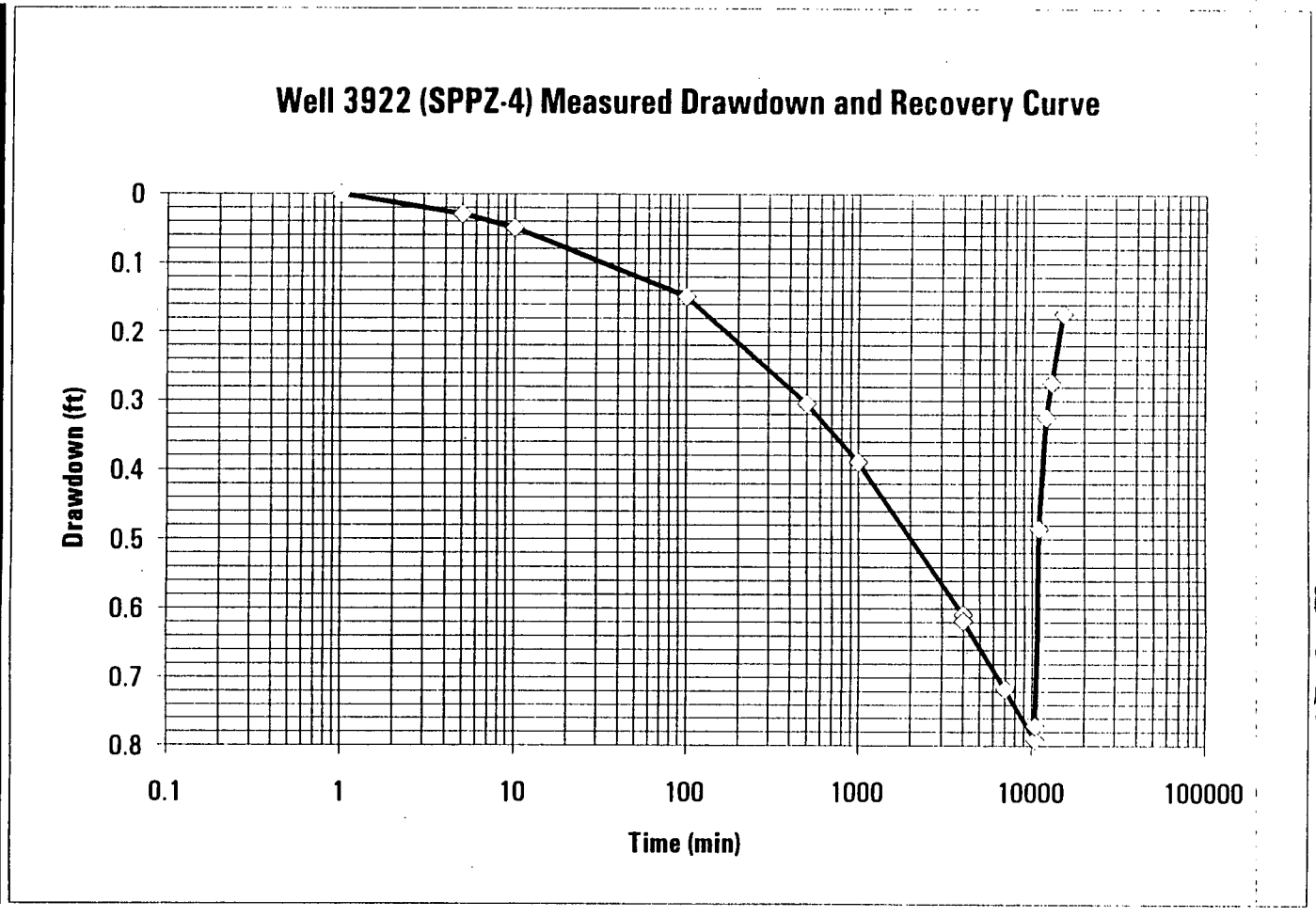
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3921 Drawdown (ft)
1.00	0.210
5.00	0.270
10.00	0.310
100.00	0.519
500.00	0.665
1000.00	0.750
3986.00	0.968
4005.00	0.968
7000.00	1.077
10431.27	1.151
10470.97	1.101
10471.02	1.161
10471.12	1.161
10471.22	1.141
10471.43	1.021
10472.32	0.951
11006.38	0.495
12037.61	0.335
13009.34	0.264
15032.14	0.193



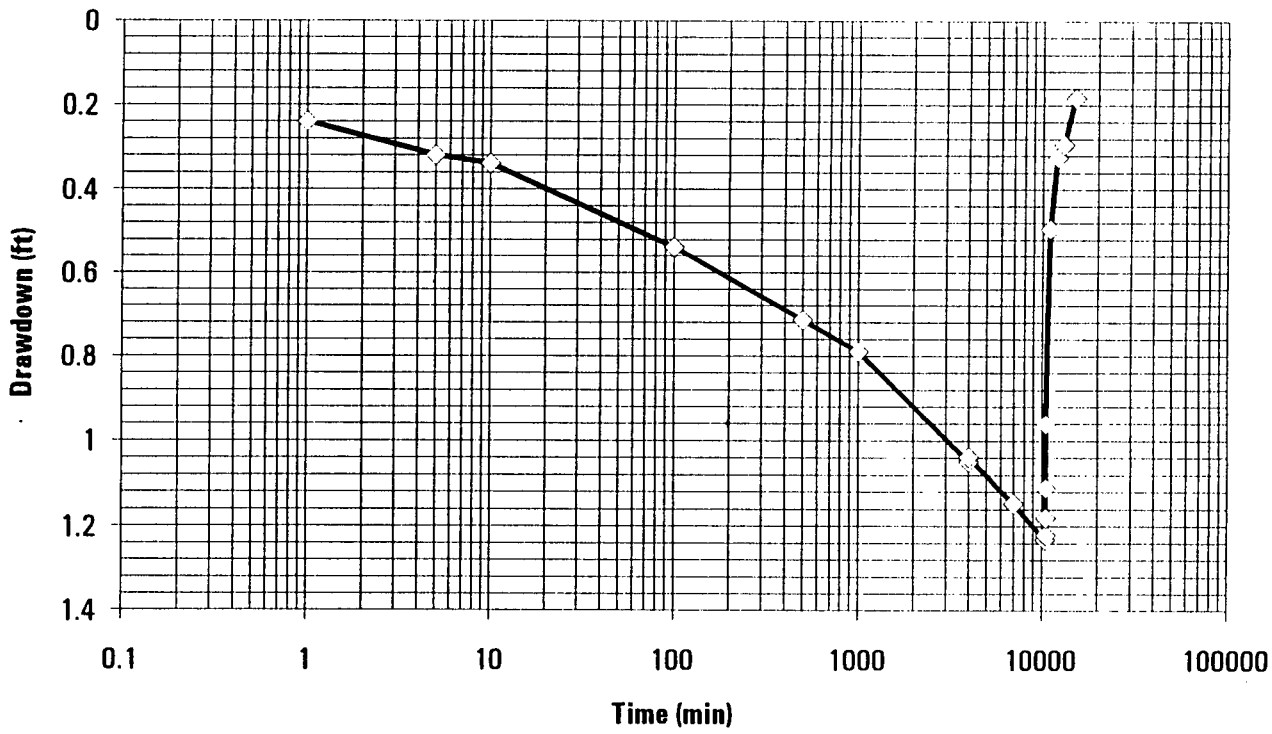
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3922 Drawdown (ft)
1.00	0.000
5.00	0.030
10.00	0.050
100.00	0.149
500.00	0.305
1000.00	0.390
3986.00	0.609
4005.00	0.618
7000.00	0.717
10431.27	0.791
10470.97	0.791
10471.02	0.791
10471.12	0.791
10471.22	0.791
10471.43	0.791
10472.32	0.771
11006.38	0.485
12037.61	0.325
13009.34	0.274
15032.14	0.173



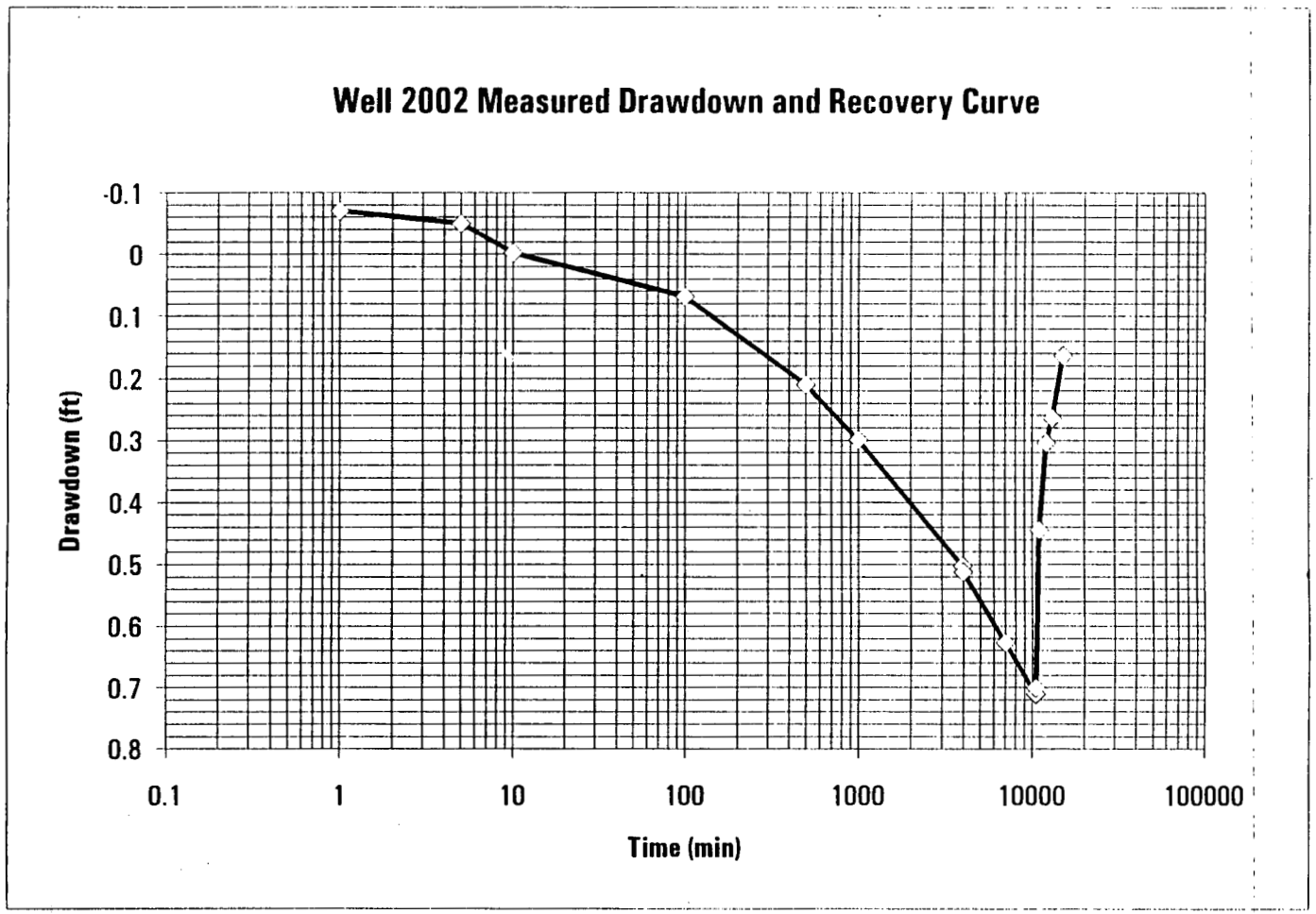
Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 3923 Drawdown (ft)
1.00	0.240
5.00	0.320
10.00	0.340
100.00	0.539
500.00	0.715
1000.00	0.790
3986.00	1.049
4005.00	1.038
7000.00	1.147
10431.27	1.231
10470.97	1.221
10471.02	1.221
10471.12	1.221
10471.22	1.181
10471.43	1.111
10472.32	0.961
11006.38	0.495
12037.61	0.325
13009.34	0.294
15032.14	0.183



Constant Recovery Test Data for Transient Flow Model Calibration
Fernald, Ohio

Time (min)	Well 2002 Drawdown (ft)
1.00	-0.070
5.00	-0.050
10.00	-0.002
100.00	0.069
500.00	0.210
1000.00	0.300
3986.00	0.503
4005.00	0.513
7000.00	0.627
10431.27	0.711
10470.97	0.711
10471.02	0.711
10471.12	0.711
10471.22	0.711
10471.43	0.711
10472.32	0.701
11006.38	0.445
12037.61	0.305
13009.34	0.264
15032.14	0.163



APPENDIX A3

SUMMARY LIST OF CALIBRATION MODEL RUNS

Summary of SWIFT Input Files Used for Transient Flow Calibration

Filename	Parameters used in Model
TRANBASE.DAT:	Kh=600 & Kv=60 ft/day for Layer 1 & 2 in North Zone; Kh=400 & Kv=40 ft/day for Layer 1 & 2 South Zone; Kh=600 & Kv=60 ft/day for Layers 3 to 7; Porosity=0.25; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61).
TRANWIC2.DAT:	Kh=600 & Kv=30 ft/day for Layer 1 & 2 North Zone; Kh=375 & Kv=18.8 ft/day for Layer 1 & 2 South Zone; Kh=600 & Kv=30 ft/day for Layers 3 to 7; Porosity=0.25; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61).
TRANWIC3.DAT:	Kh=600 & Kv=30 ft/day for Layer 1 & 2 North Zone; Kh=375 & Kv=18.8 ft/day for Layer 1 & 2 South Zone; Kh=500 & Kv=25 ft/day for Layers 3 to 7; Porosity=0.25; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61).
TRANWIC4.DAT:	Same as TRANWIC3.DAT except smaller time step was used in the first minute. Results showed time step change had no effect on drawdown results.
TRANWIC5.DAT:	Same as TRANWIC3.DAT except porosity=0.40.
TRANWIC6.DAT:	Kh=600 & Kv=30 ft/day for Layer 1 & 2 North Zone; Kh=300 & Kv=15 ft/day for Layer 1 & 2 South Zone; Kh=400 & Kv=20 ft/day for Layers 3 to 7; Porosity=0.25; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61).
TRANWIC7.DAT:	Same as TRANWIC3.DAT except porosity=0.20.
TRANWIC8.DAT:	Kh=700 & Kv=35 ft/day for Layer 1 & 2 North Zone; Kh=500 & Kv=25 ft/day for Layer 1 & 2 South Zone; Kh=350 & Kv=17.5 ft/day for Layers 3 to 7; Porosity=0.20; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61).
TRANWIC9.DAT:	(1) Kh=600 & Kv=30 ft/day for Layer 1 & 2 North Zone; Kh=325 & Kv=16.2 ft/day for Layer 1 & 2 South Zone; Kh=400 & Kv=20 ft/day for Layers 3 to 7; Porosity=0.40; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61). (2) Kh=600 & Kv=30 ft/day for Layer 1 & 2 North Zone; Kh=325 & Kv=16.2 ft/day for Layer 1 & 2 South Zone; Kh=280 & Kv=14 ft/day for Layers 3 to 4; Kh=200 & Kv=10 ft/day for Layers 5 to 7; Porosity=0.40; (North: Y Grid Blocks > 61; South: Y Grid Blocks < 61).
TRANWI10.DAT:	Same as TRANWIC6.DAT except Kv/Kh ratio was changed to 0.25 throughout the model domain.
TRANWI11.DAT:	Same as TRANWIC8.DAT except Kv/Kh ratio was changed to 0.10 and the porosity changed to 0.35 throughout the model domain.

TRANWI12.DAT: Kh=560 & Kv=95 ft/day for Layer 1 & 2 North Zone; Kh=375 & Kv=64 ft/day for Layer 1 & 2 Central Zone; Kh=280 & Kv=48 ft/day for Layer 1 & 2 South Zone; Kh=280 & Kv=48 ft/day for Layers 3 to 4; Kh=200 & Kv=34 ft/day for Layers 5 to 7; Porosity=0.30;
(North: Y Grid Blocks > 61; Central: 52<= Y Grid Blocks <=61; South: 52 > Y Grid Blocks).

TRANWI13.DAT: Kh=638 & Kv=77 ft/day for Layer 1 & 2 North Zone; Kh=425 & Kv=51 ft/day for Layer 1 & 2 Central Zone; Kh=280 & Kv=34 ft/day for Layer 1 & 2 South Zone; Kh=300 & Kv=36 ft/day for Layers 3 to 4; Kh=200 & Kv=24 ft/day for Layers 5 to 7; Porosity=0.30;
(North: Y Grid Blocks > 61; Central: 52<= Y Grid Blocks <=61; South: 52 > Y Grid Blocks).

TRANWI14.DAT: Kh=638 & Kv=51 ft/day for Layer 1 & 2 North Zone; Kh=425 & Kv=34 ft/day for Layer 1 & 2 Central Zone; Kh=280 & Kv=22.4 ft/day for Layer 1 & 2 South Zone; Kh=300 & Kv=36 ft/day for Layers 3 to 4; Kh=200 & Kv=24 ft/day for Layers 5; Kh=200 & Kv=34 ft/day for Layers 6 to 7; Porosity=0.30; (North: Y Grid Blocks > 61; Central: 52<= Y Grid Blocks <=61; South: 52 > Y Grid Blocks).

APPENDIX A4

DRAWDOWN FIGURES FOR FOUR MODEL RUNS

File : wellwii1.dat

- 5490

Well No. : RW-4

Well Coord. : X = 58 Y = 58 Z = 1- 2

Time Sequence (min.)	Drawdown (ft)	BHP Drawdown (ft)
0.000E+00	0.0000E+0	0.0000E+0
0.100E+01	0.1923E+0	0.1643E+2
0.500E+01	0.6810E+0	0.1685E+2
0.100E+02	0.9844E+0	0.1711E+2
0.100E+03	0.1808E+1	0.1783E+2
0.500E+03	0.2214E+1	0.1821E+2
0.100E+04	0.2354E+1	0.1835E+2
0.399E+04	0.2592E+1	0.1858E+2
0.400E+04	0.2593E+1	0.1627E+2
0.700E+04	0.2679E+1	0.1636E+2
0.104E+05	0.2728E+1	0.1641E+2

Well No. : SPPZ-1

Well Coord. : X = 60 Y = 58 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1323E+0
0.500E+01	0.1448E+0
0.100E+02	0.1605E+0
0.100E+03	0.3449E+0
0.500E+03	0.5885E+0
0.100E+04	0.7000E+0
0.399E+04	0.9120E+0
0.400E+04	0.9127E+0
0.700E+04	0.9921E+0
0.104E+05	0.1038E+1

Well No. : SPPZ-2A

Well Coord. : X = 58 Y = 57 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.3163E+0
0.500E+01	0.3429E+0
0.100E+02	0.3724E+0
0.100E+03	0.6091E+0
0.500E+03	0.8667E+0
0.100E+04	0.9808E+0
0.399E+04	0.1195E+1
0.400E+04	0.1196E+1

0.700E+04	0.1276E+1
0.104E+05	0.1322E+1

Well No. : SPPZ-2C

Well Coord. : X = 58 Y = 57 Z = 4- 4

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1004E+0
0.500E+01	0.1087E+0
0.100E+02	0.1184E+0
0.100E+03	0.2297E+0
0.500E+03	0.4158E+0
0.100E+04	0.5149E+0
0.399E+04	0.7169E+0
0.400E+04	0.7176E+0
0.700E+04	0.7954E+0
0.104E+05	0.8402E+0

Well No. : SPPZ-2E

Well Coord. : X = 58 Y = 57 Z = 6- 6

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.4733E-1
0.500E+01	0.5149E-1
0.100E+02	0.5656E-1
0.100E+03	0.1270E+0
0.500E+03	0.2784E+0
0.100E+04	0.3689E+0
0.399E+04	0.5636E+0
0.400E+04	0.5643E+0
0.700E+04	0.6407E+0
0.104E+05	0.6848E+0

Well No. : SPPZ-3

Well Coord. : X = 58 Y = 56 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1332E+0
0.500E+01	0.1457E+0
0.100E+02	0.1614E+0
0.100E+03	0.3479E+0
0.500E+03	0.5952E+0

0.100E+04	0.7083E+0
0.399E+04	0.9219E+0
0.400E+04	0.9226E+0
0.700E+04	0.1003E+1
0.104E+05	0.1049E+1

Well No. : SPPZ-4

Well Coord. : X = 58 Y = 50 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.7618E-2
0.500E+01	0.8543E-2
0.100E+02	0.9468E-2
0.100E+03	0.3464E-1
0.500E+03	0.1572E+0
0.100E+04	0.2482E+0
0.399E+04	0.4477E+0
0.400E+04	0.4484E+0
0.700E+04	0.5269E+0
0.104E+05	0.5724E+0

Well No. : SPPZ-5

Well Coord. : X = 58 Y = 60 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1256E+0
0.500E+01	0.1374E+0
0.100E+02	0.1524E+0
0.100E+03	0.3292E+0
0.500E+03	0.5668E+0
0.100E+04	0.6769E+0
0.399E+04	0.8870E+0
0.400E+04	0.8877E+0
0.700E+04	0.9665E+0
0.104E+05	0.1012E+1

Well No. : 2002

Well Coord. : X = 62 Y = 65 Z = 1- 1

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.4624E-4
0.500E+01	0.2075E-3

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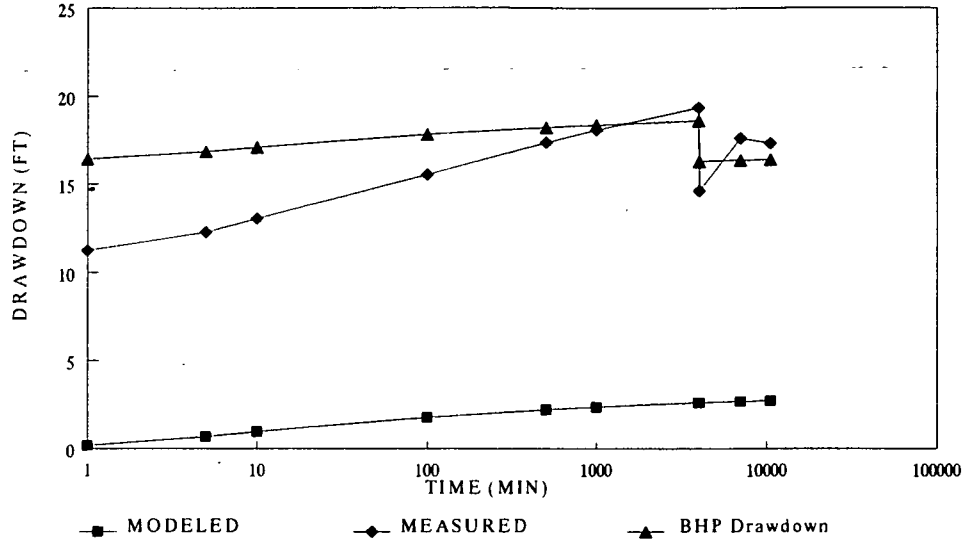
0.100E+02	0.4387E-3
0.100E+03	0.1570E-1
0.500E+03	0.1522E+0
0.100E+04	0.2487E+0
0.399E+04	0.4493E+0
0.400E+04	0.4500E+0
0.700E+04	0.5264E+0
0.104E+05	0.5701E+0

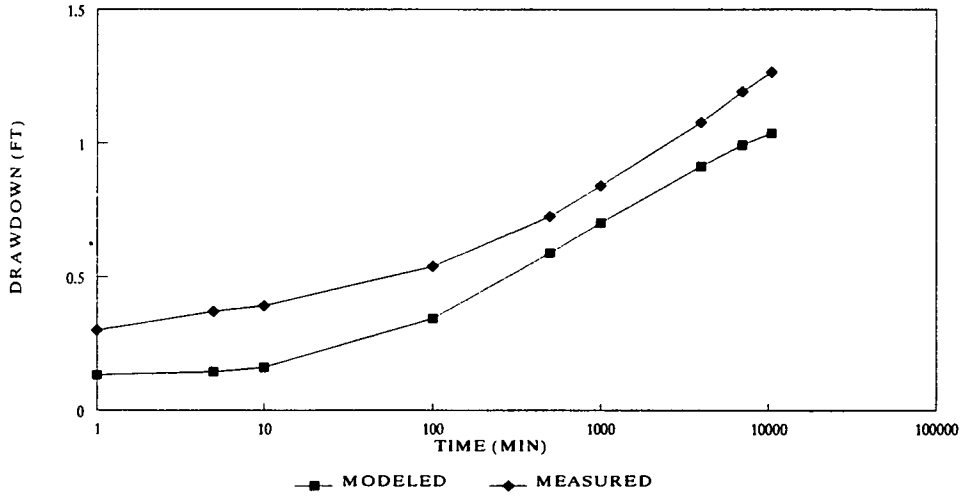
WELL: RW-4

MEASURED VS MODELED DRAWDOWN



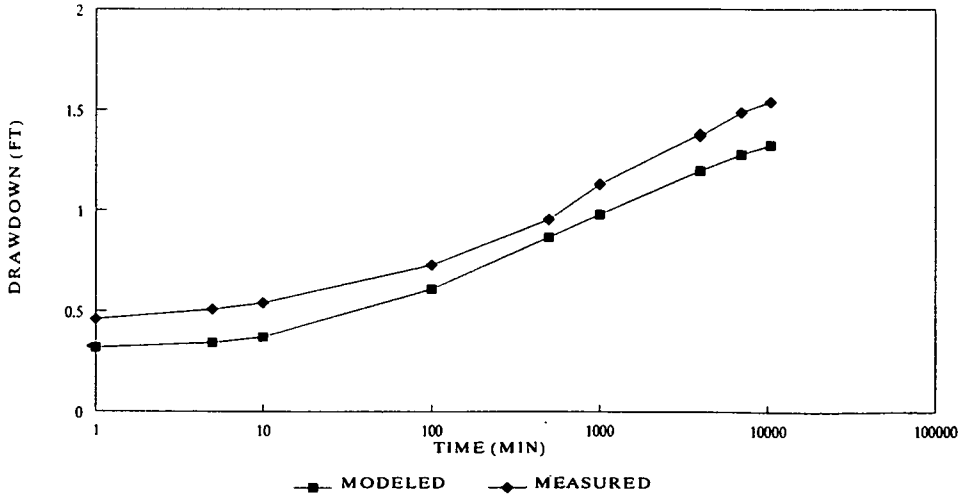
WELL: SPPZ-1

MEASURED VS MODELED DRAWDOWN



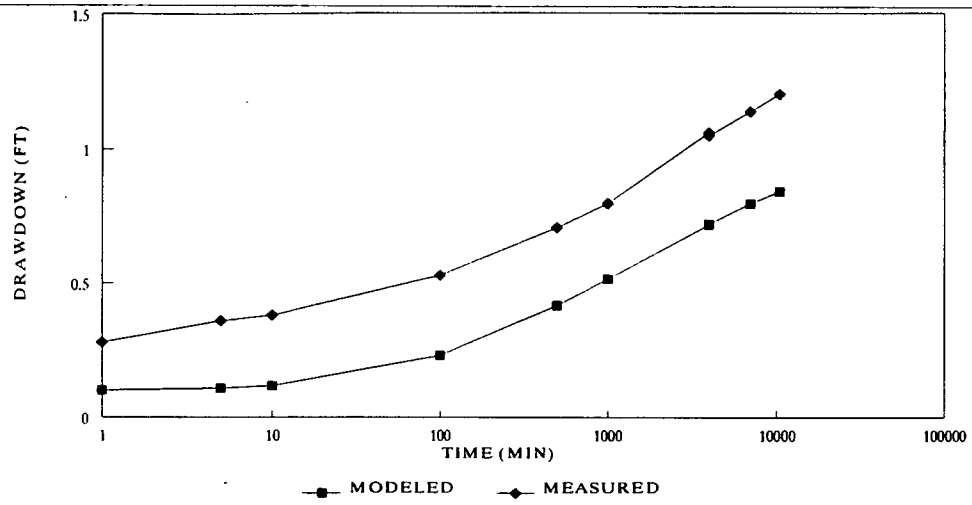
WELL: SPPZ-2A

MEASURED VS MODELED DRAWDOWN



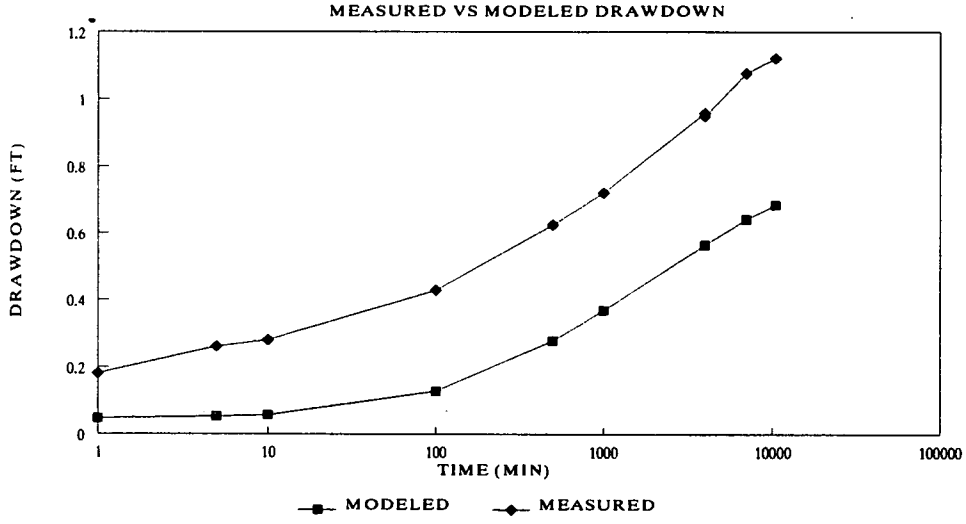
WELL: SPPZ-2C

MEASURED VS MODELED DRAWDOWN



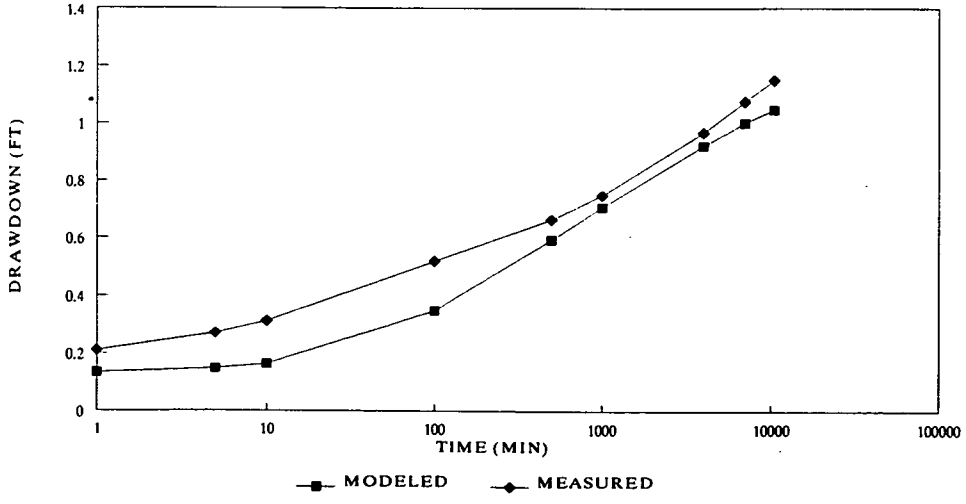
WELL: SPPZ-2E

MEASURED VS MODELED DRAWDOWN



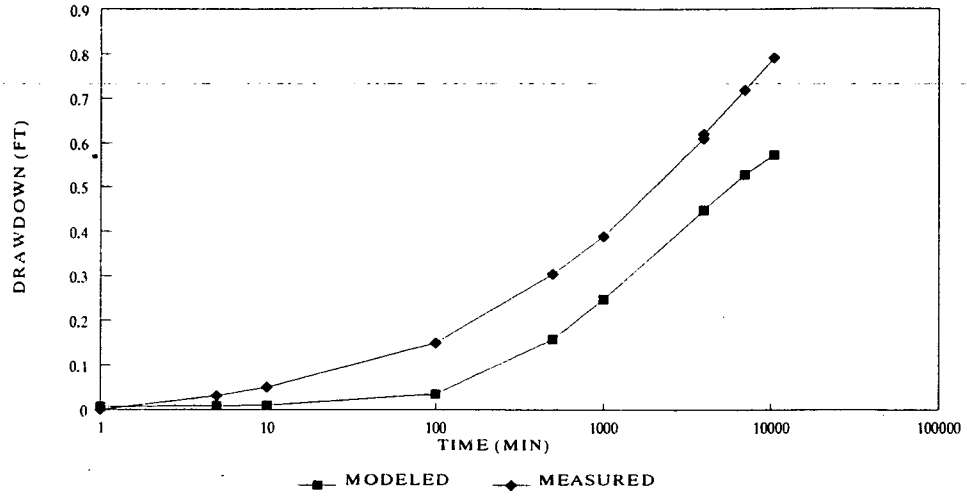
WELL: SPPZ-3

MEASURED VS MODELED DRAWDOWN



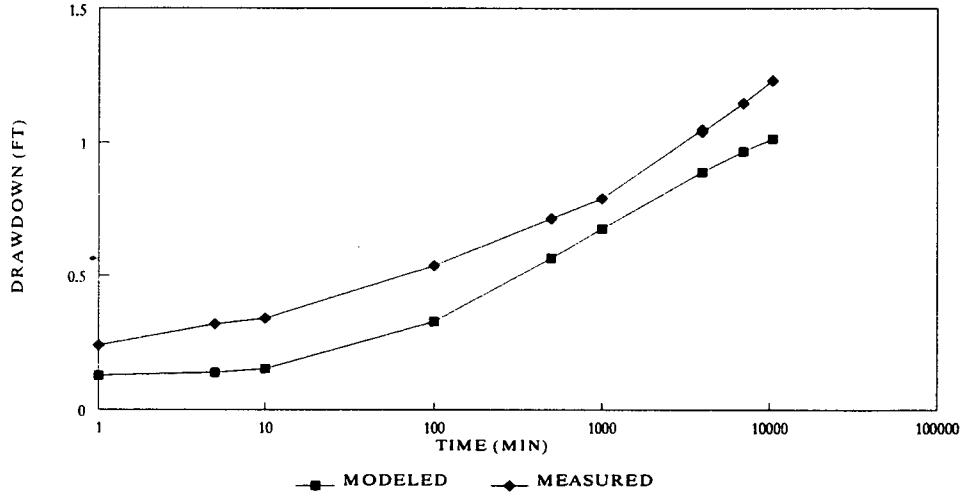
WELL: SPPZ-4

MEASURED VS MODELED DRAWDOWN



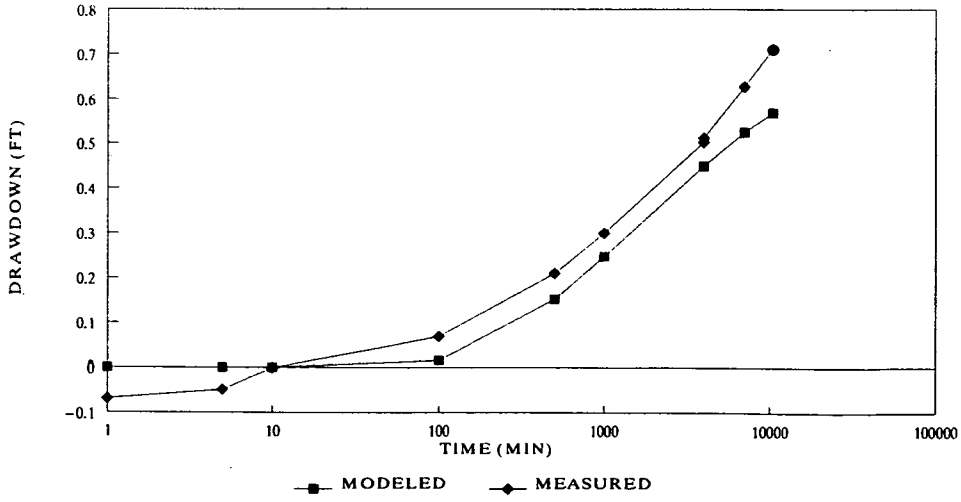
WELL: SPPZ-5

MEASURED VS MODELED DRAWDOWN



WELL: 2002

MEASURED VS MODELED DRAWDOWN



File : wellwi12.dat

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Well No. : RW-4

Well Coord. : X = 58 Y = 58 Z = 1- 2

Time Sequence (min.)	Drawdown (ft)	BHP Drawdown (ft)
0.000E+00	0.0000E+0	0.0000E+0
0.100E+01	0.2292E+0	0.1648E+2
0.500E+01	0.8376E+0	0.1701E+2
0.100E+02	0.1237E+1	0.1735E+2
0.100E+03	0.2345E+1	0.1834E+2
0.500E+03	0.2885E+1	0.1885E+2
0.100E+04	0.3078E+1	0.1904E+2
0.399E+04	0.3422E+1	0.1937E+2
0.400E+04	0.3424E+1	0.1707E+2
0.700E+04	0.3555E+1	0.1720E+2
0.104E+05	0.3638E+1	0.1728E+2

Well No. : SPPZ-1

Well Coord. : X = 60 Y = 58 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1214E+0
0.500E+01	0.1388E+0
0.100E+02	0.1614E+0
0.100E+03	0.4343E+0
0.500E+03	0.7859E+0
0.100E+04	0.9457E+0
0.399E+04	0.1255E+1
0.400E+04	0.1256E+1
0.700E+04	0.1378E+1
0.104E+05	0.1455E+1

Well No. : SPPZ-2A

Well Coord. : X = 58 Y = 57 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.3207E+0
0.500E+01	0.3618E+0
0.100E+02	0.4087E+0
0.100E+03	0.7746E+0
0.500E+03	0.1151E+1
0.100E+04	0.1316E+1
0.399E+04	0.1631E+1
0.400E+04	0.1632E+1

0.700E+04	0.1756E+1
0.104E+05	0.1834E+1

5490

Well No. : SPPZ-2C

Well Coord. : X = 58 Y = 57 Z = 4- 4

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1353E+0
0.500E+01	0.1517E+0
0.100E+02	0.1708E+0
0.100E+03	0.3715E+0
0.500E+03	0.6684E+0
0.100E+04	0.8180E+0
0.399E+04	0.1120E+1
0.400E+04	0.1121E+1
0.700E+04	0.1242E+1
0.104E+05	0.1318E+1

Well No. : SPPZ-2E

Well Coord. : X = 58 Y = 57 Z = 6- 6

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.6950E-1
0.500E+01	0.7827E-1
0.100E+02	0.8889E-1
0.100E+03	0.2246E+0
0.500E+03	0.4768E+0
0.100E+04	0.6167E+0
0.399E+04	0.9104E+0
0.400E+04	0.9113E+0
0.700E+04	0.1030E+1
0.104E+05	0.1106E+1

Well No. : SPPZ-3

Well Coord. : X = 58 Y = 56 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1217E+0
0.500E+01	0.1390E+0
0.100E+02	0.1616E+0
0.100E+03	0.4364E+0
0.500E+03	0.7951E+0

000243

0.100E+04	0.9586E+0
0.399E+04	0.1273E+1
0.400E+04	0.1274E+1
0.700E+04	0.1397E+1
0.104E+05	0.1475E+1

Well No. : SPPZ-4

Well Coord. : X = 58 Y = 50 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.5773E-2
0.500E+01	0.6698E-2
0.100E+02	0.8081E-2
0.100E+03	0.3856E-1
0.500E+03	0.2039E+0
0.100E+04	0.3339E+0
0.399E+04	0.6278E+0
0.400E+04	0.6287E+0
0.700E+04	0.7501E+0
0.104E+05	0.8284E+0

Well No. : SPPZ-5

Well Coord. : X = 58 Y = 60 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1201E+0
0.500E+01	0.1371E+0
0.100E+02	0.1593E+0
0.100E+03	0.4267E+0
0.500E+03	0.7674E+0
0.100E+04	0.9233E+0
0.399E+04	0.1227E+1
0.400E+04	0.1229E+1
0.700E+04	0.1349E+1
0.104E+05	0.1425E+1

Well No. : 2002

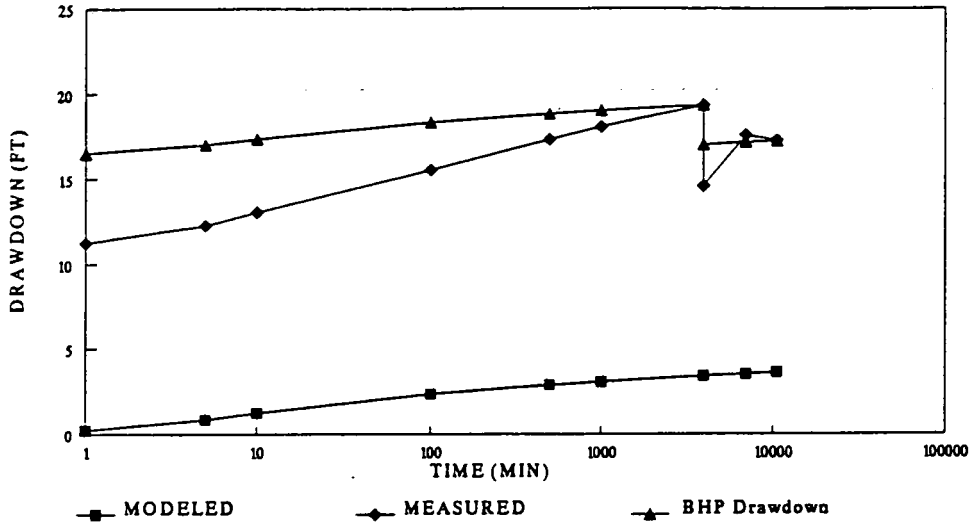
Well Coord. : X = 62 Y = 65 Z = 1- 1

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.2312E-4
0.500E+01	0.1850E-3

0.100E+02	0.4156E-3
0.100E+03	0.1709E-1
0.500E+03	0.1803E+0
0.100E+04	0.3047E+0
0.399E+04	0.5811E+0
0.400E+04	0.5820E+0
0.700E+04	0.6955E+0
0.104E+05	0.7671E+0

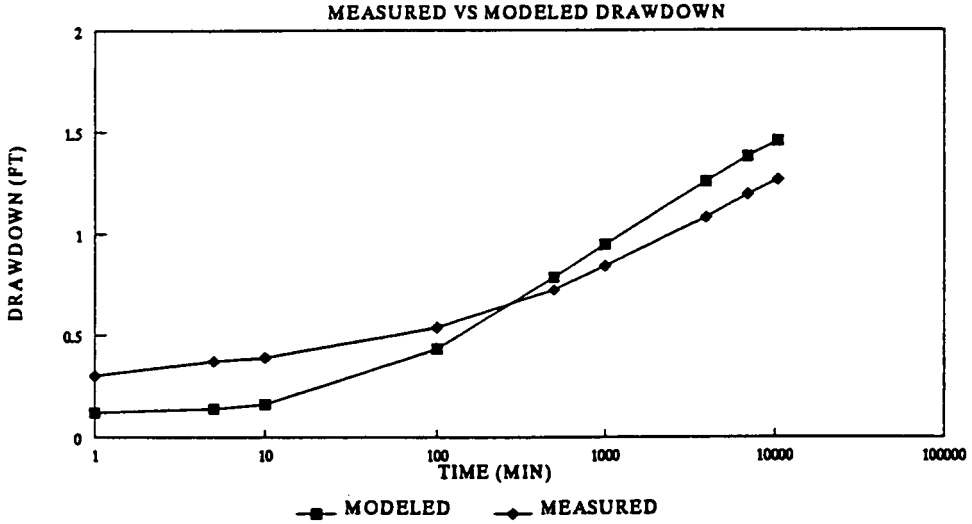
WELL: RW-4

MEASURED VS MODELED DRAWDOWN



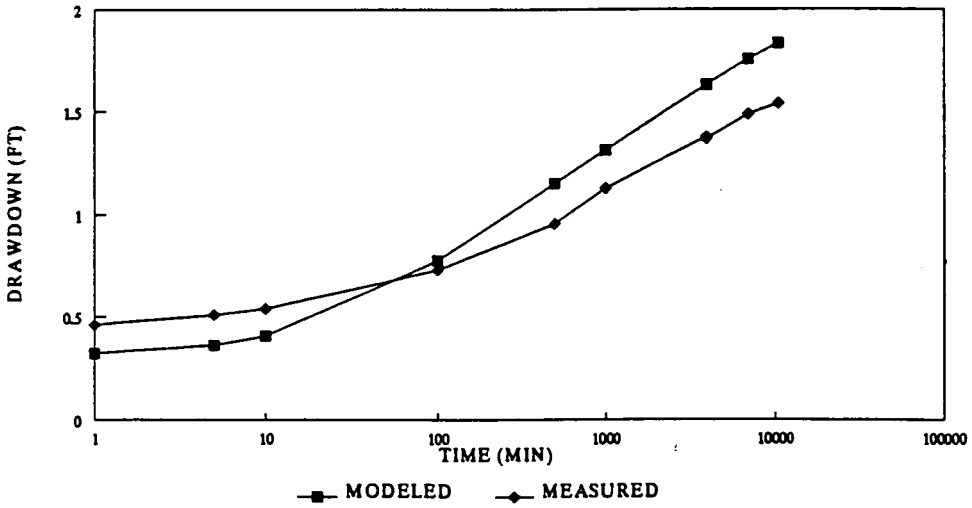
WELL: SPPZ-1

MEASURED VS MODELED DRAWDOWN



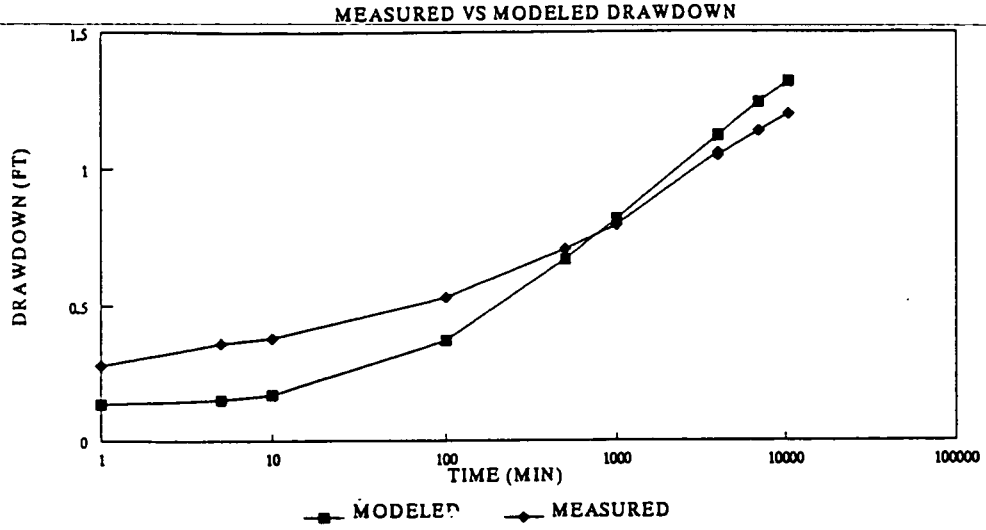
WELL: SPPZ-2A

MEASURED VS MODELED DRAWDOWN



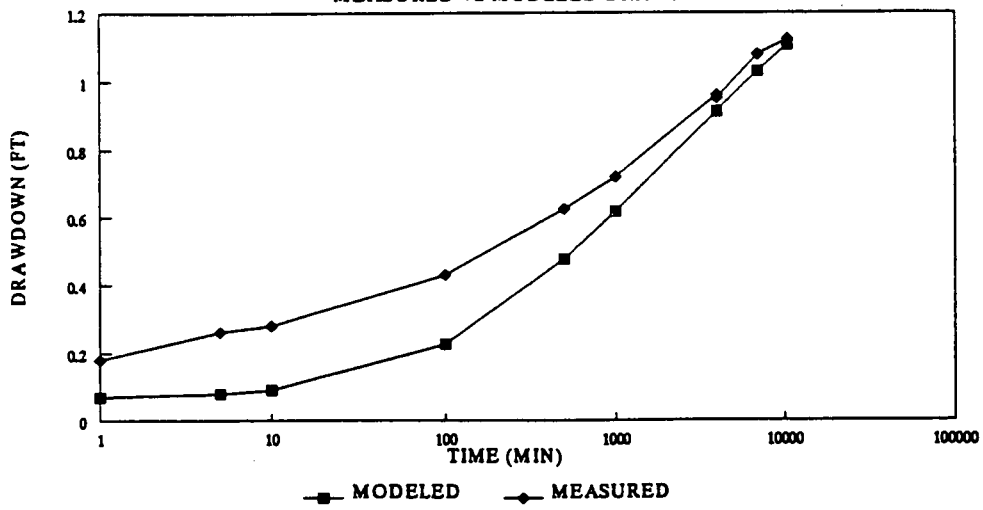
WELL: SPPZ-2C

MEASURED VS MODELED DRAWDOWN



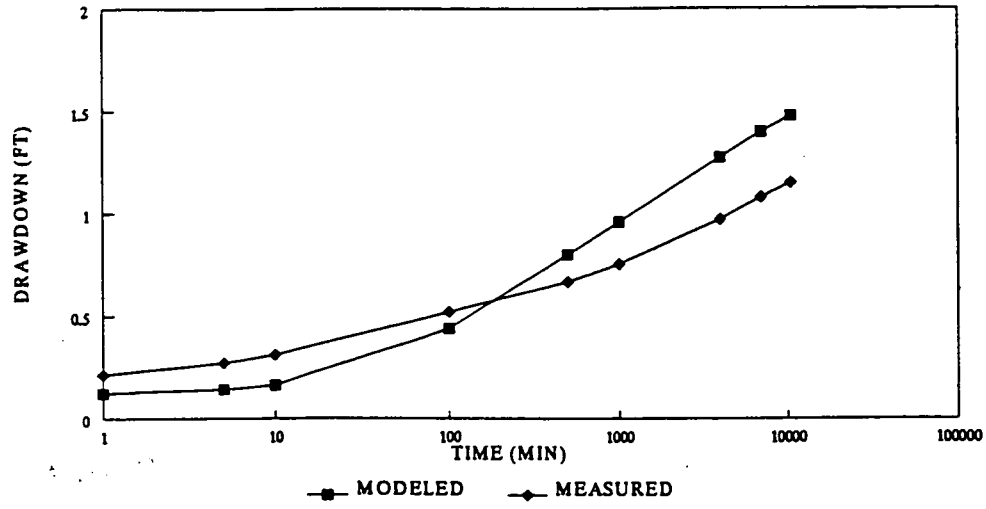
WELL: SPPZ-2E

MEASURED VS MODELED DRAWDOWN



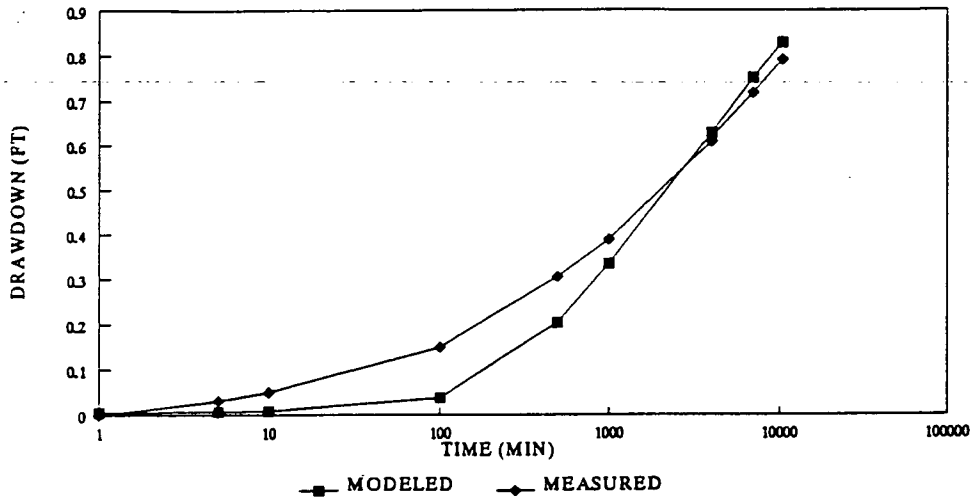
WELL: SPPZ-3

MEASURED VS MODELED DRAWDOWN



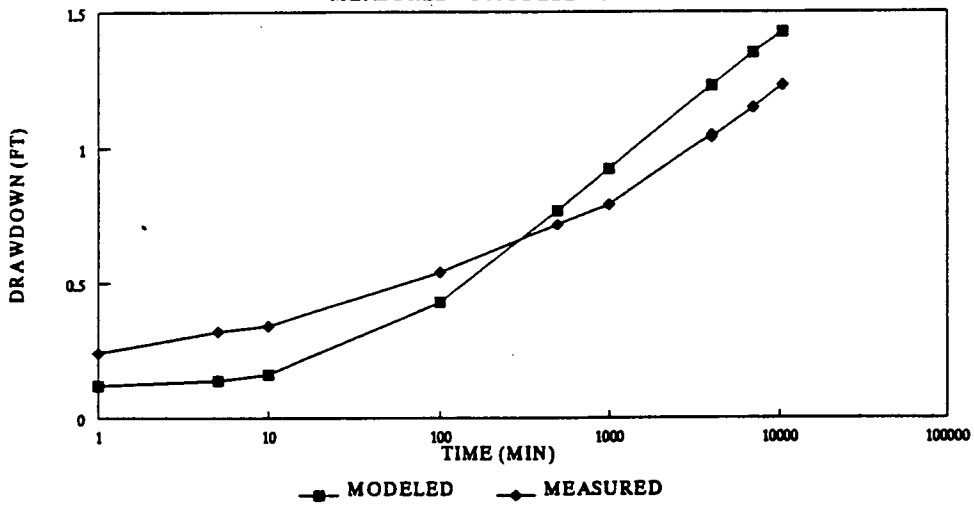
WELL: SPPZ-4

MEASURED VS MODELED DRAWDOWN



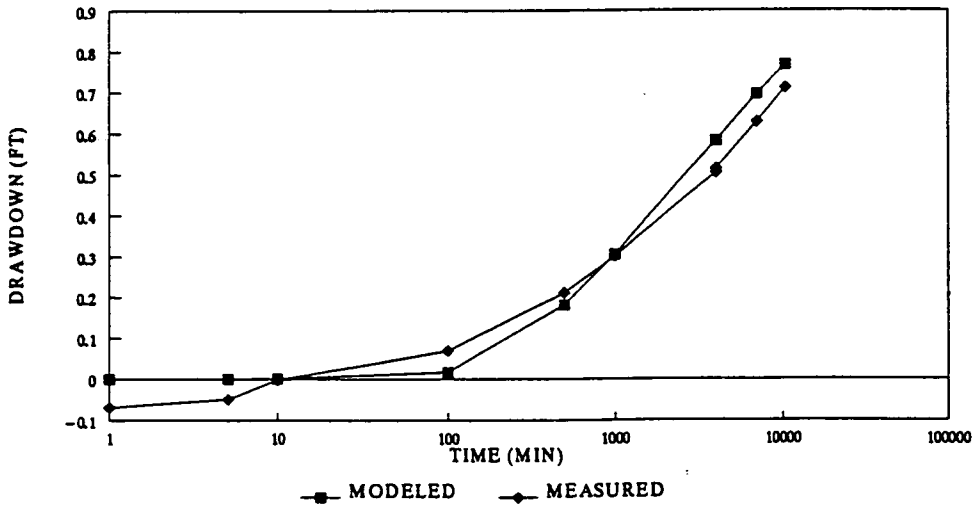
WELL: SPPZ-5

MEASURED VS MODELED DRAWDOWN



WELL: 2002

MEASURED VS MODELED DRAWDOWN



File : wellwi13.dat

Well No. : RW-4

Well Coord. : X = 58 Y = 58 Z = 1- 2

Time Sequence (min.)	Drawdown (ft)	BHP Drawdown (ft)
0.000E+00	0.0000E+0	0.0000E+0
0.100E+01	0.2250E+0	0.1647E+2
0.500E+01	0.7970E+0	0.1697E+2
0.100E+02	0.1153E+1	0.1728E+2
0.100E+03	0.2124E+1	0.1813E+2
0.500E+03	0.2618E+1	0.1860E+2
0.100E+04	0.2797E+1	0.1877E+2
0.399E+04	0.3119E+1	0.1909E+2
0.400E+04	0.3120E+1	0.1678E+2
0.700E+04	0.3242E+1	0.1690E+2
0.104E+05	0.3317E+1	0.1698E+2

Well No. : SPPZ-1

Well Coord. : X = 60 Y = 58 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1436E+0
0.500E+01	0.1595E+0
0.100E+02	0.1801E+0
0.100E+03	0.4190E+0
0.500E+03	0.7330E+0
0.100E+04	0.8799E+0
0.399E+04	0.1168E+1
0.400E+04	0.1169E+1
0.700E+04	0.1282E+1
0.104E+05	0.1352E+1

Well No. : SPPZ-2A

Well Coord. : X = 58 Y = 57 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.3500E+0
0.500E+01	0.3851E+0
0.100E+02	0.4244E+0
0.100E+03	0.7319E+0
0.500E+03	0.1066E+1
0.100E+04	0.1218E+1
0.399E+04	0.1511E+1
0.400E+04	0.1512E+1

0.700E+04	0.1627E+1
0.104E+05	0.1697E+1

Well No. : SPPZ-2C

Well Coord. : X = 58 Y = 57 Z = 4- 4

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1288E+0
0.500E+01	0.1413E+0
0.100E+02	0.1558E+0
0.100E+03	0.3168E+0
0.500E+03	0.5735E+0
0.100E+04	0.7088E+0
0.399E+04	0.9879E+0
0.400E+04	0.9889E+0
0.700E+04	0.1100E+1
0.104E+05	0.1169E+1

Well No. : SPPZ-2E

Well Coord. : X = 58 Y = 57 Z = 6- 6

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.6326E-1
0.500E+01	0.6996E-1
0.100E+02	0.7780E-1
0.100E+03	0.1833E+0
0.500E+03	0.3962E+0
0.100E+04	0.5209E+0
0.399E+04	0.7908E+0
0.400E+04	0.7917E+0
0.700E+04	0.9014E+0
0.104E+05	0.9697E+0

Well No. : SPPZ-3

Well Coord. : X = 58 Y = 56 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1441E+0
0.500E+01	0.1600E+0
0.100E+02	0.1805E+0
0.100E+03	0.4218E+0
0.500E+03	0.7434E+0

0.100E+04	0.8942E+0
0.399E+04	0.1188E+1
0.400E+04	0.1189E+1
0.700E+04	0.1303E+1
0.104E+05	0.1374E+1

Well No. : SPPZ-4

Well Coord. : X = 58 Y = 50 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.8543E-2
0.500E+01	0.9697E-2
0.100E+02	0.1108E-1
0.100E+03	0.4410E-1
0.500E+03	0.2050E+0
0.100E+04	0.3281E+0
0.399E+04	0.6056E+0
0.400E+04	0.6068E+0
0.700E+04	0.7203E+0
0.104E+05	0.7919E+0

Well No. : SPPZ-5

Well Coord. : X = 58 Y = 60 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1415E+0
0.500E+01	0.1572E+0
0.100E+02	0.1773E+0
0.100E+03	0.4107E+0
0.500E+03	0.7148E+0
0.100E+04	0.8577E+0
0.399E+04	0.1141E+1
0.400E+04	0.1142E+1
0.700E+04	0.1253E+1
0.104E+05	0.1321E+1

Well No. : 2002

Well Coord. : X = 62 Y = 65 Z = 1- 1

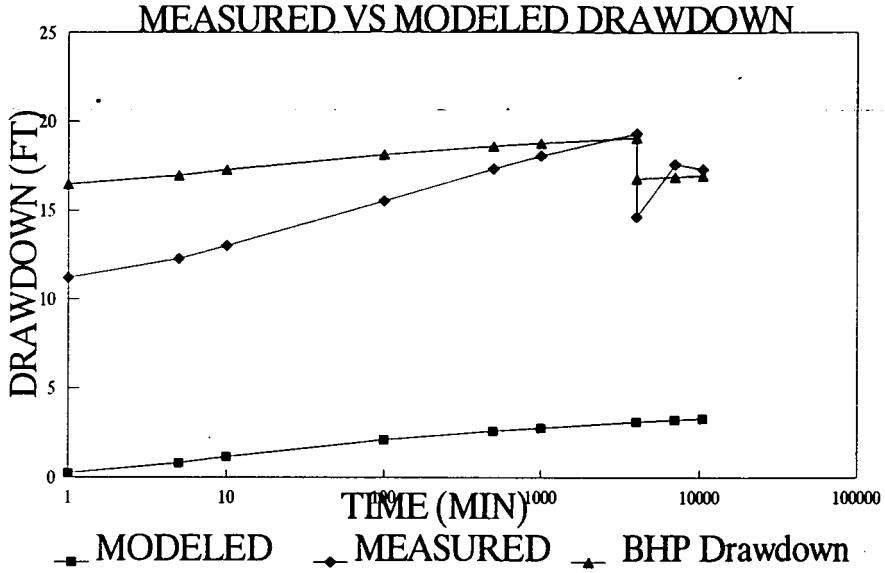
Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.4624E-4
0.500E+01	0.2306E-3

5490

0.100E+02	0.5081E-3
0.100E+03	0.1856E-1
0.500E+03	0.1790E+0
0.100E+04	0.2967E+0
0.399E+04	0.5564E+0
0.400E+04	0.5573E+0
0.700E+04	0.6625E+0
0.104E+05	0.7269E+0

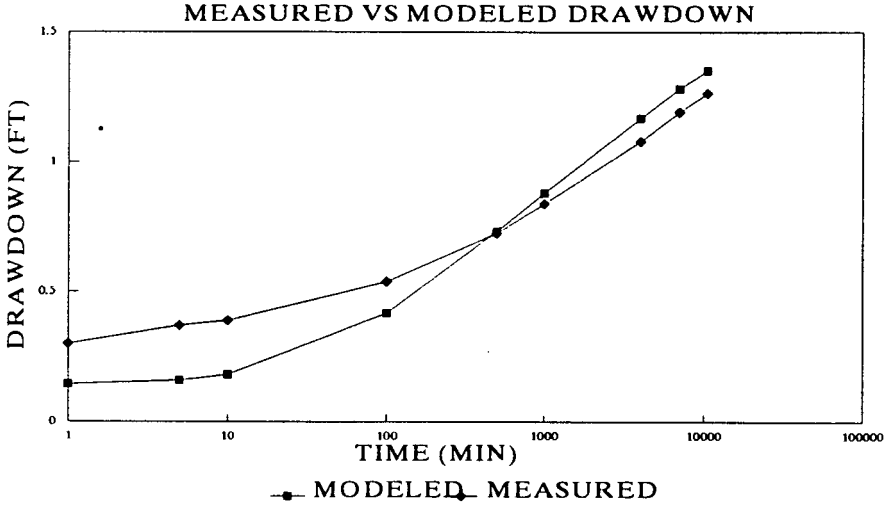
WELL: RW-4

MEASURED VS MODELED DRAWDOWN



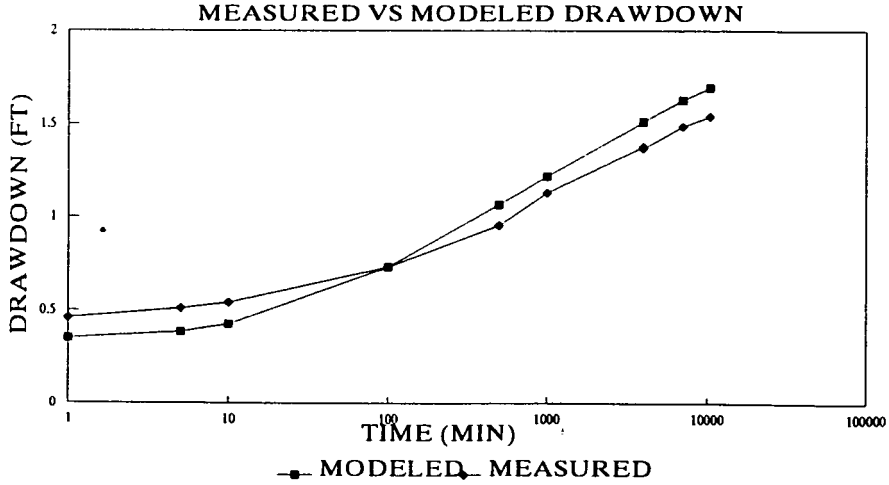
WELL: SPPZ-1

MEASURED VS MODELED DRAWDOWN



WELL: SPPZ-2A

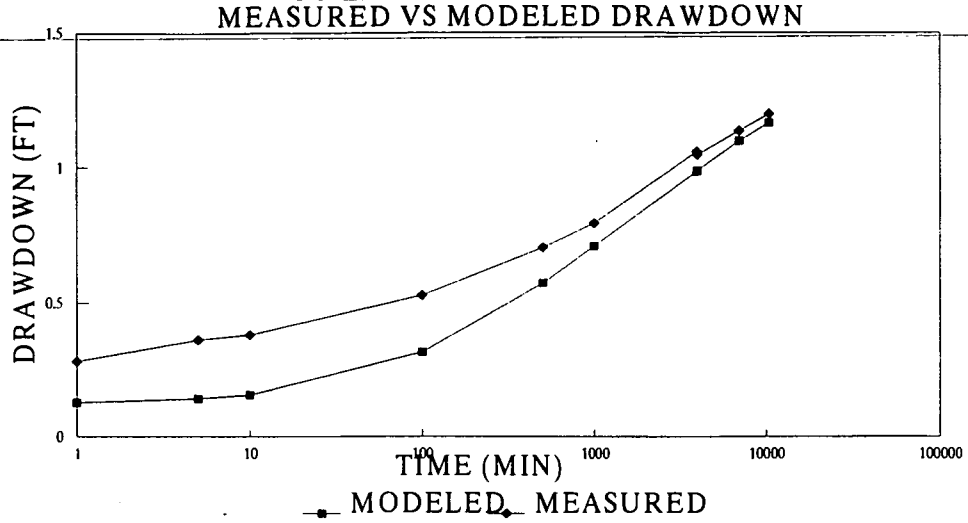
MEASURED VS MODELED DRAWDOWN



5490

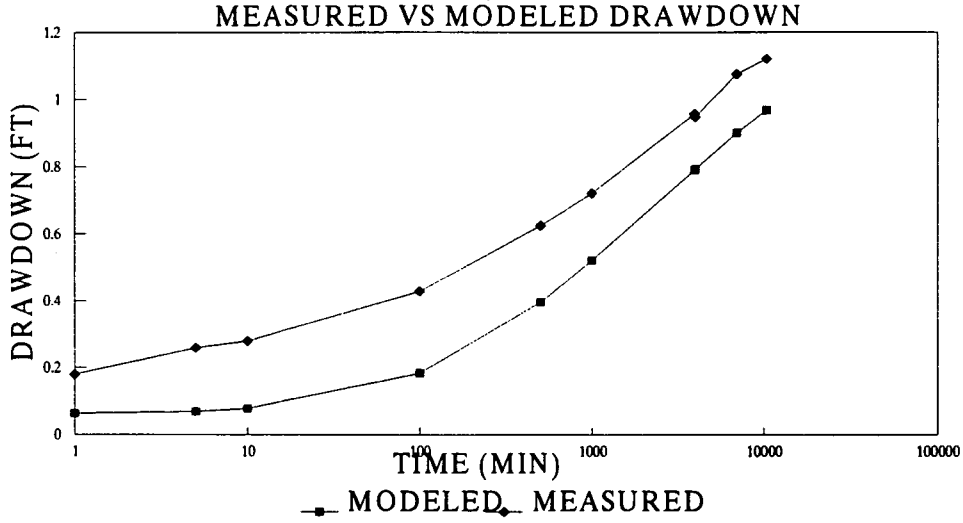
WELL: SPPZ-2C

MEASURED VS MODELED DRAWDOWN



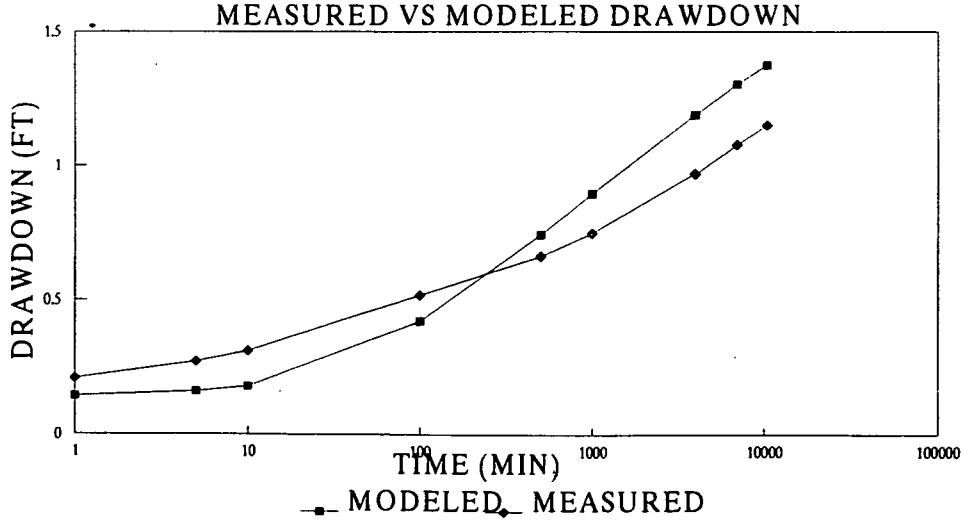
WELL: SPPZ-2E

MEASURED VS MODELED DRAWDOWN



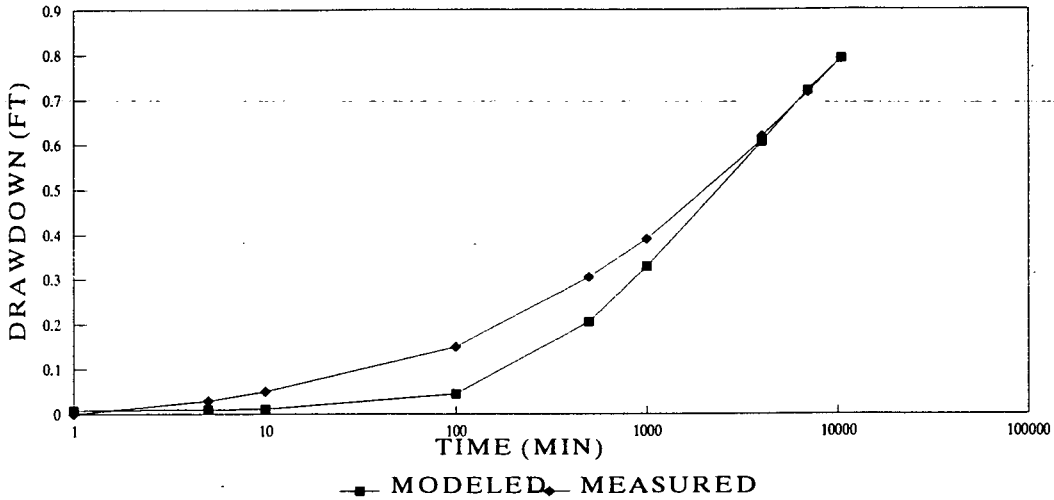
WELL: SPPZ-3

MEASURED VS MODELED DRAWDOWN



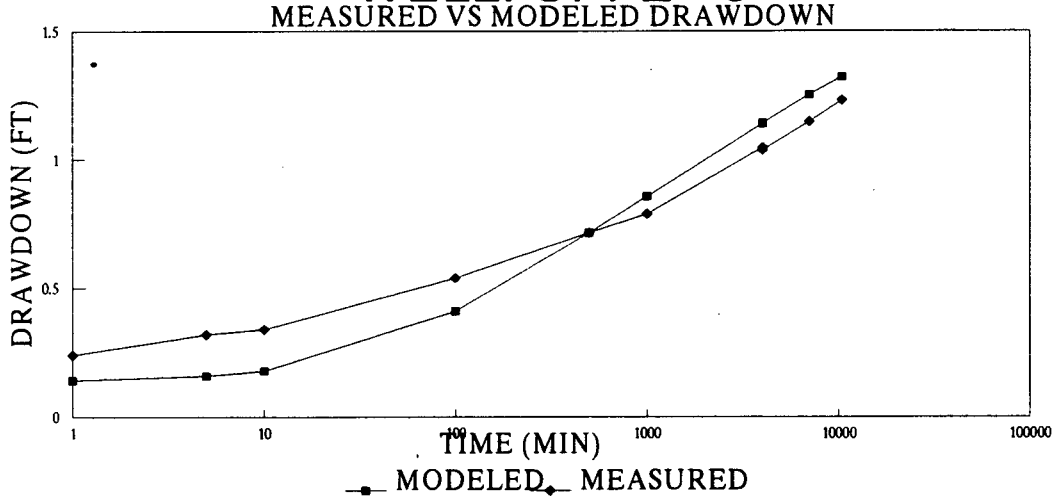
WELL: SPPZ-4

MEASURED VS MODELED DRAWDOWN



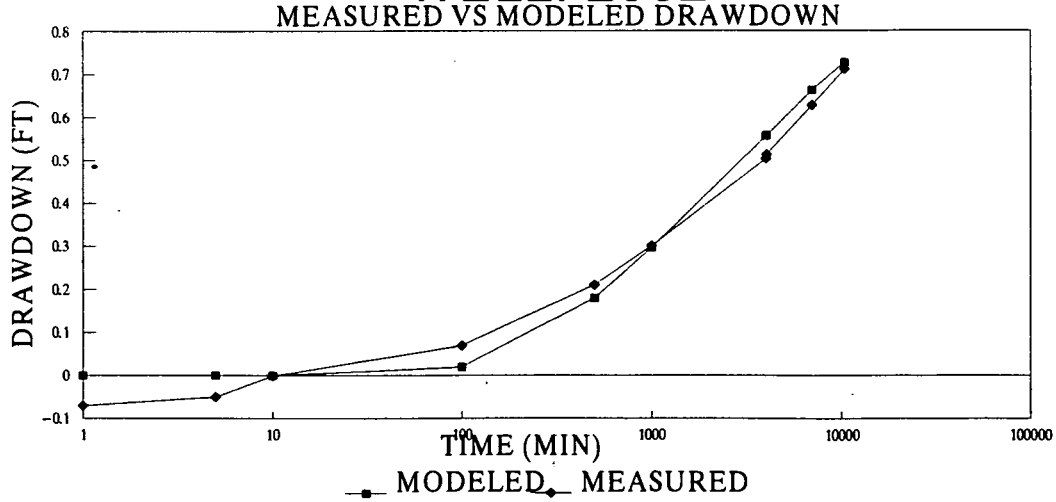
WELL: SPPZ-5

MEASURED VS MODELED DRAWDOWN



WELL: 2002

MEASURED VS MODELED DRAWDOWN



File : wellwi14.dat

Well No. : RW-4

Well Coord. : X = 58 Y = 58 Z = 1- 2

Time Sequence (min.)	Drawdown (ft)	BHP Drawdown (ft)
0.000E+00	0.0000E+0	0.0000E+0
0.100E+01	0.2238E+0	0.1649E+2
0.500E+01	0.7940E+0	0.1698E+2
0.100E+02	0.1150E+1	0.1728E+2
0.100E+03	0.2136E+1	0.1814E+2
0.500E+03	0.2651E+1	0.1862E+2
0.100E+04	0.2838E+1	0.1880E+2
0.399E+04	0.3167E+1	0.1912E+2
0.400E+04	0.3168E+1	0.1682E+2
0.700E+04	0.3291E+1	0.1694E+2
0.104E+05	0.3367E+1	0.1701E+2

Well No. : SPPZ-1

Well Coord. : X = 60 Y = 58 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1829E+0
0.500E+01	0.1960E+0
0.100E+02	0.2129E+0
0.100E+03	0.4163E+0
0.500E+03	0.7086E+0
0.100E+04	0.8524E+0
0.399E+04	0.1139E+1
0.400E+04	0.1140E+1
0.700E+04	0.1253E+1
0.104E+05	0.1322E+1

Well No. : SPPZ-2A

Well Coord. : X = 58 Y = 57 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.4114E+0
0.500E+01	0.4387E+0
0.100E+02	0.4692E+0
0.100E+03	0.7259E+0
0.500E+03	0.1036E+1
0.100E+04	0.1184E+1
0.399E+04	0.1476E+1

0.400E+04	0.1477E+1
0.700E+04	0.1591E+1
0.104E+05	0.1661E+1

Well No. : SPPZ-2C

Well Coord. : X = 58 Y = 57 Z = 4- 4

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1471E+0
0.500E+01	0.1568E+0
0.100E+02	0.1679E+0
0.100E+03	0.3011E+0
0.500E+03	0.5361E+0
0.100E+04	0.6668E+0
0.399E+04	0.9429E+0
0.400E+04	0.9438E+0
0.700E+04	0.1055E+1
0.104E+05	0.1124E+1

Well No. : SPPZ-2E

Well Coord. : X = 58 Y = 57 Z = 6- 6

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.7781E-1
0.500E+01	0.8312E-1
0.100E+02	0.8959E-1
0.100E+03	0.1806E+0
0.500E+03	0.3784E+0
0.100E+04	0.4994E+0
0.399E+04	0.7665E+0
0.400E+04	0.7674E+0
0.700E+04	0.8769E+0
0.104E+05	0.9448E+0

Well No. : SPPZ-3

Well Coord. : X = 58 Y = 56 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1838E+0
0.500E+01	0.1969E+0
0.100E+02	0.2140E+0
0.100E+03	0.4193E+0

0.500E+03	0.7185E+0
0.100E+04	0.8658E+0
0.399E+04	0.1157E+1
0.400E+04	0.1159E+1
0.700E+04	0.1273E+1
0.104E+05	0.1343E+1

Well No. : SPPZ-4

Well Coord. : X = 58 Y = 50 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1524E-1
0.500E+01	0.1639E-1
0.100E+02	0.1801E-1
0.100E+03	0.5195E-1
0.500E+03	0.2055E+0
0.100E+04	0.3246E+0
0.399E+04	0.5996E+0
0.400E+04	0.6005E+0
0.700E+04	0.7139E+0
0.104E+05	0.7852E+0

Well No. : SPPZ-5

Well Coord. : X = 58 Y = 60 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.1796E+0
0.500E+01	0.1928E+0
0.100E+02	0.2092E+0
0.100E+03	0.4075E+0
0.500E+03	0.6915E+0
0.100E+04	0.8314E+0
0.399E+04	0.1113E+1
0.400E+04	0.1114E+1
0.700E+04	0.1225E+1
0.104E+05	0.1293E+1

Well No. : 2002

Well Coord. : X = 62 Y = 65 Z = 1- 1

Time Sequence (min.)	Drawdown (ft)
0.000E+00	0.0000E+0
0.100E+01	0.4624E-4

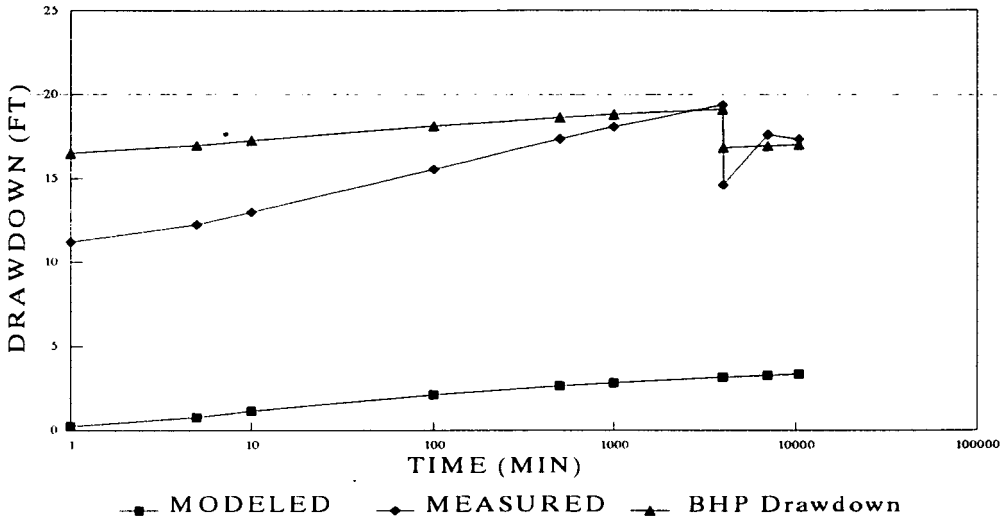
- 5490

0.500E+01	0.2543E-3
0.100E+02	0.5774E-3
0.100E+03	0.1780E-1
0.500E+03	0.1778E+0
0.100E+04	0.2972E+0
0.399E+04	0.5601E+0
0.400E+04	0.5610E+0
0.700E+04	0.6668E+0
0.104E+05	0.7316E+0

5490

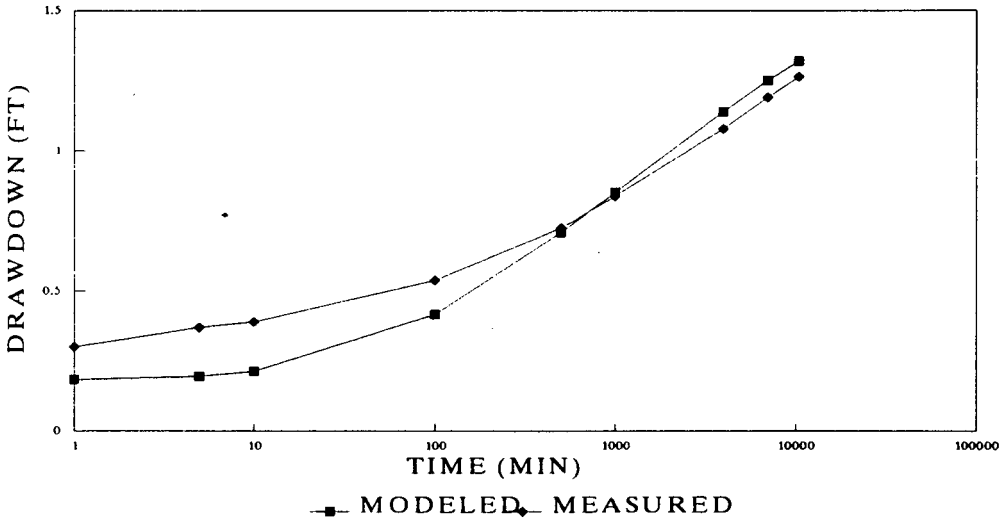
WELL: RW-4

MEASURED VS MODELED DRAWDOWN



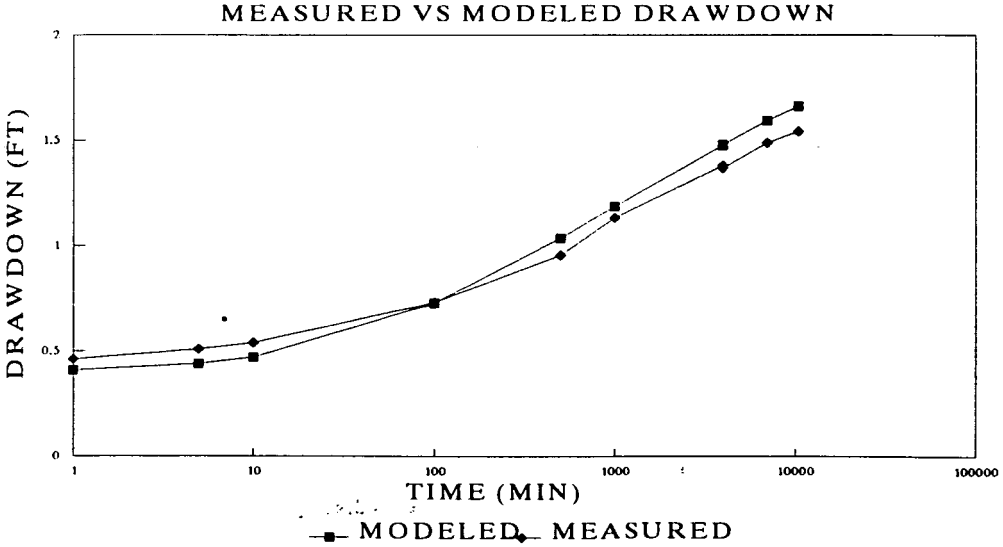
WELL: SPPZ-1

MEASURED VS MODELED DRAWDOWN



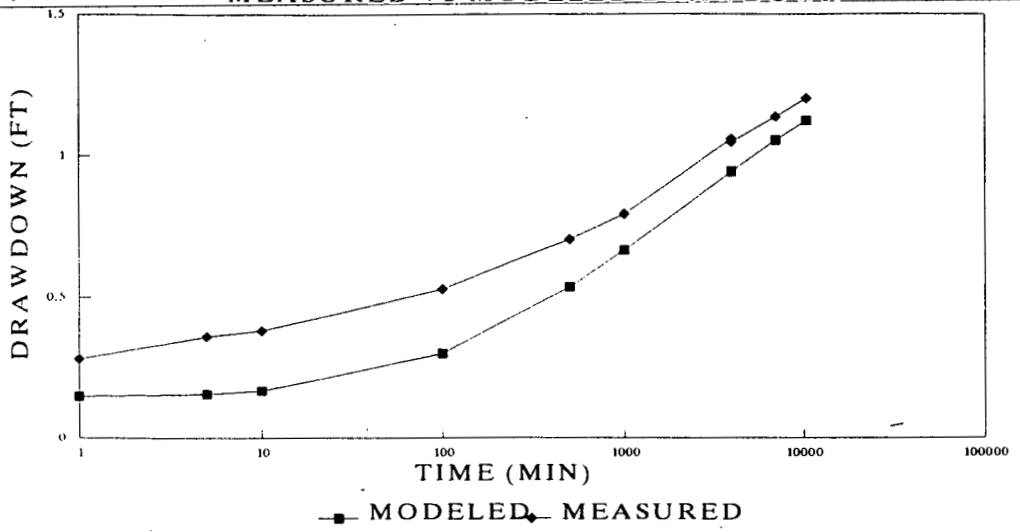
WELL: SPPZ-2A

MEASURED VS MODELED DRAWDOWN



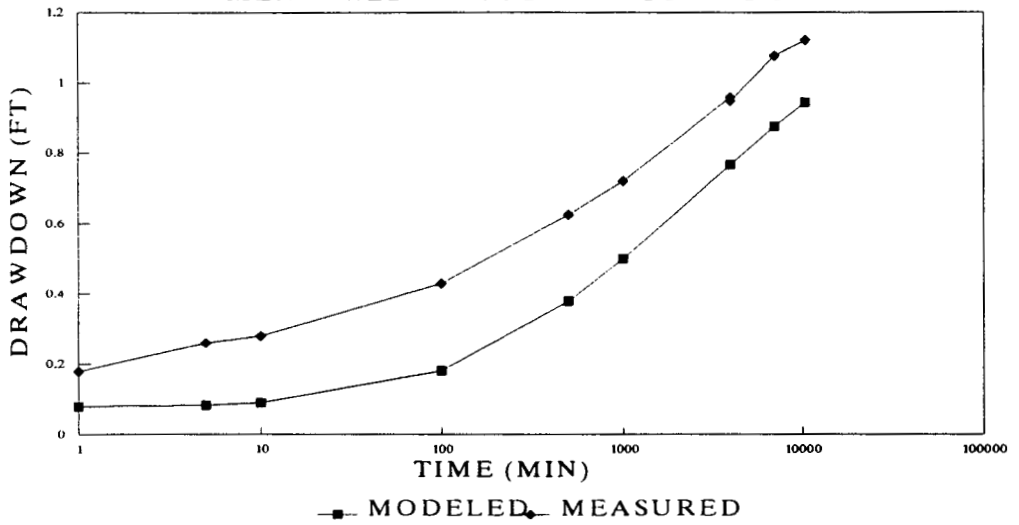
WELL: SPPZ-2C

MEASURED VS MODELED DRAWDOWN



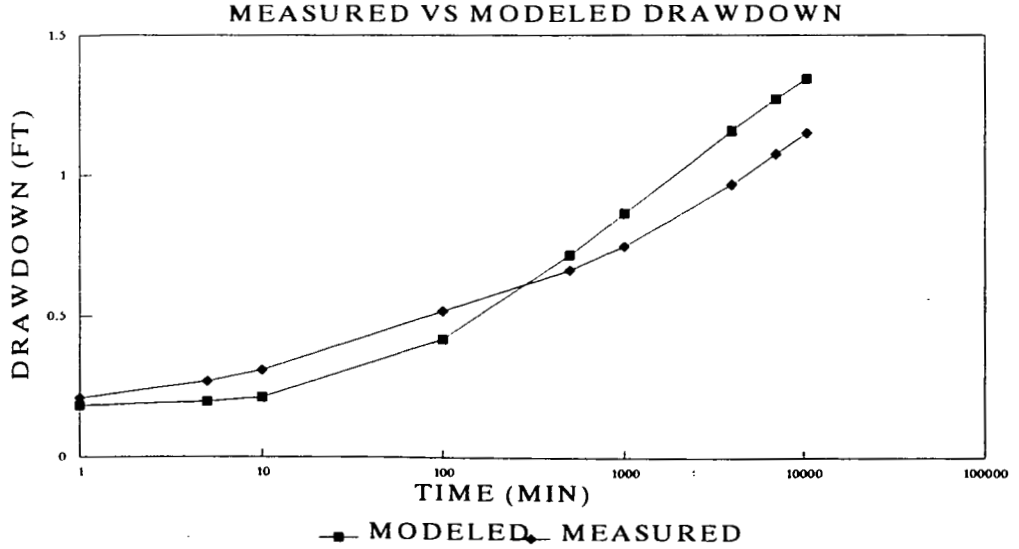
WELL: SPPZ-2E

MEASURED VS MODELED DRAWDOWN



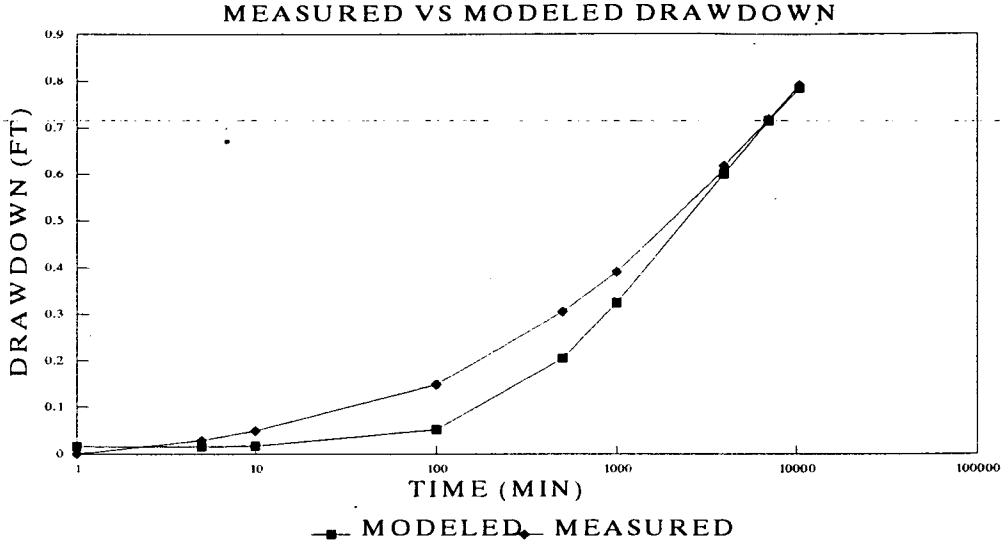
WELL: SPPZ-3

MEASURED VS MODELED DRAWDOWN



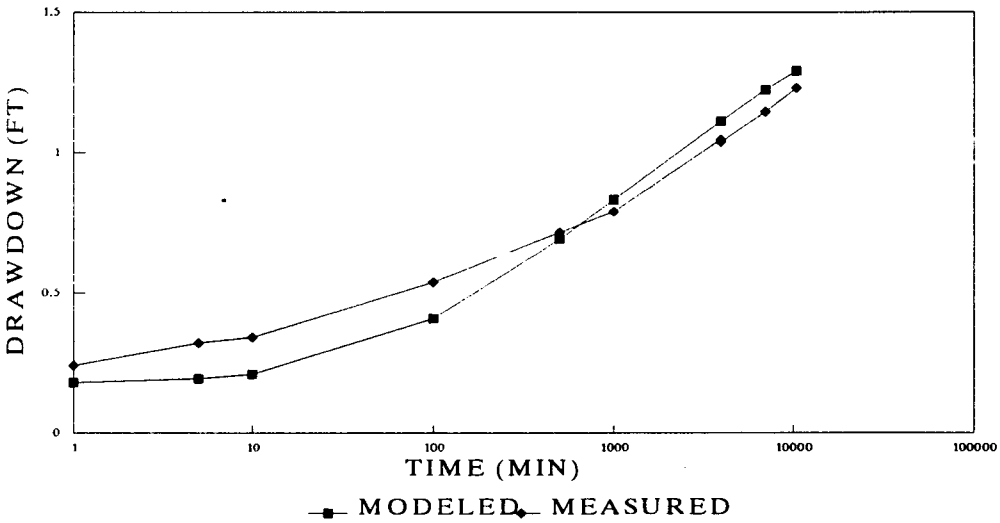
WELL: SPPZ-4

MEASURED VS MODELED DRAWDOWN



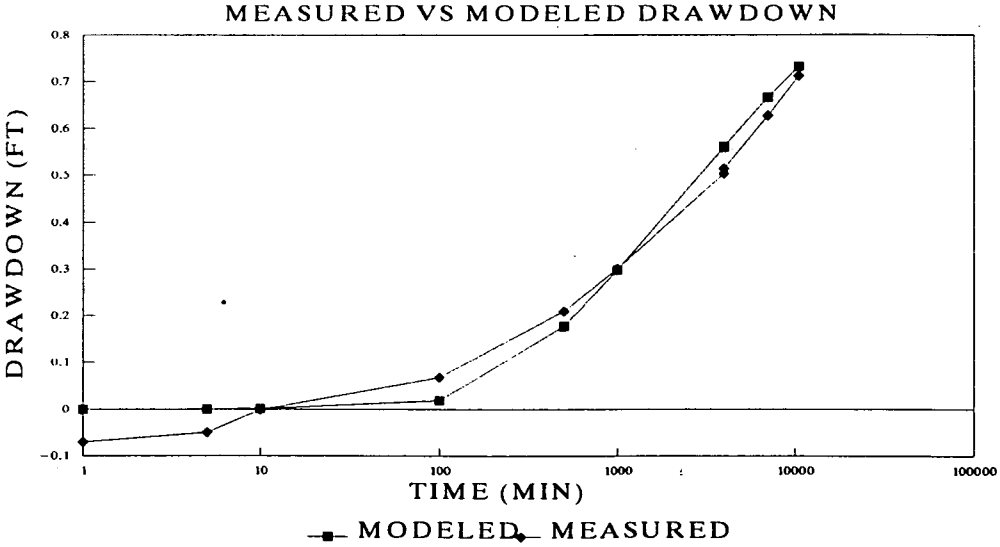
WELL: SPPZ-5

MEASURED VS MODELED DRAWDOWN



WELL: 2002

MEASURED VS MODELED DRAWDOWN



APPENDIX A5

STATISTICAL RESULTS FOR FOUR MODEL RUNS

SUMMARY TABLE OF CALIBRATION STATISTICS
(SELECTED MODEL RUNS - DRAWDOWN ONLY - CONSTANT RECOVERY TEST)
SWIFT MODEL IMPROVEMENTS
TRANSIENT CALIBRATION

Well Number	Individual Well Time-Weighted Absolute % Difference			
	TRANWI11	TRANWI12	TRANWI13	TRANWI14*
RW-4 (3927)	5.35	1.57	2.85	2.70
SPPZ-1 (3910)	17.08	15.25	7.30	4.93
SPPZ-2A (3911)	13.75	18.37	9.64	7.17
SPPZ-2C (3916)	31.63	8.17	5.38	9.46
SPPZ-2E (3918)	41.46	5.23	17.47	19.84
SPPZ-3 (3921)	7.28	29.10	20.49	17.55
SPPZ-4 (3922)	28.66	6.45	2.98	3.48
SPPZ-5 (3923)	16.68	16.46	8.26	6.00
2002	16.67	11.31	6.51	7.16
Run Time-Weighted Average Absolute % Difference	19.84	12.43	8.99	8.70
Run Time-Weighted Residual Variance (ft^2)	0.0508	0.0141	0.0234	0.0195

* = Best Calibration Run

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
RW-4	1.00	11.2330	16.4300	9.615E-05	-5.197E+00	-4.997E-04	-4.627E+01	-4.449E-03	5.197E+00	4.997E-04	4.627E+01	4.449E-03
(3927)	5.00	12.2680	16.8500	3.846E-04	-4.582E+00	-1.762E-03	-3.735E+01	-1.437E-02	4.582E+00	1.762E-03	3.735E+01	1.437E-02
	10.00	13.0230	17.1100	4.808E-04	-4.087E+00	-1.965E-03	-3.138E+01	-1.509E-02	4.087E+00	1.965E-03	3.138E+01	1.509E-02
	100.00	15.5330	17.8300	8.654E-03	-2.297E+00	-1.988E-02	-1.479E+01	-1.280E-01	2.297E+00	1.988E-02	1.479E+01	1.280E-01
	500.00	17.3330	18.2100	3.846E-02	-8.770E-01	-3.373E-02	-5.060E+00	-1.946E-01	8.770E-01	3.373E-02	5.060E+00	1.946E-01
	1000.00	18.0630	18.3500	4.808E-02	-2.870E-01	-1.380E-02	-1.589E+00	-7.639E-02	2.870E-01	1.380E-02	1.589E+00	7.639E-02
	3990.00	19.3513	18.5800	2.875E-01	7.713E-01	2.217E-01	3.986E+00	1.146E+00	7.713E-01	2.217E-01	3.986E+00	1.146E+00
	4000.00	14.6313	16.2700	9.615E-04	-1.639E+00	-1.576E-03	-1.120E+01	-1.077E-02	1.639E+00	1.576E-03	1.120E+01	1.077E-02
	7000.00	17.6000	16.3600	2.885E-01	1.240E+00	3.577E-01	7.045E+00	2.032E+00	1.240E+00	3.577E-01	7.045E+00	2.032E+00
	10400.00	17.3243	16.4100	3.269E-01	9.143E-01	2.989E-01	5.278E+00	1.725E+00	9.143E-01	2.989E-01	5.278E+00	1.725E+00
AVERAGE				1.000E+00	-1.604E+00	8.051E-01	-1.313E+01	4.460E+00	2.189E+00	9.516E-01	1.639E+01	5.347E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-1	1.00	0.3000	0.1323	9.615E-05	1.677E-01	1.613E-05	5.590E+01	5.375E-03	1.677E-01	1.613E-05	5.590E+01	5.375E-03
(3910)	5.00	0.3699	0.1448	3.846E-04	2.251E-01	8.660E-05	6.086E+01	2.341E-02	2.251E-01	8.660E-05	6.086E+01	2.341E-02
	10.00	0.3899	0.1605	4.808E-04	2.294E-01	1.103E-04	5.884E+01	2.829E-02	2.294E-01	1.103E-04	5.884E+01	2.829E-02
	100.00	0.5390	0.3449	8.654E-03	1.941E-01	1.679E-03	3.601E+01	3.116E-01	1.941E-01	1.679E-03	3.601E+01	3.116E-01
	500.00	0.7250	0.5885	3.846E-02	1.365E-01	5.250E-03	1.883E+01	7.241E-01	1.365E-01	5.250E-03	1.883E+01	7.241E-01
	1000.00	0.8396	0.7000	4.808E-02	1.396E-01	6.712E-03	1.663E+01	7.994E-01	1.396E-01	6.712E-03	1.663E+01	7.994E-01
	3990.00	1.0785	0.9120	2.875E-01	1.665E-01	4.787E-02	1.544E+01	4.438E+00	1.665E-01	4.787E-02	1.544E+01	4.438E+00
	4000.00	1.0782	0.9127	9.615E-04	1.655E-01	1.591E-04	1.535E+01	1.476E-02	1.655E-01	1.591E-04	1.535E+01	1.476E-02
	7000.00	1.1921	0.9921	2.885E-01	2.000E-01	5.769E-02	1.678E+01	4.840E+00	2.000E-01	5.769E-02	1.678E+01	4.840E+00
	10400.00	1.2663	1.0380	3.269E-01	2.283E-01	7.465E-02	1.803E+01	5.895E+00	2.283E-01	7.465E-02	1.803E+01	5.895E+00
AVERAGE				1.000E+00	1.853E-01	1.942E-01	3.127E+01	1.708E+01	1.853E-01	1.942E-01	3.127E+01	1.708E+01

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2A	1.00	0.4600	0.3163	9.615E-05	1.437E-01	1.382E-05	3.124E+01	3.004E-03	1.437E-01	1.382E-05	3.124E+01	3.004E-03
(3911)	5.00	0.5099	0.3429	3.846E-04	1.670E-01	6.423E-05	3.275E+01	1.260E-02	1.670E-01	6.423E-05	3.275E+01	1.260E-02
	10.00	0.5399	0.3724	4.808E-04	1.675E-01	8.053E-05	3.102E+01	1.492E-02	1.675E-01	8.053E-05	3.102E+01	1.492E-02
	100.00	0.7290	0.6091	8.654E-03	1.199E-01	1.037E-03	1.644E+01	1.423E-01	1.199E-01	1.037E-03	1.644E+01	1.423E-01
	500.00	0.9548	0.8667	3.846E-02	8.814E-02	3.390E-03	9.230E+00	3.550E-01	8.814E-02	3.390E-03	9.230E+00	3.550E-01
	1000.00	1.1300	0.9808	4.808E-02	1.492E-01	7.173E-03	1.320E+01	6.348E-01	1.492E-01	7.173E-03	1.320E+01	6.348E-01

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	3990.00	1.3785	1.1950	2.875E-01	1.835E-01	5.275E-02	1.331E+01	3.827E+00	1.835E-01	5.275E-02	1.331E+01	3.827E+00
	4000.00	1.3683	1.1960	9.615E-04	1.723E-01	1.656E-04	1.259E+01	1.211E-02	1.723E-01	1.656E-04	1.259E+01	1.211E-02
	7000.00	1.4871	1.2760	2.885E-01	2.111E-01	6.089E-02	1.419E+01	4.094E+00	2.111E-01	6.089E-02	1.419E+01	4.094E+00
	10400.00	1.5413	1.3220	3.269E-01	2.193E-01	7.171E-02	1.423E+01	4.652E+00	2.193E-01	7.171E-02	1.423E+01	4.652E+00
AVERAGE				1.000E+00	1.622E-01	1.973E-01	1.882E+01	1.375E+01	1.622E-01	1.973E-01	1.882E+01	1.375E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2C	1.00	0.2800	0.1004	9.615E-05	1.796E-01	1.727E-05	6.414E+01	6.168E-03	1.796E-01	1.727E-05	6.414E+01	6.168E-03
(3916)	5.00	0.3599	0.1087	3.846E-04	2.512E-01	9.662E-05	6.980E+01	2.685E-02	2.512E-01	9.662E-05	6.980E+01	2.685E-02
	10.00	0.3799	0.1184	4.808E-04	2.615E-01	1.257E-04	6.883E+01	3.309E-02	2.615E-01	1.257E-04	6.883E+01	3.309E-02
	100.00	0.5290	0.2297	8.654E-03	2.993E-01	2.590E-03	5.658E+01	4.896E-01	2.993E-01	2.590E-03	5.658E+01	4.896E-01
	500.00	0.7048	0.4158	3.846E-02	2.890E-01	1.112E-02	4.100E+01	1.577E+00	2.890E-01	1.112E-02	4.100E+01	1.577E+00
	1000.00	0.7945	0.5149	4.808E-02	2.796E-01	1.344E-02	3.519E+01	1.692E+00	2.796E-01	1.344E-02	3.519E+01	1.692E+00
	3990.00	1.0585	0.7169	2.875E-01	3.416E-01	9.821E-02	3.227E+01	9.278E+00	3.416E-01	9.821E-02	3.227E+01	9.278E+00
	4000.00	1.0483	0.7176	9.615E-04	3.307E-01	3.180E-04	3.155E+01	3.033E-02	3.307E-01	3.180E-04	3.155E+01	3.033E-02
	7000.00	1.1371	0.7954	2.885E-01	3.417E-01	9.857E-02	3.005E+01	8.668E+00	3.417E-01	9.857E-02	3.005E+01	8.668E+00
	10400.00	1.2013	0.8402	3.269E-01	3.611E-01	1.181E-01	3.006E+01	9.828E+00	3.611E-01	1.181E-01	3.006E+01	9.828E+00
AVERAGE				1.000E+00	2.935E-01	3.425E-01	4.595E+01	3.163E+01	2.935E-01	3.425E-01	4.595E+01	3.163E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2E	1.00	0.1800	0.0473	9.615E-05	1.327E-01	1.276E-05	7.371E+01	7.087E-03	1.327E-01	1.276E-05	7.371E+01	7.087E-03
(3918)	5.00	0.2599	0.0515	3.846E-04	2.084E-01	8.016E-05	8.019E+01	3.084E-02	2.084E-01	8.016E-05	8.019E+01	3.084E-02
	10.00	0.2799	0.0566	4.808E-04	2.233E-01	1.074E-04	7.979E+01	3.836E-02	2.233E-01	1.074E-04	7.979E+01	3.836E-02
	100.00	0.4290	0.1270	8.654E-03	3.020E-01	2.613E-03	7.040E+01	6.092E-01	3.020E-01	2.613E-03	7.040E+01	6.092E-01
	500.00	0.6248	0.2784	3.846E-02	3.464E-01	1.332E-02	5.544E+01	2.132E+00	3.464E-01	1.332E-02	5.544E+01	2.132E+00
	1000.00	0.7197	0.3689	4.808E-02	3.508E-01	1.687E-02	4.874E+01	2.343E+00	3.508E-01	1.687E-02	4.874E+01	2.343E+00
	3990.00	0.9585	0.5636	2.875E-01	3.949E-01	1.135E-01	4.120E+01	1.184E+01	3.949E-01	1.135E-01	4.120E+01	1.184E+01
	4000.00	0.9483	0.5643	9.615E-04	3.840E-01	3.692E-04	4.049E+01	3.894E-02	3.840E-01	3.692E-04	4.049E+01	3.894E-02
	7000.00	1.0771	0.6407	2.885E-01	4.364E-01	1.259E-01	4.052E+01	1.169E+01	4.364E-01	1.259E-01	4.052E+01	1.169E+01
	10400.00	1.1213	0.6848	3.269E-01	4.365E-01	1.427E-01	3.893E+01	1.273E+01	4.365E-01	1.427E-01	3.893E+01	1.273E+01
AVERAGE				1.000E+00	3.215E-01	4.155E-01	5.694E+01	4.146E+01	3.215E-01	4.155E-01	5.694E+01	4.146E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-3	1.00	0.2100	0.1332	9.615E-05	7.680E-02	7.385E-06	3.657E+01	3.516E-03	7.680E-02	7.385E-06	3.657E+01	3.516E-03

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(3921)	5.00	0.2699	0.1457	3.846E-04	1.242E-01	4.777E-05	4.602E+01	1.770E-02	1.242E-01	4.777E-05	4.602E+01	1.770E-02
	10.00	0.3099	0.1614	4.808E-04	1.485E-01	7.139E-05	4.792E+01	2.304E-02	1.485E-01	7.139E-05	4.792E+01	2.304E-02
	100.00	0.5190	0.3479	8.654E-03	1.711E-01	1.481E-03	3.297E+01	2.853E-01	1.711E-01	1.481E-03	3.297E+01	2.853E-01
	500.00	0.6648	0.5952	3.846E-02	6.960E-02	2.677E-03	1.047E+01	4.027E-01	6.960E-02	2.677E-03	1.047E+01	4.027E-01
	1000.00	0.7496	0.7083	4.808E-02	4.130E-02	1.986E-03	5.510E+00	2.649E-01	4.130E-02	1.986E-03	5.510E+00	2.649E-01
	3990.00	0.9685	0.9219	2.875E-01	4.660E-02	1.340E-02	4.812E+00	1.383E+00	4.660E-02	1.340E-02	4.812E+00	1.383E+00
	4000.00	0.9683	0.9226	9.615E-04	4.570E-02	4.394E-05	4.720E+00	4.538E-03	4.570E-02	4.394E-05	4.720E+00	4.538E-03
	7000.00	1.0771	1.0030	2.885E-01	7.410E-02	2.138E-02	6.880E+00	1.984E+00	7.410E-02	2.138E-02	6.880E+00	1.984E+00
	10400.00	1.1513	1.0490	3.269E-01	1.023E-01	3.346E-02	8.889E+00	2.906E+00	1.023E-01	3.346E-02	8.889E+00	2.906E+00
AVERAGE				1.000E+00	9.002E-02	7.454E-02	2.048E+01	7.275E+00	9.002E-02	7.454E-02	2.048E+01	7.275E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-4	1.00	0.0100	0.0076	9.615E-05	2.382E-03	2.290E-07	2.382E+01	2.290E-03	2.382E-03	2.290E-07	2.382E+01	2.290E-03
(3922)	5.00	0.0299	0.0085	3.846E-04	2.136E-02	8.214E-06	7.143E+01	2.747E-02	2.136E-02	8.214E-06	7.143E+01	2.747E-02
	10.00	0.0499	0.0095	4.808E-04	4.043E-02	1.944E-05	8.103E+01	3.895E-02	4.043E-02	1.944E-05	8.103E+01	3.895E-02
	100.00	0.1490	0.0346	8.654E-03	1.144E-01	9.897E-04	7.675E+01	6.642E-01	1.144E-01	9.897E-04	7.675E+01	6.642E-01
	500.00	0.3048	0.1572	3.846E-02	1.476E-01	5.677E-03	4.843E+01	1.863E+00	1.476E-01	5.677E-03	4.843E+01	1.863E+00
	1000.00	0.3896	0.2482	4.808E-02	1.414E-01	6.798E-03	3.629E+01	1.745E+00	1.414E-01	6.798E-03	3.629E+01	1.745E+00
	3990.00	0.6085	0.4477	2.875E-01	1.608E-01	4.623E-02	2.643E+01	7.597E+00	1.608E-01	4.623E-02	2.643E+01	7.597E+00
	4000.00	0.6183	0.4484	9.615E-04	1.699E-01	1.634E-04	2.748E+01	2.642E-02	1.699E-01	1.634E-04	2.748E+01	2.642E-02
	7000.00	0.7171	0.5269	2.885E-01	1.902E-01	5.487E-02	2.652E+01	7.651E+00	1.902E-01	5.487E-02	2.652E+01	7.651E+00
	10400.00	0.7913	0.5724	3.269E-01	2.189E-01	7.158E-02	2.767E+01	9.045E+00	2.189E-01	7.158E-02	2.767E+01	9.045E+00
AVERAGE				1.000E+00	1.207E-01	1.863E-01	4.458E+01	2.866E+01	1.207E-01	1.863E-01	4.458E+01	2.866E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-5	1.00	0.2400	0.1256	9.615E-05	1.144E-01	1.100E-05	4.767E+01	4.583E-03	1.144E-01	1.100E-05	4.767E+01	4.583E-03
(3923)	5.00	0.3199	0.1374	3.846E-04	1.825E-01	7.019E-05	5.705E+01	2.194E-02	1.825E-01	7.019E-05	5.705E+01	2.194E-02
	10.00	0.3399	0.1524	4.808E-04	1.875E-01	9.014E-05	5.516E+01	2.652E-02	1.875E-01	9.014E-05	5.516E+01	2.652E-02
	100.00	0.5390	0.3292	8.654E-03	2.098E-01	1.816E-03	3.892E+01	3.368E-01	2.098E-01	1.816E-03	3.892E+01	3.368E-01
	500.00	0.7148	0.5668	3.846E-02	1.480E-01	5.692E-03	2.071E+01	7.963E-01	1.480E-01	5.692E-03	2.071E+01	7.963E-01
	1000.00	0.7896	0.6769	4.808E-02	1.127E-01	5.418E-03	1.427E+01	6.862E-01	1.127E-01	5.418E-03	1.427E+01	6.862E-01
	3990.00	1.0485	0.8870	2.875E-01	1.615E-01	4.643E-02	1.540E+01	4.428E+00	1.615E-01	4.643E-02	1.540E+01	4.428E+00
	4000.00	1.0383	0.8877	9.615E-04	1.506E-01	1.448E-04	1.450E+01	1.395E-02	1.506E-01	1.448E-04	1.450E+01	1.395E-02
	7000.00	1.1471	0.9665	2.885E-01	1.806E-01	5.210E-02	1.574E+01	4.542E+00	1.806E-01	5.210E-02	1.574E+01	4.542E+00
	10400.00	1.2313	1.0120	3.269E-01	2.193E-01	7.169E-02	1.781E+01	5.823E+00	2.193E-01	7.169E-02	1.781E+01	5.823E+00
AVERAGE				1.000E+00	1.667E-01	1.835E-01	2.972E+01	1.668E+01	1.667E-01	1.835E-01	2.972E+01	1.668E+01

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
2002	1.00	-0.0700	0.0000	9.615E-05	-7.005E-02	-6.735E-06	1.001E+02	9.622E-03	7.005E-02	6.735E-06	-1.001E+02	-9.622E-03
	5.00	-0.0500	0.0002	3.846E-04	-5.021E-02	-1.931E-05	1.004E+02	3.862E-02	5.021E-02	1.931E-05	-1.004E+02	-3.862E-02
	10.00	-0.0020	0.0004	4.808E-04	-2.439E-03	-1.173E-06	1.220E+02	5.863E-02	2.439E-03	1.173E-06	-1.220E+02	-5.863E-02
	100.00	0.0690	0.0157	8.654E-03	5.330E-02	4.613E-04	7.725E+01	6.685E-01	5.330E-02	4.613E-04	7.725E+01	6.685E-01
	500.00	0.2098	0.1522	3.846E-02	5.760E-02	2.215E-03	2.745E+01	1.056E+00	5.760E-02	2.215E-03	2.745E+01	1.056E+00
	1000.00	0.3000	0.2487	4.808E-02	5.130E-02	2.466E-03	1.710E+01	8.221E-01	5.130E-02	2.466E-03	1.710E+01	8.221E-01
	3990.00	0.5035	0.4493	2.875E-01	5.420E-02	1.558E-02	1.076E+01	3.095E+00	5.420E-02	1.558E-02	1.076E+01	3.095E+00
	4000.00	0.5133	0.4500	9.615E-04	6.330E-02	6.087E-05	1.233E+01	1.186E-02	6.330E-02	6.087E-05	1.233E+01	1.186E-02
	7000.00	0.6271	0.5264	2.885E-01	1.007E-01	2.905E-02	1.606E+01	4.632E+00	1.007E-01	2.905E-02	1.606E+01	4.632E+00
	10400.00	0.7113	0.5701	3.269E-01	1.412E-01	4.617E-02	1.986E+01	6.491E+00	1.412E-01	4.617E-02	1.986E+01	6.491E+00
AVERAGE				1.000E+00	3.989E-02	9.598E-02	5.032E+01	1.688E+01	6.443E-02	9.604E-02	-1.416E+01	1.667E+01
					Variance =	0.050793004					Averge =	1.984E+01

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
RW-4	1.00	11.2330	16.4800	9.615E-05	-5.247E+00	-5.045E-04	-4.671E+01	-4.491E-03	5.247E+00	5.045E-04	4.671E+01	4.491E-03
(3927)	5.00	12.2680	17.0100	3.846E-04	-4.742E+00	-1.824E-03	-3.865E+01	-1.487E-02	4.742E+00	1.824E-03	3.865E+01	1.487E-02
	10.00	13.0230	17.3500	4.808E-04	-4.327E+00	-2.080E-03	-3.323E+01	-1.597E-02	4.327E+00	2.080E-03	3.323E+01	1.597E-02
	100.00	15.5330	18.3400	8.654E-03	-2.807E+00	-2.429E-02	-1.807E+01	-1.564E-01	2.807E+00	2.429E-02	1.807E+01	1.564E-01
	500.00	17.3330	18.8500	3.846E-02	-1.517E+00	-5.835E-02	-8.752E+00	-3.366E-01	1.517E+00	5.835E-02	8.752E+00	3.366E-01
	1000.00	18.0630	19.0400	4.808E-02	-9.770E-01	-4.697E-02	-5.409E+00	-2.600E-01	9.770E-01	4.697E-02	5.409E+00	2.600E-01
	3990.00	19.3513	19.3700	2.875E-01	-1.870E-02	-5.376E-03	-9.663E-02	-2.778E-02	1.870E-02	5.376E-03	9.663E-02	2.778E-02
	4000.00	14.6313	17.0700	9.615E-04	-2.439E+00	-2.345E-03	-1.667E+01	-1.603E-02	2.439E+00	2.345E-03	1.667E+01	1.603E-02
	7000.00	17.6000	17.2000	2.885E-01	4.000E-01	1.154E-01	2.273E+00	6.556E-01	4.000E-01	1.154E-01	2.273E+00	6.556E-01
	10400.00	17.3243	17.2800	3.269E-01	4.430E-02	1.448E-02	2.557E-01	8.360E-02	4.430E-02	1.448E-02	2.557E-01	8.360E-02
AVERAGE				1.000E+00	-2.163E+00	-1.187E-02	-1.651E+01	-9.299E-02	2.252E+00	2.716E-01	1.701E+01	1.571E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-1	1.00	0.3000	0.1214	9.615E-05	1.786E-01	1.717E-05	5.953E+01	5.724E-03	1.786E-01	1.717E-05	5.953E+01	5.724E-03
(3910)	5.00	0.3699	0.1388	3.846E-04	2.311E-01	8.890E-05	6.248E+01	2.403E-02	2.311E-01	8.890E-05	6.248E+01	2.403E-02
	10.00	0.3899	0.1614	4.808E-04	2.285E-01	1.099E-04	5.860E+01	2.818E-02	2.285E-01	1.099E-04	5.860E+01	2.818E-02
	100.00	0.5390	0.4343	8.654E-03	1.047E-01	9.058E-04	1.942E+01	1.681E-01	1.047E-01	9.058E-04	1.942E+01	1.681E-01
	500.00	0.7250	0.7859	3.846E-02	-6.090E-02	-2.342E-03	-8.400E+00	-3.231E-01	6.090E-02	2.342E-03	8.400E+00	3.231E-01
	1000.00	0.8396	0.9457	4.808E-02	-1.061E-01	-5.101E-03	-1.264E+01	-6.075E-01	1.061E-01	5.101E-03	1.264E+01	6.075E-01
	3990.00	1.0785	1.2550	2.875E-01	-1.765E-01	-5.074E-02	-1.637E+01	-4.705E+00	1.765E-01	5.074E-02	1.637E+01	4.705E+00
	4000.00	1.0782	1.2560	9.615E-04	-1.778E-01	-1.710E-04	-1.649E+01	-1.586E-02	1.778E-01	1.710E-04	1.649E+01	1.586E-02
	7000.00	1.1921	1.3780	2.885E-01	-1.859E-01	-5.363E-02	-1.559E+01	-4.498E+00	1.859E-01	5.363E-02	1.559E+01	4.498E+00
	10400.00	1.2663	1.4550	3.269E-01	-1.887E-01	-6.168E-02	-1.490E+01	-4.870E+00	1.887E-01	6.168E-02	1.490E+01	4.870E+00
AVERAGE				1.000E+00	-1.529E-02	-1.725E-01	1.157E+01	-1.479E+01	1.639E-01	1.748E-01	2.844E+01	1.525E+01

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2A	1.00	0.4600	0.3207	9.615E-05	1.393E-01	1.339E-05	3.028E+01	2.912E-03	1.393E-01	1.339E-05	3.028E+01	2.912E-03
(3911)	5.00	0.5099	0.3618	3.846E-04	1.481E-01	5.696E-05	2.904E+01	1.117E-02	1.481E-01	5.696E-05	2.904E+01	1.117E-02
	10.00	0.5399	0.4087	4.808E-04	1.312E-01	6.308E-05	2.430E+01	1.168E-02	1.312E-01	6.308E-05	2.430E+01	1.168E-02
	100.00	0.7290	0.7746	8.654E-03	-4.563E-02	-3.949E-04	-6.260E+00	-5.417E-02	4.563E-02	3.949E-04	6.260E+00	5.417E-02
	500.00	0.9548	1.1510	3.846E-02	-1.962E-01	-7.545E-03	-2.054E+01	-7.902E-01	1.962E-01	7.545E-03	2.054E+01	7.902E-01
	1000.00	1.1300	1.3160	4.808E-02	-1.860E-01	-8.942E-03	-1.646E+01	-7.914E-01	1.860E-01	8.942E-03	1.646E+01	7.914E-01

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	3990.00	1.3785	1.6310	2.875E-01	-2.525E-01	-7.260E-02	-1.832E+01	-5.267E+00	2.525E-01	7.260E-02	1.832E+01	5.267E+00
	4000.00	1.3683	1.6320	9.615E-04	-2.637E-01	-2.536E-04	-1.927E+01	-1.853E-02	2.637E-01	2.536E-04	1.927E+01	1.853E-02
	7000.00	1.4871	1.7560	2.885E-01	-2.689E-01	-7.757E-02	-1.808E+01	-5.216E+00	2.689E-01	7.757E-02	1.808E+01	5.216E+00
	10400.00	1.5413	1.8340	3.269E-01	-2.927E-01	-9.568E-02	-1.899E+01	-6.207E+00	2.927E-01	9.568E-02	1.899E+01	6.207E+00
AVERAGE				1.000E+00	-1.087E-01	-2.629E-01	-3.430E+00	-1.832E+01	1.924E-01	2.631E-01	2.016E+01	1.837E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2C	1.00	0.2800	0.1353	9.615E-05	1.447E-01	1.391E-05	5.168E+01	4.969E-03	1.447E-01	1.391E-05	5.168E+01	4.969E-03
(3916)	5.00	0.3599	0.1517	3.846E-04	2.082E-01	8.008E-05	5.785E+01	2.225E-02	2.082E-01	8.008E-05	5.785E+01	2.225E-02
	10.00	0.3799	0.1708	4.808E-04	2.091E-01	1.005E-04	5.504E+01	2.646E-02	2.091E-01	1.005E-04	5.504E+01	2.646E-02
	100.00	0.5290	0.3715	8.654E-03	1.575E-01	1.363E-03	2.977E+01	2.577E-01	1.575E-01	1.363E-03	2.977E+01	2.577E-01
	500.00	0.7048	0.6684	3.846E-02	3.640E-02	1.400E-03	5.165E+00	1.986E-01	3.640E-02	1.400E-03	5.165E+00	1.986E-01
	1000.00	0.7945	0.8180	4.808E-02	-2.350E-02	-1.130E-03	-2.958E+00	-1.422E-01	2.350E-02	1.130E-03	2.958E+00	1.422E-01
	3990.00	1.0585	1.1200	2.875E-01	-6.150E-02	-1.768E-02	-5.810E+00	-1.670E+00	6.150E-02	1.768E-02	5.810E+00	1.670E+00
	4000.00	1.0483	1.1210	9.615E-04	-7.270E-02	-6.990E-05	-6.935E+00	-6.668E-03	7.270E-02	6.990E-05	6.935E+00	6.668E-03
	7000.00	1.1371	1.2420	2.885E-01	-1.049E-01	-3.026E-02	-9.225E+00	-2.661E+00	1.049E-01	3.026E-02	9.225E+00	2.661E+00
	10400.00	1.2013	1.3180	3.269E-01	-1.167E-01	-3.814E-02	-9.711E+00	-3.175E+00	1.167E-01	3.814E-02	9.711E+00	3.175E+00
AVERAGE				1.000E+00	3.766E-02	-8.432E-02	1.649E+01	-7.145E+00	1.135E-01	9.024E-02	2.341E+01	8.165E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2E	1.00	0.1800	0.0695	9.615E-05	1.105E-01	1.063E-05	6.139E+01	5.903E-03	1.105E-01	1.063E-05	6.139E+01	5.903E-03
(3918)	5.00	0.2599	0.0783	3.846E-04	1.816E-01	6.986E-05	6.988E+01	2.688E-02	1.816E-01	6.986E-05	6.988E+01	2.688E-02
	10.00	0.2799	0.0889	4.808E-04	1.910E-01	9.183E-05	6.824E+01	3.281E-02	1.910E-01	9.183E-05	6.824E+01	3.281E-02
	100.00	0.4290	0.2246	8.654E-03	2.044E-01	1.769E-03	4.765E+01	4.123E-01	2.044E-01	1.769E-03	4.765E+01	4.123E-01
	500.00	0.6248	0.4768	3.846E-02	1.480E-01	5.692E-03	2.369E+01	9.111E-01	1.480E-01	5.692E-03	2.369E+01	9.111E-01
	1000.00	0.7197	0.6167	4.808E-02	1.030E-01	4.952E-03	1.431E+01	6.881E-01	1.030E-01	4.952E-03	1.431E+01	6.881E-01
	3990.00	0.9585	0.9104	2.875E-01	4.810E-02	1.383E-02	5.018E+00	1.443E+00	4.810E-02	1.383E-02	5.018E+00	1.443E+00
	4000.00	0.9483	0.9113	9.615E-04	3.700E-02	3.558E-05	3.902E+00	3.752E-03	3.700E-02	3.558E-05	3.902E+00	3.752E-03
	7000.00	1.0771	1.0300	2.885E-01	4.710E-02	1.359E-02	4.373E+00	1.261E+00	4.710E-02	1.359E-02	4.373E+00	1.261E+00
	10400.00	1.1213	1.1060	3.269E-01	1.534E-02	5.015E-03	1.368E+00	4.473E-01	1.534E-02	5.015E-03	1.368E+00	4.473E-01
AVERAGE				1.000E+00	1.086E-01	4.505E-02	2.998E+01	5.232E+00	1.086E-01	4.505E-02	2.998E+01	5.232E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-3	1.00	0.2100	0.1217	9.615E-05	8.830E-02	8.490E-06	4.205E+01	4.043E-03	8.830E-02	8.490E-06	4.205E+01	4.043E-03

(3921)	5.00	0.2699	0.1390	3.846E-04	1.309E-01	5.035E-05	4.850E+01	1.865E-02	1.309E-01	5.035E-05	4.850E+01	1.865E-02
	10.00	0.3099	0.1616	4.808E-04	1.483E-01	7.130E-05	4.785E+01	2.301E-02	1.483E-01	7.130E-05	4.785E+01	2.301E-02
	100.00	0.5190	0.4364	8.654E-03	8.260E-02	7.148E-04	1.592E+01	1.377E-01	8.260E-02	7.148E-04	1.592E+01	1.377E-01
	500.00	0.6648	0.7951	3.846E-02	-1.303E-01	-5.012E-03	-1.960E+01	-7.538E-01	1.303E-01	5.012E-03	1.960E+01	7.538E-01
	1000.00	0.7496	0.9586	4.808E-02	-2.090E-01	-1.005E-02	-2.788E+01	-1.340E+00	2.090E-01	1.005E-02	2.788E+01	1.340E+00
	3990.00	0.9685	1.2730	2.875E-01	-3.045E-01	-8.754E-02	-3.144E+01	-9.039E+00	3.045E-01	8.754E-02	3.144E+01	9.039E+00
	4000.00	0.9683	1.2740	9.615E-04	-3.057E-01	-2.939E-04	-3.157E+01	-3.036E-02	3.057E-01	2.939E-04	3.157E+01	3.036E-02
	7000.00	1.0771	1.3970	2.885E-01	-3.199E-01	-9.228E-02	-2.970E+01	-8.567E+00	3.199E-01	9.228E-02	2.970E+01	8.567E+00
	10400.00	1.1513	1.4750	3.269E-01	-3.237E-01	-1.058E-01	-2.811E+01	-9.190E+00	3.237E-01	1.058E-01	2.811E+01	9.190E+00
AVERAGE				1.000E+00	-1.143E-01	-3.001E-01	-1.399E+00	-2.874E+01	2.043E-01	3.018E-01	3.226E+01	2.910E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-4	1.00	0.0100	0.0058	9.615E-05	4.227E-03	4.064E-07	4.227E+01	4.064E-03	4.227E-03	4.064E-07	4.227E+01	4.064E-03
(3922)	5.00	0.0299	0.0067	3.846E-04	2.320E-02	8.924E-06	7.760E+01	2.985E-02	2.320E-02	8.924E-06	7.760E+01	2.985E-02
	10.00	0.0499	0.0081	4.808E-04	4.182E-02	2.011E-05	8.381E+01	4.029E-02	4.182E-02	2.011E-05	8.381E+01	4.029E-02
	100.00	0.1490	0.0386	8.654E-03	1.104E-01	9.557E-04	7.412E+01	6.414E-01	1.104E-01	9.557E-04	7.412E+01	6.414E-01
	500.00	0.3048	0.2039	3.846E-02	1.009E-01	3.881E-03	3.310E+01	1.273E+00	1.009E-01	3.881E-03	3.310E+01	1.273E+00
	1000.00	0.3896	0.3339	4.808E-02	5.570E-02	2.678E-03	1.430E+01	6.873E-01	5.570E-02	2.678E-03	1.430E+01	6.873E-01
	3990.00	0.6085	0.6278	2.875E-01	-1.930E-02	-5.549E-03	-3.172E+00	-9.119E-01	1.930E-02	5.549E-03	3.172E+00	9.119E-01
	4000.00	0.6183	0.6287	9.615E-04	-1.040E-02	-1.000E-05	-1.682E+00	-1.617E-03	1.040E-02	1.000E-05	1.682E+00	1.617E-03
	7000.00	0.7171	0.7501	2.885E-01	-3.300E-02	-9.519E-03	-4.602E+00	-1.327E+00	3.300E-02	9.519E-03	4.602E+00	1.327E+00
	10400.00	0.7913	0.8284	3.269E-01	-3.706E-02	-1.212E-02	-4.683E+00	-1.531E+00	3.706E-02	1.212E-02	4.683E+00	1.531E+00
AVERAGE				1.000E+00	2.365E-02	-1.965E-02	3.111E+01	-1.096E+00	4.360E-02	3.474E-02	3.393E+01	6.448E+00
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-5	1.00	0.2400	0.1201	9.615E-05	1.199E-01	1.153E-05	4.996E+01	4.804E-03	1.199E-01	1.153E-05	4.996E+01	4.804E-03
(3923)	5.00	0.3199	0.1371	3.846E-04	1.828E-01	7.031E-05	5.714E+01	2.198E-02	1.828E-01	7.031E-05	5.714E+01	2.198E-02
	10.00	0.3399	0.1593	4.808E-04	1.806E-01	8.683E-05	5.313E+01	2.554E-02	1.806E-01	8.683E-05	5.313E+01	2.554E-02
	100.00	0.5390	0.4267	8.654E-03	1.123E-01	9.718E-04	2.083E+01	1.803E-01	1.123E-01	9.718E-04	2.083E+01	1.803E-01
	500.00	0.7148	0.7674	3.846E-02	-5.260E-02	-2.023E-03	-7.359E+00	-2.830E-01	5.260E-02	2.023E-03	7.359E+00	2.830E-01
	1000.00	0.7896	0.9233	4.808E-02	-1.337E-01	-6.428E-03	-1.693E+01	-8.141E-01	1.337E-01	6.428E-03	1.693E+01	8.141E-01
	3990.00	1.0485	1.2270	2.875E-01	-1.785E-01	-5.132E-02	-1.702E+01	-4.894E+00	1.785E-01	5.132E-02	1.702E+01	4.894E+00
	4000.00	1.0383	1.2290	9.615E-04	-1.907E-01	-1.834E-04	-1.837E+01	-1.766E-02	1.907E-01	1.834E-04	1.837E+01	1.766E-02
	7000.00	1.1471	1.3490	2.885E-01	-2.019E-01	-5.824E-02	-1.760E+01	-5.077E+00	2.019E-01	5.824E-02	1.760E+01	5.077E+00
	10400.00	1.2313	1.4250	3.269E-01	-1.937E-01	-6.333E-02	-1.573E+01	-5.143E+00	1.937E-01	6.333E-02	1.573E+01	5.143E+00
AVERAGE				1.000E+00	-3.555E-02	-1.804E-01	8.805E+00	-1.600E+01	1.547E-01	1.827E-01	2.741E+01	1.646E+01

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
2002	1.00	-0.0700	0.0000	9.615E-05	-7.002E-02	-6.733E-06	1.000E+02	9.619E-03	7.002E-02	6.733E-06	-1.000E+02	-9.619E-03
	5.00	-0.0500	0.0002	3.846E-04	-5.019E-02	-1.930E-05	1.004E+02	3.860E-02	5.019E-02	1.930E-05	-1.004E+02	-3.860E-02
	10.00	-0.0020	0.0004	4.808E-04	-2.416E-03	-1.162E-06	1.208E+02	5.808E-02	2.416E-03	1.162E-06	-1.208E+02	-5.808E-02
	100.00	0.0690	0.0171	8.654E-03	5.191E-02	4.492E-04	7.523E+01	6.510E-01	5.191E-02	4.492E-04	7.523E+01	6.510E-01
	500.00	0.2098	0.1803	3.846E-02	2.950E-02	1.135E-03	1.406E+01	5.408E-01	2.950E-02	1.135E-03	1.406E+01	5.408E-01
	1000.00	0.3000	0.3047	4.808E-02	-4.700E-03	-2.260E-04	-1.567E+00	-7.532E-02	4.700E-03	2.260E-04	1.567E+00	7.532E-02
	3990.00	0.5035	0.5811	2.875E-01	-7.760E-02	-2.231E-02	-1.541E+01	-4.431E+00	7.760E-02	2.231E-02	1.541E+01	4.431E+00
	4000.00	0.5133	0.5820	9.615E-04	-6.870E-02	-6.606E-05	-1.338E+01	-1.287E-02	6.870E-02	6.606E-05	1.338E+01	1.287E-02
	7000.00	0.6271	0.6955	2.885E-01	-6.840E-02	-1.973E-02	-1.091E+01	-3.146E+00	6.840E-02	1.973E-02	1.091E+01	3.146E+00
	10400.00	0.7113	0.7671	3.269E-01	-5.576E-02	-1.823E-02	-7.839E+00	-2.563E+00	5.576E-02	1.823E-02	7.839E+00	2.563E+00
AVERAGE				1.000E+00	-3.164E-02	-5.901E-02	3.614E+01	-8.930E+00	4.792E-02	6.217E-02	-1.828E+01	1.131E+01
					Variance =	0.014141349					Average =	1.243E+01

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
RW-4	1.00	11.2330	16.4700	9.615E-05	-5.237E+00	-5.036E-04	-4.662E+01	-4.483E-03	5.237E+00	5.036E-04	4.662E+01	4.483E-03
(3927)	5.00	12.2680	16.9700	3.846E-04	-4.702E+00	-1.808E-03	-3.833E+01	-1.474E-02	4.702E+00	1.808E-03	3.833E+01	1.474E-02
	10.00	13.0230	17.2800	4.808E-04	-4.257E+00	-2.047E-03	-3.269E+01	-1.572E-02	4.257E+00	2.047E-03	3.269E+01	1.572E-02
	100.00	15.5330	18.1300	8.654E-03	-2.597E+00	-2.247E-02	-1.672E+01	-1.447E-01	2.597E+00	2.247E-02	1.672E+01	1.447E-01
	500.00	17.3330	18.6000	3.846E-02	-1.267E+00	-4.873E-02	-7.310E+00	-2.811E-01	1.267E+00	4.873E-02	7.310E+00	2.811E-01
	1000.00	18.0630	18.7700	4.808E-02	-7.070E-01	-3.399E-02	-3.914E+00	-1.882E-01	7.070E-01	3.399E-02	3.914E+00	1.882E-01
	3990.00	19.3513	19.0900	2.875E-01	2.613E-01	7.512E-02	1.350E+00	3.882E-01	2.613E-01	7.512E-02	1.350E+00	3.882E-01
	4000.00	14.6313	16.7800	9.615E-04	-2.149E+00	-2.066E-03	-1.469E+01	-1.412E-02	2.149E+00	2.066E-03	1.469E+01	1.412E-02
	7000.00	17.6000	16.9000	2.885E-01	7.000E-01	2.019E-01	3.977E+00	1.147E+00	7.000E-01	2.019E-01	3.977E+00	1.147E+00
	10400.00	17.3243	16.9800	3.269E-01	3.443E-01	1.126E-01	1.987E+00	6.497E-01	3.443E-01	1.126E-01	1.987E+00	6.497E-01
AVERAGE				1.000E+00	-1.961E+00	2.780E-01	-1.530E+01	1.522E+00	2.222E+00	5.012E-01	1.676E+01	2.848E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-1	1.00	0.3000	0.1436	9.615E-05	1.564E-01	1.504E-05	5.213E+01	5.013E-03	1.564E-01	1.504E-05	5.213E+01	5.013E-03
(3910)	5.00	0.3699	0.1595	3.846E-04	2.104E-01	8.094E-05	5.689E+01	2.188E-02	2.104E-01	8.094E-05	5.689E+01	2.188E-02
	10.00	0.3899	0.1801	4.808E-04	2.098E-01	1.009E-04	5.381E+01	2.587E-02	2.098E-01	1.009E-04	5.381E+01	2.587E-02
	100.00	0.5390	0.4190	8.654E-03	1.200E-01	1.038E-03	2.226E+01	1.926E-01	1.200E-01	1.038E-03	2.226E+01	1.926E-01
	500.00	0.7250	0.7330	3.846E-02	-8.000E-03	-3.077E-04	-1.103E+00	-4.244E-02	8.000E-03	3.077E-04	1.103E+00	4.244E-02
	1000.00	0.8396	0.8799	4.808E-02	-4.030E-02	-1.938E-03	-4.800E+00	-2.308E-01	4.030E-02	1.938E-03	4.800E+00	2.308E-01
	3990.00	1.0785	1.1680	2.875E-01	-8.950E-02	-2.573E-02	-8.299E+00	-2.386E+00	8.950E-02	2.573E-02	8.299E+00	2.386E+00
	4000.00	1.0782	1.1690	9.615E-04	-9.080E-02	-8.731E-05	-8.421E+00	-8.098E-03	9.080E-02	8.731E-05	8.421E+00	8.098E-03
	7000.00	1.1921	1.2820	2.885E-01	-8.990E-02	-2.593E-02	-7.541E+00	-2.175E+00	8.990E-02	2.593E-02	7.541E+00	2.175E+00
	10400.00	1.2663	1.3520	3.269E-01	-8.566E-02	-2.800E-02	-6.764E+00	-2.211E+00	8.566E-02	2.800E-02	6.764E+00	2.211E+00
AVERAGE				1.000E+00	2.925E-02	-8.077E-02	1.482E+01	-6.809E+00	1.101E-01	8.324E-02	2.220E+01	7.299E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2A	1.00	0.4600	0.3500	9.615E-05	1.100E-01	1.058E-05	2.391E+01	2.299E-03	1.100E-01	1.058E-05	2.391E+01	2.299E-03
(3911)	5.00	0.5099	0.3851	3.846E-04	1.248E-01	4.800E-05	2.448E+01	9.414E-03	1.248E-01	4.800E-05	2.448E+01	9.414E-03
	10.00	0.5399	0.4244	4.808E-04	1.155E-01	5.553E-05	2.139E+01	1.029E-02	1.155E-01	5.553E-05	2.139E+01	1.029E-02
	100.00	0.7290	0.7319	8.654E-03	-2.933E-03	-2.538E-05	-4.024E-01	-3.482E-03	2.933E-03	2.538E-05	4.024E-01	3.482E-03
	500.00	0.9548	1.0660	3.846E-02	-1.112E-01	-4.276E-03	-1.164E+01	-4.478E-01	1.112E-01	4.276E-03	1.164E+01	4.478E-01
	1000.00	1.1300	1.2180	4.808E-02	-8.800E-02	-4.231E-03	-7.788E+00	-3.744E-01	8.800E-02	4.231E-03	7.788E+00	3.744E-01

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	3990.00	1.3785	1.5110	2.875E-01	-1.325E-01	-3.810E-02	-9.614E+00	-2.764E+00	1.325E-01	3.810E-02	9.614E+00	2.764E+00
	4000.00	1.3683	1.5120	9.615E-04	-1.437E-01	-1.382E-04	-1.050E+01	-1.010E-02	1.437E-01	1.382E-04	1.050E+01	1.010E-02
	7000.00	1.4871	1.6270	2.885E-01	-1.399E-01	-4.036E-02	-9.409E+00	-2.714E+00	1.399E-01	4.036E-02	9.409E+00	2.714E+00
	10400.00	1.5413	1.6970	3.269E-01	-1.557E-01	-5.089E-02	-1.010E+01	-3.302E+00	1.557E-01	5.089E-02	1.010E+01	3.302E+00
AVERAGE				1.000E+00	-4.236E-02	-1.379E-01	1.032E+00	-9.593E+00	1.124E-01	1.381E-01	1.292E+01	9.637E+00
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2C	1.00	0.2800	0.1288	9.615E-05	1.512E-01	1.454E-05	5.400E+01	5.192E-03	1.512E-01	1.454E-05	5.400E+01	5.192E-03
(3916)	5.00	0.3599	0.1413	3.846E-04	2.186E-01	8.408E-05	6.074E+01	2.336E-02	2.186E-01	8.408E-05	6.074E+01	2.336E-02
	10.00	0.3799	0.1558	4.808E-04	2.241E-01	1.077E-04	5.899E+01	2.836E-02	2.241E-01	1.077E-04	5.899E+01	2.836E-02
	100.00	0.5290	0.3168	8.654E-03	2.122E-01	1.836E-03	4.011E+01	3.471E-01	2.122E-01	1.836E-03	4.011E+01	3.471E-01
	500.00	0.7048	0.5735	3.846E-02	1.313E-01	5.050E-03	1.863E+01	7.165E-01	1.313E-01	5.050E-03	1.863E+01	7.165E-01
	1000.00	0.7945	0.7088	4.808E-02	8.570E-02	4.120E-03	1.079E+01	5.186E-01	8.570E-02	4.120E-03	1.079E+01	5.186E-01
	3990.00	1.0585	0.9879	2.875E-01	7.060E-02	2.030E-02	6.670E+00	1.918E+00	7.060E-02	2.030E-02	6.670E+00	1.918E+00
	4000.00	1.0483	0.9889	9.615E-04	5.940E-02	5.712E-05	5.666E+00	5.448E-03	5.940E-02	5.712E-05	5.666E+00	5.448E-03
	7000.00	1.1371	1.1000	2.885E-01	3.710E-02	1.070E-02	3.263E+00	9.412E-01	3.710E-02	1.070E-02	3.263E+00	9.412E-01
	10400.00	1.2013	1.1690	3.269E-01	3.234E-02	1.057E-02	2.692E+00	8.801E-01	3.234E-02	1.057E-02	2.692E+00	8.801E-01
AVERAGE				1.000E+00	1.223E-01	5.284E-02	2.615E+01	5.383E+00	1.223E-01	5.284E-02	2.615E+01	5.383E+00
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2E	1.00	0.1800	0.0633	9.615E-05	1.167E-01	1.123E-05	6.486E+01	6.236E-03	1.167E-01	1.123E-05	6.486E+01	6.236E-03
(3918)	5.00	0.2599	0.0700	3.846E-04	1.899E-01	7.305E-05	7.308E+01	2.811E-02	1.899E-01	7.305E-05	7.308E+01	2.811E-02
	10.00	0.2799	0.0778	4.808E-04	2.021E-01	9.716E-05	7.220E+01	3.471E-02	2.021E-01	9.716E-05	7.220E+01	3.471E-02
	100.00	0.4290	0.1833	8.654E-03	2.457E-01	2.126E-03	5.727E+01	4.956E-01	2.457E-01	2.126E-03	5.727E+01	4.956E-01
	500.00	0.6248	0.3962	3.846E-02	2.286E-01	8.792E-03	3.659E+01	1.407E+00	2.286E-01	8.792E-03	3.659E+01	1.407E+00
	1000.00	0.7197	0.5209	4.808E-02	1.988E-01	9.558E-03	2.762E+01	1.328E+00	1.988E-01	9.558E-03	2.762E+01	1.328E+00
	3990.00	0.9585	0.7908	2.875E-01	1.677E-01	4.821E-02	1.750E+01	5.030E+00	1.677E-01	4.821E-02	1.750E+01	5.030E+00
	4000.00	0.9483	0.7917	9.615E-04	1.566E-01	1.506E-04	1.651E+01	1.588E-02	1.566E-01	1.506E-04	1.651E+01	1.588E-02
	7000.00	1.0771	0.9014	2.885E-01	1.757E-01	5.068E-02	1.631E+01	4.705E+00	1.757E-01	5.068E-02	1.631E+01	4.705E+00
	10400.00	1.1213	0.9697	3.269E-01	1.516E-01	4.957E-02	1.352E+01	4.421E+00	1.516E-01	4.957E-02	1.352E+01	4.421E+00
AVERAGE				1.000E+00	1.834E-01	1.693E-01	3.955E+01	1.747E+01	1.834E-01	1.693E-01	3.955E+01	1.747E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-3	1.00	0.2100	0.1441	9.615E-05	6.590E-02	6.337E-06	3.138E+01	3.017E-03	6.590E-02	6.337E-06	3.138E+01	3.017E-03

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(3921)	5.00	0.2699	0.1600	3.846E-04	1.099E-01	4.227E-05	4.072E+01	1.566E-02	1.099E-01	4.227E-05	4.072E+01	1.566E-02
	10.00	0.3099	0.1805	4.808E-04	1.294E-01	6.221E-05	4.176E+01	2.007E-02	1.294E-01	6.221E-05	4.176E+01	2.007E-02
	100.00	0.5190	0.4218	8.654E-03	9.720E-02	8.412E-04	1.873E+01	1.621E-01	9.720E-02	8.412E-04	1.873E+01	1.621E-01
	500.00	0.6648	0.7434	3.846E-02	-7.860E-02	-3.023E-03	-1.182E+01	-4.547E-01	7.860E-02	3.023E-03	1.182E+01	4.547E-01
	1000.00	0.7496	0.8942	4.808E-02	-1.446E-01	-6.952E-03	-1.929E+01	-9.274E-01	1.446E-01	6.952E-03	1.929E+01	9.274E-01
	3990.00	0.9685	1.1880	2.875E-01	-2.195E-01	-6.311E-02	-2.266E+01	-6.516E+00	2.195E-01	6.311E-02	2.266E+01	6.516E+00
	4000.00	0.9683	1.1890	9.615E-04	-2.207E-01	-2.122E-04	-2.279E+01	-2.192E-02	2.207E-01	2.122E-04	2.279E+01	2.192E-02
	7000.00	1.0771	1.3030	2.885E-01	-2.259E-01	-6.516E-02	-2.097E+01	-6.050E+00	2.259E-01	6.516E-02	2.097E+01	6.050E+00
	10400.00	1.1513	1.3740	3.269E-01	-2.227E-01	-7.279E-02	-1.934E+01	-6.322E+00	2.227E-01	7.279E-02	1.934E+01	6.322E+00
AVERAGE				1.000E+00	-7.096E-02	-2.103E-01	1.570E+00	-2.009E+01	1.514E-01	2.122E-01	2.495E+01	2.049E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-4	1.00	0.0100	0.0085	9.615E-05	1.457E-03	1.401E-07	1.457E+01	1.401E-03	1.457E-03	1.401E-07	1.457E+01	1.401E-03
(3922)	5.00	0.0299	0.0097	3.846E-04	2.020E-02	7.770E-06	6.757E+01	2.599E-02	2.020E-02	7.770E-06	6.757E+01	2.599E-02
	10.00	0.0499	0.0111	4.808E-04	3.882E-02	1.866E-05	7.780E+01	3.740E-02	3.882E-02	1.866E-05	7.780E+01	3.740E-02
	100.00	0.1490	0.0441	8.654E-03	1.049E-01	9.078E-04	7.040E+01	6.093E-01	1.049E-01	9.078E-04	7.040E+01	6.093E-01
	500.00	0.3048	0.2050	3.846E-02	9.980E-02	3.838E-03	3.274E+01	1.259E+00	9.980E-02	3.838E-03	3.274E+01	1.259E+00
	1000.00	0.3896	0.3281	4.808E-02	6.150E-02	2.957E-03	1.579E+01	7.589E-01	6.150E-02	2.957E-03	1.579E+01	7.589E-01
	3990.00	0.6085	0.6056	2.875E-01	2.900E-03	8.338E-04	4.766E-01	1.370E-01	2.900E-03	8.338E-04	4.766E-01	1.370E-01
	4000.00	0.6183	0.6068	9.615E-04	1.150E-02	1.106E-05	1.860E+00	1.788E-03	1.150E-02	1.106E-05	1.860E+00	1.788E-03
	7000.00	0.7171	0.7203	2.885E-01	-3.200E-03	-9.231E-04	-4.462E-01	-1.287E-01	3.200E-03	9.231E-04	4.462E-01	1.287E-01
	10400.00	0.7913	0.7919	3.269E-01	-5.590E-04	-1.828E-04	-7.064E-02	-2.309E-02	5.590E-04	1.828E-04	7.064E-02	2.309E-02
AVERAGE				1.000E+00	3.373E-02	7.469E-03	2.807E+01	2.679E+00	3.448E-02	9.680E-03	2.817E+01	2.983E+00
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-5	1.00	0.2400	0.1415	9.615E-05	9.850E-02	9.471E-06	4.104E+01	3.946E-03	9.850E-02	9.471E-06	4.104E+01	3.946E-03
(3923)	5.00	0.3199	0.1572	3.846E-04	1.627E-01	6.258E-05	5.086E+01	1.956E-02	1.627E-01	6.258E-05	5.086E+01	1.956E-02
	10.00	0.3399	0.1773	4.808E-04	1.626E-01	7.817E-05	4.784E+01	2.300E-02	1.626E-01	7.817E-05	4.784E+01	2.300E-02
	100.00	0.5390	0.4107	8.654E-03	1.283E-01	1.110E-03	2.380E+01	2.060E-01	1.283E-01	1.110E-03	2.380E+01	2.060E-01
	500.00	0.7148	0.7148	3.846E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
	1000.00	0.7896	0.8577	4.808E-02	-6.810E-02	-3.274E-03	-8.625E+00	-4.146E-01	6.810E-02	3.274E-03	8.625E+00	4.146E-01
	3990.00	1.0485	1.1410	2.875E-01	-9.250E-02	-2.659E-02	-8.822E+00	-2.536E+00	9.250E-02	2.659E-02	8.822E+00	2.536E+00
	4000.00	1.0383	1.1420	9.615E-04	-1.037E-01	-9.971E-05	-9.987E+00	-9.603E-03	1.037E-01	9.971E-05	9.987E+00	9.603E-03
	7000.00	1.1471	1.2530	2.885E-01	-1.059E-01	-3.055E-02	-9.232E+00	-2.663E+00	1.059E-01	3.055E-02	9.232E+00	2.663E+00
	10400.00	1.2313	1.3210	3.269E-01	-8.970E-02	-2.933E-02	-7.285E+00	-2.382E+00	8.970E-02	2.933E-02	7.285E+00	2.382E+00
AVERAGE				1.000E+00	9.220E-03	-8.858E-02	1.196E+01	-7.753E+00	1.012E-01	9.110E-02	2.075E+01	8.258E+00

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
2002	1.00	-0.0700	0.0000	9.615E-05	-7.005E-02	-6.735E-06	1.001E+02	9.622E-03	7.005E-02	6.735E-06	-1.001E+02	-9.622E-03
	5.00	-0.0500	0.0002	3.846E-04	-5.023E-02	-1.932E-05	1.005E+02	3.864E-02	5.023E-02	1.932E-05	-1.005E+02	-3.864E-02
	10.00	-0.0020	0.0005	4.808E-04	-2.508E-03	-1.206E-06	1.254E+02	6.029E-02	2.508E-03	1.206E-06	-1.254E+02	-6.029E-02
	100.00	0.0690	0.0186	8.654E-03	5.044E-02	4.365E-04	7.310E+01	6.326E-01	5.044E-02	4.365E-04	7.310E+01	6.326E-01
	500.00	0.2098	0.1790	3.846E-02	3.080E-02	1.185E-03	1.468E+01	5.646E-01	3.080E-02	1.185E-03	1.468E+01	5.646E-01
	1000.00	0.3000	0.2967	4.808E-02	3.300E-03	1.587E-04	1.100E+00	5.288E-02	3.300E-03	1.587E-04	1.100E+00	5.288E-02
	3990.00	0.5035	0.5564	2.875E-01	-5.290E-02	-1.521E-02	-1.051E+01	-3.021E+00	5.290E-02	1.521E-02	1.051E+01	3.021E+00
	4000.00	0.5133	0.5573	9.615E-04	-4.400E-02	-4.231E-05	-8.572E+00	-8.242E-03	4.400E-02	4.231E-05	8.572E+00	8.242E-03
	7000.00	0.6271	0.6625	2.885E-01	-3.540E-02	-1.021E-02	-5.645E+00	-1.628E+00	3.540E-02	1.021E-02	5.645E+00	1.628E+00
	10400.00	0.7113	0.7269	3.269E-01	-1.556E-02	-5.087E-03	-2.187E+00	-7.151E-01	1.556E-02	5.087E-03	2.187E+00	7.151E-01
AVERAGE				1.000E+00	-1.861E-02	-2.880E-02	3.879E+01	-4.014E+00	3.552E-02	3.236E-02	-2.101E+01	6.514E+00
					Variance =	0.023381877					Average =	8.988E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
RW-4	1.00	11.2330	16.4900	9.615E-05	-5.257E+00	-5.055E-04	-4.680E+01	-4.500E-03	5.257E+00	5.055E-04	4.680E+01	4.500E-03
(3927)	5.00	12.2680	16.9800	3.846E-04	-4.712E+00	-1.812E-03	-3.841E+01	-1.477E-02	4.712E+00	1.812E-03	3.841E+01	1.477E-02
	10.00	13.0230	17.2800	4.808E-04	-4.257E+00	-2.047E-03	-3.269E+01	-1.572E-02	4.257E+00	2.047E-03	3.269E+01	1.572E-02
	100.00	15.5330	18.1400	8.654E-03	-2.607E+00	-2.256E-02	-1.678E+01	-1.452E-01	2.607E+00	2.256E-02	1.678E+01	1.452E-01
	500.00	17.3330	18.6200	3.846E-02	-1.287E+00	-4.950E-02	-7.425E+00	-2.856E-01	1.287E+00	4.950E-02	7.425E+00	2.856E-01
	1000.00	18.0630	18.8000	4.808E-02	-7.370E-01	-3.543E-02	-4.080E+00	-1.962E-01	7.370E-01	3.543E-02	4.080E+00	1.962E-01
	3990.00	19.3513	19.1200	2.875E-01	2.313E-01	6.650E-02	1.195E+00	3.436E-01	2.313E-01	6.650E-02	1.195E+00	3.436E-01
	4000.00	14.6313	16.8200	9.615E-04	-2.189E+00	-2.105E-03	-1.496E+01	-1.438E-02	2.189E+00	2.105E-03	1.496E+01	1.438E-02
	7000.00	17.6000	16.9400	2.885E-01	6.600E-01	1.904E-01	3.750E+00	1.082E+00	6.600E-01	1.904E-01	3.750E+00	1.082E+00
	10400.00	17.3243	17.0100	3.269E-01	3.143E-01	1.028E-01	1.814E+00	5.931E-01	3.143E-01	1.028E-01	1.814E+00	5.931E-01
AVERAGE				1.000E+00	-1.984E+00	2.457E-01	-1.544E+01	1.342E+00	2.225E+00	4.736E-01	1.679E+01	2.695E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-1	1.00	0.3000	0.1829	9.615E-05	1.171E-01	1.126E-05	3.903E+01	3.753E-03	1.171E-01	1.126E-05	3.903E+01	3.753E-03
(3910)	5.00	0.3699	0.1960	3.846E-04	1.739E-01	6.688E-05	4.701E+01	1.808E-02	1.739E-01	6.688E-05	4.701E+01	1.808E-02
	10.00	0.3899	0.2129	4.808E-04	1.770E-01	8.510E-05	4.540E+01	2.183E-02	1.770E-01	8.510E-05	4.540E+01	2.183E-02
	100.00	0.5390	0.4163	8.654E-03	1.227E-01	1.062E-03	2.276E+01	1.970E-01	1.227E-01	1.062E-03	2.276E+01	1.970E-01
	500.00	0.7250	0.7086	3.846E-02	1.640E-02	6.308E-04	2.262E+00	8.700E-02	1.640E-02	6.308E-04	2.262E+00	8.700E-02
	1000.00	0.8396	0.8524	4.808E-02	-1.280E-02	-6.154E-04	-1.525E+00	-7.329E-02	1.280E-02	6.154E-04	1.525E+00	7.329E-02
	3990.00	1.0785	1.1390	2.875E-01	-6.050E-02	-1.739E-02	-5.610E+00	-1.613E+00	6.050E-02	1.739E-02	5.610E+00	1.613E+00
	4000.00	1.0782	1.1400	9.615E-04	-6.180E-02	-5.942E-05	-5.732E+00	-5.511E-03	6.180E-02	5.942E-05	5.732E+00	5.511E-03
	7000.00	1.1921	1.2530	2.885E-01	-6.090E-02	-1.757E-02	-5.109E+00	-1.474E+00	6.090E-02	1.757E-02	5.109E+00	1.474E+00
	10400.00	1.2663	1.3220	3.269E-01	-5.566E-02	-1.820E-02	-4.395E+00	-1.437E+00	5.566E-02	1.820E-02	4.395E+00	1.437E+00
AVERAGE				1.000E+00	3.554E-02	-5.198E-02	1.341E+01	-4.274E+00	8.588E-02	5.569E-02	1.788E+01	4.930E+00

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2A	1.00	0.4600	0.4114	9.615E-05	4.860E-02	4.673E-06	1.057E+01	1.016E-03	4.860E-02	4.673E-06	1.057E+01	1.016E-03
(3911)	5.00	0.5099	0.4387	3.846E-04	7.120E-02	2.738E-05	1.396E+01	5.371E-03	7.120E-02	2.738E-05	1.396E+01	5.371E-03
	10.00	0.5399	0.4692	4.808E-04	7.070E-02	3.399E-05	1.310E+01	6.296E-03	7.070E-02	3.399E-05	1.310E+01	6.296E-03
	100.00	0.7290	0.7259	8.654E-03	3.100E-03	2.683E-05	4.252E-01	3.680E-03	3.100E-03	2.683E-05	4.252E-01	3.680E-03
	500.00	0.9548	1.0360	3.846E-02	-8.120E-02	-3.123E-03	-8.504E+00	-3.271E-01	8.120E-02	3.123E-03	8.504E+00	3.271E-01
	1000.00	1.1300	1.1840	4.808E-02	-5.400E-02	-2.596E-03	-4.779E+00	-2.297E-01	5.400E-02	2.596E-03	4.779E+00	2.297E-01

	3990.00	1.3785	1.4760	2.875E-01	-9.750E-02	-2.803E-02	-7.073E+00	-2.033E+00	9.750E-02	2.803E-02	7.073E+00	2.033E+00
	4000.00	1.3683	1.4770	9.615E-04	-1.087E-01	-1.045E-04	-7.944E+00	-7.639E-03	1.087E-01	1.045E-04	7.944E+00	7.639E-03
	7000.00	1.4871	1.5910	2.885E-01	-1.039E-01	-2.997E-02	-6.987E+00	-2.015E+00	1.039E-01	2.997E-02	6.987E+00	2.015E+00
	10400.00	1.5413	1.6610	3.269E-01	-1.197E-01	-3.912E-02	-7.763E+00	-2.538E+00	1.197E-01	3.912E-02	7.763E+00	2.538E+00
AVERAGE				1.000E+00	-3.714E-02	-1.029E-01	-5.001E-01	-7.135E+00	7.586E-02	1.030E-01	8.110E+00	7.168E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2C	1.00	0.2800	0.1471	9.615E-05	1.329E-01	1.278E-05	4.746E+01	4.564E-03	1.329E-01	1.278E-05	4.746E+01	4.564E-03
(3916)	5.00	0.3599	0.1568	3.846E-04	2.031E-01	7.812E-05	5.643E+01	2.170E-02	2.031E-01	7.812E-05	5.643E+01	2.170E-02
	10.00	0.3799	0.1679	4.808E-04	2.120E-01	1.019E-04	5.580E+01	2.683E-02	2.120E-01	1.019E-04	5.580E+01	2.683E-02
	100.00	0.5290	0.3011	8.654E-03	2.279E-01	1.972E-03	4.308E+01	3.728E-01	2.279E-01	1.972E-03	4.308E+01	3.728E-01
	500.00	0.7048	0.5361	3.846E-02	1.687E-01	6.488E-03	2.394E+01	9.206E-01	1.687E-01	6.488E-03	2.394E+01	9.206E-01
	1000.00	0.7945	0.6668	4.808E-02	1.277E-01	6.139E-03	1.607E+01	7.727E-01	1.277E-01	6.139E-03	1.607E+01	7.727E-01
	3990.00	1.0585	0.9429	2.875E-01	1.156E-01	3.324E-02	1.092E+01	3.140E+00	1.156E-01	3.324E-02	1.092E+01	3.140E+00
	4000.00	1.0483	0.9438	9.615E-04	1.045E-01	1.005E-04	9.969E+00	9.585E-03	1.045E-01	1.005E-04	9.969E+00	9.585E-03
	7000.00	1.1371	1.0550	2.885E-01	8.210E-02	2.368E-02	7.220E+00	2.083E+00	8.210E-02	2.368E-02	7.220E+00	2.083E+00
	10400.00	1.2013	1.1240	3.269E-01	7.734E-02	2.528E-02	6.438E+00	2.105E+00	7.734E-02	2.528E-02	6.438E+00	2.105E+00
AVERAGE				1.000E+00	1.452E-01	9.710E-02	2.773E+01	9.456E+00	1.452E-01	9.710E-02	2.773E+01	9.456E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2E	1.00	0.1800	0.0778	9.615E-05	1.022E-01	9.827E-06	5.678E+01	5.459E-03	1.022E-01	9.827E-06	5.678E+01	5.459E-03
(3918)	5.00	0.2599	0.0831	3.846E-04	1.768E-01	6.800E-05	6.803E+01	2.616E-02	1.768E-01	6.800E-05	6.803E+01	2.616E-02
	10.00	0.2799	0.0896	4.808E-04	1.903E-01	9.149E-05	6.799E+01	3.269E-02	1.903E-01	9.149E-05	6.799E+01	3.269E-02
	100.00	0.4290	0.1806	8.654E-03	2.484E-01	2.150E-03	5.790E+01	5.011E-01	2.484E-01	2.150E-03	5.790E+01	5.011E-01
	500.00	0.6248	0.3784	3.846E-02	2.464E-01	9.477E-03	3.944E+01	1.517E+00	2.464E-01	9.477E-03	3.944E+01	1.517E+00
	1000.00	0.7197	0.4994	4.808E-02	2.203E-01	1.059E-02	3.061E+01	1.472E+00	2.203E-01	1.059E-02	3.061E+01	1.472E+00
	3990.00	0.9585	0.7665	2.875E-01	1.920E-01	5.520E-02	2.003E+01	5.759E+00	1.920E-01	5.520E-02	2.003E+01	5.759E+00
	4000.00	0.9483	0.7674	9.615E-04	1.809E-01	1.739E-04	1.908E+01	1.834E-02	1.809E-01	1.739E-04	1.908E+01	1.834E-02
	7000.00	1.0771	0.8769	2.885E-01	2.002E-01	5.775E-02	1.859E+01	5.362E+00	2.002E-01	5.775E-02	1.859E+01	5.362E+00
	10400.00	1.1213	0.9448	3.269E-01	1.765E-01	5.772E-02	1.574E+01	5.147E+00	1.765E-01	5.772E-02	1.574E+01	5.147E+00
AVERAGE				1.000E+00	1.934E-01	1.932E-01	3.942E+01	1.984E+01	1.934E-01	1.932E-01	3.942E+01	1.984E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-3	1.00	0.2100	0.1838	9.615E-05	2.620E-02	2.519E-06	1.248E+01	1.200E-03	2.620E-02	2.519E-06	1.248E+01	1.200E-03

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(3921)	5.00	0.2699	0.1969	3.846E-04	7.300E-02	2.808E-05	2.705E+01	1.040E-02	7.300E-02	2.808E-05	2.705E+01	1.040E-02
	10.00	0.3099	0.2140	4.808E-04	9.590E-02	4.611E-05	3.095E+01	1.488E-02	9.590E-02	4.611E-05	3.095E+01	1.488E-02
	100.00	0.5190	0.4193	8.654E-03	9.970E-02	8.628E-04	1.921E+01	1.662E-01	9.970E-02	8.628E-04	1.921E+01	1.662E-01
	500.00	0.6648	0.7185	3.846E-02	-5.370E-02	-2.065E-03	-8.078E+00	-3.107E-01	5.370E-02	2.065E-03	8.078E+00	3.107E-01
	1000.00	0.7496	0.8658	4.808E-02	-1.162E-01	-5.587E-03	-1.550E+01	-7.453E-01	1.162E-01	5.587E-03	1.550E+01	7.453E-01
	3990.00	0.9685	1.1570	2.875E-01	-1.885E-01	-5.419E-02	-1.946E+01	-5.596E+00	1.885E-01	5.419E-02	1.946E+01	5.596E+00
	4000.00	0.9683	1.1590	9.615E-04	-1.907E-01	-1.834E-04	-1.969E+01	-1.894E-02	1.907E-01	1.834E-04	1.969E+01	1.894E-02
	7000.00	1.0771	1.2730	2.885E-01	-1.959E-01	-5.651E-02	-1.819E+01	-5.246E+00	1.959E-01	5.651E-02	1.819E+01	5.246E+00
	10400.00	1.1513	1.3430	3.269E-01	-1.917E-01	-6.266E-02	-1.665E+01	-5.442E+00	1.917E-01	6.266E-02	1.665E+01	5.442E+00
AVERAGE				1.000E+00	-6.419E-02	-1.803E-01	-7.892E-01	-1.717E+01	1.231E-01	1.821E-01	1.872E+01	1.755E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-4	1.00	0.0100	0.0152	9.615E-05	-5.200E-03	-5.000E-07	-5.200E+01	-5.000E-03	5.200E-03	5.000E-07	5.200E+01	5.000E-03
(3922)	5.00	0.0299	0.0164	3.846E-04	1.350E-02	5.192E-06	4.515E+01	1.737E-02	1.350E-02	5.192E-06	4.515E+01	1.737E-02
	10.00	0.0499	0.0180	4.808E-04	3.190E-02	1.534E-05	6.393E+01	3.073E-02	3.190E-02	1.534E-05	6.393E+01	3.073E-02
	100.00	0.1490	0.0520	8.654E-03	9.700E-02	8.394E-04	6.510E+01	5.634E-01	9.700E-02	8.394E-04	6.510E+01	5.634E-01
	500.00	0.3048	0.2055	3.846E-02	9.930E-02	3.819E-03	3.258E+01	1.253E+00	9.930E-02	3.819E-03	3.258E+01	1.253E+00
	1000.00	0.3896	0.3246	4.808E-02	6.500E-02	3.125E-03	1.668E+01	8.021E-01	6.500E-02	3.125E-03	1.668E+01	8.021E-01
	3990.00	0.6085	0.5996	2.875E-01	8.900E-03	2.559E-03	1.463E+00	4.205E-01	8.900E-03	2.559E-03	1.463E+00	4.205E-01
	4000.00	0.6183	0.6005	9.615E-04	1.780E-02	1.712E-05	2.879E+00	2.768E-03	1.780E-02	1.712E-05	2.879E+00	2.768E-03
	7000.00	0.7171	0.7139	2.885E-01	3.200E-03	9.231E-04	4.462E-01	1.287E-01	3.200E-03	9.231E-04	4.462E-01	1.287E-01
	10400.00	0.7913	0.7852	3.269E-01	6.141E-03	2.008E-03	7.760E-01	2.537E-01	6.141E-03	2.008E-03	7.760E-01	2.537E-01
AVERAGE				1.000E+00	3.375E-02	1.331E-02	1.770E+01	3.467E+00	3.479E-02	1.331E-02	2.810E+01	3.477E+00
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-5	1.00	0.2400	0.1796	9.615E-05	6.040E-02	5.808E-06	2.517E+01	2.420E-03	6.040E-02	5.808E-06	2.517E+01	2.420E-03
(3923)	5.00	0.3199	0.1928	3.846E-04	1.271E-01	4.888E-05	3.973E+01	1.528E-02	1.271E-01	4.888E-05	3.973E+01	1.528E-02
	10.00	0.3399	0.2092	4.808E-04	1.307E-01	6.284E-05	3.845E+01	1.849E-02	1.307E-01	6.284E-05	3.845E+01	1.849E-02
	100.00	0.5390	0.4075	8.654E-03	1.315E-01	1.138E-03	2.440E+01	2.111E-01	1.315E-01	1.138E-03	2.440E+01	2.111E-01
	500.00	0.7148	0.6915	3.846E-02	2.330E-02	8.962E-04	3.260E+00	1.254E-01	2.330E-02	8.962E-04	3.260E+00	1.254E-01
	1000.00	0.7896	0.8314	4.808E-02	-4.180E-02	-2.010E-03	-5.294E+00	-2.545E-01	4.180E-02	2.010E-03	5.294E+00	2.545E-01
	3990.00	1.0485	1.1130	2.875E-01	-6.450E-02	-1.854E-02	-6.152E+00	-1.769E+00	6.450E-02	1.854E-02	6.152E+00	1.769E+00
	4000.00	1.0383	1.1140	9.615E-04	-7.570E-02	-7.279E-05	-7.291E+00	-7.010E-03	7.570E-02	7.279E-05	7.291E+00	7.010E-03
	7000.00	1.1471	1.2250	2.885E-01	-7.790E-02	-2.247E-02	-6.791E+00	-1.959E+00	7.790E-02	2.247E-02	6.791E+00	1.959E+00
	10400.00	1.2313	1.2930	3.269E-01	-6.166E-02	-2.016E-02	-5.007E+00	-1.637E+00	6.166E-02	2.016E-02	5.007E+00	1.637E+00
AVERAGE				1.000E+00	1.514E-02	-6.110E-02	1.005E+01	-5.253E+00	7.946E-02	6.541E-02	1.615E+01	5.999E+00

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
2002	1.00	-0.0700	0.0000	9.615E-05	-7.000E-02	-6.731E-06	1.000E+02	9.615E-03	7.000E-02	6.731E-06	-1.000E+02	-9.615E-03
	5.00	-0.0500	0.0003	3.846E-04	-5.030E-02	-1.935E-05	1.006E+02	3.869E-02	5.030E-02	1.935E-05	-1.006E+02	-3.869E-02
	10.00	-0.0020	0.0006	4.808E-04	-2.600E-03	-1.250E-06	1.300E+02	6.250E-02	2.600E-03	1.250E-06	-1.300E+02	-6.250E-02
	100.00	0.0690	0.0178	8.654E-03	5.120E-02	4.431E-04	7.420E+01	6.421E-01	5.120E-02	4.431E-04	7.420E+01	6.421E-01
	500.00	0.2098	0.1778	3.846E-02	3.200E-02	1.231E-03	1.525E+01	5.866E-01	3.200E-02	1.231E-03	1.525E+01	5.866E-01
	1000.00	0.3000	0.2972	4.808E-02	2.800E-03	1.346E-04	9.333E-01	4.487E-02	2.800E-03	1.346E-04	9.333E-01	4.487E-02
	3990.00	0.5035	0.5601	2.875E-01	-5.660E-02	-1.627E-02	-1.124E+01	-3.232E+00	5.660E-02	1.627E-02	1.124E+01	3.232E+00
	4000.00	0.5133	0.5610	9.615E-04	-4.770E-02	-4.587E-05	-9.293E+00	-8.935E-03	4.770E-02	4.587E-05	9.293E+00	8.935E-03
	7000.00	0.6271	0.6668	2.885E-01	-3.970E-02	-1.145E-02	-6.331E+00	-1.826E+00	3.970E-02	1.145E-02	6.331E+00	1.826E+00
	10400.00	0.7113	0.7316	3.269E-01	-2.026E-02	-6.623E-03	-2.848E+00	-9.311E-01	2.026E-02	6.623E-03	2.848E+00	9.311E-01
AVERAGE				1.000E+00	-2.012E-02	-3.261E-02	3.913E+01	-4.614E+00	3.732E-02	3.623E-02	-2.105E+01	7.161E+00
					Variance =	0.019531619					Average =	8.697E+00

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APPENDIX A6

FINAL DRAWDOWN AND RECOVERY CURVES FOR CALIBRATION (CRT)

File : wellw14r.dat
Comment : With Recovery Period

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Well No. : RW-4

Well Coord. : X = 58 Y = 58 Z = 1- 2

Time Sequence (min.)	Drawdown (ft)	BHP Drawdown (ft)
0.00000E+00	0.0000E+0	0.0000E+0
0.99994E+00	0.2238E+0	0.1649E+2
0.49997E+01	0.7940E+0	0.1698E+2
0.99994E+01	0.1150E+1	0.1728E+2
0.99994E+02	0.2136E+1	0.1814E+2
0.49997E+03	0.2651E+1	0.1862E+2
0.99994E+03	0.2838E+1	0.1880E+2
0.39859E+04	0.3167E+1	0.1912E+2
0.40046E+04	0.3168E+1	0.1682E+2
0.69998E+04	0.3291E+1	0.1694E+2
0.10440E+05	0.3367E+1	0.1701E+2
0.10471E+05	0.3368E+1	0.1702E+2
0.10471E+05	0.3357E+1	0.3357E+1
0.10471E+05	0.3332E+1	0.3332E+1
0.10471E+05	0.3308E+1	0.3308E+1
0.10471E+05	0.3257E+1	0.3257E+1
0.10472E+05	0.3075E+1	0.3075E+1
0.11006E+05	0.6564E+0	0.6564E+0
0.12038E+05	0.4092E+0	0.4092E+0
0.13009E+05	0.3132E+0	0.3132E+0
0.15032E+05	0.2039E+0	0.2039E+0
0.17280E+05	0.1354E+0	0.1354E+0
0.20160E+05	0.8282E-1	0.8282E-1

Well No. : SPPZ-1

Well Coord. : X = 60 Y = 58 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.1829E+0
0.49997E+01	0.1960E+0
0.99994E+01	0.2129E+0
0.99994E+02	0.4163E+0
0.49997E+03	0.7086E+0
0.99994E+03	0.8524E+0
0.39859E+04	0.1139E+1
0.40046E+04	0.1140E+1
0.69998E+04	0.1253E+1
0.10440E+05	0.1322E+1
0.10471E+05	0.1322E+1
0.10471E+05	0.1153E+1
0.10471E+05	0.1147E+1
0.10471E+05	0.1146E+1
0.10471E+05	0.1145E+1

0.10472E+05	0.1142E+1
0.11006E+05	0.5982E+0
0.12038E+05	0.3904E+0
0.13009E+05	0.3020E+0
0.15032E+05	0.1981E+0
0.17280E+05	0.1318E+0
0.20160E+05	0.8081E-1

Well No. : SPPZ-2A

Well Coord. : X = 58 Y = 57 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.4114E+0
0.49997E+01	0.4387E+0
0.99994E+01	0.4692E+0
0.99994E+02	0.7259E+0
0.49997E+03	0.1036E+1
0.99994E+03	0.1184E+1
0.39859E+04	0.1476E+1
0.40046E+04	0.1477E+1
0.69998E+04	0.1591E+1
0.10440E+05	0.1661E+1
0.10471E+05	0.1662E+1
0.10471E+05	0.1270E+1
0.10471E+05	0.1263E+1
0.10471E+05	0.1262E+1
0.10471E+05	0.1260E+1
0.10472E+05	0.1254E+1
0.11006E+05	0.6068E+0
0.12038E+05	0.3946E+0
0.13009E+05	0.3050E+0
0.15032E+05	0.2002E+0
0.17280E+05	0.1334E+0
0.20160E+05	0.8196E-1

Well No. : SPPZ-2C

Well Coord. : X = 58 Y = 57 Z = 4- 4

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.1471E+0
0.49997E+01	0.1568E+0
0.99994E+01	0.1679E+0
0.99994E+02	0.3011E+0
0.49997E+03	0.5361E+0
0.99994E+03	0.6668E+0
0.39859E+04	0.9429E+0
0.40046E+04	0.9438E+0
0.69998E+04	0.1055E+1

0.10440E+05	0.1124E+1
0.10471E+05	0.1124E+1
0.10471E+05	0.9937E+0
0.10471E+05	0.9829E+0
0.10471E+05	0.9817E+0
0.10471E+05	0.9810E+0
0.10472E+05	0.9787E+0
0.11006E+05	0.5770E+0
0.12038E+05	0.3844E+0
0.13009E+05	0.2990E+0
0.15032E+05	0.1969E+0
0.17280E+05	0.1316E+0
0.20160E+05	0.8058E-1

Well No. : SPPZ-2E

Well Coord. : X = 58 Y = 57 Z = 6- 6

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.7781E-1
0.49997E+01	0.8312E-1
0.99994E+01	0.8959E-1
0.99994E+02	0.1806E+0
0.49997E+03	0.3784E+0
0.99994E+03	0.4994E+0
0.39859E+04	0.7665E+0
0.40046E+04	0.7674E+0
0.69998E+04	0.8769E+0
0.10440E+05	0.9448E+0
0.10471E+05	0.9452E+0
0.10471E+05	0.8859E+0
0.10471E+05	0.8713E+0
0.10471E+05	0.8702E+0
0.10471E+05	0.8697E+0
0.10472E+05	0.8686E+0
0.11006E+05	0.5587E+0
0.12038E+05	0.3780E+0
0.13009E+05	0.2951E+0
0.15032E+05	0.1951E+0
0.17280E+05	0.1302E+0
0.20160E+05	0.7989E-1

Well No. : SPPZ-3

Well Coord. : X = 58 Y = 56 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.1838E+0
0.49997E+01	0.1969E+0
0.99994E+01	0.2140E+0

0.99994E+02	0.4193E+0
0.49997E+03	0.7185E+0
0.99994E+03	0.8658E+0
0.39859E+04	0.1157E+1
0.40046E+04	0.1159E+1
0.69998E+04	0.1273E+1
0.10440E+05	0.1343E+1
0.10471E+05	0.1344E+1
0.10471E+05	0.1174E+1
0.10471E+05	0.1167E+1
0.10471E+05	0.1167E+1
0.10471E+05	0.1166E+1
0.10472E+05	0.1163E+1
0.11006E+05	0.6091E+0
0.12038E+05	0.3964E+0
0.13009E+05	0.3066E+0
0.15032E+05	0.2013E+0
0.17280E+05	0.1344E+0
0.20160E+05	0.8242E-1

Well No. : SPPZ-4

Well Coord. : X = 58 Y = 50 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.1524E-1
0.49997E+01	0.1639E-1
0.99994E+01	0.1801E-1
0.99994E+02	0.5195E-1
0.49997E+03	0.2055E+0
0.99994E+03	0.3246E+0
0.39859E+04	0.5996E+0
0.40046E+04	0.6005E+0
0.69998E+04	0.7139E+0
0.10440E+05	0.7852E+0
0.10471E+05	0.7857E+0
0.10471E+05	0.7762E+0
0.10471E+05	0.7721E+0
0.10471E+05	0.7716E+0
0.10471E+05	0.7714E+0
0.10472E+05	0.7711E+0
0.11006E+05	0.5760E+0
0.12038E+05	0.3941E+0
0.13009E+05	0.3085E+0
0.15032E+05	0.2053E+0
0.17280E+05	0.1383E+0
0.20160E+05	0.8566E-1

Well No. : SPPZ-5

Well Coord. : X = 58 Y = 60 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.1796E+0
0.49997E+01	0.1928E+0
0.99994E+01	0.2092E+0
0.99994E+02	0.4075E+0
0.49997E+03	0.6915E+0
0.99994E+03	0.8314E+0
0.39859E+04	0.1113E+1
0.40046E+04	0.1114E+1
0.69998E+04	0.1225E+1
0.10440E+05	0.1293E+1
0.10471E+05	0.1294E+1
0.10471E+05	0.1127E+1
0.10471E+05	0.1121E+1
0.10471E+05	0.1120E+1
0.10471E+05	0.1120E+1
0.10472E+05	0.1117E+1
0.11006E+05	0.5874E+0
0.12038E+05	0.3844E+0
0.13009E+05	0.2974E+0
0.15032E+05	0.1949E+0
0.17280E+05	0.1295E+0
0.20160E+05	0.7919E-1

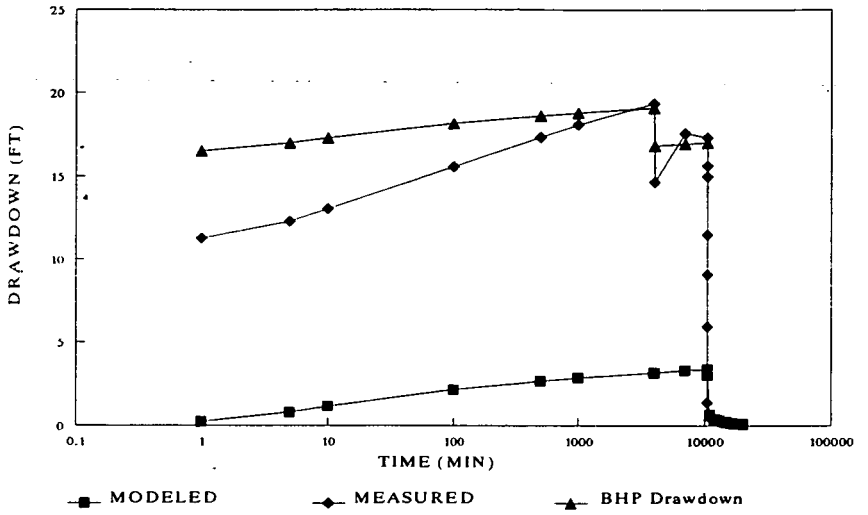
Well No. : 2002

Well Coord. : X = 62 Y = 65 Z = 1- 1

Time Sequence (min.)	Drawdown (ft)
0.00000E+00	0.0000E+0
0.99994E+00	0.4624E-4
0.49997E+01	0.2543E-3
0.99994E+01	0.5774E-3
0.99994E+02	0.1780E-1
0.49997E+03	0.1778E+0
0.99994E+03	0.2972E+0
0.39859E+04	0.5601E+0
0.40046E+04	0.5610E+0
0.69998E+04	0.6668E+0
0.10440E+05	0.7316E+0
0.10471E+05	0.7320E+0
0.10471E+05	0.7320E+0
0.10471E+05	0.7320E+0
0.10471E+05	0.7320E+0
0.10471E+05	0.7320E+0
0.10472E+05	0.7320E+0
0.11006E+05	0.5494E+0
0.12038E+05	0.3688E+0
0.13009E+05	0.2864E+0
0.15032E+05	0.1873E+0
0.17280E+05	0.1239E+0
0.20160E+05	0.7534E-1

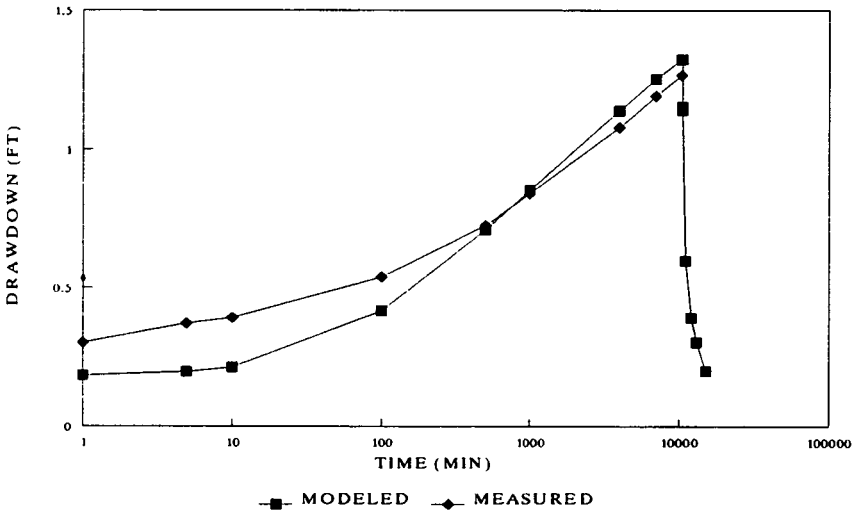
WELL: RW-4

MEASURED VS MODELED DRAWDOWN



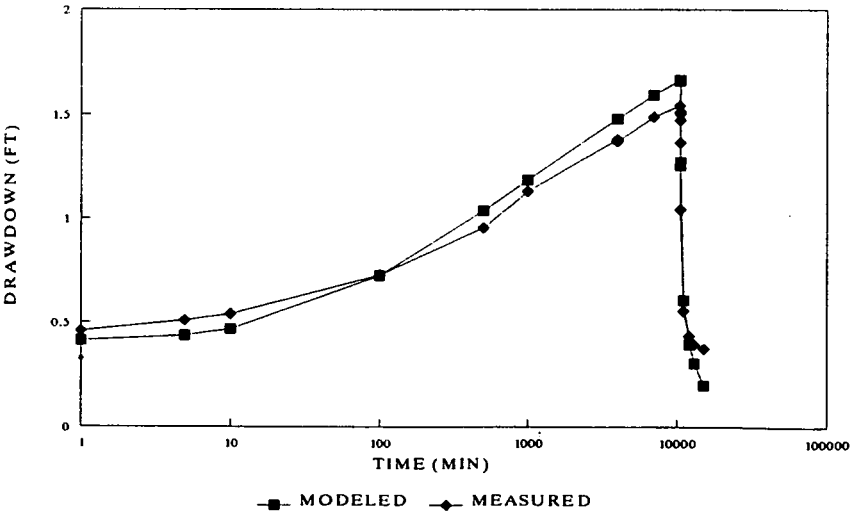
WELL: SPPZ-1

MEASURED VS MODELED DRAWDOWN



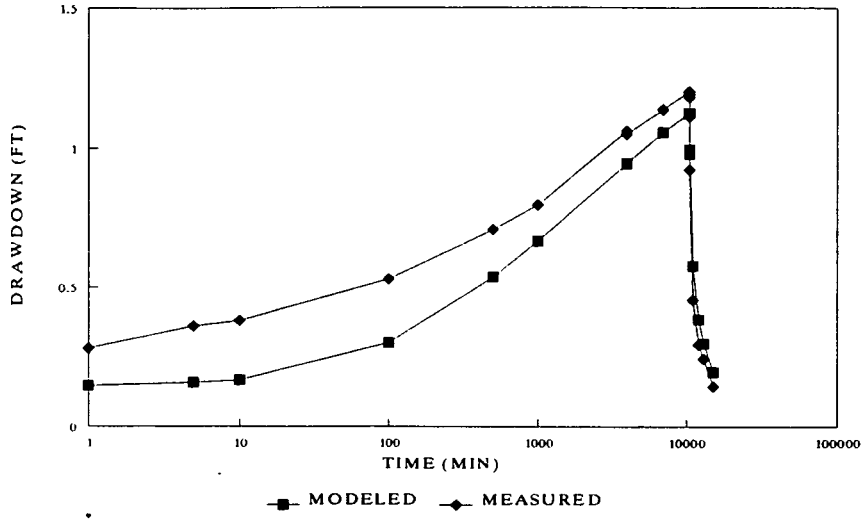
WELL: SPPZ-2A

MEASURED VS MODELED DRAWDOWN



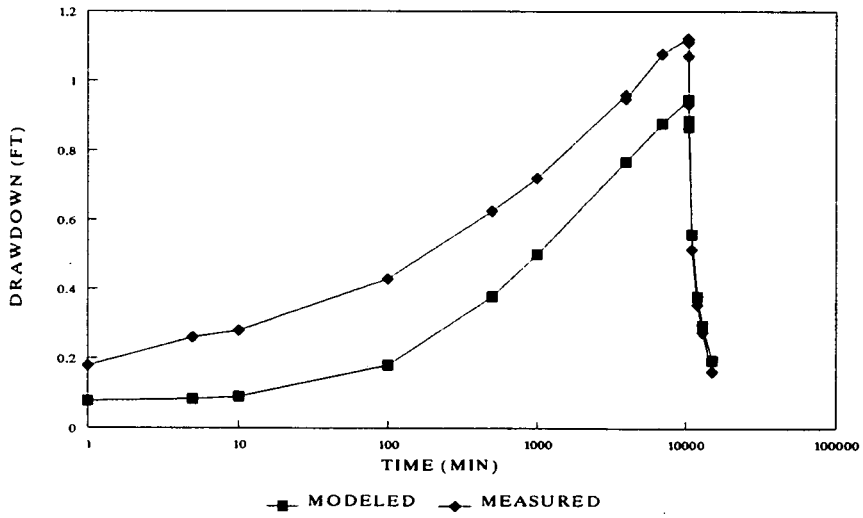
WELL: SPPZ-2C

MEASURED VS MODELED DRAWDOWN



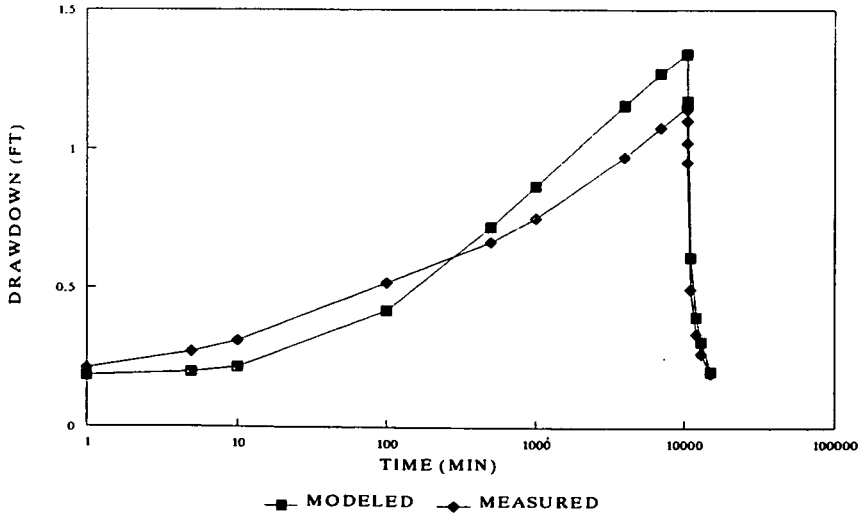
WELL: SPPZ-2E

MEASURED VS MODELED DRAWDOWN



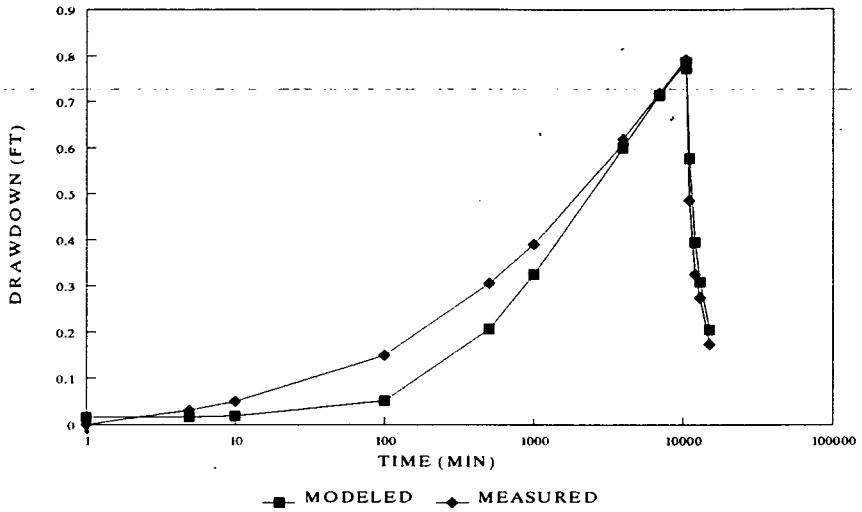
WELL: SPPZ-3

MEASURED VS MODELED DRAWDOWN



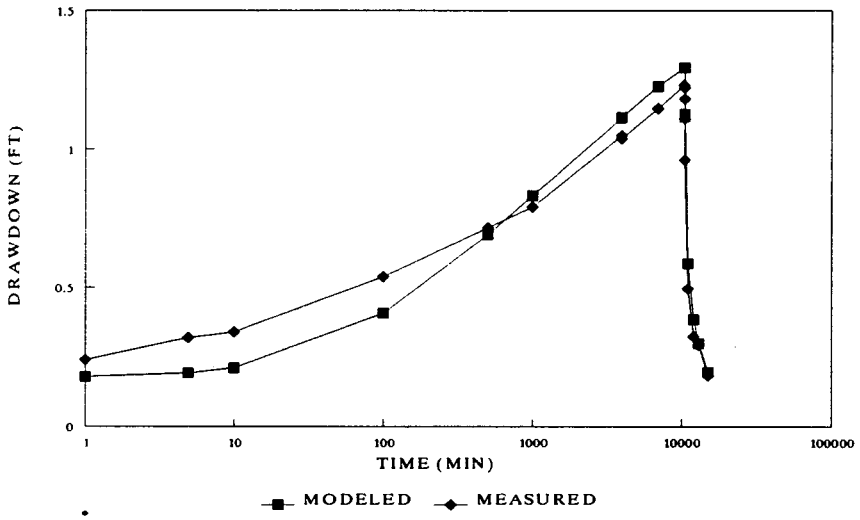
WELL: SPPZ-4

MEASURED VS MODELED DRAWDOWN



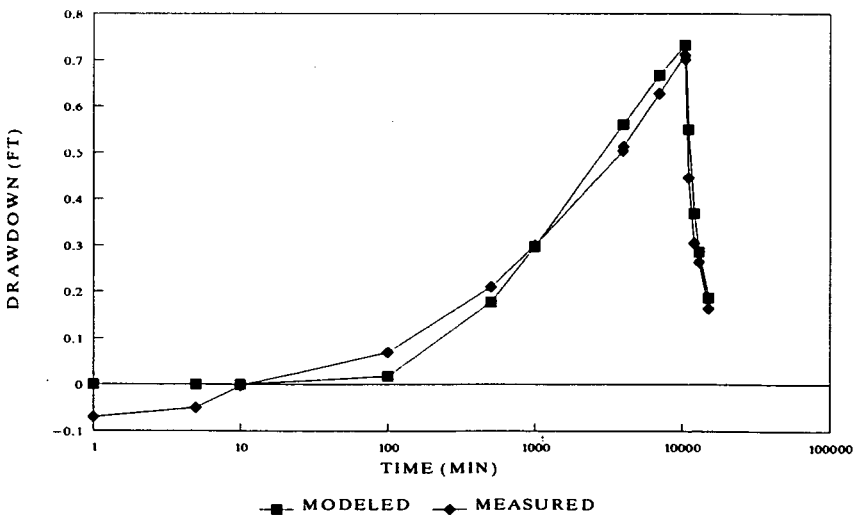
WELL: SPPZ-5

MEASURED VS MODELED DRAWDOWN



WELL: 2002

MEASURED VS MODELED DRAWDOWN



APPENDIX A7

FINAL CALIBRATION RUN STATISTICS (CRT)

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
RW-4	1.00	11.2330	16.4900	6.652E-05	-5.257E+00	-3.497E-04	-4.680E+01	-3.113E-03	5.257E+00	3.497E-04	4.680E+01	3.113E-03
(3927)	5.00	12.2680	16.9800	2.661E-04	-4.712E+00	-1.254E-03	-3.841E+01	-1.022E-02	4.712E+00	1.254E-03	3.841E+01	1.022E-02
	10.00	13.0230	17.2800	3.326E-04	-4.257E+00	-1.416E-03	-3.269E+01	-1.087E-02	4.257E+00	1.416E-03	3.269E+01	1.087E-02
	100.00	15.5330	18.1400	5.987E-03	-2.607E+00	-1.561E-02	-1.678E+01	-1.005E-01	2.607E+00	1.561E-02	1.678E+01	1.005E-01
	500.00	17.3330	18.6200	2.661E-02	-1.287E+00	-3.425E-02	-7.425E+00	-1.976E-01	1.287E+00	3.425E-02	7.425E+00	1.976E-01
	1000.00	18.0630	18.8000	3.326E-02	-7.370E-01	-2.451E-02	-4.080E+00	-1.357E-01	7.370E-01	2.451E-02	4.080E+00	1.357E-01
	3990.00	19.3513	19.1200	1.989E-01	2.313E-01	4.601E-02	1.195E+00	2.377E-01	2.313E-01	4.601E-02	1.195E+00	2.377E-01
	4000.00	14.6313	16.8200	6.652E-04	-2.189E+00	-1.456E-03	-1.496E+01	-9.951E-03	2.189E+00	1.456E-03	1.496E+01	9.951E-03
	7000.00	17.6000	16.9400	1.996E-01	6.600E-01	1.317E-01	3.750E+00	7.484E-01	6.600E-01	1.317E-01	3.750E+00	7.484E-01
	10400.00	17.3243	17.0100	2.262E-01	3.143E-01	7.109E-02	1.814E+00	4.103E-01	3.143E-01	7.109E-02	1.814E+00	4.103E-01
	10470.97	15.6040	17.0200	4.721E-03	-1.416E+00	-6.685E-03	-9.075E+00	-4.284E-02	1.416E+00	6.685E-03	9.075E+00	4.284E-02
	10471.02	14.9840	3.3570	3.326E-06	1.163E+01	3.867E-05	7.760E+01	2.581E-04	1.163E+01	3.867E-05	7.760E+01	2.581E-04
	10471.12	11.4840	3.3320	6.652E-06	8.152E+00	5.423E-05	7.099E+01	4.722E-04	8.152E+00	5.423E-05	7.099E+01	4.722E-04
	10471.22	9.0740	3.3080	6.652E-06	5.766E+00	3.836E-05	6.354E+01	4.227E-04	5.766E+00	3.836E-05	6.354E+01	4.227E-04
	10471.43	5.9540	3.2570	1.397E-05	2.697E+00	3.768E-05	4.530E+01	6.328E-04	2.697E+00	3.768E-05	4.530E+01	6.328E-04
	10472.32	1.3840	3.0750	5.921E-05	-1.691E+00	-1.001E-04	-1.222E+02	-7.234E-03	1.691E+00	1.001E-04	1.222E+02	7.234E-03
	11006.38	0.4680	0.6564	3.553E-02	-1.884E-01	-6.693E-03	-4.026E+01	-1.430E+00	1.884E-01	6.693E-03	4.026E+01	1.430E+00
	12307.61	0.3080	0.4092	8.656E-02	-1.012E-01	-8.760E-03	-3.286E+01	-2.844E+00	1.012E-01	8.760E-03	3.286E+01	2.844E+00
	13009.34	0.2480	0.3132	4.668E-02	-6.520E-02	-3.044E-03	-2.629E+01	-1.227E+00	6.520E-02	3.044E-03	2.629E+01	1.227E+00
	15032.14	0.1460	0.2039	1.346E-01	-5.790E-02	-7.791E-03	-3.966E+01	-5.337E+00	5.790E-02	7.791E-03	3.966E+01	5.337E+00
AVERAGE				1.000E+00	2.441E-01	1.371E-01	-8.364E+00	-9.958E+00	2.701E+00	3.609E-01	3.478E+01	1.275E+01

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-1	1.00	0.3000	0.1829	6.652E-05	1.171E-01	7.790E-06	3.903E+01	2.597E-03	1.171E-01	7.790E-06	3.903E+01	2.597E-03
(3910)	5.00	0.3699	0.1960	2.661E-04	1.739E-01	4.627E-05	4.701E+01	1.251E-02	1.739E-01	4.627E-05	4.701E+01	1.251E-02
	10.00	0.3899	0.2129	3.326E-04	1.770E-01	5.887E-05	4.540E+01	1.510E-02	1.770E-01	5.887E-05	4.540E+01	1.510E-02
	100.00	0.5390	0.4163	5.987E-03	1.227E-01	7.346E-04	2.276E+01	1.363E-01	1.227E-01	7.346E-04	2.276E+01	1.363E-01
	500.00	0.7250	0.7086	2.661E-02	1.640E-02	4.364E-04	2.262E+00	6.019E-02	1.640E-02	4.364E-04	2.262E+00	6.019E-02
	1000.00	0.8396	0.8524	3.326E-02	-1.280E-02	-4.258E-04	-1.525E+00	-5.071E-02	1.280E-02	4.258E-04	1.525E+00	5.071E-02
	3990.00	1.0785	1.1390	1.989E-01	-6.050E-02	-1.203E-02	-5.610E+00	-1.116E+00	6.050E-02	1.203E-02	5.610E+00	1.116E+00
	4000.00	1.0782	1.1400	6.652E-04	-6.180E-02	-4.111E-05	-5.732E+00	-3.813E-03	6.180E-02	4.111E-05	5.732E+00	3.813E-03
	7000.00	1.1921	1.2530	1.996E-01	-6.090E-02	-1.215E-02	-5.109E+00	-1.020E+00	6.090E-02	1.215E-02	5.109E+00	1.020E+00
	10400.00	1.2663	1.3220	2.262E-01	-5.570E-02	-1.260E-02	-4.399E+00	-9.949E-01	5.570E-02	1.260E-02	4.399E+00	9.949E-01
	10470.97	1.2659	1.3220	4.721E-03	-5.610E-02	-2.649E-04	-4.432E+00	-2.092E-02	5.610E-02	2.649E-04	4.432E+00	2.092E-02
	10471.02	1.2659	1.1530	3.326E-06	1.129E-01	3.755E-07	8.919E+00	2.966E-05	1.129E-01	3.755E-07	8.919E+00	2.966E-05
	10471.12	1.2559	1.1470	6.652E-06	1.089E-01	7.244E-07	8.671E+00	5.768E-05	1.089E-01	7.244E-07	8.671E+00	5.768E-05

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	10471.22	1.2259	1.1460	6.652E-06	7.990E-02	5.315E-07	6.518E+00	4.336E-05	7.990E-02	5.315E-07	6.518E+00	4.336E-05
	10471.43	1.1559	1.1450	1.397E-05	1.090E-02	1.523E-07	9.430E-01	1.317E-05	1.090E-02	1.523E-07	9.430E-01	1.317E-05
	10472.32	0.9759	1.1420	5.921E-05	-1.661E-01	-9.834E-06	-1.702E+01	-1.008E-03	1.661E-01	9.834E-06	1.702E+01	1.008E-03
	11006.38	0.5004	0.5982	3.553E-02	-9.780E-02	-3.475E-03	-1.954E+01	-6.944E-01	9.780E-02	3.475E-03	1.954E+01	6.944E-01
	12307.61	0.3396	0.3904	8.656E-02	-5.080E-02	-4.397E-03	-1.496E+01	-1.295E+00	5.080E-02	4.397E-03	1.496E+01	1.295E+00
	13009.34	0.2695	0.3020	4.668E-02	-3.250E-02	-1.517E-03	-1.206E+01	-5.630E-01	3.250E-02	1.517E-03	1.206E+01	5.630E-01
	15032.14	0.1684	0.1981	1.346E-01	-2.970E-02	-3.997E-03	-1.764E+01	-2.373E+00	2.970E-02	3.997E-03	1.764E+01	2.373E+00
AVERAGE				1.000E+00	1.175E-02	-4.963E-02	3.675E+00	-7.905E+00	8.022E-02	5.220E-02	1.448E+01	8.359E+00
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2A	1.00	0.4600	0.4114	6.652E-05	4.860E-02	3.233E-06	1.057E+01	7.028E-04	4.860E-02	3.233E-06	1.057E+01	7.028E-04
(3911)	5.00	0.5099	0.4387	2.661E-04	7.120E-02	1.895E-05	1.396E+01	3.716E-03	7.120E-02	1.895E-05	1.396E+01	3.716E-03
	10.00	0.5399	0.4692	3.326E-04	7.070E-02	2.352E-05	1.310E+01	4.356E-03	7.070E-02	2.352E-05	1.310E+01	4.356E-03
	100.00	0.7290	0.7259	5.987E-03	3.100E-03	1.856E-05	4.252E-01	2.546E-03	3.100E-03	1.856E-05	4.252E-01	2.546E-03
	500.00	0.9548	1.0360	2.661E-02	-8.120E-02	-2.161E-03	-8.504E+00	-2.263E-01	8.120E-02	2.161E-03	8.504E+00	2.263E-01
	1000.00	1.1300	1.1840	3.326E-02	-5.400E-02	-1.796E-03	-4.779E+00	-1.590E-01	5.400E-02	1.796E-03	4.779E+00	1.590E-01
	3990.00	1.3785	1.4760	1.989E-01	-9.750E-02	-1.939E-02	-7.073E+00	-1.407E+00	9.750E-02	1.939E-02	7.073E+00	1.407E+00
	4000.00	1.3683	1.4770	6.652E-04	-1.087E-01	-7.231E-05	-7.944E+00	-5.285E-03	1.087E-01	7.231E-05	7.944E+00	5.285E-03
	7000.00	1.4871	1.5910	1.996E-01	-1.039E-01	-2.074E-02	-6.987E+00	-1.394E+00	1.039E-01	2.074E-02	6.987E+00	1.394E+00
	10400.00	1.5413	1.6610	2.262E-01	-1.197E-01	-2.707E-02	-7.766E+00	-1.757E+00	1.197E-01	2.707E-02	7.766E+00	1.757E+00
	10470.97	1.4709	1.6620	4.721E-03	-1.911E-01	-9.022E-04	-1.299E+01	-6.134E-02	1.911E-01	9.022E-04	1.299E+01	6.134E-02
	10471.02	1.5009	1.2700	3.326E-06	2.309E-01	7.680E-07	1.538E+01	5.117E-05	2.309E-01	7.680E-07	1.538E+01	5.117E-05
	10471.12	1.5109	1.2630	6.652E-06	2.479E-01	1.649E-06	1.641E+01	1.091E-04	2.479E-01	1.649E-06	1.641E+01	1.091E-04
	10471.22	1.5009	1.2620	6.652E-06	2.389E-01	1.589E-06	1.592E+01	1.059E-04	2.389E-01	1.589E-06	1.592E+01	1.059E-04
	10471.43	1.3609	1.2600	1.397E-05	1.009E-01	1.410E-06	7.414E+00	1.036E-04	1.009E-01	1.410E-06	7.414E+00	1.036E-04
	10472.32	1.0409	1.2540	5.921E-05	-2.131E-01	-1.262E-05	-2.047E+01	-1.212E-03	2.131E-01	1.262E-05	2.047E+01	1.212E-03
	11006.38	0.5554	0.6068	3.553E-02	-5.140E-02	-1.826E-03	-9.255E+00	-3.288E-01	5.140E-02	1.826E-03	9.255E+00	3.288E-01
	12307.61	0.4346	0.3946	8.656E-02	4.000E-02	3.463E-03	9.204E+00	7.967E-01	4.000E-02	3.463E-03	9.204E+00	7.967E-01
	13009.34	0.3945	0.3050	4.668E-02	8.950E-02	4.178E-03	2.269E+01	1.059E+00	8.950E-02	4.178E-03	2.269E+01	1.059E+00
	15032.14	0.3734	0.2002	1.346E-01	1.732E-01	2.331E-02	4.638E+01	6.242E+00	1.732E-01	2.331E-02	4.638E+01	6.242E+00
AVERAGE				1.000E+00	1.472E-02	-4.296E-02	4.284E+00	2.770E+00	1.168E-01	1.050E-01	1.286E+01	1.345E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2C	1.00	0.2800	0.1471	6.652E-05	1.329E-01	8.841E-06	4.746E+01	3.158E-03	1.329E-01	8.841E-06	4.746E+01	3.158E-03
(3916)	5.00	0.3599	0.1568	2.661E-04	2.031E-01	5.404E-05	5.643E+01	1.502E-02	2.031E-01	5.404E-05	5.643E+01	1.502E-02
	10.00	0.3799	0.1679	3.326E-04	2.120E-01	7.052E-05	5.580E+01	1.856E-02	2.120E-01	7.052E-05	5.580E+01	1.856E-02
	100.00	0.5290	0.3011	5.987E-03	2.279E-01	1.364E-03	4.308E+01	2.579E-01	2.279E-01	1.364E-03	4.308E+01	2.579E-01
	500.00	0.7048	0.5361	2.661E-02	1.687E-01	4.489E-03	2.394E+01	6.369E-01	1.687E-01	4.489E-03	2.394E+01	6.369E-01

	1000.00	0.7945	0.6668	3.326E-02	1.277E-01	4.248E-03	1.607E+01	5.346E-01	1.277E-01	4.248E-03	1.607E+01	5.346E-01
	3990.00	1.0585	0.9429	1.989E-01	1.156E-01	2.299E-02	1.092E+01	2.172E+00	1.156E-01	2.299E-02	1.092E+01	2.172E+00
	4000.00	1.0483	0.9438	6.652E-04	1.045E-01	6.952E-05	9.969E+00	6.631E-03	1.045E-01	6.952E-05	9.969E+00	6.631E-03
	7000.00	1.1371	1.0550	1.996E-01	8.210E-02	1.638E-02	7.220E+00	1.441E+00	8.210E-02	1.638E-02	7.220E+00	1.441E+00
	10400.00	1.2013	1.1240	2.262E-01	7.730E-02	1.748E-02	6.435E+00	1.455E+00	7.730E-02	1.748E-02	6.435E+00	1.455E+00
	10470.97	1.2009	1.1240	4.721E-03	7.690E-02	3.631E-04	6.404E+00	3.023E-02	7.690E-02	3.631E-04	6.404E+00	3.023E-02
	10471.02	1.2009	0.9937	3.326E-06	2.072E-01	6.892E-07	1.725E+01	5.739E-05	2.072E-01	6.892E-07	1.725E+01	5.739E-05
	10471.12	1.1909	0.9829	6.652E-06	2.080E-01	1.384E-06	1.747E+01	1.162E-04	2.080E-01	1.384E-06	1.747E+01	1.162E-04
	10471.22	1.1809	0.9817	6.652E-06	1.992E-01	1.325E-06	1.687E+01	1.122E-04	1.992E-01	1.325E-06	1.687E+01	1.122E-04
	10471.43	1.1109	0.9810	1.397E-05	1.299E-01	1.815E-06	1.169E+01	1.634E-04	1.299E-01	1.815E-06	1.169E+01	1.634E-04
	10472.32	0.9209	0.9787	5.921E-05	-5.780E-02	-3.422E-06	-6.276E+00	-3.716E-04	5.780E-02	3.422E-06	6.276E+00	3.716E-04
	11006.38	0.4554	0.5770	3.553E-02	-1.216E-01	-4.320E-03	-2.670E+01	-9.487E-01	1.216E-01	4.320E-03	2.670E+01	9.487E-01
	12307.61	0.2946	0.3844	8.656E-02	-8.980E-02	-7.773E-03	-3.048E+01	-2.639E+00	8.980E-02	7.773E-03	3.048E+01	2.639E+00
	13009.34	0.2445	0.2990	4.668E-02	-5.450E-02	-2.544E-03	-2.229E+01	-1.041E+00	5.450E-02	2.544E-03	2.229E+01	1.041E+00
	15032.14	0.1434	0.1969	1.346E-01	-5.350E-02	-7.199E-03	-3.731E+01	-5.020E+00	5.350E-02	7.199E-03	3.731E+01	5.020E+00
AVERAGE				1.000E+00	9.479E-02	4.569E-02	1.120E+01	-3.076E+00	1.325E-01	8.938E-02	2.350E+01	1.622E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2E	1.00	0.1800	0.0778	6.652E-05	1.022E-01	6.799E-06	5.678E+01	3.777E-03	1.022E-01	6.799E-06	5.678E+01	3.777E-03
(3918)	5.00	0.2599	0.0831	2.661E-04	1.768E-01	4.705E-05	6.803E+01	1.810E-02	1.768E-01	4.705E-05	6.803E+01	1.810E-02
	10.00	0.2799	0.0896	3.326E-04	1.903E-01	6.330E-05	6.799E+01	2.261E-02	1.903E-01	6.330E-05	6.799E+01	2.261E-02
	100.00	0.4290	0.1806	5.987E-03	2.484E-01	1.487E-03	5.790E+01	3.467E-01	2.484E-01	1.487E-03	5.790E+01	3.467E-01
	500.00	0.6248	0.3784	2.661E-02	2.464E-01	6.557E-03	3.944E+01	1.049E+00	2.464E-01	6.557E-03	3.944E+01	1.049E+00
	1000.00	0.7197	0.4994	3.326E-02	2.203E-01	7.328E-03	3.061E+01	1.018E+00	2.203E-01	7.328E-03	3.061E+01	1.018E+00
	3990.00	0.9585	0.7665	1.989E-01	1.920E-01	3.819E-02	2.003E+01	3.984E+00	1.920E-01	3.819E-02	2.003E+01	3.984E+00
	4000.00	0.9483	0.7674	6.652E-04	1.809E-01	1.203E-04	1.908E+01	1.269E-02	1.809E-01	1.203E-04	1.908E+01	1.269E-02
	7000.00	1.0771	0.8769	1.996E-01	2.002E-01	3.995E-02	1.859E+01	3.709E+00	2.002E-01	3.995E-02	1.859E+01	3.709E+00
	10400.00	1.1213	0.9448	2.262E-01	1.765E-01	3.992E-02	1.574E+01	3.560E+00	1.765E-01	3.992E-02	1.574E+01	3.560E+00
	10470.97	1.1209	0.9452	4.721E-03	1.757E-01	8.295E-04	1.567E+01	7.400E-02	1.757E-01	8.295E-04	1.567E+01	7.400E-02
	10471.02	1.1209	0.8859	3.326E-06	2.350E-01	7.817E-07	2.097E+01	6.973E-05	2.350E-01	7.817E-07	2.097E+01	6.973E-05
	10471.12	1.1209	0.8713	6.652E-06	2.496E-01	1.660E-06	2.227E+01	1.481E-04	2.496E-01	1.660E-06	2.227E+01	1.481E-04
	10471.22	1.1109	0.8702	6.652E-06	2.407E-01	1.601E-06	2.167E+01	1.441E-04	2.407E-01	1.601E-06	2.167E+01	1.441E-04
	10471.43	1.0709	0.8697	1.397E-05	2.012E-01	2.811E-06	1.879E+01	2.625E-04	2.012E-01	2.811E-06	1.879E+01	2.625E-04
	10472.32	0.9309	0.8686	5.921E-05	6.230E-02	3.689E-06	6.692E+00	3.962E-04	6.230E-02	3.689E-06	6.692E+00	3.962E-04
	11006.38	0.5154	0.5587	3.553E-02	-4.330E-02	-1.538E-03	-8.401E+00	-2.985E-01	4.330E-02	1.538E-03	8.401E+00	2.985E-01
	12307.61	0.3546	0.3780	8.656E-02	-2.340E-02	-2.026E-03	-6.599E+00	-5.712E-01	2.340E-02	2.026E-03	6.599E+00	5.712E-01
	13009.34	0.2745	0.2951	4.668E-02	-2.060E-02	-9.616E-04	-7.505E+00	-3.503E-01	2.060E-02	9.616E-04	7.505E+00	3.503E-01
	15032.14	0.1634	0.1951	1.346E-01	-3.170E-02	-4.266E-03	-1.940E+01	-2.611E+00	3.170E-02	4.266E-03	1.940E+01	2.611E+00
AVERAGE				1.000E+00	1.490E-01	1.257E-01	2.292E+01	9.970E+00	1.609E-01	1.433E-01	2.711E+01	1.763E+01
				Time		Time		Individual		Time	Absolute	Individual

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Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Weighting Factor ( )	Residual (ft)	Weighted Residual (ft)	Percent Difference (%)	Time Weighted % Diff	Absolute Residual (ft)	Weighted Abs Residual (ft)	Percent Difference (%)	Time Weighted % Diff
SPPZ-3	1.00	0.2100	0.1838	6.652E-05	2.620E-02	1.743E-06	1.248E+01	8.300E-04	2.620E-02	1.743E-06	1.248E+01	8.300E-04
(3921)	5.00	0.2699	0.1969	2.661E-04	7.300E-02	1.943E-05	2.705E+01	7.197E-03	7.300E-02	1.943E-05	2.705E+01	7.197E-03
	10.00	0.3099	0.2140	3.326E-04	9.590E-02	3.190E-05	3.095E+01	1.029E-02	9.590E-02	3.190E-05	3.095E+01	1.029E-02
	100.00	0.5190	0.4193	5.987E-03	9.970E-02	5.969E-04	1.921E+01	1.150E-01	9.970E-02	5.969E-04	1.921E+01	1.150E-01
	500.00	0.6648	0.7185	2.661E-02	-5.370E-02	-1.429E-03	-8.078E+00	-2.149E-01	5.370E-02	1.429E-03	8.078E+00	2.149E-01
	1000.00	0.7496	0.8658	3.326E-02	-1.162E-01	-3.865E-03	-1.550E+01	-5.156E-01	1.162E-01	3.865E-03	1.550E+01	5.156E-01
	3990.00	0.9685	1.1570	1.989E-01	-1.885E-01	-3.749E-02	-1.946E+01	-3.871E+00	1.885E-01	3.749E-02	1.946E+01	3.871E+00
	4000.00	0.9683	1.1590	6.652E-04	-1.907E-01	-1.269E-04	-1.969E+01	-1.310E-02	1.907E-01	1.269E-04	1.969E+01	1.310E-02
	7000.00	1.0771	1.2730	1.996E-01	-1.959E-01	-3.910E-02	-1.819E+01	-3.630E+00	1.959E-01	3.910E-02	1.819E+01	3.630E+00
	10400.00	1.1513	1.3430	2.262E-01	-1.917E-01	-4.336E-02	-1.665E+01	-3.766E+00	1.917E-01	4.336E-02	1.665E+01	3.766E+00
	10470.97	1.1009	1.3440	4.721E-03	-2.431E-01	-1.148E-03	-2.208E+01	-1.043E-01	2.431E-01	1.148E-03	2.208E+01	1.043E-01
	10471.02	1.1609	1.1740	3.326E-06	-1.310E-02	-4.357E-08	-1.128E+00	-3.753E-06	1.310E-02	4.357E-08	1.128E+00	3.753E-06
	10471.12	1.1609	1.1670	6.652E-06	-6.100E-03	-4.058E-08	-5.255E-01	-3.496E-06	6.100E-03	4.058E-08	5.255E-01	3.496E-06
	10471.22	1.1409	1.1670	6.652E-06	-2.610E-02	-1.736E-07	-2.288E+00	-1.522E-05	2.610E-02	1.736E-07	2.288E+00	1.522E-05
	10471.43	1.0209	1.1660	1.397E-05	-1.451E-01	-2.027E-06	-1.421E+01	-1.986E-04	1.451E-01	2.027E-06	1.421E+01	1.986E-04
	10472.32	0.9509	1.1630	5.921E-05	-2.121E-01	-1.256E-05	-2.231E+01	-1.321E-03	2.121E-01	1.256E-05	2.231E+01	1.321E-03
	11006.38	0.4954	0.6091	3.553E-02	-1.137E-01	-4.040E-03	-2.295E+01	-8.154E-01	1.137E-01	4.040E-03	2.295E+01	8.154E-01
	12307.61	0.3346	0.3964	8.656E-02	-6.180E-02	-5.350E-03	-1.847E+01	-1.599E+00	6.180E-02	5.350E-03	1.847E+01	1.599E+00
	13009.34	0.2645	0.3066	4.668E-02	-4.210E-02	-1.965E-03	-1.592E+01	-7.430E-01	4.210E-02	1.965E-03	1.592E+01	7.430E-01
	15032.14	0.1934	0.2013	1.346E-01	-7.900E-03	-1.063E-03	-4.085E+00	-5.497E-01	7.900E-03	1.063E-03	4.085E+00	5.497E-01
AVERAGE				1.000E+00	-7.565E-02	-1.383E-01	-6.593E+00	-1.569E+01	1.051E-01	1.396E-01	1.556E+01	1.596E+01

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-4	1.00	0.0100	0.0152	6.652E-05	-5.200E-03	-3.459E-07	-5.200E+01	-3.459E-03	5.200E-03	3.459E-07	5.200E+01	3.459E-03
(3922)	5.00	0.0299	0.0164	2.661E-04	1.350E-02	3.592E-06	4.515E+01	1.201E-02	1.350E-02	3.592E-06	4.515E+01	1.201E-02
	10.00	0.0499	0.0180	3.326E-04	3.190E-02	1.061E-05	6.393E+01	2.126E-02	3.190E-02	1.061E-05	6.393E+01	2.126E-02
	100.00	0.1490	0.0520	5.987E-03	9.700E-02	5.808E-04	6.510E+01	3.898E-01	9.700E-02	5.808E-04	6.510E+01	3.898E-01
	500.00	0.3048	0.2055	2.661E-02	9.930E-02	2.642E-03	3.258E+01	8.669E-01	9.930E-02	2.642E-03	3.258E+01	8.669E-01
	1000.00	0.3896	0.3246	3.326E-02	6.500E-02	2.162E-03	1.668E+01	5.549E-01	6.500E-02	2.162E-03	1.668E+01	5.549E-01
	3990.00	0.6085	0.5996	1.989E-01	8.900E-03	1.770E-03	1.463E+00	2.909E-01	8.900E-03	1.770E-03	1.463E+00	2.909E-01
	4000.00	0.6183	0.6005	6.652E-04	1.780E-02	1.184E-05	2.879E+00	1.915E-03	1.780E-02	1.184E-05	2.879E+00	1.915E-03
	7000.00	0.7171	0.7139	1.996E-01	3.200E-03	6.386E-04	4.462E-01	8.906E-02	3.200E-03	6.386E-04	4.462E-01	8.906E-02
	10400.00	0.7913	0.7852	2.262E-01	6.100E-03	1.380E-03	7.709E-01	1.744E-01	6.100E-03	1.380E-03	7.709E-01	1.744E-01
	10470.97	0.7909	0.7857	4.721E-03	5.200E-03	2.455E-05	6.575E-01	3.104E-03	5.200E-03	2.455E-05	6.575E-01	3.104E-03
	10471.02	0.7909	0.7762	3.326E-06	1.470E-02	4.890E-08	1.859E+00	6.182E-06	1.470E-02	4.890E-08	1.859E+00	6.182E-06
	10471.12	0.7909	0.7721	6.652E-06	1.880E-02	1.251E-07	2.377E+00	1.581E-05	1.880E-02	1.251E-07	2.377E+00	1.581E-05
	10471.22	0.7909	0.7716	6.652E-06	1.930E-02	1.284E-07	2.440E+00	1.623E-05	1.930E-02	1.284E-07	2.440E+00	1.623E-05

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	10471.43	0.7909	0.7714	1.397E-05	1.950E-02	2.724E-07	2.466E+00	3.444E-05	1.950E-02	2.724E-07	2.466E+00	3.444E-05
	10472.32	0.7709	0.7711	5.921E-05	-2.000E-04	-1.184E-08	-2.594E-02	-1.536E-06	2.000E-04	1.184E-08	2.594E-02	1.536E-06
	11006.38	0.4854	0.5760	3.553E-02	-9.060E-02	-3.219E-03	-1.867E+01	-6.631E-01	9.060E-02	3.219E-03	1.867E+01	6.631E-01
	12307.61	0.3246	0.3941	8.656E-02	-6.950E-02	-6.016E-03	-2.141E+01	-1.853E+00	6.950E-02	6.016E-03	2.141E+01	1.853E+00
	13009.34	0.2745	0.3085	4.668E-02	-3.400E-02	-1.587E-03	-1.239E+01	-5.782E-01	3.400E-02	1.587E-03	1.239E+01	5.782E-01
	15032.14	0.1734	0.2053	1.346E-01	-3.190E-02	-4.293E-03	-1.840E+01	-2.476E+00	3.190E-02	4.293E-03	1.840E+01	2.476E+00
AVERAGE				1.000E+00	9.440E-03	-5.890E-03	5.796E+00	-3.169E+00	3.258E-02	2.434E-02	1.808E+01	7.978E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-5	1.00	0.2400	0.1796	6.652E-05	6.040E-02	4.018E-06	2.517E+01	1.674E-03	6.040E-02	4.018E-06	2.517E+01	1.674E-03
(3923)	5.00	0.3199	0.1928	2.661E-04	1.271E-01	3.382E-05	3.973E+01	1.057E-02	1.271E-01	3.382E-05	3.973E+01	1.057E-02
	10.00	0.3399	0.2092	3.326E-04	1.307E-01	4.347E-05	3.845E+01	1.279E-02	1.307E-01	4.347E-05	3.845E+01	1.279E-02
	100.00	0.5390	0.4075	5.987E-03	1.315E-01	7.873E-04	2.440E+01	1.461E-01	1.315E-01	7.873E-04	2.440E+01	1.461E-01
	500.00	0.7148	0.6915	2.661E-02	2.330E-02	6.200E-04	3.260E+00	8.674E-02	2.330E-02	6.200E-04	3.260E+00	8.674E-02
	1000.00	0.7896	0.8314	3.326E-02	-4.180E-02	-1.390E-03	-5.294E+00	-1.761E-01	4.180E-02	1.390E-03	5.294E+00	1.761E-01
	3990.00	1.0485	1.1130	1.989E-01	-6.450E-02	-1.283E-02	-6.152E+00	-1.224E+00	6.450E-02	1.283E-02	6.152E+00	1.224E+00
	4000.00	1.0383	1.1140	6.652E-04	-7.570E-02	-5.036E-05	-7.291E+00	-4.850E-03	7.570E-02	5.036E-05	7.291E+00	4.850E-03
	7000.00	1.1471	1.2250	1.996E-01	-7.790E-02	-1.555E-02	-6.791E+00	-1.355E+00	7.790E-02	1.555E-02	6.791E+00	1.355E+00
	10400.00	1.2313	1.2930	2.262E-01	-6.170E-02	-1.396E-02	-5.011E+00	-1.133E+00	6.170E-02	1.396E-02	5.011E+00	1.133E+00
	10470.97	1.2209	1.2940	4.721E-03	-7.310E-02	-3.451E-04	-5.987E+00	-2.827E-02	7.310E-02	3.451E-04	5.987E+00	2.827E-02
	10471.02	1.2209	1.1270	3.326E-06	9.390E-02	3.123E-07	7.691E+00	2.558E-05	9.390E-02	3.123E-07	7.691E+00	2.558E-05
	10471.12	1.2209	1.1210	6.652E-06	9.990E-02	6.646E-07	8.182E+00	5.443E-05	9.990E-02	6.646E-07	8.182E+00	5.443E-05
	10471.22	1.1809	1.1200	6.652E-06	6.090E-02	4.051E-07	5.157E+00	3.431E-05	6.090E-02	4.051E-07	5.157E+00	3.431E-05
	10471.43	1.1109	1.1200	1.397E-05	-9.100E-03	-1.271E-07	-8.192E-01	-1.144E-05	9.100E-03	1.271E-07	8.192E-01	1.144E-05
	10472.32	0.9609	1.1170	5.921E-05	-1.561E-01	-9.242E-06	-1.625E+01	-9.618E-04	1.561E-01	9.242E-06	1.625E+01	9.618E-04
	11006.38	0.4954	0.5874	3.553E-02	-9.200E-02	-3.269E-03	-1.857E+01	-6.598E-01	9.200E-02	3.269E-03	1.857E+01	6.598E-01
	12307.61	0.3246	0.3844	8.656E-02	-5.980E-02	-5.176E-03	-1.842E+01	-1.595E+00	5.980E-02	5.176E-03	1.842E+01	1.595E+00
	13009.34	0.2945	0.2974	4.668E-02	-2.900E-03	-1.354E-04	-9.847E-01	-4.597E-02	2.900E-03	1.354E-04	9.847E-01	4.597E-02
	15032.14	0.1834	0.1949	1.346E-01	-1.150E-02	-1.547E-03	-6.270E+00	-8.438E-01	1.150E-02	1.547E-03	6.270E+00	8.438E-01
AVERAGE				1.000E+00	8.000E-05	-5.276E-02	2.710E+00	-6.809E+00	7.269E-02	5.574E-02	1.249E+01	7.325E+00
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
2002	1.00	-0.0700	0.0000	6.652E-05	-7.000E-02	-4.657E-06	1.000E+02	6.652E-03	7.000E-02	4.657E-06	-1.000E+02	-6.652E-03
	5.00	-0.0500	0.0003	2.661E-04	-5.030E-02	-1.338E-05	1.006E+02	2.677E-02	5.030E-02	1.338E-05	-1.006E+02	-2.677E-02
	10.00	-0.0020	0.0006	3.326E-04	-2.600E-03	-8.648E-07	1.300E+02	4.324E-02	2.600E-03	8.648E-07	-1.300E+02	-4.324E-02
	100.00	0.0690	0.0178	5.987E-03	5.120E-02	3.065E-04	7.420E+01	4.443E-01	5.120E-02	3.065E-04	7.420E+01	4.443E-01
	500.00	0.2098	0.1778	2.661E-02	3.200E-02	8.515E-04	1.525E+01	4.059E-01	3.200E-02	8.515E-04	1.525E+01	4.059E-01
	1000.00	0.3000	0.2972	3.326E-02	2.800E-03	9.313E-05	9.333E-01	3.104E-02	2.800E-03	9.313E-05	9.333E-01	3.104E-02

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	3990.00	0.5035	0.5601	1.989E-01	-5.660E-02	-1.126E-02	-1.124E+01	-2.236E+00	5.660E-02	1.126E-02	1.124E+01	2.236E+00
	4000.00	0.5133	0.5610	6.652E-04	-4.770E-02	-3.173E-05	-9.293E+00	-6.182E-03	4.770E-02	3.173E-05	9.293E+00	6.182E-03
	7000.00	0.6271	0.6668	1.996E-01	-3.970E-02	-7.923E-03	-6.331E+00	-1.263E+00	3.970E-02	7.923E-03	6.331E+00	1.263E+00
	10400.00	0.7113	0.7316	2.262E-01	-2.030E-02	-4.591E-03	-2.854E+00	-6.455E-01	2.030E-02	4.591E-03	2.854E+00	6.455E-01
	10470.97	0.7109	0.7320	4.721E-03	-2.110E-02	-9.962E-05	-2.968E+00	-1.401E-02	2.110E-02	9.962E-05	2.968E+00	1.401E-02
	10471.02	0.7109	0.7320	3.326E-06	-2.110E-02	-7.018E-08	-2.968E+00	-9.872E-06	2.110E-02	7.018E-08	2.968E+00	9.872E-06
	10471.12	0.7109	0.7320	6.652E-06	-2.110E-02	-1.404E-07	-2.968E+00	-1.974E-05	2.110E-02	1.404E-07	2.968E+00	1.974E-05
	10471.22	0.7109	0.7320	6.652E-06	-2.110E-02	-1.404E-07	-2.968E+00	-1.974E-05	2.110E-02	1.404E-07	2.968E+00	1.974E-05
	10471.43	0.7109	0.7320	1.397E-05	-2.110E-02	-2.948E-07	-2.968E+00	-4.146E-05	2.110E-02	2.948E-07	2.968E+00	4.146E-05
	10472.32	0.7009	0.7320	5.921E-05	-3.110E-02	-1.841E-06	-4.437E+00	-2.627E-04	3.110E-02	1.841E-06	4.437E+00	2.627E-04
	11006.38	0.4454	0.5494	3.553E-02	-1.040E-01	-3.695E-03	-2.335E+01	-8.296E-01	1.040E-01	3.695E-03	2.335E+01	8.296E-01
	12307.61	0.3046	0.3688	8.656E-02	-6.420E-02	-5.557E-03	-2.108E+01	-1.824E+00	6.420E-02	5.557E-03	2.108E+01	1.824E+00
	13009.34	0.2645	0.2864	4.668E-02	-2.190E-02	-1.022E-03	-8.280E+00	-3.865E-01	2.190E-02	1.022E-03	8.280E+00	3.865E-01
	15032.14	0.1634	0.1873	1.346E-01	-2.390E-02	-3.216E-03	-1.463E+01	-1.968E+00	2.390E-02	3.216E-03	1.463E+01	1.968E+00
AVERAGE				1.000E+00	-2.759E-02	-3.616E-02	1.523E+01	-8.216E+00	3.619E-02	3.867E-02	-6.194E+00	9.979E+00
					Variance =	0.008026223	Average =	-4.676E+00			Average =	1.218E+01

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APPENDIX A8

FINAL DRAWDOWN CURVES FOR VALIDATION (SDT)

Well No. : RW-4

Well Coord. : X = 58 Y = 58 Z = 1- 2

Time Sequence (min.)	Drawdown (ft)	BHP Drawdown (ft)	Measured Drawdowr
0	0	0	0
110	1.006	8.542	5.288
230	1.51	11.85	8.692
330	1.983	15.16	12.113
430	2.47	18.45	15.613
530	3.373	25	23.913
574	4.265	32.48	35.747

Well No. : SPPZ-1

Well Coord. : X = 60 Y = 58 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)	
0	0	0
110	0.2023	0.366
230	0.3403	0.489
330	0.4655	0.571
430	0.5971	0.647
530	0.8092	0.855
574	0.9815	1.051

Well No. : SPPZ-2A

Well Coord. : X = 58 Y = 57 Z = 2- 2

Time Sequence (min.)	Drawdown (ft)	
0	0	0
110	0.3484	0.194
230	0.5458	0.27
330	0.7289	0.248
430	0.9189	0.321
530	1.246	0.616
574	1.544	0.88

Well No. : SPPZ-2C

Well Coord. : X = 58 Y = 57 Z = 4- 4

Time Sequence (min.)	Drawdown (ft)	
0	0	0
110	0.1464	0.288

230	0.2484	0.436
330	0.3431	0.55
430	0.4433	0.677
530	0.6028	0.879
574	0.7326	1.057

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Well No. : SPPZ-2E

Well Coord. : X = 58 Y = 57 Z = 6- 6

Time Sequence (min.)		Drawdown (ft)
0	0	0
110	0.08866	0.135
230	0.16	0.26
330	0.2265	0.411
430	0.2983	0.493
530	0.407	0.684
574	0.4892	0.835

Well No. : SPPZ-3

Well Coord. : X = 58 Y = 56 Z = 2- 2

Time Sequence (min.)		Drawdown (ft)
0	0	0
110	0.2039	0.316
230	0.3438	0.467
330	0.4705	0.591
430	0.6042	0.708
530	0.8189	0.913
574	0.993	1.068

Well No. : SPPZ-4

Well Coord. : X = 58 Y = 50 Z = 2- 2

Time Sequence (min.)		Drawdown (ft)
0	0	0
110	0.02655	0.087
230	0.06164	0.167
330	0.09743	0.217
430	0.1381	0.279
530	0.1926	0.363
574	0.2263	0.419

Well No. : SPPZ-5

Well Coord. : X = 58 Y = 60 Z = 2- 2

Time Sequence (min.)		Drawdown (ft)
0	0	0
110	0.1981	0.298
230	0.3327	0.453
330	0.4546	0.583
430	0.583	0.713
530	0.7903	0.935
574	0.9588	1.138

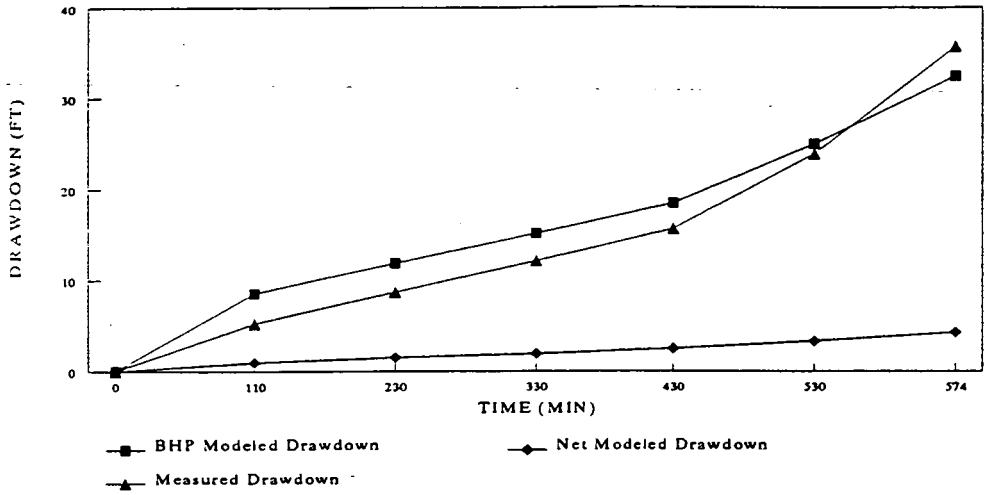
Well No. : 2002

Well Coord. : X = 62 Y = 65 Z = 1- 1

Time Sequence (min.)		Drawdown (ft)
0	0	0
110	0.01014	0.078
230	0.03973	0.138
330	0.07113	0.186
430	0.1073	0.224
530	0.151	0.29
574	0.1742	0.334

WELL: RW-4

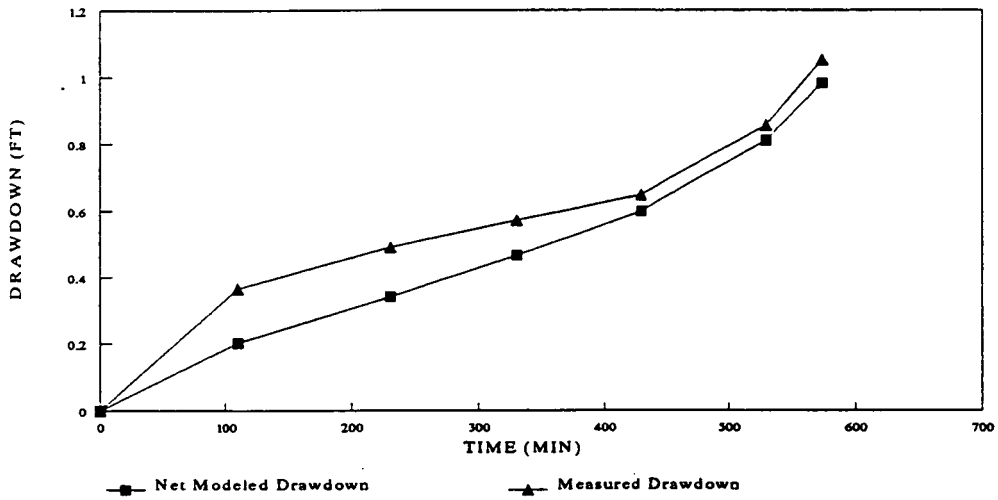
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-1

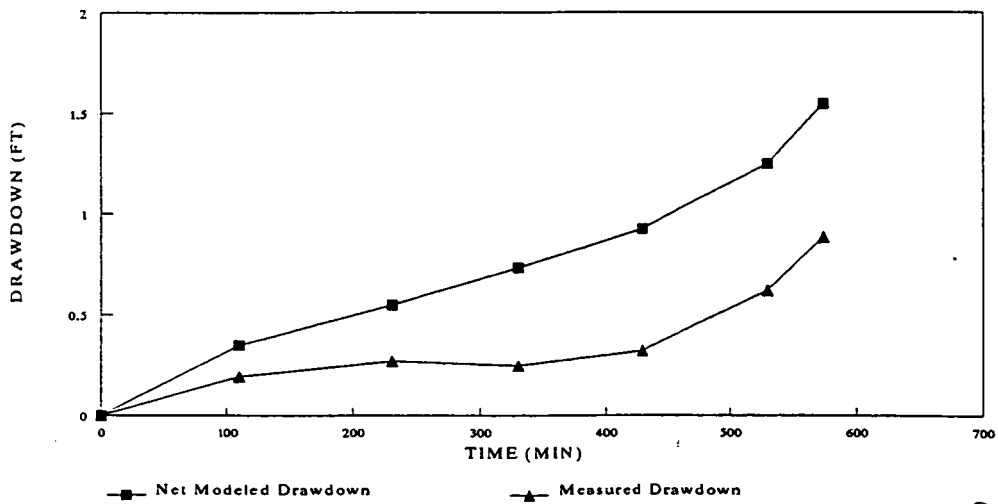
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-2A

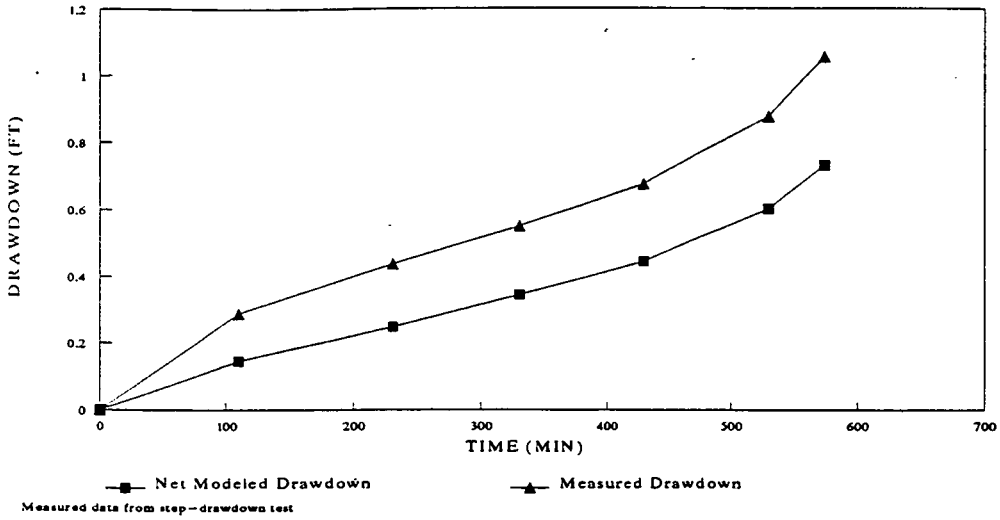
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-2C

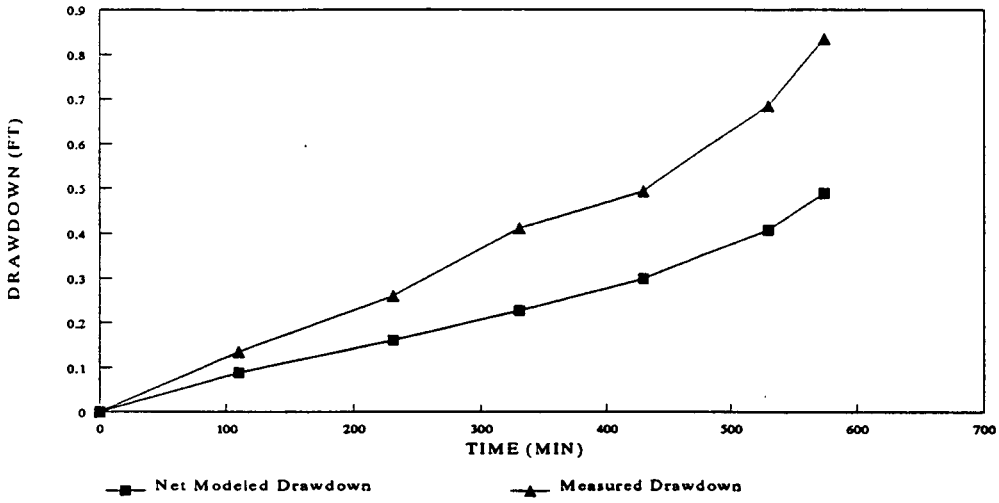
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-2E

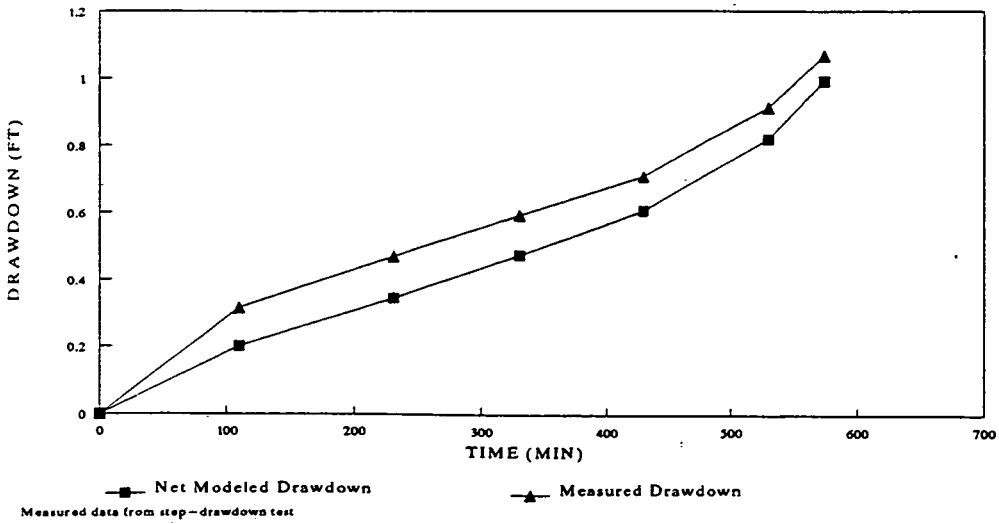
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-3

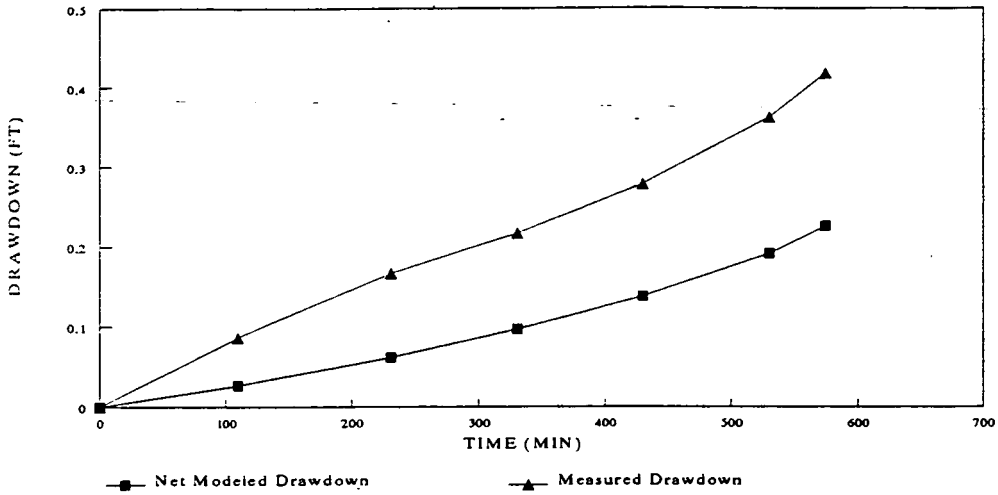
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-4

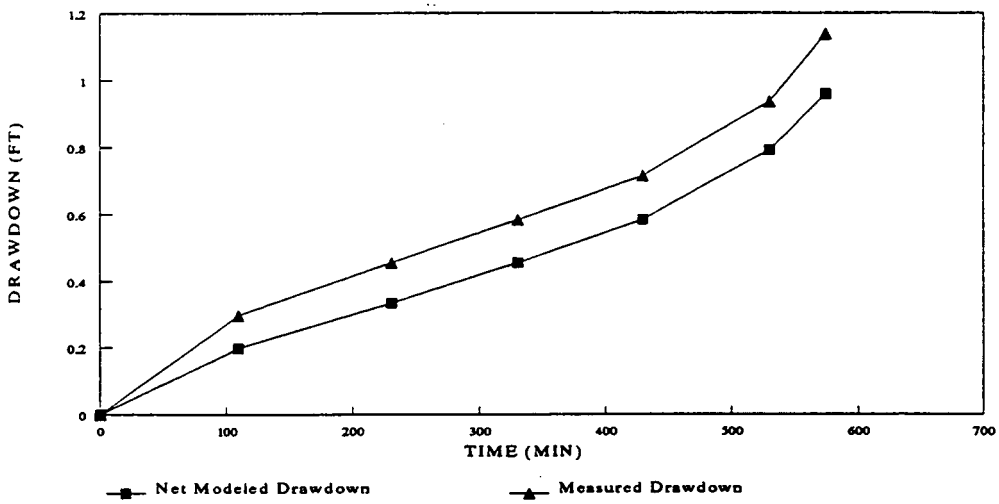
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: SPPZ-5

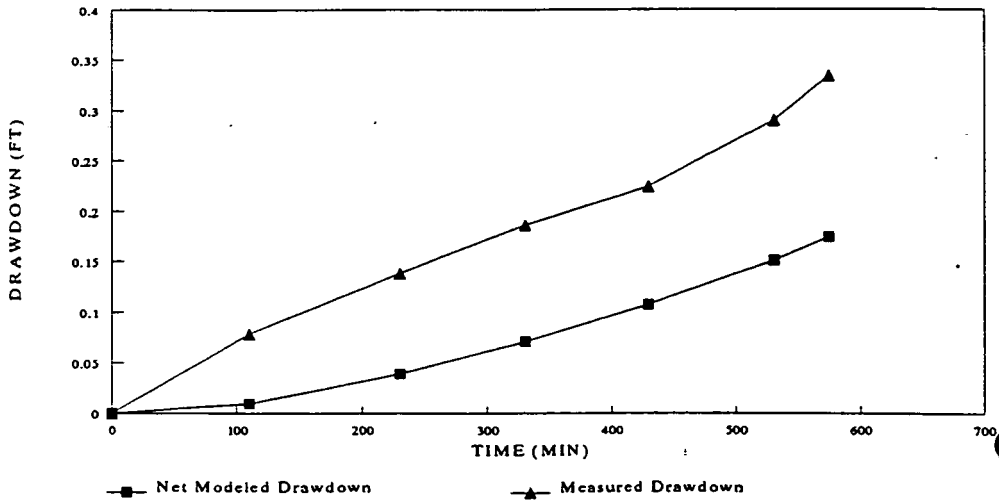
MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

WELL: 2002

MEASURED VS MODELED DRAWDOWN



Measured data from step-drawdown test

APPENDIX A9

FINAL VALIDATION RUN STATISTICS (SDT)

Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
RW-4	110.00	5.2880	8.5420	1.916E-01	-3.254E+00	-6.236E-01	-6.154E+01	-1.179E+01	3.254E+00	6.236E-01	6.154E+01	1.179E+01
(3927)	230.00	8.6920	11.8500	2.091E-01	-3.158E+00	-6.602E-01	-3.633E+01	-7.596E+00	3.158E+00	6.602E-01	3.633E+01	7.596E+00
	330.00	12.1130	15.1600	1.742E-01	-3.047E+00	-5.308E-01	-2.515E+01	-4.382E+00	3.047E+00	5.308E-01	2.515E+01	4.382E+00
	430.00	15.6130	18.4500	1.742E-01	-2.837E+00	-4.943E-01	-1.817E+01	-3.166E+00	2.837E+00	4.943E-01	1.817E+01	3.166E+00
	530.00	23.9130	25.0000	1.742E-01	-1.087E+00	-1.894E-01	-4.546E+00	-7.919E-01	1.087E+00	1.894E-01	4.546E+00	7.919E-01
	574.00	35.7470	32.4800	7.666E-02	3.267E+00	2.504E-01	9.139E+00	7.006E-01	3.267E+00	2.504E-01	9.139E+00	7.006E-01
AVERAGE				1.000E+00	-1.686E+00	-2.248E+00	-2.277E+01	-2.703E+01	2.775E+00	2.749E+00	2.581E+01	2.843E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-1	110.00	0.3660	0.2023	1.916E-01	1.637E-01	3.137E-02	4.473E+01	8.571E+00	1.637E-01	3.137E-02	4.473E+01	8.571E+00
(3910)	230.00	0.4890	0.3403	2.091E-01	1.487E-01	3.109E-02	3.041E+01	6.357E+00	1.487E-01	3.109E-02	3.041E+01	6.357E+00
	330.00	0.5710	0.4655	1.742E-01	1.055E-01	1.838E-02	1.848E+01	3.219E+00	1.055E-01	1.838E-02	1.848E+01	3.219E+00
	430.00	0.6470	0.5971	1.742E-01	4.990E-02	8.693E-03	7.713E+00	1.344E+00	4.990E-02	8.693E-03	7.713E+00	1.344E+00
	530.00	0.8550	0.8092	1.742E-01	4.580E-02	7.979E-03	5.357E+00	9.332E-01	4.580E-02	7.979E-03	5.357E+00	9.332E-01
	574.00	1.0510	0.9815	7.666E-02	6.950E-02	5.328E-03	6.613E+00	5.069E-01	6.950E-02	5.328E-03	6.613E+00	5.069E-01
AVERAGE				1.000E+00	9.718E-02	1.028E-01	1.888E+01	2.093E+01	9.718E-02	1.028E-01	1.888E+01	2.093E+01
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2A	110.00	0.1940	0.3484	1.916E-01	-1.544E-01	-2.959E-02	-7.959E+01	-1.525E+01	1.544E-01	2.959E-02	7.959E+01	1.525E+01
(3911)	230.00	0.2700	0.5458	2.091E-01	-2.758E-01	-5.766E-02	-1.021E+02	-2.136E+01	2.758E-01	5.766E-02	1.021E+02	2.136E+01
	330.00	0.2480	0.7289	1.742E-01	-4.809E-01	-8.378E-02	-1.939E+02	-3.378E+01	4.809E-01	8.378E-02	1.939E+02	3.378E+01
	430.00	0.3210	0.9189	1.742E-01	-5.979E-01	-1.042E-01	-1.863E+02	-3.245E+01	5.979E-01	1.042E-01	1.863E+02	3.245E+01
	530.00	0.6160	1.2460	1.742E-01	-6.300E-01	-1.098E-01	-1.023E+02	-1.782E+01	6.300E-01	1.098E-01	1.023E+02	1.782E+01
	574.00	0.8800	1.5440	7.666E-02	-6.640E-01	-5.090E-02	-7.545E+01	-5.784E+00	6.640E-01	5.090E-02	7.545E+01	5.784E+00
AVERAGE				1.000E+00	-4.672E-01	-4.358E-01	-1.233E+02	-1.264E+02	4.672E-01	4.358E-01	1.233E+02	1.264E+02
Well	Time (min)	Measured Drawdown (ft)	Modeled Drawdown (ft)	Time Weighting Factor ( )	Residual (ft)	Time Weighted Residual (ft)	Percent Difference (%)	Individual Time Weighted % Diff	Absolute Residual (ft)	Time Weighted Abs Residual (ft)	Absolute Percent Difference (%)	Individual Time Weighted % Diff
SPPZ-2C	110.00	0.2880	0.1464	1.916E-01	1.416E-01	2.714E-02	4.917E+01	9.422E+00	1.416E-01	2.714E-02	4.917E+01	9.422E+00
(3916)	230.00	0.4360	0.2484	2.091E-01	1.876E-01	3.922E-02	4.303E+01	8.995E+00	1.876E-01	3.922E-02	4.303E+01	8.995E+00
	330.00	0.5500	0.3431	1.742E-01	2.069E-01	3.605E-02	3.762E+01	6.554E+00	2.069E-01	3.605E-02	3.762E+01	6.554E+00

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	430.00	0.6770	0.4433	1.742E-01	2.337E-01	4.071E-02	3.452E+01	6.014E+00	2.337E-01	4.071E-02	3.452E+01	6.014E+00
	530.00	0.8790	0.6028	1.742E-01	2.762E-01	4.812E-02	3.142E+01	5.474E+00	2.762E-01	4.812E-02	3.142E+01	5.474E+00
	574.00	1.0570	0.7326	7.666E-02	3.244E-01	2.487E-02	3.069E+01	2.353E+00	3.244E-01	2.487E-02	3.069E+01	2.353E+00
AVERAGE				1.000E+00	2.284E-01	2.161E-01	3.774E+01	3.881E+01	2.284E-01	2.161E-01	3.774E+01	3.881E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-2E	110.00	0.1350	0.0887	1.916E-01	4.634E-02	8.880E-03	3.433E+01	6.578E+00	4.634E-02	8.880E-03	3.433E+01	6.578E+00
(3918)	230.00	0.2600	0.1600	2.091E-01	1.000E-01	2.091E-02	3.846E+01	8.041E+00	1.000E-01	2.091E-02	3.846E+01	8.041E+00
	330.00	0.4110	0.2265	1.742E-01	1.845E-01	3.214E-02	4.489E+01	7.821E+00	1.845E-01	3.214E-02	4.489E+01	7.821E+00
	430.00	0.4930	0.2983	1.742E-01	1.947E-01	3.392E-02	3.949E+01	6.880E+00	1.947E-01	3.392E-02	3.949E+01	6.880E+00
	530.00	0.6840	0.4070	1.742E-01	2.770E-01	4.826E-02	4.050E+01	7.055E+00	2.770E-01	4.826E-02	4.050E+01	7.055E+00
	574.00	0.8350	0.4892	7.666E-02	3.458E-01	2.651E-02	4.141E+01	3.175E+00	3.458E-01	2.651E-02	4.141E+01	3.175E+00
AVERAGE				1.000E+00	1.914E-01	1.706E-01	3.985E+01	3.955E+01	1.914E-01	1.706E-01	3.985E+01	3.955E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-3	110.00	0.3160	0.2039	1.916E-01	1.121E-01	2.148E-02	3.547E+01	6.798E+00	1.121E-01	2.148E-02	3.547E+01	6.798E+00
(3921)	230.00	0.4670	0.3438	2.091E-01	1.232E-01	2.576E-02	2.638E+01	5.515E+00	1.232E-01	2.576E-02	2.638E+01	5.515E+00
	330.00	0.5910	0.4705	1.742E-01	1.205E-01	2.099E-02	2.039E+01	3.552E+00	1.205E-01	2.099E-02	2.039E+01	3.552E+00
	430.00	0.7080	0.6042	1.742E-01	1.038E-01	1.808E-02	1.466E+01	2.554E+00	1.038E-01	1.808E-02	1.466E+01	2.554E+00
	530.00	0.9130	0.8189	1.742E-01	9.410E-02	1.639E-02	1.031E+01	1.796E+00	9.410E-02	1.639E-02	1.031E+01	1.796E+00
	574.00	1.0680	0.9930	7.666E-02	7.500E-02	5.749E-03	7.022E+00	5.383E-01	7.500E-02	5.749E-03	7.022E+00	5.383E-01
AVERAGE				1.000E+00	1.048E-01	1.085E-01	1.904E+01	2.075E+01	1.048E-01	1.085E-01	1.904E+01	2.075E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-4	110.00	0.0870	0.0266	1.916E-01	6.045E-02	1.158E-02	6.948E+01	1.332E+01	6.045E-02	1.158E-02	6.948E+01	1.332E+01
(3922)	230.00	0.1670	0.0616	2.091E-01	1.054E-01	2.203E-02	6.309E+01	1.319E+01	1.054E-01	2.203E-02	6.309E+01	1.319E+01
	330.00	0.2170	0.0974	1.742E-01	1.196E-01	2.083E-02	5.510E+01	9.600E+00	1.196E-01	2.083E-02	5.510E+01	9.600E+00
	430.00	0.2790	0.1381	1.742E-01	1.409E-01	2.455E-02	5.050E+01	8.798E+00	1.409E-01	2.455E-02	5.050E+01	8.798E+00
	530.00	0.3630	0.1926	1.742E-01	1.704E-01	2.969E-02	4.694E+01	8.178E+00	1.704E-01	2.969E-02	4.694E+01	8.178E+00
	574.00	0.4190	0.2263	7.666E-02	1.927E-01	1.477E-02	4.599E+01	3.525E+00	1.927E-01	1.477E-02	4.599E+01	3.525E+00
AVERAGE				1.000E+00	1.316E-01	1.234E-01	5.518E+01	5.661E+01	1.316E-01	1.234E-01	5.518E+01	5.661E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted

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	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
SPPZ-5	110.00	0.2980	0.1981	1.916E-01	9.990E-02	1.914E-02	3.352E+01	6.424E+00	9.990E-02	1.914E-02	3.352E+01	6.424E+00
(3923)	230.00	0.4530	0.3327	2.091E-01	1.203E-01	2.515E-02	2.656E+01	5.552E+00	1.203E-01	2.515E-02	2.656E+01	5.552E+00
	330.00	0.5830	0.4546	1.742E-01	1.284E-01	2.237E-02	2.202E+01	3.837E+00	1.284E-01	2.237E-02	2.202E+01	3.837E+00
	430.00	0.7130	0.5830	1.742E-01	1.300E-01	2.265E-02	1.823E+01	3.176E+00	1.300E-01	2.265E-02	1.823E+01	3.176E+00
	530.00	0.9350	0.7903	1.742E-01	1.447E-01	2.521E-02	1.548E+01	2.696E+00	1.447E-01	2.521E-02	1.548E+01	2.696E+00
	574.00	1.1380	0.9588	7.666E-02	1.792E-01	1.374E-02	1.575E+01	1.207E+00	1.792E-01	1.374E-02	1.575E+01	1.207E+00
AVERAGE				1.000E+00	1.338E-01	1.283E-01	2.193E+01	2.289E+01	1.338E-01	1.283E-01	2.193E+01	2.289E+01
				Time		Time		Individual		Time	Absolute	Individual
		Measured	Modeled	Weighting		Weighted	Percent	Time	Absolute	Weighted	Percent	Time
Well	Time	Drawdown	Drawdown	Factor	Residual	Residual	Difference	Weighted	Residual	Abs Residual	Difference	Weighted
	(min)	(ft)	(ft)	( )	(ft)	(ft)	(%)	% Diff	(ft)	(ft)	(%)	% Diff
2002	110.00	0.0780	0.0101	1.916E-01	6.786E-02	1.300E-02	8.700E+01	1.667E+01	6.786E-02	1.300E-02	8.700E+01	1.667E+01
	230.00	0.1380	0.0397	2.091E-01	9.827E-02	2.054E-02	7.121E+01	1.489E+01	9.827E-02	2.054E-02	7.121E+01	1.489E+01
	330.00	0.1860	0.0711	1.742E-01	1.149E-01	2.001E-02	6.176E+01	1.076E+01	1.149E-01	2.001E-02	6.176E+01	1.076E+01
	430.00	0.2240	0.1073	1.742E-01	1.167E-01	2.033E-02	5.210E+01	9.076E+00	1.167E-01	2.033E-02	5.210E+01	9.076E+00
	530.00	0.2900	0.1510	1.742E-01	1.390E-01	2.422E-02	4.793E+01	8.350E+00	1.390E-01	2.422E-02	4.793E+01	8.350E+00
	574.00	0.3340	0.1742	7.666E-02	1.598E-01	1.225E-02	4.784E+01	3.668E+00	1.598E-01	1.225E-02	4.784E+01	3.668E+00
AVERAGE				1.000E+00	1.161E-01	1.104E-01	6.131E+01	6.341E+01	1.161E-01	1.104E-01	6.131E+01	6.341E+01
					Variance1 =	0.63182624					Average1 =	4.643E+01
					Variance2 =	0.810298864					Average2 =	3.598E+01

Variance1 = Variance of all nine wells time-weighted residual.

Variance2 = Variance of all wells time-weighted residual except SPPZ-2A and SPPZ-2E.

Average1 = Average of all nine wells individual time-weighted absolute percent difference.

Average2 = Average of all wells individual time-weighted absolute percent difference except SPPZ-2A and SPPZ-2E.

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APPENDIX B

ECTRAN RESULTS

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BROWN & ROOT ENVIRONMENTAL

SCREENING-LEVEL EXCEL-CRYSTAL BALL TRANSPORT (ECTran) MODEL

SITE: CRU5 FEMP
MODEL IMPROVEMENT
SENSITIVITY ANALYSIS
CASE 2 Uranium loading at well 2046
INVESTIGATOR: RDW
DATE: 3/25/94

CONTAMINANT: U238		SPECIFIC ACTIVITY (Ci/g):	3.36E-07
KOC (L/KG):	0.00	WATER CRITERIA (UG/L):	1.39E+00
HALF LIFE (YRS):		PRECIPITATION CONC. (UG/L)	0.00E+00
LAYER 1:	4.51E+09		
LAYER 2:	4.51E+09		
GMA:	4.51E+09		

UNSAT. SOURCE	AREA:	VADOSE ZONE		GREAT MIAMI AQUIFER		GREAT MIAMI AQUIFER (SAT. S. & G.)			
INFILT(FT/YR)	0.522	CU1(0) (PPB)	0.00E+00	CU2(0) (PPB):	0.00E+00	B (FT):	75	Vzo (FT/YR):	4.34
LENGTH (FT)	125	FOC (KG/KG):	0.005	FOC (KG/KG):	0.0050	GW Q3 (L/DAY):	1.01E+04	FOC (KG/KG):	0.005
WIDTH (FT)	125	Kd (L/KG):	1.78	Kd (L/KG):	1.780	GW V.(FT/YR):	495.01	Kd (L/KG):	1.78
POROSITY 1	0.2	SATURATION:	0.30	SATURATION:	1.00	H (FT):	6.9800	RETARDATION:	11.79867
POROSITY 2	0.3	THICKNESS (FT):	0.01	THICKNESS (FT):	6.98	EFF. POROSITY:	0.30	q (FT/YR) :	0.5
DENSITY 1 (G/CM3)	1.78	DECAY (1/DAY):	4.21E-13	DECAY (1/DAY):	4.21E-13	DISPERSIVITY:		DECAY (1/YR):	2.2E-02
DENSITY 2 (G/CM3)	1.60	CAo (UG/L):	0.00E+00	CBo (PPB):	0.00E+00	Az(FT):	0.14	CU3 (PPB):	0
U.G. GW V (FT/YR)	463.85417	D.F. 1 (1/YR):	0	D.F. 2 (1/YR):	0.000	Ax (FT):	100.00	P&T(YEARS):	0
AGE (YEARS):	0	Q1 (L/DAY):	6.33E+02	Q2 (L/DAY):	9.42E+03	Ay (FT):	33.33	DISTANCE TO F.L.(FT):	2500
		Ts 1 (YEARS):	100	Ts 2 (YEARS):	100				

TIME INTERVAL (YRS) 10

	ELAPSED TIME - YRS	CU1(PPB)	CU2(PPB)	UNSAT S&G CONC. (UG/L)	SOURCE AREA CONC. (UG/L)	SOURCE AREA CONC. (UG/L)	FENCE LINE CONC. (UG/L)
1950	0	3.57E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	10	3.57E+07	0.00E+00	3.57E+07	2.19E+06	2.19E+06	0.00E+00
1970	20	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.54E-08
1980	30	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	4.51E+00
1990	40	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	9.97E+02
2000	50	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	9.86E+03
2010	60	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	2.93E+04
2020	70	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	4.98E+04
2030	80	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	6.40E+04
2040	90	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.17E+04
2050	100	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.52E+04
2060	110	0.00E+00	0.00E+00	1.96E-63	5.27E+04	5.27E+04	7.67E+04
2070	120	0.00E+00	0.00E+00	1.08E-133	1.21E+03	1.21E+03	7.72E+04
2080	130	0.00E+00	0.00E+00	5.92E-204	2.77E+01	2.77E+01	7.74E+04
2090	140	0.00E+00	0.00E+00	3.25E-274	6.35E-01	6.35E-01	7.65E+04
2100	150	0.00E+00	0.00E+00	0.00E+00	1.45E-02	1.45E-02	6.76E+04
2110	160	0.00E+00	0.00E+00	0.00E+00	3.33E-04	3.33E-04	4.82E+04
2120	170	0.00E+00	0.00E+00	0.00E+00	7.64E-06	7.64E-06	2.77E+04
2130	180	0.00E+00	0.00E+00	0.00E+00	1.75E-07	1.75E-07	1.35E+04
2140	190	0.00E+00	0.00E+00	0.00E+00	4.01E-09	4.01E-09	5.79E+03
2150	200	0.00E+00	0.00E+00	0.00E+00	9.19E-11	9.19E-11	2.28E+03
2160	210	0.00E+00	0.00E+00	0.00E+00	2.11E-12	2.11E-12	8.38E+02
2170	220	0.00E+00	0.00E+00	0.00E+00	4.83E-14	4.83E-14	2.93E+02
2180	230	0.00E+00	0.00E+00	0.00E+00	1.11E-15	1.11E-15	9.89E+01
2190	240	0.00E+00	0.00E+00	0.00E+00	2.53E-17	2.53E-17	3.23E+01
2200	250	0.00E+00	0.00E+00	0.00E+00	5.81E-19	5.81E-19	1.03E+01
2210	260	0.00E+00	0.00E+00	0.00E+00	1.33E-20	1.33E-20	3.24E+00
2220	270	0.00E+00	0.00E+00	0.00E+00	3.05E-22	3.05E-22	1.00E+00
2230	280	0.00E+00	0.00E+00	0.00E+00	6.99E-24	6.99E-24	3.05E-01
2240	290	0.00E+00	0.00E+00	0.00E+00	1.60E-25	1.60E-25	9.21E-02
2250	300	0.00E+00	0.00E+00	0.00E+00	3.67E-27	3.67E-27	2.75E-02
2260	310	0.00E+00	0.00E+00	0.00E+00	8.41E-29	8.41E-29	8.17E-03
2270	320	0.00E+00	0.00E+00	0.00E+00	1.93E-30	1.93E-30	2.41E-03
2280	330	0.00E+00	0.00E+00	0.00E+00	4.42E-32	4.42E-32	7.07E-04
2290	340	0.00E+00	0.00E+00	0.00E+00	1.01E-33	1.01E-33	2.07E-04
2300	350	0.00E+00	0.00E+00	0.00E+00	2.32E-35	2.32E-35	6.01E-05
2310	360	0.00E+00	0.00E+00	0.00E+00	5.32E-37	5.32E-37	1.74E-05
2320	370	0.00E+00	0.00E+00	0.00E+00	1.22E-38	1.22E-38	5.03E-06
2330	380	0.00E+00	0.00E+00	0.00E+00	2.79E-40	2.79E-40	1.45E-06
2340	390	0.00E+00	0.00E+00	0.00E+00	6.40E-42	6.40E-42	4.16E-07
2350	400	0.00E+00	0.00E+00	0.00E+00	1.47E-43	1.47E-43	1.19E-07
2360	410	0.00E+00	0.00E+00	0.00E+00	3.36E-45	3.36E-45	2.83E-09
2370	420	0.00E+00	0.00E+00	0.00E+00	7.70E-47	7.70E-47	0.00E+00
2380	430	0.00E+00	0.00E+00	0.00E+00	1.76E-48	1.76E-48	0.00E+00
2390	440	0.00E+00	0.00E+00	0.00E+00	4.04E-50	4.04E-50	0.00E+00
2400	450	0.00E+00	0.00E+00	0.00E+00	9.26E-52	9.26E-52	0.00E+00
2410	460	0.00E+00	0.00E+00	0.00E+00	2.12E-53	2.12E-53	0.00E+00
2420	470	0.00E+00	0.00E+00	0.00E+00	4.87E-55	4.87E-55	0.00E+00
2430	480	0.00E+00	0.00E+00	0.00E+00	1.11E-56	1.11E-56	0.00E+00
2440	490	0.00E+00	0.00E+00	0.00E+00	2.56E-58	2.56E-58	0.00E+00
2450	500	0.00E+00	0.00E+00	0.00E+00	5.86E-60	5.86E-60	0.00E+00
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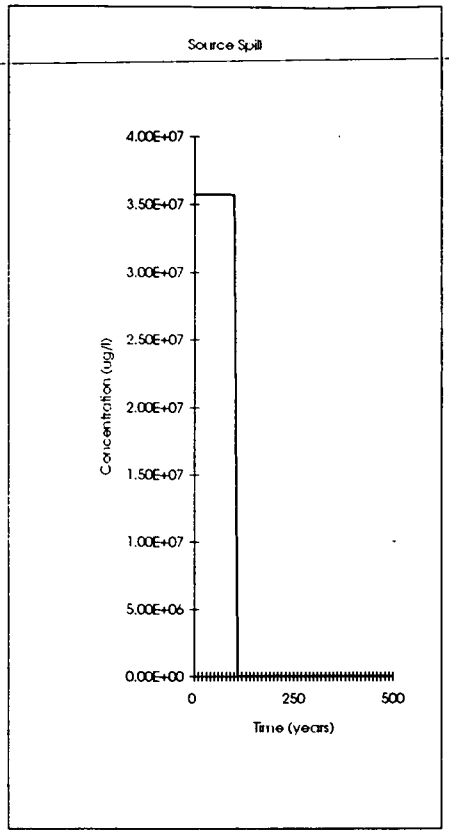
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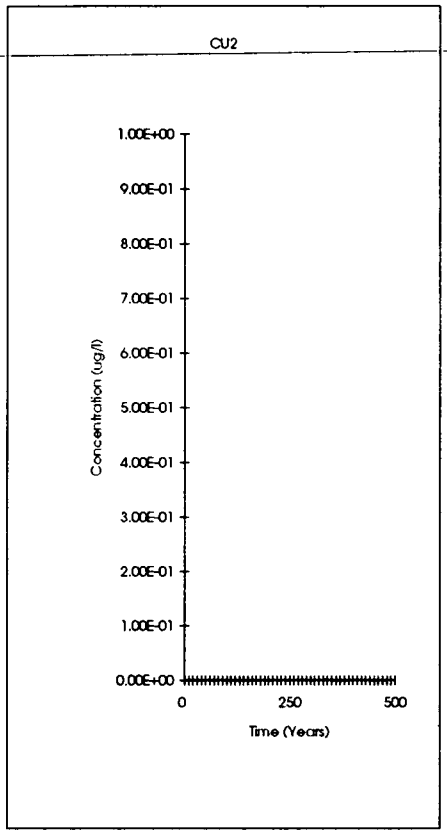
500
Time (years)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Concentration (ug/l)
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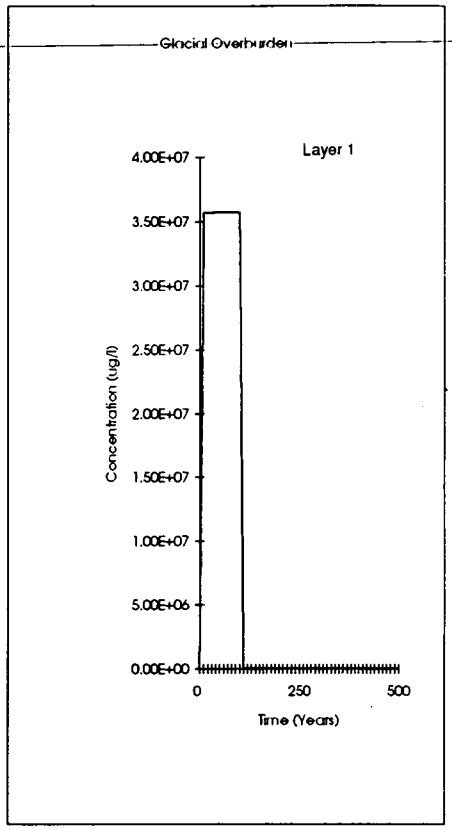
Time (Years)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Concentration (ug/l)
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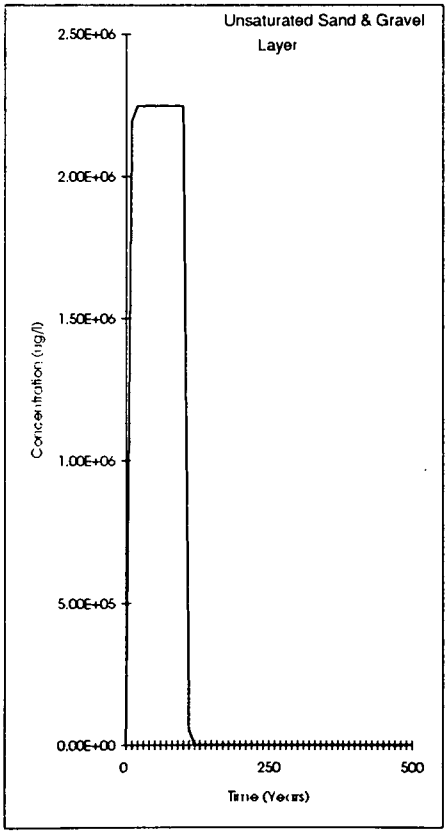
250
500
Time (Years)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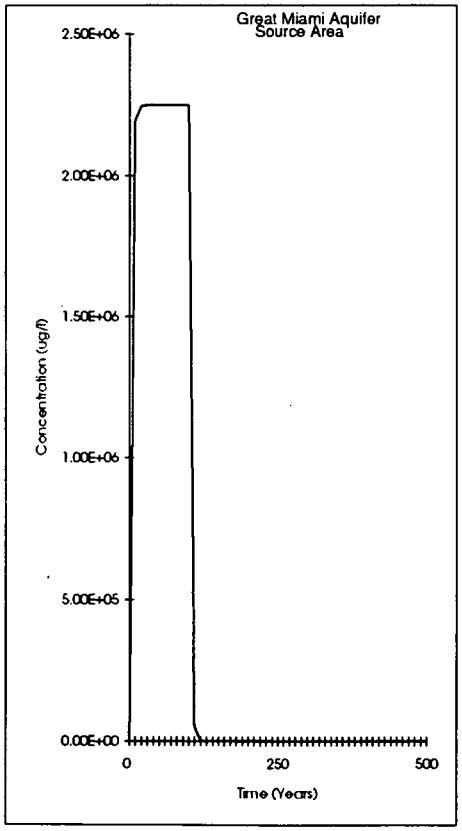
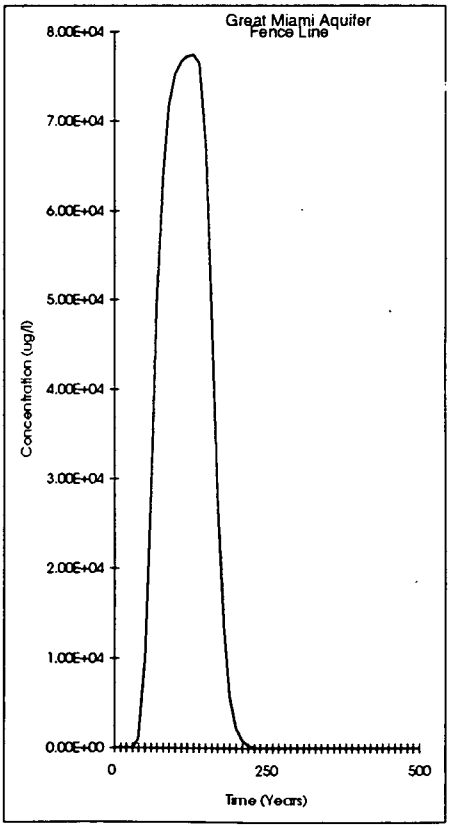
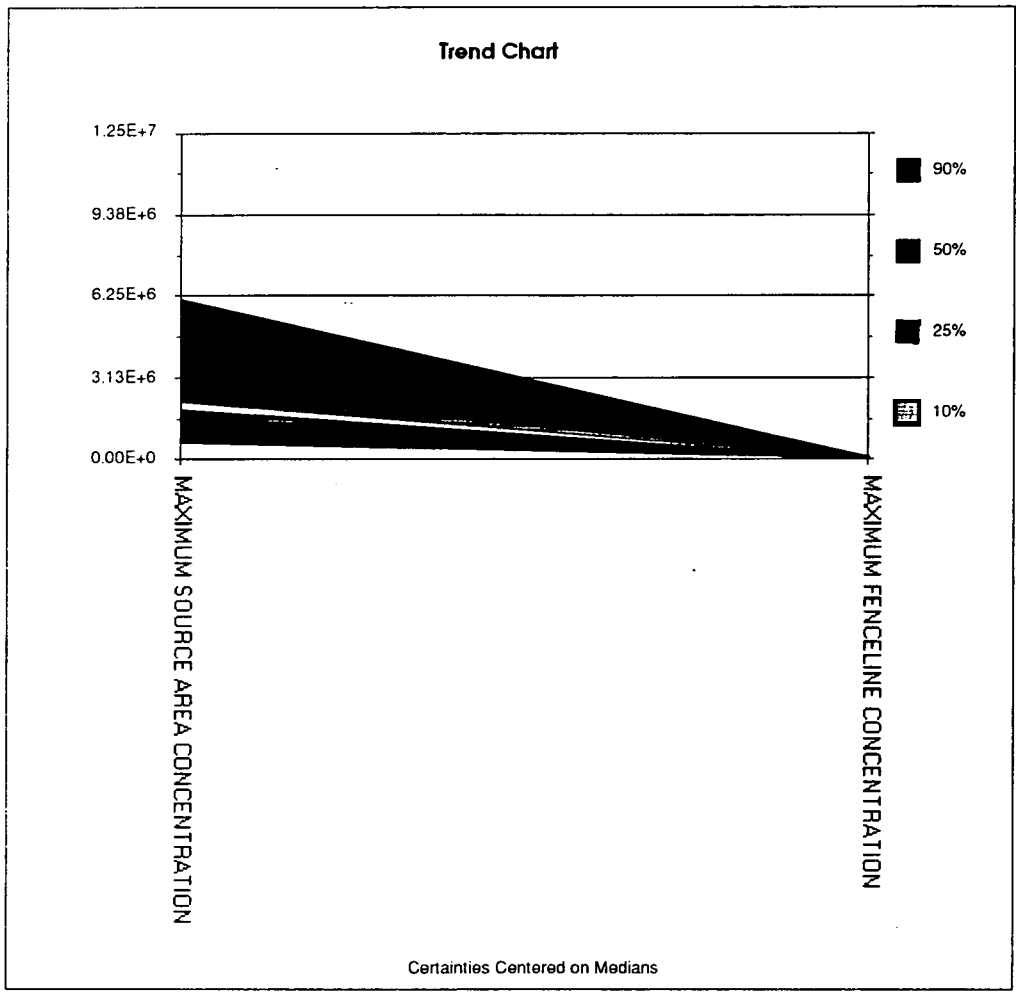
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
Concentration (ug/l)
0
250
500
Time (Years)

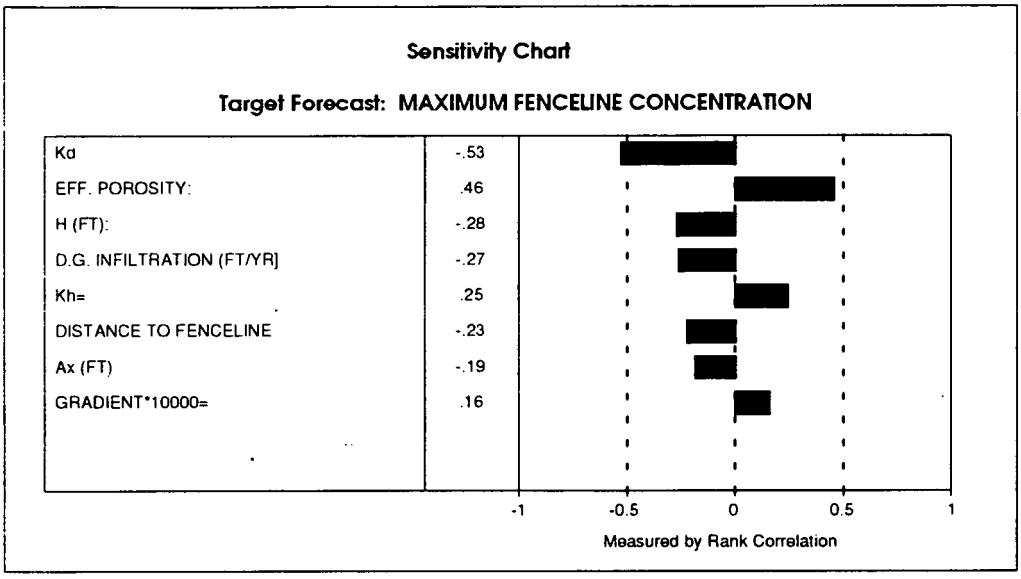

Great Miami Aquifer Source Area
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
Concentration (ug/l)
0
250
500
Time (Years)


Great Miami Aquifer Fence Line
8.00E+04
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
Concentration (ug/l)
0
250
500
Time (Years)

Crystal Ball Report
Simulation started on 4/13/94 at 9:54:58
Simulation stopped on 4/13/94 at 10:10:14



5490


Sensitivity Chart
Target Forecast: MAXIMUM FENCELINE CONCENTRATION
Kd -.53
EFF. POROSITY: .46
H (FT): -.28
D.G. INFILTRATION (FT/YR] -.27
Kh= .25
DISTANCE TO FENCELINE -.23
Ax (FT) -.19
GRADIENT*10000= .16
-1
-0.5
0
0.5
1
Measured by Rank Correlation

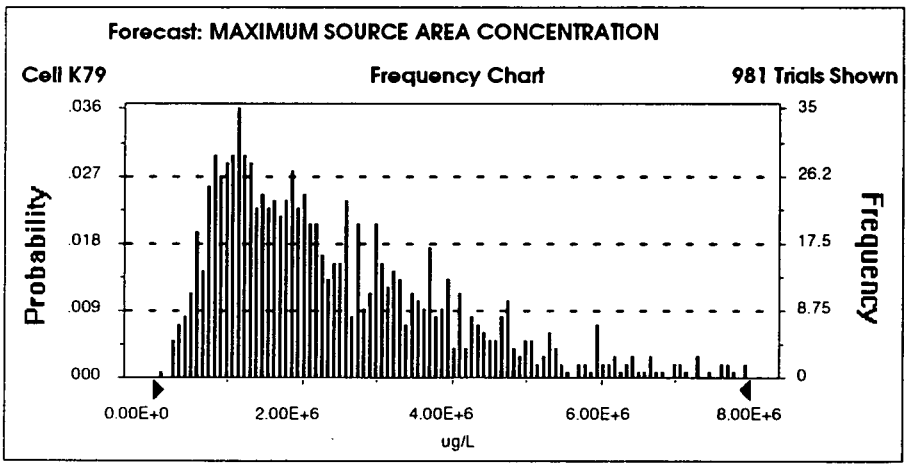
000215

Forecast: MAXIMUM SOURCE AREA CONCENTRATION **Cell: K79**

Summary:

Display Range is from 0.00E+0 to 8.00E+6 ug/L
Entire Range is from 1.46E+5 to 1.21E+7 ug/L
After 1,000 Trials, the Std. Error of the Mean is 5.77E+4

Statistics:	Value
Trials	1000
Mean	2.58E+06
Median (approx.)	2.07E+06
Mode (approx.)	1.16E+06
Standard Deviation	1.82E+06
Variance	3.33E+12
Skewness	1.62
Kurtosis	6.47
Coeff. of Variability	0.71
Range Minimum	1.46E+05
Range Maximum	1.21E+07
Range Width	1.20E+07
Mean Std. Error	5.77E+04



000216

Forecast: MAXIMUM SOURCE AREA CONCENTRATION (cont'd) **Cell: K79**

Percentiles:

Percentile	ug/L (approx.)
0%	1.46E+05
10%	8.25E+05
20%	1.11E+06
30%	1.38E+06
40%	1.73E+06
50%	2.07E+06
60%	2.55E+06
70%	3.08E+06
80%	3.77E+06
90%	4.83E+06
100%	1.21E+07

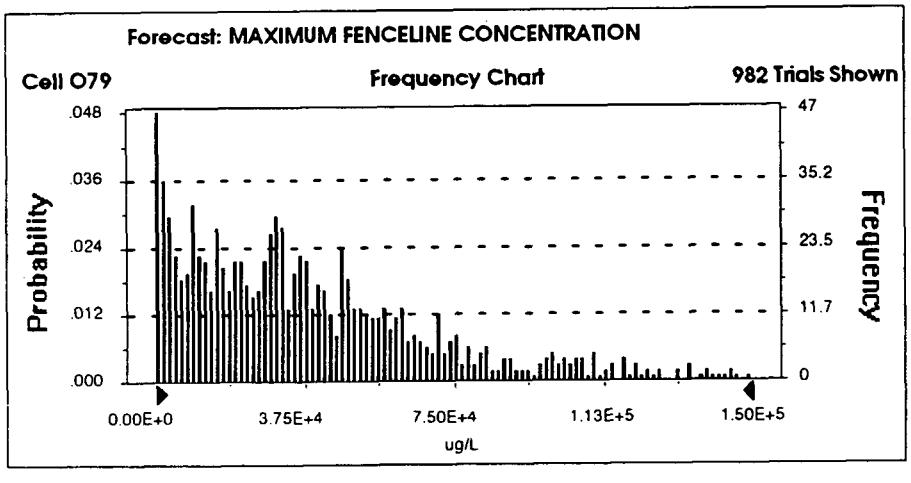
End of Forecast

Forecast: MAXIMUM FENCELINE CONCENTRATION **Cell: O79**

Summary:

Display Range is from 0.00E+0 to 1.50E+5 ug/L
Entire Range is from 1.28E+1 to 2.73E+5 ug/L
After 1,000 Trials, the Std. Error of the Mean is 1.16E+3

Statistics:	Value
Trials	1000
Mean	4.09E+04
Median (approx.)	3.19E+04
Mode (approx.)	1.38E+03
Standard Deviation	3.68E+04
Variance	1.35E+09
Skewness	1.75
Kurtosis	7.64
Coeff. of Variability	0.90
Range Minimum	1.28E+01
Range Maximum	2.73E+05
Range Width	2.73E+05
Mean Std. Error	1.16E+03



000218

Forecast: MAXIMUM FENCELINE CONCENTRATION (cont'd) **Cell: O79**

Percentiles:

Percentile	ug/L (approx.)
0%	1.28E+01
10%	3.79E+03
20%	1.03E+04
30%	1.75E+04
40%	2.58E+04
50%	3.19E+04
60%	4.03E+04
70%	4.98E+04
80%	6.24E+04
90%	8.83E+04
100%	2.73E+05

End of Forecast

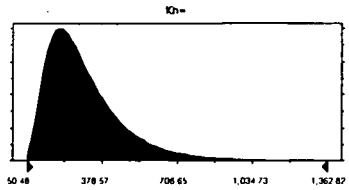
Assumptions

Assumption: Kh= **Cell: Z22**

Lognormal distribution with parameters:

Mean	305.00
Standard Dev.	181.00

Selected range is from 0.00 to +Infinity
Mean value in simulation was 298.45

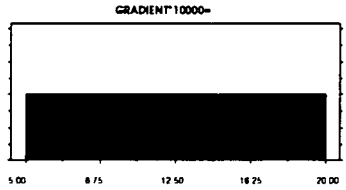


Assumption: GRADIENT*10000= **Cell: Z21**

Uniform distribution with parameters:

Minimum	5.00
Maximum	20.00

Mean value in simulation was 12.62

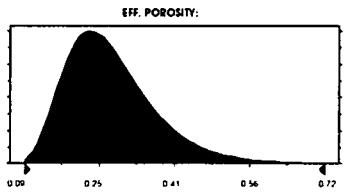


Assumption: EFF. POROSITY: **Cell: L18**

Lognormal distribution with parameters:

Mean	0.27
Standard Dev.	0.10

Selected range is from 0.00 to +Infinity
Mean value in simulation was 0.28

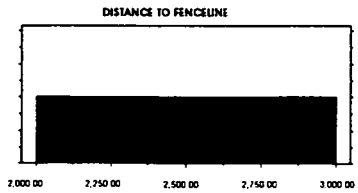


Assumption: DISTANCE TO FENCELINE **Cell: P22**

Uniform distribution with parameters:

Minimum	2,000.00
Maximum	3,000.00

Mean value in simulation was 2,506.97

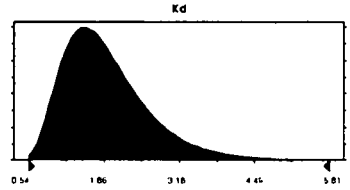


Assumption: Kd **Cell: P16**

Lognormal distribution with parameters:

Mean	1.91
Standard Dev.	0.79

Selected range is from 0.00 to +Infinity
Mean value in simulation was 1.92

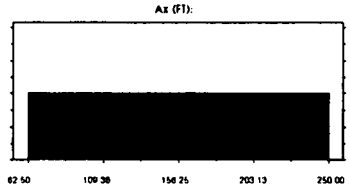


Assumption: Ax (FT): **Cell: L21**

Uniform distribution with parameters:

Minimum	62.50
Maximum	250.00

Mean value in simulation was 154.21

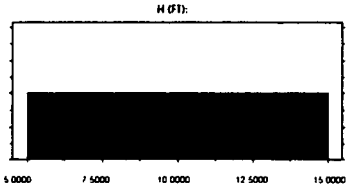


Assumption: H (FT): **Cell: L17**

Uniform distribution with parameters:

Minimum	5.0000
Maximum	15.0000

Mean value in simulation was 9.9540

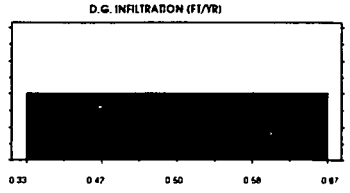


Assumption: D.G. INFILTRATION (FT/YR) **Cell: P18**

Uniform distribution with parameters:

Minimum	0.33
Maximum	0.67

Mean value in simulation was 0.50



End of Assumptions

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BROWN & ROOT ENVIRONMENTAL

SCREENING-LEVEL EXCEL-CRYSTAL BALL TRANSPORT (ECTran) MODEL

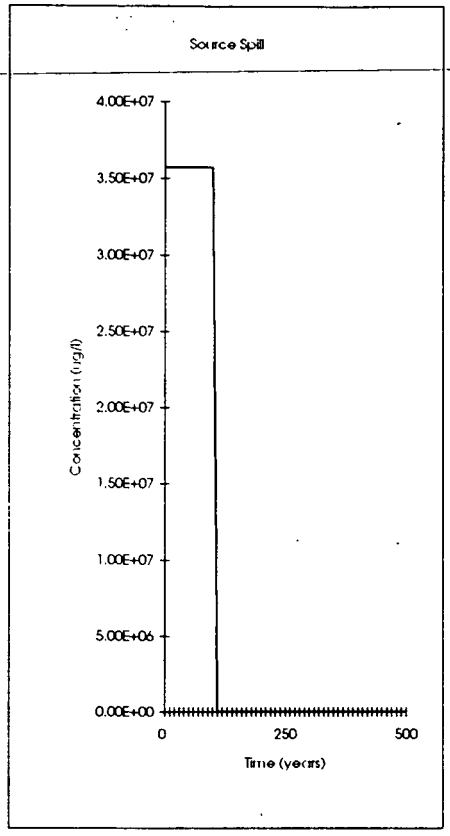
SITE: CRUS FEMP
MODEL IMPROVEMENT
SENSITIVITY ANALYSIS
CASE 1 Uranium loading at well 2055

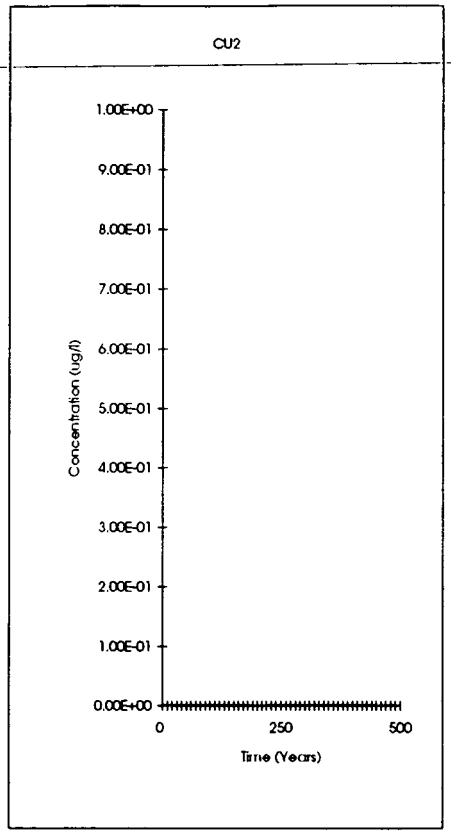
INVESTIGATOR: RDW
DATE: 3/25/94

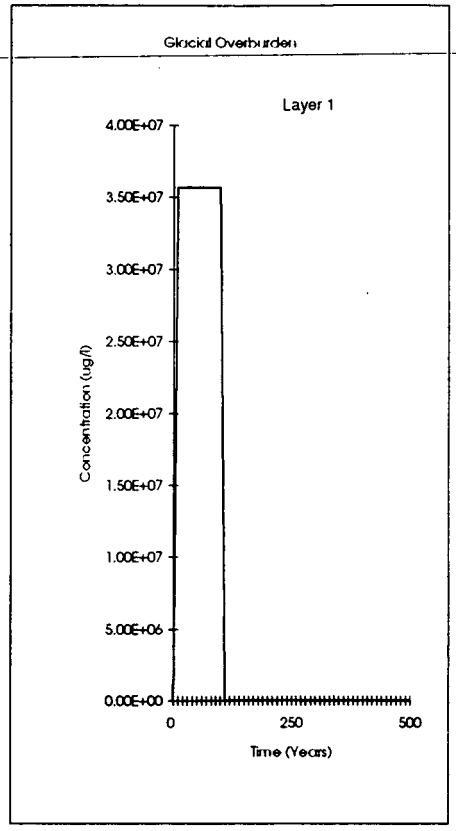
CONTAMINANT: U238		SPECIFIC ACTIVITY (Ci/g):	3.36E-07
KOC (L/KG):	0.00	WATER CRITERIA (UG/L):	1.39E+00
HALF LIFE (YRS):		PRECIPITATION CONC. (UG/L)	0.00E+00
LAYER 1:	4.51E+09		
LAYER 2:	4.51E+09		
GMA:	4.51E+09		

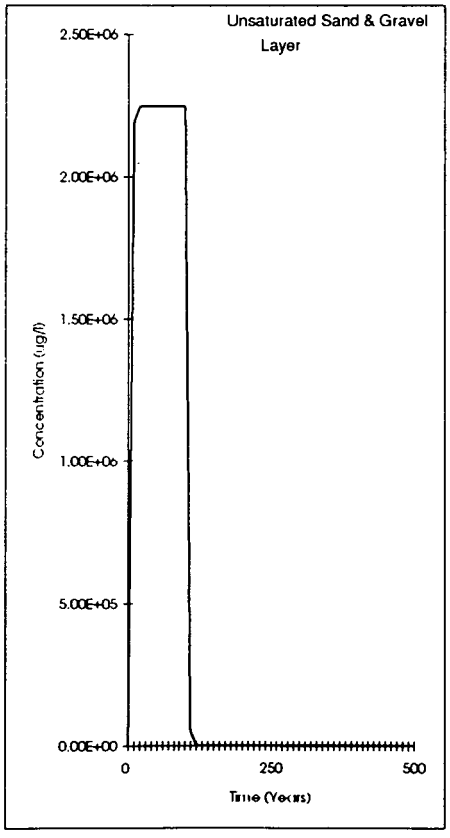
UNSAT. SOURCE	AREA:	VADOSE ZONE		GREAT MIAMI AQUIFER		GREAT MIAMI AQUIFER (SAT. S. & G.)			
INFILT(FT/YR):	0.522	CU1(0) (PPB)	0.00E+00	CU2(0) (PPB):	0.00E+00	B (FT):	75	Vzo (FT/YR):	4.34
LENGTH (FT)	125	FOC (KG/KG):	0.005	FOC (KG/KG):	0.0050	GW Q3 (L/DAY):	1.01E+04	FOC (KG/KG):	0.005
WIDTH (FT)	125	Kd (L/KG):	1.78	Kd (L/KG):	1.780	GW V.(FT/YR):	495.01	Kd (L/KG):	1.78
POROSITY 1:	0.2	SATURATION:	0.30	SATURATION:	1.00	H (FT):	6.9800	RETARDATION:	11.79867
POROSITY 2:	0.3	THICKNESS (FT):	0.01	THICKNESS (FT):	6.98	EFF. POROSITY:	0.30	q (FT/YR) :	0.5
DENSITY 1 (G/CM3):	1.78	DECAY (1/DAY):	4.21E-13	DECAY (1/DAY):	4.21E-13	DISPERSIVITY:		DECAY (1/YR):	2.2E-02
DENSITY 2 (G/CM3):	1.60	CAo (UG/L):	0.00E+00	CBo (PPB):	0.00E+00	Az(FT):	0.14	CU3 (PPB):	0
U.G. GW V (FT/YR)	463.85417	D.F. 1 (1/YR):	0	D.F. 2 (1/YR):	0.000	Ax (FT):	100.00	P&T(YEARS):	0
AGE (YEARS)	0	Q1 (L/DAY):	6.33E+02	Q2 (L/DAY):	9.42E+03	Ay (FT):	33.33	DISTANCE TO F.L.(FT):	2500
		Ts 1 (YEARS):	100	Ts 2 (YEARS):	100				

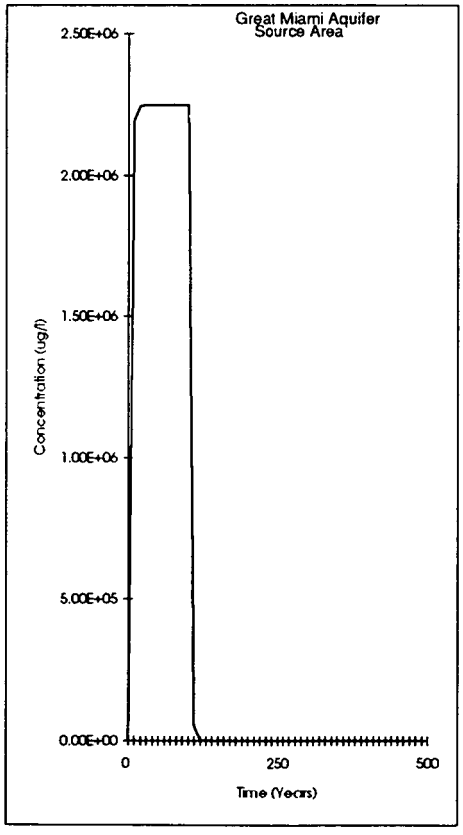
TIME INTERVAL (YRS)		10		UNSAT S&G	SOURCE AREA CONC.	SOURCE AREA CONC.	FENCE LINE CONC.
ELAPSED TIME - YRS		CU1(PPB)	CU2(PPB)	CONC. (UG/L)	(UG/L)	(UG/L)	(UG/L)
1950	0	3.57E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	10	3.57E+07	0.00E+00	3.57E+07	2.19E+06	2.19E+06	0.00E+00
1970	20	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.54E-08
1980	30	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	4.51E+00
1990	40	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	9.97E+02
2000	50	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	9.86E+03
2010	60	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	2.93E+04
2020	70	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	4.98E+04
2030	80	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	6.40E+04
2040	90	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.17E+04
2050	100	3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.52E+04
2060	110	0.00E+00	0.00E+00	1.96E-63	5.27E+04	5.27E+04	7.67E+04
2070	120	0.00E+00	0.00E+00	1.08E-133	1.21E+03	1.21E+03	7.72E+04
2080	130	0.00E+00	0.00E+00	5.92E-204	2.77E+01	2.77E+01	7.74E+04
2090	140	0.00E+00	0.00E+00	3.25E-274	6.35E-01	6.35E-01	7.65E+04
2100	150	0.00E+00	0.00E+00	0.00E+00	1.45E-02	1.45E-02	6.76E+04
2110	160	0.00E+00	0.00E+00	0.00E+00	3.33E-04	3.33E-04	4.82E+04
2120	170	0.00E+00	0.00E+00	0.00E+00	7.64E-06	7.64E-06	2.77E+04
2130	180	0.00E+00	0.00E+00	0.00E+00	1.75E-07	1.75E-07	1.35E+04
2140	190	0.00E+00	0.00E+00	0.00E+00	4.01E-09	4.01E-09	5.79E+03
2150	200	0.00E+00	0.00E+00	0.00E+00	9.19E-11	9.19E-11	2.28E+03
2160	210	0.00E+00	0.00E+00	0.00E+00	2.11E-12	2.11E-12	8.38E+02
2170	220	0.00E+00	0.00E+00	0.00E+00	4.83E-14	4.83E-14	2.93E+02
2180	230	0.00E+00	0.00E+00	0.00E+00	1.11E-15	1.11E-15	9.89E+01
2190	240	0.00E+00	0.00E+00	0.00E+00	2.53E-17	2.53E-17	3.23E+01
2200	250	0.00E+00	0.00E+00	0.00E+00	5.81E-19	5.81E-19	1.03E+01
2210	260	0.00E+00	0.00E+00	0.00E+00	1.33E-20	1.33E-20	3.24E+00
2220	270	0.00E+00	0.00E+00	0.00E+00	3.05E-22	3.05E-22	1.00E+00
2230	280	0.00E+00	0.00E+00	0.00E+00	6.99E-24	6.99E-24	3.05E-01
2240	290	0.00E+00	0.00E+00	0.00E+00	1.60E-25	1.60E-25	9.21E-02
2250	300	0.00E+00	0.00E+00	0.00E+00	3.67E-27	3.67E-27	2.75E-02
2260	310	0.00E+00	0.00E+00	0.00E+00	8.41E-29	8.41E-29	8.17E-03
2270	320	0.00E+00	0.00E+00	0.00E+00	1.93E-30	1.93E-30	2.41E-03
2280	330	0.00E+00	0.00E+00	0.00E+00	4.42E-32	4.42E-32	7.07E-04
2290	340	0.00E+00	0.00E+00	0.00E+00	1.01E-33	1.01E-33	2.07E-04
2300	350	0.00E+00	0.00E+00	0.00E+00	2.32E-35	2.32E-35	6.01E-05
2310	360	0.00E+00	0.00E+00	0.00E+00	5.32E-37	5.32E-37	1.74E-05
2320	370	0.00E+00	0.00E+00	0.00E+00	1.22E-38	1.22E-38	5.03E-06
2330	380	0.00E+00	0.00E+00	0.00E+00	2.79E-40	2.79E-40	1.45E-06
2340	390	0.00E+00	0.00E+00	0.00E+00	6.40E-42	6.40E-42	4.16E-07
2350	400	0.00E+00	0.00E+00	0.00E+00	1.47E-43	1.47E-43	1.19E-07
2360	410	0.00E+00	0.00E+00	0.00E+00	3.36E-45	3.36E-45	2.83E-09
2370	420	0.00E+00	0.00E+00	0.00E+00	7.70E-47	7.70E-47	0.00E+00
2380	430	0.00E+00	0.00E+00	0.00E+00	1.76E-48	1.76E-48	0.00E+00
2390	440	0.00E+00	0.00E+00	0.00E+00	4.04E-50	4.04E-50	0.00E+00
2400	450	0.00E+00	0.00E+00	0.00E+00	9.26E-52	9.26E-52	0.00E+00
2410	460	0.00E+00	0.00E+00	0.00E+00	2.12E-53	2.12E-53	0.00E+00
2420	470	0.00E+00	0.00E+00	0.00E+00	4.87E-55	4.87E-55	0.00E+00
2430	480	0.00E+00	0.00E+00	0.00E+00	1.11E-56	1.11E-56	0.00E+00
2440	490	0.00E+00	0.00E+00	0.00E+00	2.56E-58	2.56E-58	0.00E+00
2450	500	0.00E+00	0.00E+00	0.00E+00	5.86E-60	5.86E-60	0.00E+00
MAXIMUM:		3.57E+07	0.00E+00	3.57E+07	2.25E+06	2.25E+06	7.74E+04

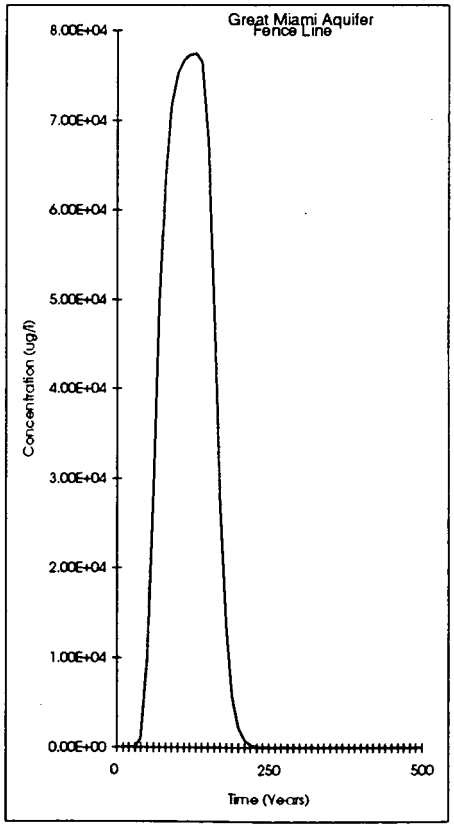

Source Spill
Concentration (ug/l)
4.00E+07
3.50E+07
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
0
250
500
Time (years)


CU2
Concentration (ug/l)
1.00E+00
9.00E-01
8.00E-01
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
0
250
500
Time (Years)


Glacial Overburden
Layer 1
Concentration (ug/l)
4.00E+07
3.50E+07
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
0
250
500
Time (Years)

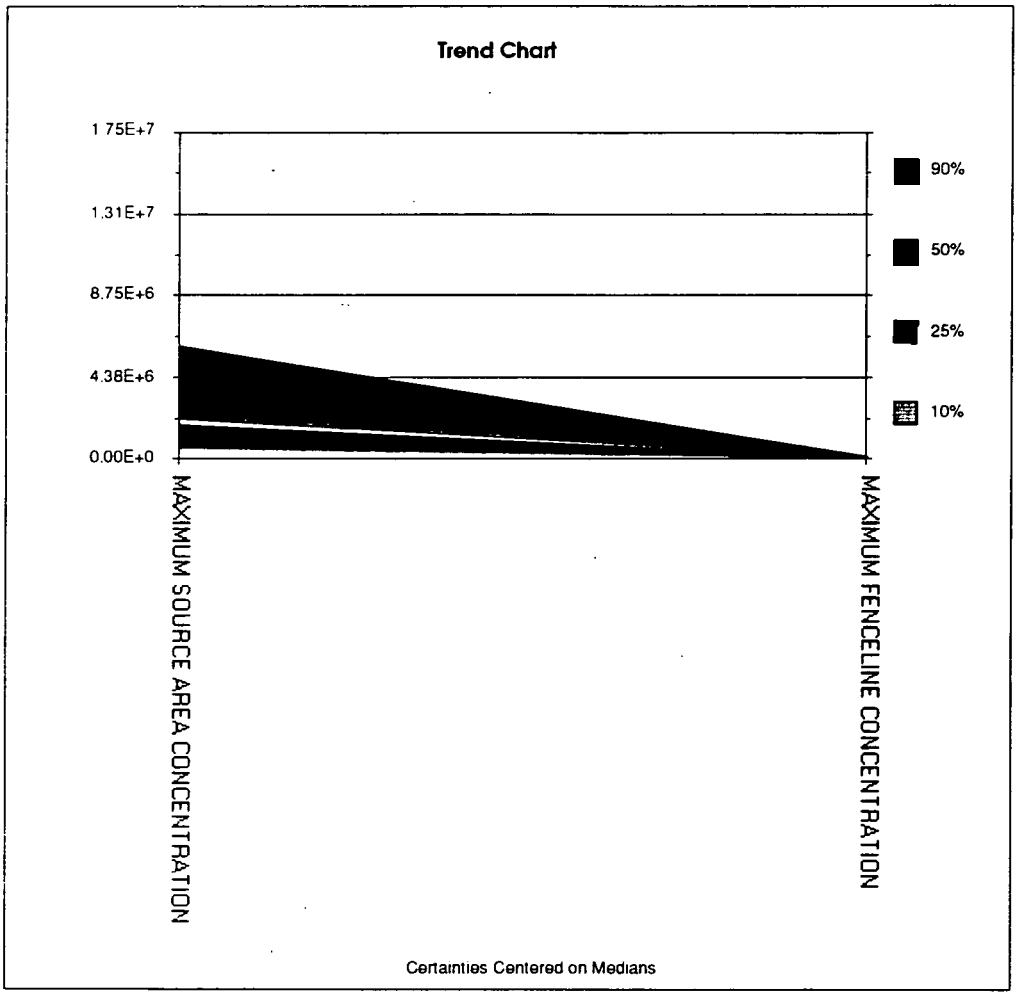

Unsaturated Sand & Gravel Layer
Concentration (ug/l)
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
0
250
500
Time (Years)


Great Miami Aquifer Source Area
Concentration (ug/l)
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
0
250
500
Time (Years)


Great Miami Aquifer Fence Line
Concentration (ug/l)
8.00E+04
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
0
250
500
Time (Years)

5490

Crystal Ball Report
Simulation started on 4/13/94 at 10:35:05
Simulation stopped on 4/13/94 at 10:50:19

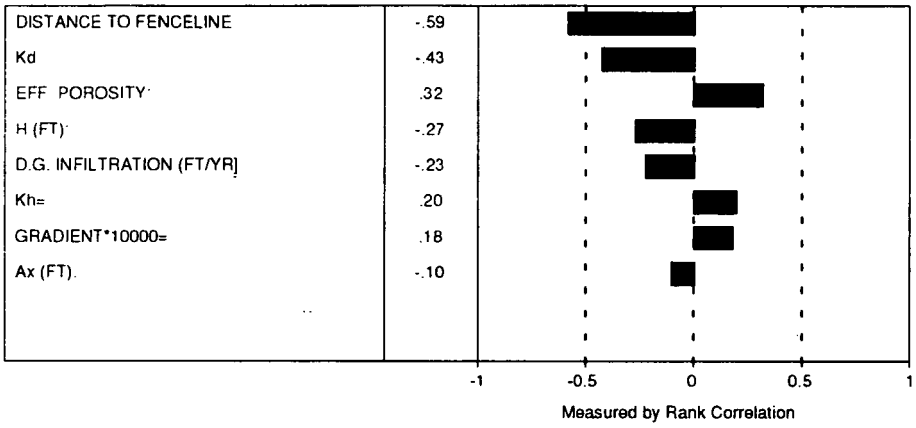


000224

5490

Sensitivity Chart

Target Forecast: MAXIMUM FENCELINE CONCENTRATION



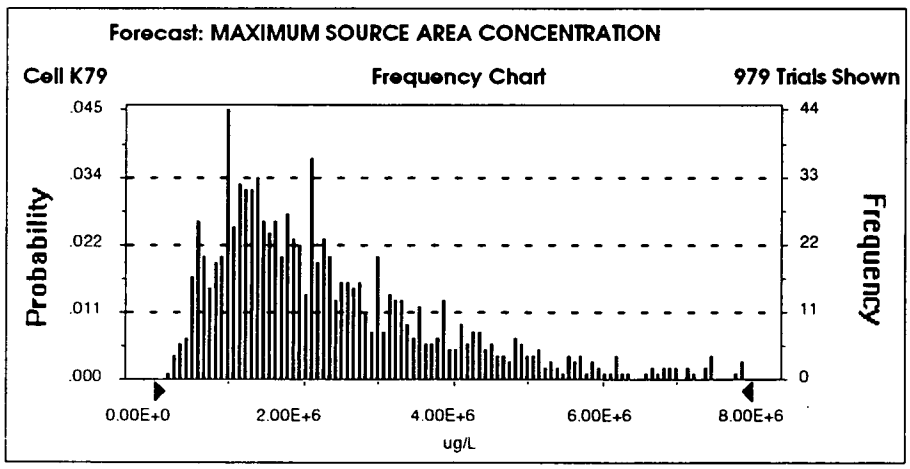
000225

Forecast: MAXIMUM SOURCE AREA CONCENTRATION **Cell: K79**

Summary:

Display Range is from 0.00E+0 to 8.00E+6 ug/L
Entire Range is from 2.03E+5 to 1.54E+7 ug/L
After 1,000 Trials, the Std. Error of the Mean is 5.82E+4

Statistics:	Value
Trials	1000
Mean	2.50E+06
Median (approx.)	2.02E+06
Mode (approx.)	1.04E+06
Standard Deviation	1.84E+06
Variance	3.38E+12
Skewness	1.96
Kurtosis	8.83
Coeff. of Variability	0.74
Range Minimum	2.03E+05
Range Maximum	1.54E+07
Range Width	1.52E+07
Mean Std. Error	5.82E+04



Forecast: MAXIMUM SOURCE AREA CONCENTRATION (cont'd) **Cell: K79**

Percentiles:

Percentile	ug/L (approx.)
0%	2.03E+05
10%	8.20E+05
20%	1.11E+06
30%	1.37E+06
40%	1.66E+06
50%	2.02E+06
60%	2.36E+06
70%	2.91E+06
80%	3.59E+06
90%	4.80E+06
100%	1.54E+07

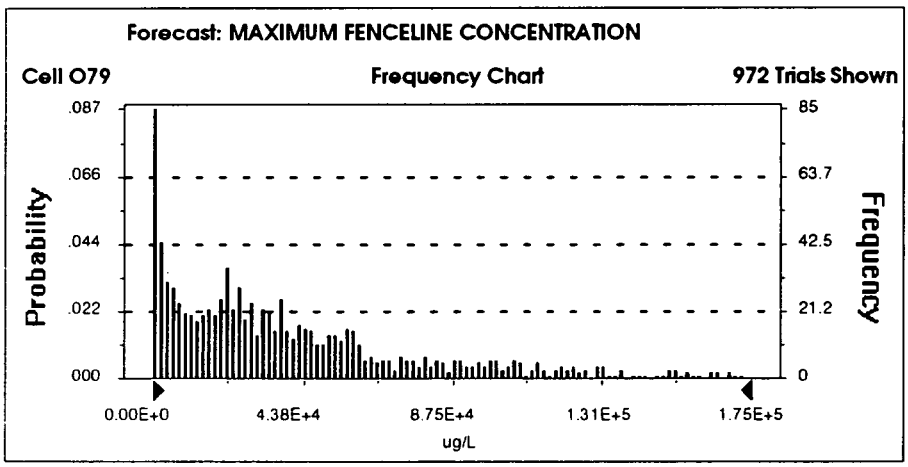
End of Forecast

Forecast: MAXIMUM FENCELINE CONCENTRATION **Cell: O79**

Summary:

Display Range is from 0.00E+0 to 1.75E+5 ug/L
Entire Range is from 5.83E-2 to 3.83E+5 ug/L
After 1,000 Trials, the Std. Error of the Mean is 1.52E+3

Statistics:	Value
Trials	1000
Mean	4.55E+04
Median (approx.)	3.15E+04
Mode (approx.)	1.91E+03
Standard Deviation	4.79E+04
Variance	2.30E+09
Skewness	2.01
Kurtosis	8.55
Coeff. of Variability	1.05
Range Minimum	5.83E-02
Range Maximum	3.83E+05
Range Width	3.83E+05
Mean Std. Error	1.52E+03



Forecast: MAXIMUM FENCELINE CONCENTRATION (cont'd) **Cell: O79**

Percentiles:

Percentile	ug/L (approx.)
0%	5.83E-02
10%	2.38E+03
20%	7.97E+03
30%	1.65E+04
40%	2.34E+04
50%	3.15E+04
60%	4.04E+04
70%	5.32E+04
80%	7.28E+04
90%	1.07E+05
100%	3.83E+05

End of Forecast

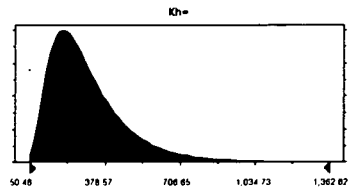
Assumptions

Assumption: Kh= **Cell: Z22**

Lognormal distribution with parameters:

Mean	305.00
Standard Dev.	181.00

Selected range is from 0.00 to +Infinity
Mean value in simulation was 305.00

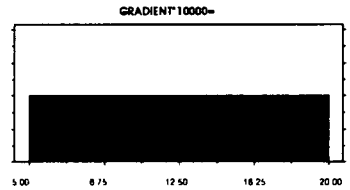


Assumption: GRADIENT*10000= **Cell: Z21**

Uniform distribution with parameters:

Minimum	5.00
Maximum	20.00

Mean value in simulation was 12.75

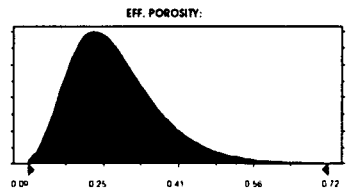


Assumption: EFF. POROSITY: **Cell: L18**

Lognormal distribution with parameters:

Mean	0.27
Standard Dev.	0.10

Selected range is from 0.00 to +Infinity
Mean value in simulation was 0.27

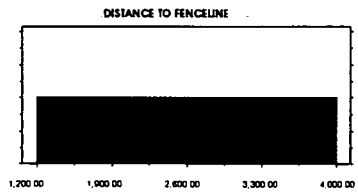


Assumption: DISTANCE TO FENCELINE **Cell: P22**

Uniform distribution with parameters:

Minimum	1,200.00
Maximum	4,000.00

Mean value in simulation was 2,618.67



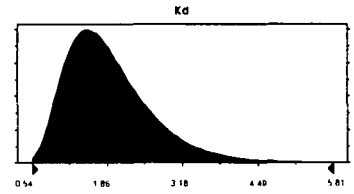
000230

Assumption: Kd **Cell: P16**

Lognormal distribution with parameters:

Mean	1.91
Standard Dev.	0.79

Selected range is from 0.00 to +Infinity
Mean value in simulation was 1.90

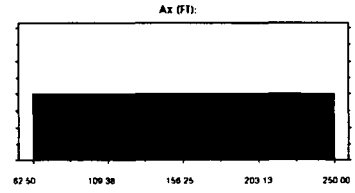


Assumption: Ax (FT): **Cell: L21**

Uniform distribution with parameters:

Minimum	62.50
Maximum	250.00

Mean value in simulation was 155.59

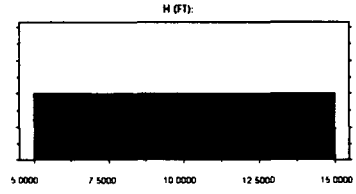


Assumption: H (FT): **Cell: L17**

Uniform distribution with parameters:

Minimum	5.0000
Maximum	15.0000

Mean value in simulation was 10.0256

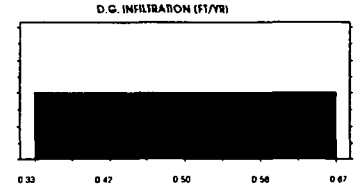


Assumption: D.G. INFILTRATION (FT/YR) **Cell: P18**

Uniform distribution with parameters:

Minimum	0.33
Maximum	0.67

Mean value in simulation was 0.50



End of Assumptions

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BROWN & ROOT ENVIRONMENTAL

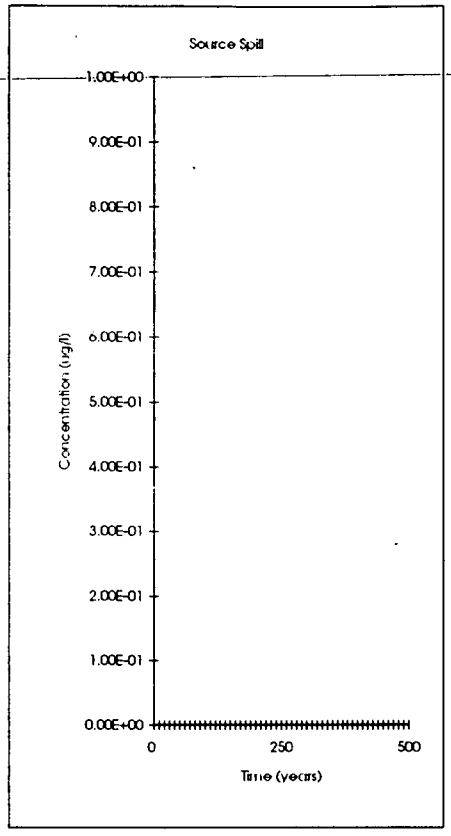
SCREENING-LEVEL EXCEL-CRYSTAL BALL TRANSPORT (ECTran) MODEL

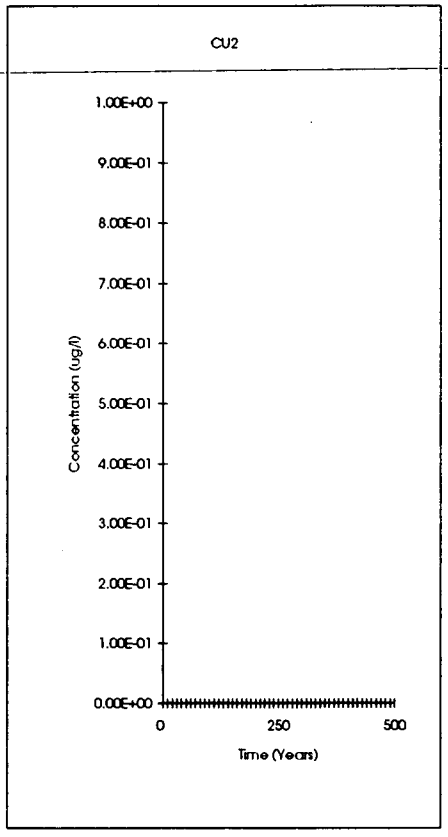
SITE:	CRU5 FEMP
	MODEL IMPROVEMENT
	SENSITIVITY ANALYSIS
	CASE 3
INVESTIGATOR:	RDW
DATE:	3/30/94

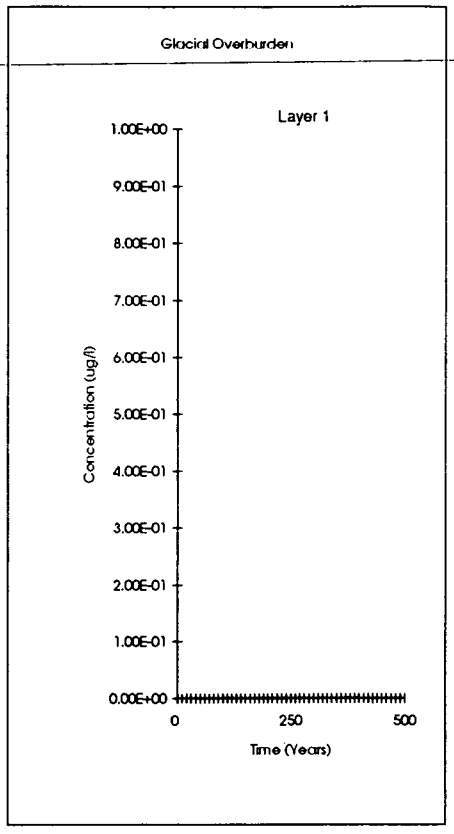
CONTAMINANT: U238		SPECIFIC ACTIVITY (Ci/g):	3.36E-07
KOC (L/KG):	0.00	WATER CRITERIA (UG/L):	1.39E+00
HALF LIFE (YRS):		PRECIPITATION CONC. (UG/L)	0.00E+00
LAYER 1:	4.51E+09		
LAYER 2:	4.51E+09		
GMA:	4.51E+09		

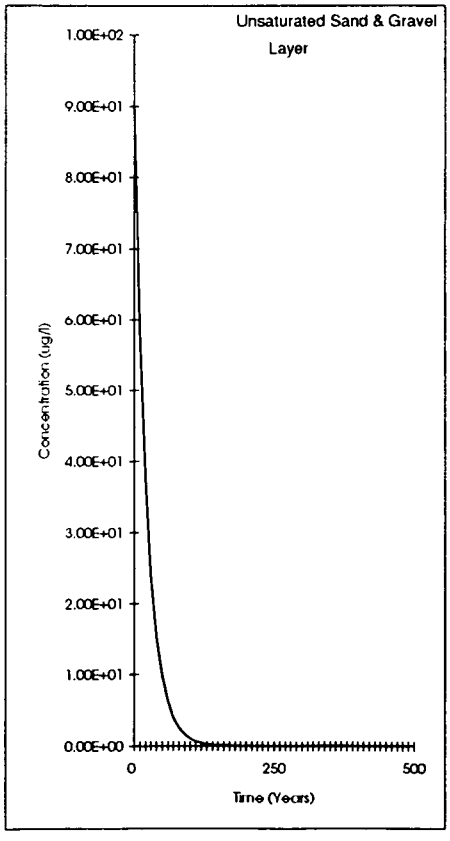
UNSAT. SOURCE	AREA:	VADOSE ZONE		GREAT MIAMI AQUIFER		GREAT MIAMI AQUIFER (SAT. S. & G.)			
INFILT(FT/YR)	0.522	CU1(0) (PPB)	0.00E+00	CU2(0) (PPB):	0.00E+00	B (FT):	75	Vzo (FT/YR):	4.34
LENGTH (FT):	1600	FOC (KG/KG):	0.005	FOC (KG/KG):	0.0050	GW Q3 (L/DAY):	1.73E+05	FOC (KG/KG):	0.005
WIDTH (FT)	1000	Kd (L/KG):	1.78	Kd (L/KG):	1.780	GW V.(FT/YR):	742.25	Kd (L/KG):	1.78
POROSITY 1	0.2	SATURATION:	0.30	SATURATION:	1.00	H (FT):	10.0000	RETARDATION:	11.79867
POROSITY 2.	0.3	THICKNESS (FT):	0.01	THICKNESS (FT):	10.00	EFF. POROSITY:	0.30	q (FT/YR) :	0.5
DENSITY 1 (G/CM3):	1.78	DECAY (1/DAY):	4.21E-13	DECAY (1/DAY):	4.21E-13	DISPERSIVITY:		DECAY (1/YR):	2.2E-02
DENSITY 2 (G/CM3):	1.60	CAo (UG/L):	0.00E+00	CBo (PPB):	9.05E+01	Az(FT):	0.14	CU3 (PPB):	0
U.G. GW V (FT/YR)	463.85417	D.F. 1 (1/YR):	0	D.F. 2 (1/YR):	0.000	Ax (FT):	100.00	P&T(YEARS):	0
AGE (YEARS)	40	Q1 (L/DAY):	6.48E+04	Q2 (L/DAY):	1.08E+05	Ay (FT):	33.33	DISTANCE TO E.P.(FT):	4000
		Ts 1 (YEARS):	0	Ts 2 (YEARS):	0				

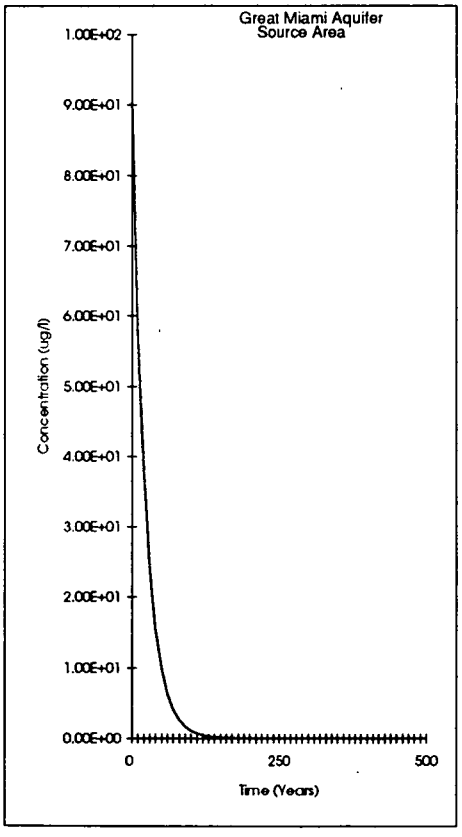
TIME INTERVAL (YRS)	10			UNSAT S&G	SOURCE AREA CONC.	SOURCE AREA CONC.	EXPOSURE POINT CONC.
ELAPSED TIME - YRS		CU1(PPB)	CU2(PPB)	CONC. (UG/L)	(UG/L)	(UG/L)	(UG/L)
1993	0	0.00E+00	0.00E+00	0.00E+00	9.05E+01	9.05E+01	4.96E-01
2003	10	0.00E+00	0.00E+00	0.00E+00	5.81E+01	5.81E+01	3.23E+00
2013	20	0.00E+00	0.00E+00	0.00E+00	3.74E+01	3.74E+01	7.93E+00
2023	30	0.00E+00	0.00E+00	0.00E+00	2.40E+01	2.40E+01	1.19E+01
2033	40	0.00E+00	0.00E+00	0.00E+00	1.54E+01	1.54E+01	1.41E+01
2043	50	0.00E+00	0.00E+00	0.00E+00	9.91E+00	9.91E+00	1.48E+01
2053	60	0.00E+00	0.00E+00	0.00E+00	6.37E+00	6.37E+00	1.40E+01
2063	70	0.00E+00	0.00E+00	0.00E+00	4.09E+00	4.09E+00	1.17E+01
2073	80	0.00E+00	0.00E+00	0.00E+00	2.63E+00	2.63E+00	8.79E+00
2083	90	0.00E+00	0.00E+00	0.00E+00	1.69E+00	1.69E+00	6.12E+00
2093	100	0.00E+00	0.00E+00	0.00E+00	1.09E+00	1.09E+00	4.08E+00
2103	110	0.00E+00	0.00E+00	0.00E+00	6.97E-01	6.97E-01	2.66E+00
2113	120	0.00E+00	0.00E+00	0.00E+00	4.48E-01	4.48E-01	1.72E+00
2123	130	0.00E+00	0.00E+00	0.00E+00	2.88E-01	2.88E-01	1.11E+00
2133	140	0.00E+00	0.00E+00	0.00E+00	1.85E-01	1.85E-01	7.13E-01
2143	150	0.00E+00	0.00E+00	0.00E+00	1.19E-01	1.19E-01	4.58E-01
2153	160	0.00E+00	0.00E+00	0.00E+00	7.64E-02	7.64E-02	2.95E-01
2163	170	0.00E+00	0.00E+00	0.00E+00	4.91E-02	4.91E-02	1.89E-01
2173	180	0.00E+00	0.00E+00	0.00E+00	3.15E-02	3.15E-02	1.22E-01
2183	190	0.00E+00	0.00E+00	0.00E+00	2.03E-02	2.03E-02	7.82E-02
2193	200	0.00E+00	0.00E+00	0.00E+00	1.30E-02	1.30E-02	5.02E-02
2203	210	0.00E+00	0.00E+00	0.00E+00	8.37E-03	8.37E-03	3.23E-02
2213	220	0.00E+00	0.00E+00	0.00E+00	5.38E-03	5.38E-03	2.07E-02
2223	230	0.00E+00	0.00E+00	0.00E+00	3.45E-03	3.45E-03	1.33E-02
2233	240	0.00E+00	0.00E+00	0.00E+00	2.22E-03	2.22E-03	8.56E-03
2243	250	0.00E+00	0.00E+00	0.00E+00	1.43E-03	1.43E-03	5.50E-03
2253	260	0.00E+00	0.00E+00	0.00E+00	9.16E-04	9.16E-04	3.53E-03
2263	270	0.00E+00	0.00E+00	0.00E+00	5.89E-04	5.89E-04	2.27E-03
2273	280	0.00E+00	0.00E+00	0.00E+00	3.78E-04	3.78E-04	1.46E-03
2283	290	0.00E+00	0.00E+00	0.00E+00	2.43E-04	2.43E-04	9.37E-04
2293	300	0.00E+00	0.00E+00	0.00E+00	1.56E-04	1.56E-04	6.02E-04
2303	310	0.00E+00	0.00E+00	0.00E+00	1.00E-04	1.00E-04	3.87E-04
2313	320	0.00E+00	0.00E+00	0.00E+00	6.45E-05	6.45E-05	2.49E-04
2323	330	0.00E+00	0.00E+00	0.00E+00	4.14E-05	4.14E-05	1.60E-04
2333	340	0.00E+00	0.00E+00	0.00E+00	2.66E-05	2.66E-05	1.03E-04
2343	350	0.00E+00	0.00E+00	0.00E+00	1.71E-05	1.71E-05	6.60E-05
2353	360	0.00E+00	0.00E+00	0.00E+00	1.10E-05	1.10E-05	4.24E-05
2363	370	0.00E+00	0.00E+00	0.00E+00	7.06E-06	7.06E-06	2.72E-05
2373	380	0.00E+00	0.00E+00	0.00E+00	4.54E-06	4.54E-06	1.75E-05
2383	390	0.00E+00	0.00E+00	0.00E+00	2.92E-06	2.92E-06	1.12E-05
2393	400	0.00E+00	0.00E+00	0.00E+00	1.87E-06	1.87E-06	7.23E-06
2403	410	0.00E+00	0.00E+00	0.00E+00	1.20E-06	1.20E-06	4.64E-06
2413	420	0.00E+00	0.00E+00	0.00E+00	7.73E-07	7.73E-07	2.98E-06
2423	430	0.00E+00	0.00E+00	0.00E+00	4.97E-07	4.97E-07	1.92E-06
2433	440	0.00E+00	0.00E+00	0.00E+00	3.19E-07	3.19E-07	1.23E-06
2443	450	0.00E+00	0.00E+00	0.00E+00	2.05E-07	2.05E-07	7.91E-07
2453	460	0.00E+00	0.00E+00	0.00E+00	1.32E-07	1.32E-07	5.08E-07
2463	470	0.00E+00	0.00E+00	0.00E+00	8.47E-08	8.47E-08	3.27E-07
2473	480	0.00E+00	0.00E+00	0.00E+00	5.44E-08	5.44E-08	2.10E-07
2483	490	0.00E+00	0.00E+00	0.00E+00	3.50E-08	3.50E-08	1.35E-07
2493	500	0.00E+00	0.00E+00	0.00E+00	2.25E-08	2.25E-08	8.67E-08
MAXIMUM:		0.00E+00	0.00E+00	0.00E+00	9.05E+01	9.05E+01	1.48E+01

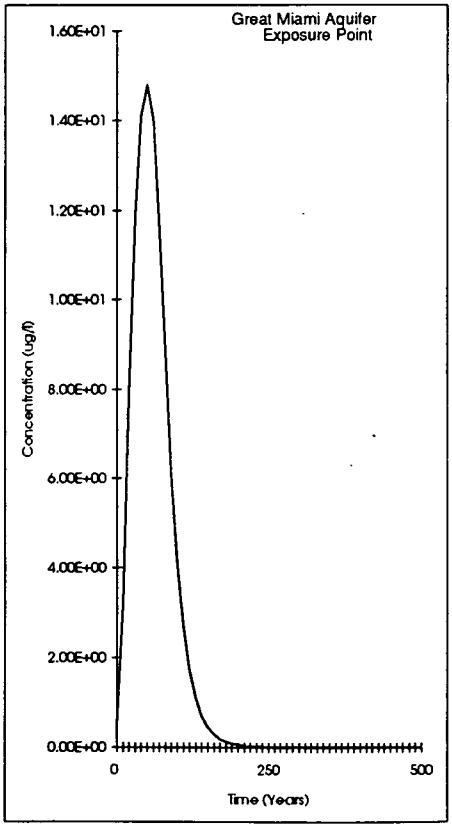

Source Spill
Concentration (ug/l)
1.00E+00
9.00E-01
8.00E-01
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
0
250
500
Time (years)


CU2
Concentration (ug/l)
1.00E+00
9.00E-01
8.00E-01
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
0
250
500
Time (Years)

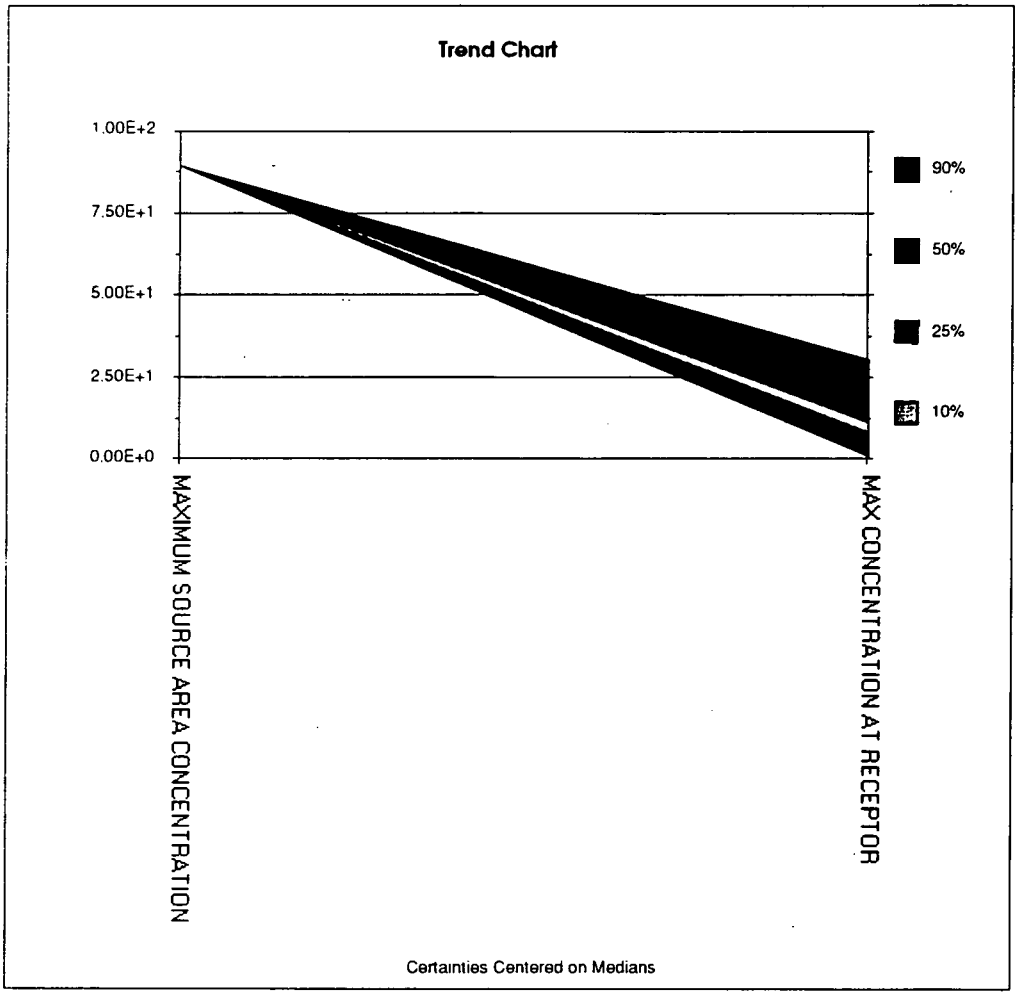

Glacial Overburden
Layer 1
Concentration (ug/l)
1.00E+00
9.00E-01
8.00E-01
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
0
250
500
Time (Years)


Unsaturated Sand & Gravel
Layer
Concentration (ug/l)
1.00E+02
9.00E+01
8.00E+01
7.00E+01
6.00E+01
5.00E+01
4.00E+01
3.00E+01
2.00E+01
1.00E+01
0.00E+00
0
250
500
Time (Years)

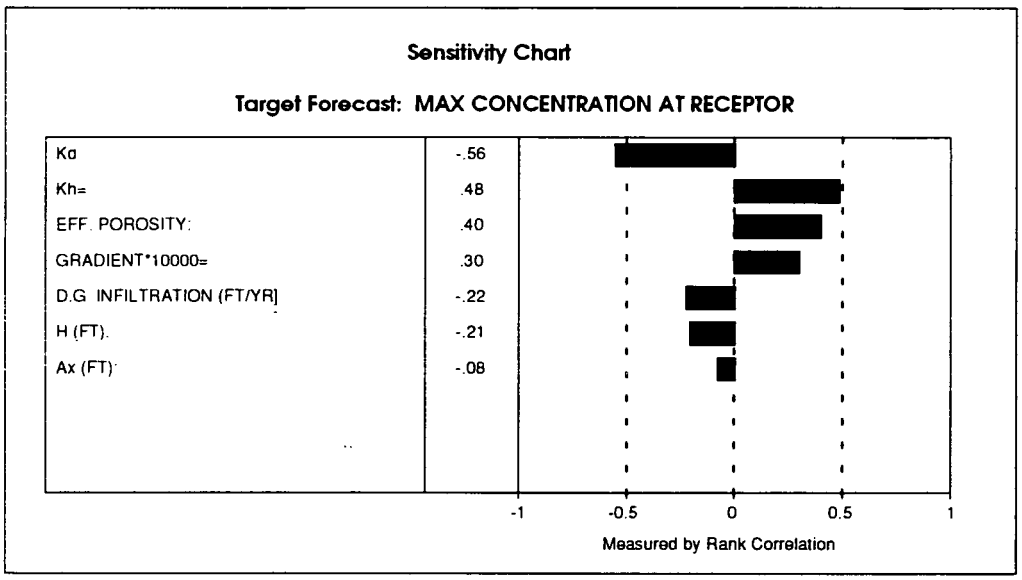

Great Miami Aquifer
Source Area
Concentration (ug/l)
1.00E+02
9.00E+01
8.00E+01
7.00E+01
6.00E+01
5.00E+01
4.00E+01
3.00E+01
2.00E+01
1.00E+01
0.00E+00
0
250
500
Time (Years)


Great Miami Aquifer
Exposure Point
Concentration (ug/l)
1.60E+01
1.40E+01
1.20E+01
1.00E+01
8.00E+00
6.00E+00
4.00E+00
2.00E+00
0.00E+00
0
250
500
Time (Years)

Crystal Ball Report
Simulation started on 4/13/94 at 13:08:33
Simulation stopped on 4/13/94 at 13:23:15



- 5490


Sensitivity Chart
Target Forecast: MAX CONCENTRATION AT RECEPTOR
Ka -.56
Kh= .48
EFF. POROSITY: .40
GRADIENT*10000= .30
D.G INFILTRATION (FT/YR] -.22
H (FT). -.21
Ax (FT) -.08
-1
-0.5
0
0.5
1
Measured by Rank Correlation

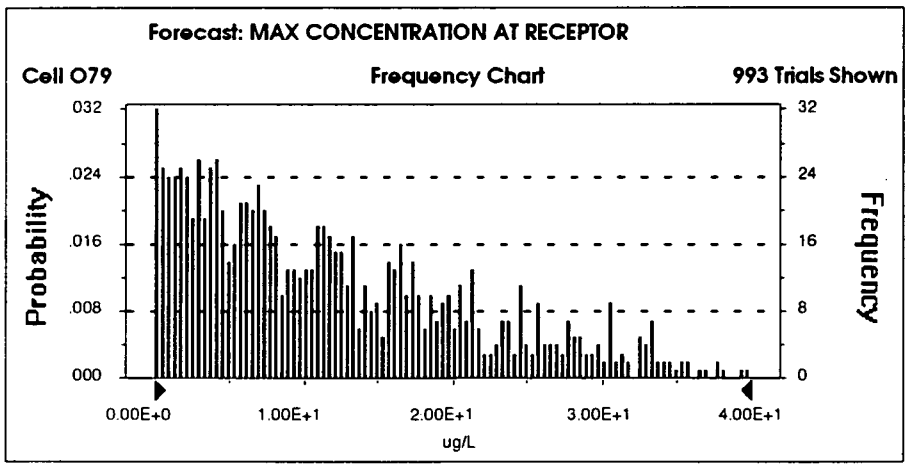
5490

Forecast: MAX CONCENTRATION AT RECEPTOR **Cell: O79**

Summary:

Display Range is from 0.00E+0 to 4.00E+1 ug/L
Entire Range is from 5.96E-3 to 5.38E+1 ug/L
After 1,000 Trials, the Std. Error of the Mean is 3.03E-1

Statistics:	Value
Trials	1000
Mean	1.20E+01
Median (approx.)	9.78E+00
Mode (approx.)	2.75E-01
Standard Deviation	9.59E+00
Variance	9.20E+01
Skewness	0.95
Kurtosis	3.46
Coeff. of Variability	0.80
Range Minimum	5.96E-03
Range Maximum	5.38E+01
Range Width	5.38E+01
Mean Std. Error	3.03E-01



000236

Forecast: MAX CONCENTRATION AT RECEPTOR (cont'd) **Cell: O79**

Percentiles:

Percentile	ug/L (approx.)
0%	5.96E-03
10%	1.52E+00
20%	3.20E+00
30%	5.13E+00
40%	7.14E+00
50%	9.78E+00
60%	1.24E+01
70%	1.62E+01
80%	1.99E+01
90%	2.61E+01
100%	5.38E+01

End of Forecast

5490

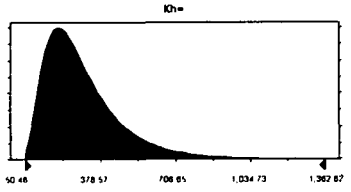
Assumptions

Assumption: Kh= **Cell: Z22**

Lognormal distribution with parameters:

Mean	305.00
Standard Dev.	181.00

Selected range is from 0.00 to +Infinity
Mean value in simulation was 304.11

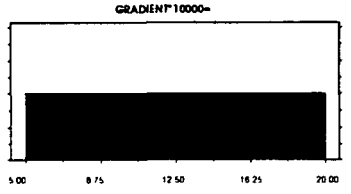


Assumption: GRADIENT*10000= **Cell: Z21**

Uniform distribution with parameters:

Minimum	5.00
Maximum	20.00

Mean value in simulation was 12.61

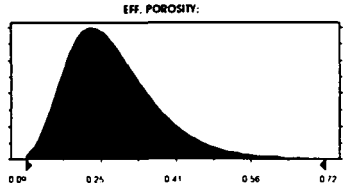


Assumption: EFF. POROSITY: **Cell: L18**

Lognormal distribution with parameters:

Mean	0.27
Standard Dev.	0.10

Selected range is from 0.00 to +Infinity
Mean value in simulation was 0.27

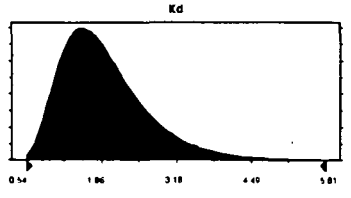


Assumption: Kd **Cell: P16**

Lognormal distribution with parameters:

Mean	1.91
Standard Dev.	0.79

Selected range is from 0.00 to +Infinity
Mean value in simulation was 1.88

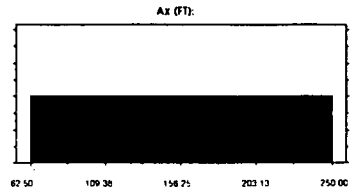


000238

Assumption: Ax (FT): **Cell: L21**

Uniform distribution with parameters:

Minimum	62.50
Maximum	250.00

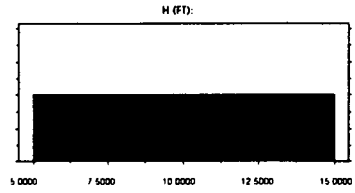


Mean value in simulation was 154.30

Assumption: H (FT): **Cell: L17**

Uniform distribution with parameters:

Minimum	5.0000
Maximum	15.0000

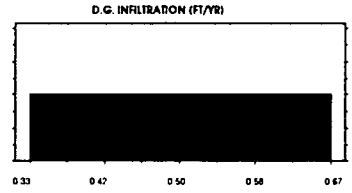


Mean value in simulation was 10.0541

Assumption: D.G. INFILTRATION (FT/YR) **Cell: P18**

Uniform distribution with parameters:

Minimum	0.33
Maximum	0.67



Mean value in simulation was 0.50

End of Assumptions

APPENDIX C

MODELING QA/QC GUIDELINES

C1.0 INTRODUCTION

This document outlines general quality assurance/quality control (QA/QC) requirements for groundwater fate and transport modeling at the Fernald Environmental Management Project (FEMP). Its purpose is to supplement the general guidelines set forth in the "Quality Assurance Program Description" (FERMCO 1993) by providing minimum acceptable standards for Fernald Environmental Restoration Management Corporation (FERMCO) and FERMCO subcontractors in the performance of, and reporting on, groundwater fate and transport modeling activities at the FEMP.

Three documents will be required during the course of a typical modeling project:

1) Task proposal
2) Work plan
3) Final modeling report

C1.1 Task Proposal

The task proposal is submitted in response to a FERMCO Request for Proposal. The proposal should clearly describe the objectives of the modeling study and should include a summary of the modeling team proposed for the project.

In describing the objectives, the proposal will clearly formulate questions that the modeling will answer, including the level of precision required. The objectives shall be written so that modeling results can be evaluated against them.

Because fate and transport modeling requires input from multiple disciplines (i.e., geology, hydrogeology, geochemistry, etc.), an integrated team approach is recommended. Team members' qualifications should be documented with company affiliations, resumes, or listings of academic backgrounds, years of experience in their respective disciplines, and any professional licenses. The responsibilities of each team member should be clearly defined.

C1.2 Work Plan

If the task proposal is accepted by FERMCO, a task-specific modeling work plan will be requested. The work plan serves as a FERMCO project management tool. As such, it should include sufficient scope and detail on the various modeling tasks to allow the progress to be tracked and intermediate results to be evaluated for quality. The modeling objectives and the modeling team descriptions from the task proposal should be included in the work plan along with a schedule of modeling activities and QA/QC procedures used.

C1.3 Modeling Report

When the modeling tasks are completed, a final modeling report shall be prepared to describe and document the modeling activities, and present results. The modeling report shall be a comprehensive description of the modeling project and the subsidiary tasks which were performed. As such, the final report should be complete enough that an experienced modeler not on the project team could reproduce the results.

C2.0 GENERAL MODELING CONSIDERATIONS

In the course of the modeling project, the following general guidelines shall be followed and reported on as indicated in either the work plan, the modeling report, or both as appropriate.

C2.1 Characterization of Model Domain

A careful review shall be conducted of available geologic, hydrologic, and contamination data. The available data should be complete enough to allow adequate interpretations of the modeling domain.

The plans for model domain characterization should be presented in the work plan, while the actual characterization results should be documented in the modeling report.

C2.2 Conceptual Model Design

The conceptual model or working hypothesis is an explicit representation of significant geologic, hydrogeologic, and geochemical features extracted from the model domain characterization.

The conceptual model need only be as precise and detailed as required to meet the modeling objectives. Since the conceptual model usually includes simplifications of the natural system, list, justify, and defend all simplifying assumptions and limitations.

The work plan should present the anticipated conceptual design process and generally outline the simplifications to be used in the conceptual model design with justifications for assumptions. The final conceptual model design should be discussed in detail in the modeling report. Any limitations imposed by the conceptual model should be defined and discussed, and its conservativeness defended.

C2.3 Mathematical Model Design

The conceptual model and the modeling objectives are used to cast the modeling domain and hydrologic and chemical processes of concern in the language of mathematics. Write the differential equation(s)

which describe the model domain and the hydrologic and chemical processes of concern to the model study in the work plan and include them in the modeling report for completeness.

The boundary and initial conditions required to meet modeling objectives should be discussed in the work plan. The final boundary and initial conditions used should be presented in the modeling report with all derivations and estimation procedures.

C2.4 Model Code Selection

Once the mathematical design has been completed, a computer modeling code designed to solve the differential equations should be selected. If possible, the code should be commonly accepted in the community of groundwater modelers with a known performance history. The code should be well documented and readily available. If the mathematical model is sufficiently complex so as to require the consideration of nonstandard or new and untested codes, the source code should be available for examination.

The work plan should present a clear strategy for model code selection including screening criteria. The final selection process should be fully documented in the modeling report with lists of alternative codes and comparisons of their respective strengths and weaknesses so that the ultimate selection is defensible.

When the modeling process involves the use or linkage of multiple codes for different phases of the modeling task, document all pre- and post-processing codes used in the Modeling Report. Include source listings for extensive pre- and post-processing codes.

C2.5 Hardware Selection

Fate and transport modeling codes require significant hardware resources both in RAM size and amount of auxiliary storage. Since execution times can be extensive and since many runs will be required to accomplish the modeling objectives, the hardware selected should be large enough with sufficient processor speed so as to provide timely results without extensive and unnecessarily long wait times. There is, of course, the inevitable trade-off between hardware size/speed and cost, so hardware selection should seek an optimum balance between these two factors as dictated by the modeling objectives.

Modeling codes generate copious amounts of output with files tens of megabytes in size. Consequently, the hardware selected should have sufficient backup capabilities to store the large input and output files associated with each phase of the modeling task.

The work plan should include a description of hardware available to run modeling applications. Any plans to purchase additional equipment for the project should also be presented and discussed.

Since modeling codes often use extended precision arithmetic, hardware selection can affect model results. The hardware used to run the model should be documented in the modeling report as to CPU processor and co-processor type and speed, RAM size, and disk size.

C2.6 Model Code Verification

If the selected modeling code is common to the groundwater modeling community and has a well-documented performance history, model verification will consist of running the code for one or more models with known or published solutions. The test models should be chosen so as to adequately test all the major features of the code which will be used in the anticipated modeling study. The test models should be run on the same hardware system which will be used for the modeling study.

If the selected modeling code is new or uncommon to the modeling community, model verification consists of several steps:

1) The source code should be examined to determine that solutions to the differential equations have been correctly implemented. Any limitations of numerical techniques used should be understood and documented.

2) Models with known and documented analytical solutions should be run with the code and output compared against the analytical solutions.

3) Models with documented numerical solutions from other codes should be run with the new code and outputs compared and documented. These comparisons should test all the features of the new code which will be used in the modeling study.

A model verification plan should be presented in the work plan with a final discussion of the verification process and results presented in the final report.

C2.7 Model Grid Design and Input File Preparations

Once the modeling code has been selected, the model design should be finalized. Consideration should be given to the mesh or element size required to adequately represent the model domain and boundary conditions to achieve modeling objectives. Mesh or element size may vary over the modeling domain so as to account for changes in hydraulic or concentration gradients near sources or sinks. In large or complex models, the grid defined in the model input file should be plotted and compared with the contour maps or surfaces used to define the grid.

All initial values and acceptable ranges of parameter values should be listed and the sources documented in the modeling report.

The modeling report must adequately document model mesh/element size, grid spatial orientation/justification with physical and/or non-physical boundaries, and flow or contaminant sources or sinks to allow an experienced modeler to independently construct and run the model.

C2.8 Model Calibration

Model calibration is the adjustment of model parameters to make the model solution match the existing field used to characterize the modeling domain. Steady state calibration is usually performed first to arrive at head or concentration distributions which can be used as initial conditions in later transient calibrations. The transient calibration is performed to confirm that the model accurately represents the aquifer system under transient stresses such as pumping or changes in contaminant loading.

Before calibration begins, the modeling team should establish the calibration criteria, determine the acceptable level of mass balance error, and establish the data sets to be used. First, the model parameters to be varied during the calibration are determined and a range of reasonably expected parameter values is set. Secondly, the modeling team should determine the acceptable variance between modeled heads/concentrations and field data as dictated by the modeling objectives. The goodness-of-fit should be calculated statistically (residual mean square error, etc.) so as to be quantifiable and comparable with other model solutions.

In performing calibrations, water or contaminant mass balance/budget calculations from the model solution should be compared and reconciled with mass balance/budget values calculated from the input data. A listing of which parameters were changed by how much and why, should be kept in a run log for each calibration run.

The work plan should include details on the calibration procedures to be used. The final calibration criteria, parameter ranges used, and run logs should be documented in the modeling report.

C2.9 Model Validation (or Performance Evaluation)

Because numerical modeling techniques do not guarantee the uniqueness of the solution, an additional model validation run needs to be made to evaluate the predictive capabilities of the calibrated model. A separate and independent data set collected under different conditions than the calibration data should be used for model validation. The model should be applied with the calibration parameters and any parameter values required to describe the conditions under which the verification data was collected. The

solution should be compared spatially and/or temporally with the new data set. The comparison should be described statistically to quantify the goodness-of-fit.

If the model cannot be validated sufficiently to meet levels of accuracy and precision required by modeling objectives, the calibration needs to be repeated with additional data for more control, and the validation repeated. If a successful validation is still not possible, initial modeling assumptions and the conceptual model need to be re-examined for representativeness of the modeling domain.

Model validation procedures should be presented in the work plan with a final discussion of validation results in the modeling report. Include sufficient detail to prove that modeling objectives were met.

C2.10 Model Applications

Once a model has been successfully calibrated and verified, the model may be used as a prediction tool in various applications as outlined in the modeling objectives. Model applications should be clearly defined and documented for final reporting. Input and output file names and associated applications should be noted along with the time and date of the runs required for each application. It is important that model applications and associated results be documented in sufficient detail in the modeling report so that an experienced modeler not on the modeling team could recreate the results if required.

C2.11 Uncertainty and Sensitivity Analyses

After each model application is complete, a sensitivity analysis should be done to determine uncertainties in the results. Ideally, a Monte Carlo simulation should be performed by making a large number of model runs with input parameters varying over their predetermined ranges to test model uncertainties. In the absence of resources for such a simulation, at least three cases should be run for each parameter independently: one with a minimum anticipated parametric value, one with the expected value, and one with the maximum anticipated value. The range of model output values is examined and compared to the range of each input parameter to determine which parameters have the greatest effect on model results.

The uncertainty analysis adds to the overall level of confidence in modeling results and sets limits on model applications by demonstrating which input parameters most critically affect model results. Potential impacts of the uncertainty on engineering designs or risk assessments using the modeling results should be addressed.

The work plan should describe procedures to be used in model uncertainty and sensitivity analyses with a thorough documentation of the analyses results in the modeling report.

C2.12 Performance Assessment

After modeling applications are complete and a sensitivity analysis has been completed, a performance assessment should be done by the modeling team and users of the modeling results to assess how well modeling objectives have been achieved.

In addition to the initial model calibration and validation, available data collected in the modeled area under similar conditions as simulated in the model applications should be used to compare with modeling results. The level of conservativeness of the model should be quantified, when possible, and documented in the modeling report.

C2.13 Model Documentation, Reporting, and Record Keeping

As indicated in the previous sections, model documentation is a continuing process from the task proposal to the final acceptance of the modeling report. The work plan will be submitted for review, and comments and responses resolved before the actual modeling task begins.

As previously discussed, all modeling projects will include the final model report. The report should be sufficiently detailed so that an experienced modeling analyst not associated with the modeling team could independently reproduce the results given the input files, the modeling software, and the report.

All backup documents, calculation sheets, model run logs, United States Department of Energy and regulatory comments, and electronic files generated during the modeling task should be securely stored in a centralized location.