Appendix D
Groundwater Pump Tests

Appendix D1 - Evaluation of Groundwater Pumping in Rainelle, West Virginia (dated: December 23, 2005)

Appendix D2 – Model Development to Evaluate Groundwater Pumping in Rainelle, West Virginia (dated: March 2007)*

Appendix D3 – Well Logs**

***Since publication of the Draft EIS, an additional pump test report (dated March 2007) has become available and has been added as Appendix D2 for the Final EIS.*

****New appendix added for Final EIS.*

INTENTIONALLY LEFT BLANK

Evaluation of Groundwater Pumping in Rainelle, West Virginia

S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

December 23, 2005

7944 Wisconsin Avenue, Bethesda, Maryland 20814-3620 • (301) 718-8900

Evaluation of Groundwater Pumping in Rainelle, West Virginia

Prepared For:

Potomac-Hudson Engineering, Inc.

Prepared By:

S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

December 23, 2005

7944 Wisconsin Avenue, Bethesda, Maryland 20814-3620 • (301) 718-8900

Appendix D1

Table of Contents

		Page
List of Figures		ii
Section 1	Introduction	1
Section 2	Groundwater Flow Analysis	2
	Geographic Information System (GIS) Application	2
	Conceptual Model	2
	Aquifer Test Data Analysis	3
	Baseflow Analysis	3
	Model Description	4
	Model Calibration	5
	Model Predictions	6
Section 3	Summary and Conclusions	7
Section 4	References	9

List of Figures

Figure 1 Location Map

Figure 2 Observed versus Simulated Drawdown – Model Calibrated to Aquifer Test Results at Well PW-1

Figure 3 Observed versus Simulated Drawdown – Model Calibrated to Aquifer Test Results at Well PW-3

Figure 4 Simulated Drawdown after 25 Years – Model Calibrated to Aquifer Test Results at Well PW-1

Figure 5 Simulated Drawdown after 25 Years – Model Calibrated to Aquifer Test Results at Well PW-3

Figure 6 Simulated Drawdown after 25 Years – Pumping from PW-1 and PW-3, Model Calibrated to Aquifer Test Results at Well PW-1

Figure 7 Simulated Drawdown after 25 Years – Pumping from PW-1 and PW-3, Model Calibrated to Aquifer Test Results at Well PW-3

REPORT

Section 1
Introduction

S.S. Papadopulos & Associates, Inc. was retained by Potomac-Hudson Engineering, Inc. (PHE) to develop a groundwater flow model to simulate groundwater conditions in Rainelle, West Virginia. The groundwater model was used to evaluate the availability of groundwater as a water source for the proposed power facility and to evaluate potential impacts to local pumping wells from groundwater withdrawals.

Groundwater flow was simulated using MODFLOW-2000 (Harbaugh et al., 2000), the most widely used program in simulating groundwater flow. For the purposes of this analysis, a GIS application was developed to assist in data management and to generate necessary input files for the model.

Appendix D1

Section 2
Groundwater Flow Analysis

Geographic Information System (GIS) Application

The GIS coordinate system was registered to the NAD 1983 West Virginia South Zone State Plane with units in feet. The following vector and raster data were included:

- A digitized basemap of roads and hydrologic features.
- Georeferenced geologic maps of Fayette (White, 1919) and Greenbrier (Price, 1937) Counties.
- A Topographic map of the area.
- A Digital Elevation Model (DEM) with 10-foot resolution.
- Mapped locations of the pumping and observation wells.
- Mapped location of the National Oceanic and Atmospheric Administration (NOAA) East Rainelle station.
- Mapped location of the U.S. Geological Survey (USGS) streamflow station on Meadow River.

Conceptual Model

The groundwater system in the study area was conceptualized as consisting of three major units: a saturated surficial alluvial overburden, 5-15 feet thick; a layer of interbedded red to green shales, sandy shales and sandstone, 25-50 feet thick (intermediate layer); and an underlying fractured sandstone layer, at least 100 feet thick. The production and deep observation wells are open to both the intermediate and sandstone layers.

The geologic units in the vicinity of Rainelle dip to the northwest; the dip is calculated to be approximately 120 feet per mile based on the structure contour map of the base of the Sewell Coal prepared by Price (1937). As a result, the sandstone unit in which the production and observation wells are completed, which is at a nominal depth of 50 feet below ground surface at Rainelle, directly underlies the alluvium in the valleys of Sewell Creek and Little Sewell Creek to the south and east of Rainelle. For the purposes of this analysis, the elevation contours of the base of the Sewell Coal were digitized and used to calculate the average dip of the formations. Given known elevations of the sandstone formation at the observation wells, the dip of the sandstone unit was determined and then three-dimensionally superimposed on the ground surface DEM, delineating the areas of sandstone outcrop.

The intermediate layer acts as an aquitard, allowing limited vertical leakage. There is limited hydraulic connection between the surficial aquifer and the sandstone aquifer. Although there is limited data regarding hydrogeologic conditions in the area, groundwater movement appears to occur primarily through horizontal fractures in the sandstone formation. According to a study by Wyrick and Borchers (1981), groundwater movement in the valleys of the

Appalachian Plateaus Physiographic Province of West Virginia is the result of stress relief fracturing. Stress relief, the removal of compressional stresses on underlying rocks by erosion of overlying rocks, results in predictable fracture patterns in valley; fractures are generally horizontal under valley floors and are generally vertical along valley walls. The horizontal fractures beneath the valley floor typically develop along bedding plane partings. Horizontal fracturing is limited beyond the valley walls, and thus the valley walls essentially act as low permeability barriers. Recharge to the aquifers primarily occurs via the vertical fractures along the valley walls. In the study area, the valleys along Sewell Creek, Little Sewell Creek, and Meadow River, define the areal extent of the aquifer systems as described above.

Aquifer Test Data Analysis

The data from the aquifer tests performed by PHE at PW-1, PW-3, and PW-4 were reviewed and analyzed using the commercially available software AQTESOLV (Duffield, 2002). For purposes of analyzing the aquifer test, the groundwater system was conceptualized as a leaky aquifer system. The analytical solution developed by Hantush (1960) for a leaky confined aquifer with storage in the aquitard was used to analyze the drawdown data from the tests.

Analysis of the data from the deep observation wells for the 72-hour pump test at well PW-1 indicated that the effective transmissivity and storativity in the vicinity of PW-1 are approximately 700 ft^2/d and $4x10^{-6}$ respectively. The effective transmissivity and storativity in the vicinity of PW-3 range between 470 and 1070 ft^2/d, and $1x10^{-5}$ and $1x10^{-7}$, respectively. It should be noted that during the aquifer tests at wells PW-1 and PW-3, at all observation wells, high drawdown was measured very soon after commencement of the test, which is indicative of a highly fractured aquifer.

Analysis of the available drawdown data in the vicinity of well PW-4, indicated that the effective transmissivity and storativity are approximately 400 ft^2/d and $2x10^{-6}$, respectively. The aquifer transmissivity is much lower at PW-4 than at PW-1 and PW-3.

The purpose of the aquifer test analyses was to provide an indicative range of values for transmissivity and storativity, to be used as initial estimates of aquifer parameters in the calibration of the groundwater flow model.

Baseflow Analysis

Baseflow, the groundwater contribution to total streamflow, for the streams in the study area was calculated using automated hydrograph separation techniques. The Meadow River station at McRoss, West Virginia, located approximately two miles northeast of well PW-1, was the closest station to the study area. Discharge data were downloaded from the USGS National Water Information System. The available data spanned the period from 1979 to 1982. The drainage area of that station was 163 square miles. Baseflow discharge was calculated using BFI (Wahl, 2001), a software package for automated hydrograph separation. The average calculated baseflow for the period that data were available was 9.5 inches per year.

Appendix D1

A rough estimate of the appropriate areal extent of the model was determined based on the baseflow calculation. Assuming all necessary groundwater withdrawals for the power plant could be derived from baseflow, the minimum areal aquifer extent to guarantee such withdrawals would be equal to the pumping rate of 760 gallons per minute divided by the baseflow rate of 9.5 inches per year, or approximately 2.3 square miles. Given the hydrogeologic and topographic conditions in the study area, and to account for boundary effects, a model area of approximately 50 square miles was considered for the model.

Model Description

The groundwater model encompasses an area of approximately 50 square miles, defined by a grid of 352 rows and 152 columns of variable spacing. The vertical model discretization includes three layers, for the representation of the alluvial overburden, the intervening aquitard layer, and the sandstone layer. The model orientation is 35 degrees east of north; which means that the model columns are oriented northeast – southwest (Figure 1).

Grid spacing along model rows varies between 60.625 feet and 485 feet. Grid spacing along columns varies between 88.75 feet and 355 feet. The top layer has variable thickness to distinguish between the alluvium, where the thickness is equal to 15 feet, and the sandstone formation everywhere else, where the thickness is equal to 10 feet. The middle layer, which represents the interbedded layers of sandstone and shales, has a thickness of 50 feet, except underneath the alluvium, where the thickness is equal to 35 feet. Finally, the bottom layer, representing the sandstone formation, has a uniform thickness of 100 feet. The middle layer was assumed to be not present in areas where the sandstone layer directly underlies the alluvium; this was simulated by specifying a very large vertical hydraulic conductivity for the middle layer in these areas.

The model boundary conditions included no-flow boundaries along the model perimeter, and river nodes in the top layer along the major streams. All river nodes were assigned a constant hydraulic head.

Different hydraulic conductivity values were specified in the upland and valley areas in all layers. However, the sandstone unit underlying the alluvium along Meadow River in the vicinity of well PW-4 was assigned upland conductivities, to reflect the conclusions from the aquifer test at that well. This suggests that stress relief fracturing is not prevalent in areas where the valleys are very narrow.

Hydraulic properties of the model, including horizontal and vertical hydraulic conductivity and storage coefficient, were determined through the calibration process. Specific yield for the top layer was set equal to 0.1.

The pumping wells PW-1, PW-3, PW-4, CW-1, and CW-2 were represented by cells in the bottom layer with assigned pumping rates based on known and/or assumed pumping schedules.

Model Calibration

Model calibration was facilitated through the use of PEST (Doherty, 2005), a nonlinear parameter estimation and model calibration software. Model calibration parameters included:

- Horizontal and vertical hydraulic conductivity.
- Specific storage.

The flow model calibration targets included measured drawdown at the deep observation wells during the aquifer tests at wells PW-1 and PW-3. For simplicity, the models were calibrated to the aquifer tests results independently. Model calibration to the aquifer test data from well PW-4 was performed to estimate hydraulic parameters of the sandstone formation in the vicinity of PW-4.

Horizontal and vertical hydraulic conductivities and storage coefficients were determined through the iterative calibration procedure. The calibrated hydraulic properties of the sandstone aquifer for the two models are summarized in the following table for models calibrated to aquifer tests at PW-1 and PW-3:

Calibration Results

	Valley		Uplands	
	PW-1	**PW-3**	**PW-1**	**PW-3**
Horizontal Conductivity (ft/d)	100.6	100.6	4.7	4.7
Vertical Conductivity (ft/d)	8.6×10^{-5}	6.1×10^{-6}	2.0×10^{-3}	4.1×10^{-3}
Specific Storage (per foot)	1.2×10^{-6}	2.3×10^{-6}	1.0×10^{-8}	1.0×10^{-8}

The values of aquifer parameters calculated from the calibration process were similar for both the calibration to the aquifer test data from PW-1 and the calibration to the aquifer test data from PW-3, with the exception of vertical hydraulic conductivities in the valley, which differed by almost an order of magnitude. Plots of calculated drawdowns and observed drawdowns from the aquifer test of PW-1 are shown in Figure 2, for calibration to the aquifer test results at well PW-1. A plot of the calculated and the observed drawdowns from the aquifer test of PW-3 are shown on Figure 3.

After calibration to aquifer test data from PW-4, the calculated horizontal hydraulic conductivity of the sandstone formation underlying the alluvium along Meadow River in the vicinity of PW-4 was 3.0 ft/d.

Appendix D1

Model Predictions

The calibrated model was run for 25 years, with a specified production rate for PW-1 of 760 gpm, to simulate long-term drawdown in the groundwater system. The model was run using parameters obtained from calibration to aquifer test results at PW-1 and PW-3 separately, to compare aquifer response for high and low vertical conductivity conditions in the valley. In addition, combined pumping from wells PW-1 and PW-3, each at a rate of 380 gallons per minute, was simulated under both high and low valley conductivity conditions.

The results of the model runs using the parameters obtained from calibration to aquifer test results at well PW-1 are shown in Figure 4. The results of the model runs using the aquifer parameters obtained from calibration to aquifer test results at well PW-3 are shown in Figure 5. Simulated pumping from PW-1 and PW-3 at equal rates for high and low vertical conductivities resulted in drawdowns shown in Figures 6 and 7, respectively.

The calculated drawdowns after 25 years of pumping at wells CW-1 and CW-2, with hydraulic parameters from calibration to well PW-1 aquifer test, are approximately 43 and 40 feet respectively. The calculated drawdown at production well PW-1 is approximately 56 feet. For hydraulic parameters from calibration to well PW-3 aquifer test, the simulated drawdowns at CW-1 and CW-2 are approximately 35 and 32 feet respectively. The calculated drawdown at production well PW-1 is approximately 47 feet. The drawdown at PW-1 was assumed to be equal to the average drawdown in the model grid cell in which the well is located. The foundation for this assumption is the drawdown data from the aquifer tests which indicated that drawdown is relatively constant for a large radial distance around the production well, likely as the result of very high transmissivity in some fractures.

When the model was run for combined pumping from wells PW-1 and PW-3 with hydraulic parameters from calibration to PW-1 aquifer test, the simulated drawdowns at wells CW-1 and CW-2 are approximately 42 and 41 feet, respectively. The calculated drawdowns at pumping wells PW-1 and PW-3 are 45 and 44 feet, respectively. For hydraulic parameters from calibration to well PW-3 aquifer test, the simulated drawdowns at both CW-1 and CW-2 are approximately 33 feet. The calculated drawdowns at both pumping wells PW-1 and PW-3 are 36 feet.

In order to address concerns regarding short-term drought periods, available data from observation wells in Greenbrier, Fayette, and Nicholas Counties, which encompass the drainage basin of Rainelle, were downloaded from the USGS NWISWeb Database. Water level data were considered only for wells with available data spanning more than one year and with sufficient number of measurements each, regardless of the formation in which they were completed. The maximum water level fluctuation for all wells did not exceed 12 feet, which could be considered as additional drawdown to reflect short-term drought conditions.

Section 3
Summary and Conclusions

Four simulations of long-term pumping at a rate of 760 gpm were conducted with the groundwater model that was developed:

- Model using aquifer parameters estimated from PW-1 aquifer test data – PW-1 pumping at a constant rate of 760 gpm;
- Model using aquifer parameters estimated from PW-3 aquifer test data – PW-1 pumping at a constant rate of 760 gpm;
- Model using aquifer parameters estimated from PW-1 aquifer test data – PW-1 pumping at a constant rate of 380 gpm and PW-3 pumping at a constant rate of 380 gpm;
- Model using aquifer parameters estimated from PW-3 aquifer test data – PW-1 pumping at a constant rate of 380 gpm and PW-3 pumping at a constant rate of 380 gpm.

The results of these simulations indicate that long-term pumping at a rate of 760 gpm will produce significant drawdowns within the sandstone aquifer. Our analysis, though, shows that it is feasible to produce 760 gpm during a 25 year period. These analyses, though, are based on the results of relatively short term aquifer tests and a conceptual geologic model that is based on limited field data. It is possible that actual drawdown will be larger than simulated in this study if actual field conditions differ from the simulated conditions.

A major uncertainty in our understanding of the groundwater system is the characteristics of the sandstone aquifer unit beneath the upland areas. The drawdown pattern reflects the effects of low hydraulic conductivity beneath the upland areas and enhanced leakage from the water table along the valley walls. Vertical hydraulic conductivities in the upland areas appear to be more critical than those in the valley with respect to expected drawdowns. Due to the limited available data, it is not possible to draw positive conclusions as to whether the model with higher vertical conductivities or the model with lower hydraulic conductivities better describes the hydrogeologic conditions in the study area. Both models predict relatively similar drawdowns at the municipal wells. If the sandstone unit is relatively impermeable beneath the upland areas, as the result of limited horizontal fracturing, then the model may be an accurate representation of the groundwater system, though in the model we assumed significant permeability in the upland areas. If the sandstone unit beneath the upland areas is much less permeable than assumed in our analyses, then the actual drawdowns from long-term pumping will be greater than those shown on the figures.

Some of the uncertainty inherent in our evaluations could be reduced by conducting longer aquifer tests at PW-1 and/or PW-3 and by monitoring water levels during the tests in wells located in the upland areas and wells located in the valleys much further from the pumping wells than was done in previous testing. Our recommendation is that a test be conducted for at least 30 days, the minimum time required to significantly improve our current understanding of

Appendix D1

the system. It must be recognized that the results of additional testing may well indicate that long-term pumping at a rate of 760 gpm is not sustainable from the sandstone aquifer.

Section 4
References

Doherty, J. 2005. PEST Version 9 User's Guide. Brisbane, Queensland, Australia: Watermark Numerical Computing.

Duffield, G.M. 2002. *AQTESOLV for Windows Version 3.50 Professional*, HydroSOLVE, Inc.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald. 2000. *MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model--User Guide to Modularization Concepts and the Ground-Water Flow Process*. U.S. Geological Survey. Open-File Report 00-92.

Kozar, M.D., and M.V. Mathes. 2001. *Aquifer Characteristics Data for West Virginia.* U.S. Geological Survey, Water-Resources Investigations Report 01-4036.

Wahl, T.L., and K.L. Wahl. 2001. *BFI – A Computer Program for Computing an Index to Baseflow, Version 4.12w.* U.S. Bureau of Reclamation – U.S. Geological Survey.

Wyrick, G.G., and J.W. Bochers. 1981. *Hydrologic Effects of Stress-Relief Fracturing in an Appalachian Valley.* U.S. Geological Survey. Water-Supply Paper 2177.

Prickett, T.A., and C.G. Lonnquist. 1971. *Selected Digital Computer Techniques for Groundwater Resource Evaluation.* Illinois State Water Survey, Urbana. Bulletin 55.

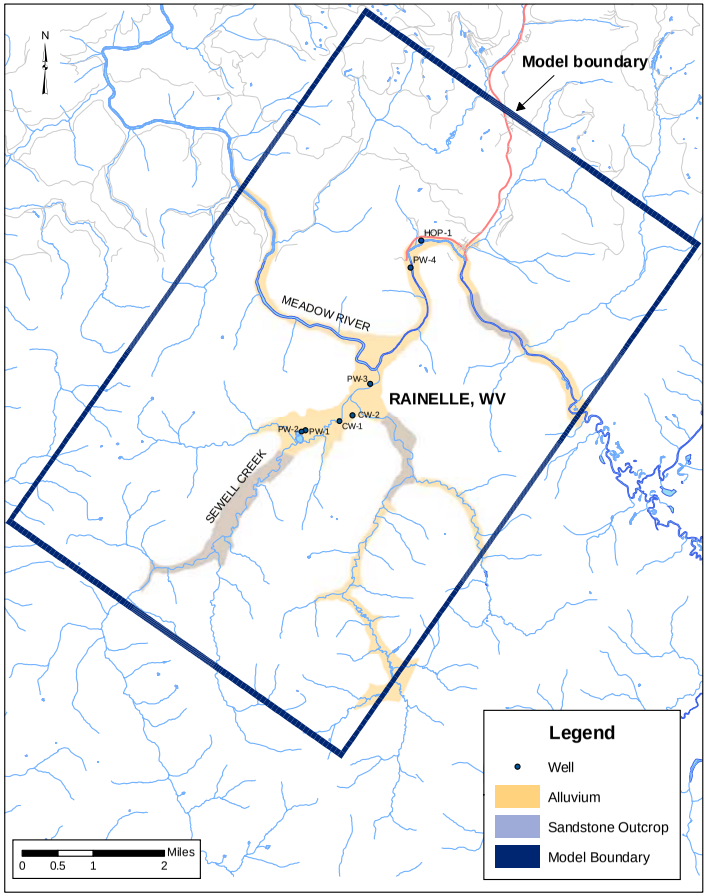
Price, P.H. 1937. *General and Economic Map of Greenbrier County.* West Virginia Geological Survey.

White, I.C. and R.V. Hennen. 1919. *General and Economic Map of Fayette County*, West Virginia Geological Survey.

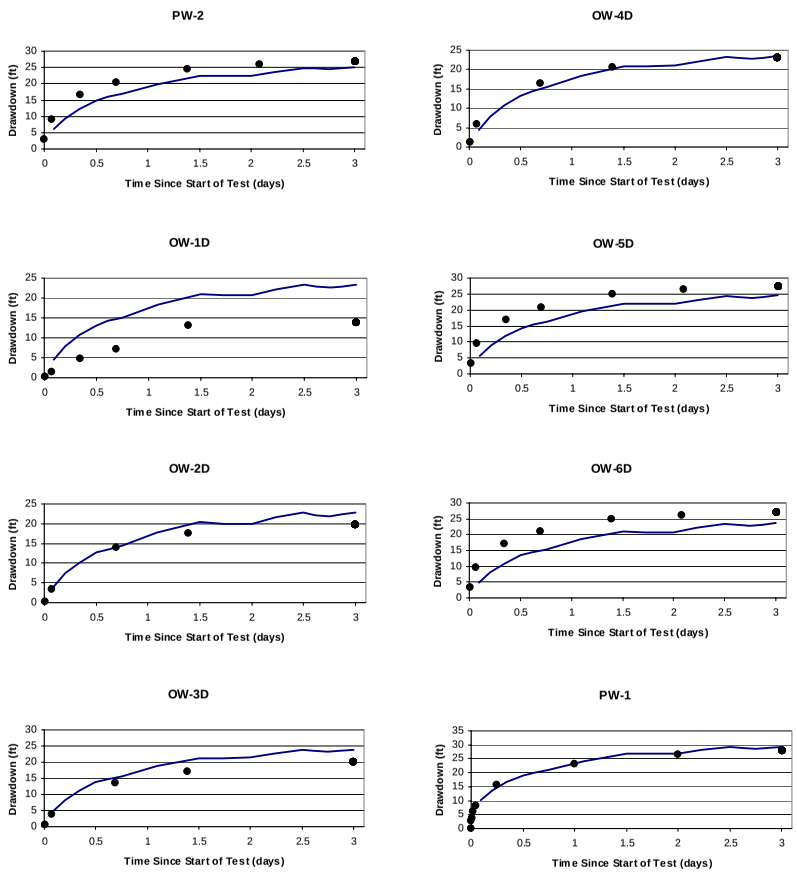
Appendix D1

FIGURES

S.S. PAPADOPULOS & ASSOCIATES, INC.

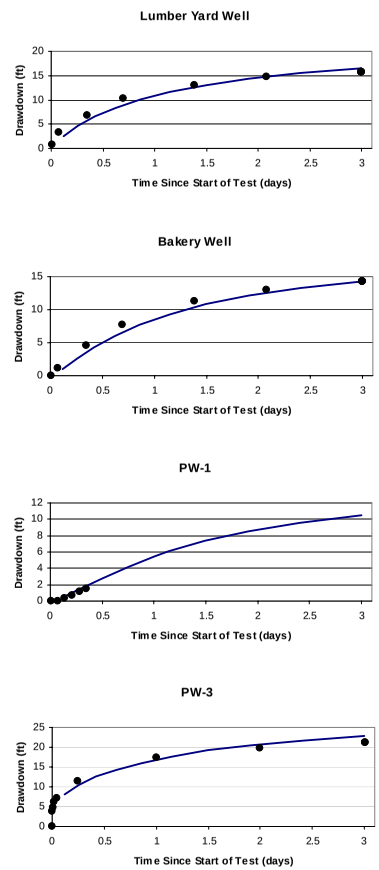


i ure ocation Map



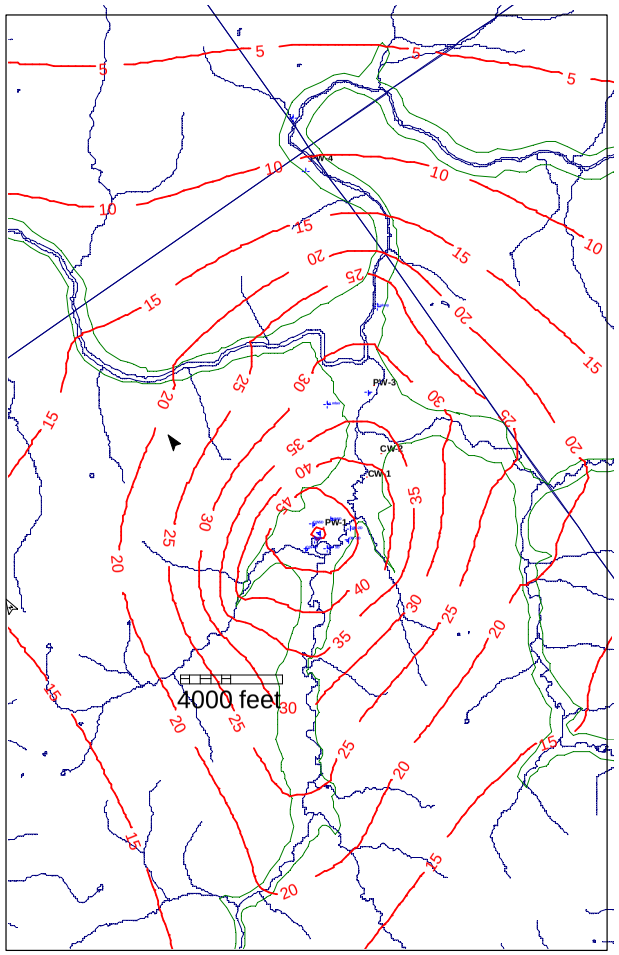
i ure Observed versus Simulated Drawdown,
Model alibrated to Aquifer Test Results at Well PW-1

S.S. PAPADOPULOS & ASSOCIATES, INC.



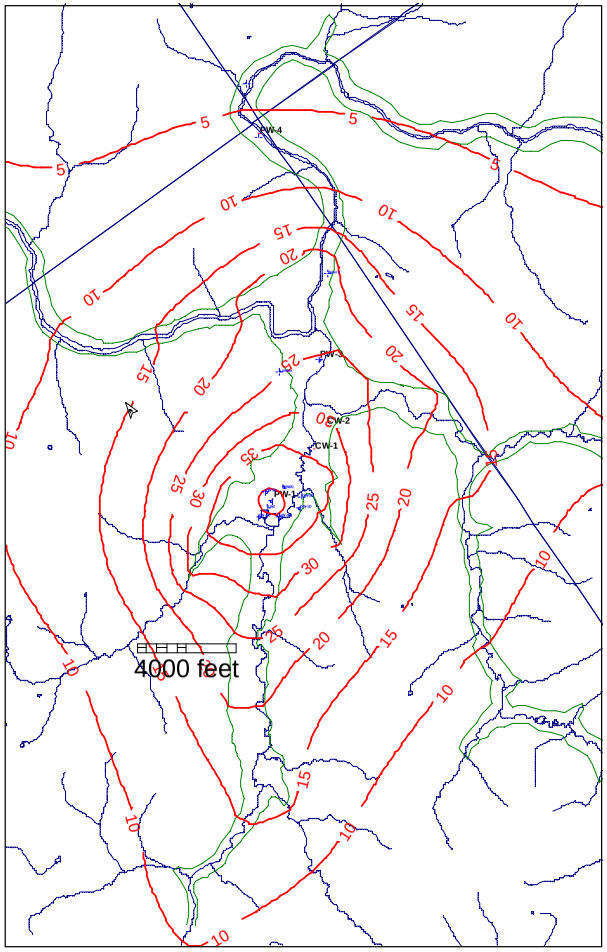
i ure 3 Observed versus Simulated Drawdown,
Model alibrated to Aquifer Test Results at Well PW-3

Appendix D1



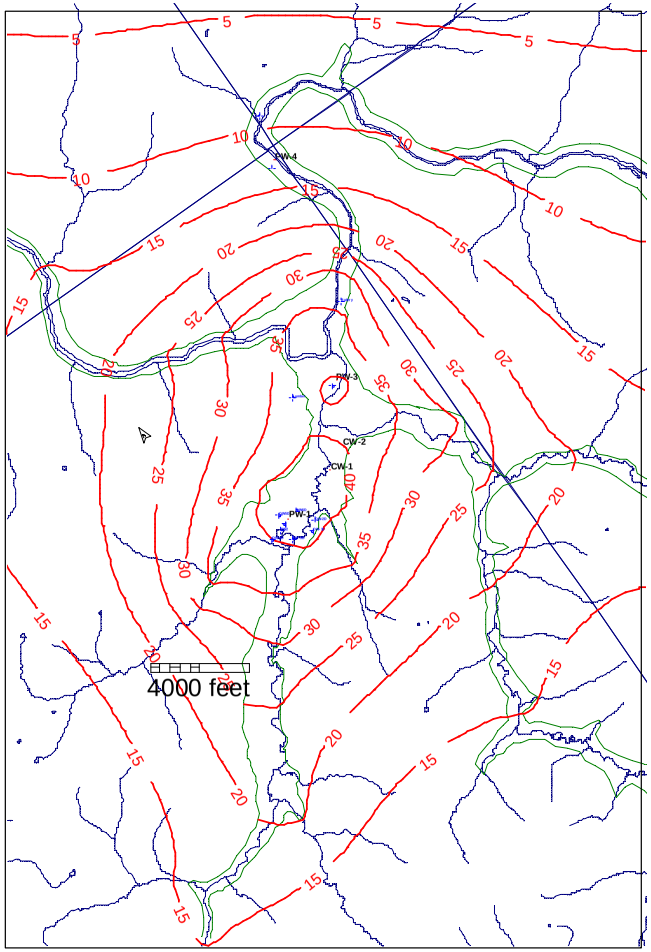
i ure 4 Simulated Drawdown after 25 ears,
Model alibrated to Aquifer Test Results at Well PW-1

S.S. PAPADOPULOS & ASSOCIATES, INC.



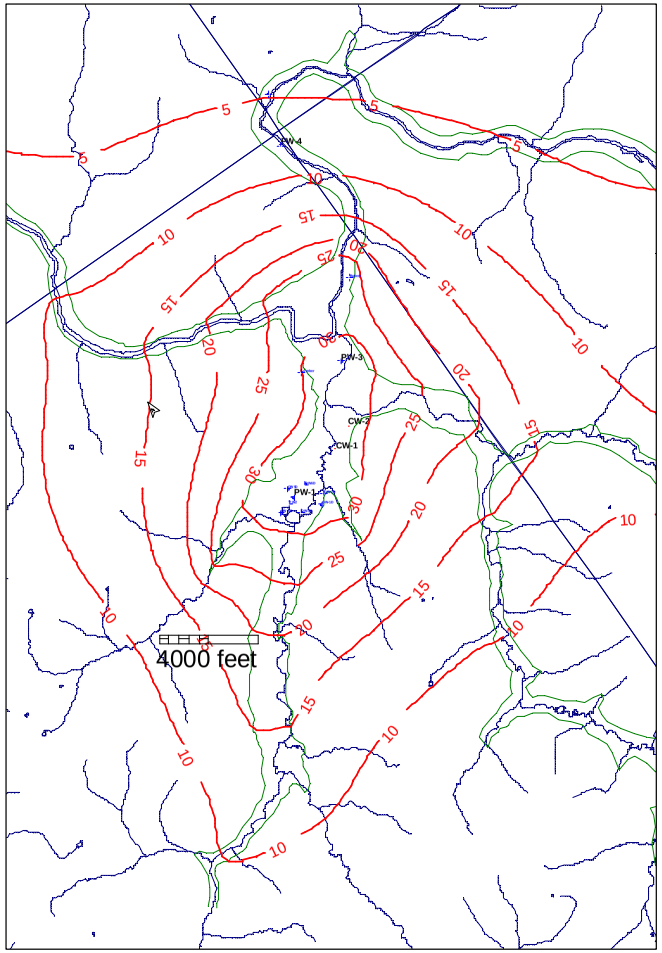
i ure 5 Simulated Drawdown after 25 ears,
Model alibrated to Aquifer Test Results at Well PW-3

Appendix D1



i ure 6 Simulated Drawdown after 25 ears,
Pumping from PW-1 and PW-3,
Model alibrated to Aquifer Test Results at Well PW-1

S.S. PAPADOPULOS & ASSOCIATES, INC.



i ure 7 Simulated Drawdown after 25 ears,
Pumping from PW-1 and PW-3,
Model alibrated to Aquifer Test Results at Well PW-3

Appendix D1

Model Development to Evaluate Groundwater Pumping in Rainelle, West Virginia

S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

June 5, 2007

7944 Wisconsin Avenue, Bethesda, Maryland 20814-3620 • (301) 718-8900

Model Development to Evaluate Groundwater Pumping in Rainelle, West Virginia

Prepared For:

Potomac-Hudson Engineering, Inc.

Prepared By:

S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

June 5, 2007

7944 Wisconsin Avenue, Bethesda, Maryland 20814-3620 • (301) 718-8900

Appendix D2

Table of Contents

		Page
List of Figures		ii
Section 1	Introduction	1
Section 2	Groundwater Flow Analysis	2
	New Monitoring Well Data	2
	Conceptual Model	2
	Model Modification	3
	Model Calibration	4
	Model Predictions	5
	Pumping Scenarios	5
	Model Results – Drawdown	7
	Model Results – Streamflow Depletion	9
Section 3	Summary and Conclusions	10
Section 4	References	11

S.S. PAPADOPULOS & ASSOCIATES, INC.

List of Figures

Figure 1 Location Map

Figure 2 Observed versus Simulated Drawdown

Figure 3 Streamflow Data for Meadow River (USGS 03189890, McRoss WV)

Figure 4 Streamflow Data for Meadow River (USGS 03190400, Mt. Lookout WV)

Figure 5 Annual Number of Days per Season for Groundwater Pumping

Figure 6 Simulated Drawdown after 25 Years (Q=1,049 gpm)

Figure 7 Simulated Drawdown after 25 Years (Q=1,179 gpm)

Figure 8 Simulated Drawdown after 25 Years (Q=960 gpm Winter – 1,139 gpm Summer)

Figure 9 Simulated Drawdown after 25 Years (Weighted Q=280 gpm Winter – 707 gpm Summer)

Figure 10 Observed Water Levels prior to Aquifer Test

Figure 11 Storage Depletion versus River Leakage over a 25-Year Period (Q=1,049 gpm)

Figure 12 Storage Depletion versus River Leakage over a 25-Year Period (Q=1,179 gpm)

Figure 13 Storage Depletion versus River Leakage over a 25-Year Period (960 gpm Winter – 1,139 gpm Summer)

Figure 14 Storage Depletion versus River Leakage over a 25-Year Period (Weighted Q=280 gpm Winter – 707 gpm Summer)

Figure 15 Storage Depletion versus River Leakage over a 25-Year Period, CW-1 (Q=150 gpm)

Figure 16 Minimum Streamflow and Adjusted Minimum Streamflow Values for Meadow River

Appendix D2

REPORT

Section 1
Introduction

S.S. Papadopulos & Associates, Inc. (SSP&A) was retained by Potomac-Hudson Engineering, Inc. (PHE) to develop a groundwater flow model to simulate groundwater conditions in Rainelle, West Virginia. The purpose of the groundwater model was to evaluate the availability of groundwater as a water source for the proposed power facility, to evaluate potential impacts to local pumping wells from groundwater withdrawals, and to evaluate potential impacts to the Meadow River.

The initial groundwater model was developed and calibrated based on data and results obtained from three aquifer tests performed by PHE in the vicinity of the proposed power facility (S.S. Papadopulos and Associates, Inc., 2005). The calibrated model was used to determine drawdowns at the pumping wells within a 25-year period of constant pumping. Although it was shown that it is feasible to produce the necessary groundwater withdrawals during a 25-year period, the analysis was based on the results of relatively short term aquifer tests and a conceptual geologic model that was based on limited field data.

To confirm the conclusions of the initial groundwater model and develop a more thorough understanding of the aquifer system, SSP&A (2005) recommended a long term aquifer test with additional monitoring wells in locations that would provide information with respect to the hydrogeologic conditions over a much larger area. PHE subsequently constructed two new monitoring wells and conducted a 60-day long-term aquifer test at the proposed pumping wells during October and November 2006.

The data obtained from drilling two new monitoring wells were used to refine the structure of the groundwater flow model and the revised model was recalibrated to the data from the long-term aquifer test. After the model was recalibrated, new predictions of drawdown at the local pumping wells were made for a 25-year period of various scenarios of constant and seasonal pumping. In addition, a detailed streamflow analysis for Meadow River was conducted to estimate long term impacts on streamflow from pumping.

Appendix D2

Section 2
Groundwater Flow Analysis

New Monitoring Well Data

PHE conducted a long-term aquifer test at wells PW-1 and PW-3 (Figure 1) from October through November 2006. Water level data were collected during a period of approximately 35 days prior to the test, during the two month pumping period, and for a month after the pumps were shut off. For the purposes of the aquifer test, two new monitoring wells were drilled, OW-8 and OW-9 (Figure 1), in the southern part of the Sewell Creek valley and in the Little Sewell Creek valley respectively.

The lithology at monitoring well OW-8 is very similar to that at well PW-1 and the surrounding observation wells. Below the surficial alluvium, which is approximately 15 feet thick, there is a 25-foot thick unit of interbedded silts, sands and clays. Below this unit, from a depth of 40 to 60 feet, is a blue sandy shale and from a depth of 60 feet to 200 feet is the sandstone unit that is seen at PW-1. The well was cased from land surface to a depth of 40 feet and has an open hole completion to total depth of 200 feet.

Well OW-9 was completed at a depth of 160 feet below ground surface and it was cased off the first 40 feet. Blue gray and red shales and sandy shales were encountered at that well from land surface to total depth. Based on the structure contour map of the base of the Sewell Coal prepared by Price (1937) the sandstone unit observed at PW-1 was anticipated at this location. However, unlike well PW-1, no sandstone was encountered in well OW-9. In addition, visual inspection of the hillside along Little Sewell Creek confirmed sandstone outcrops at elevations above the valley floor. Based on the above, it appears that the sandstone outcrops in the valley further north and that OW-9 penetrates a unit stratigraphically below the sandstone.

Conceptual Model

The conceptual model of the groundwater system developed previously by SSP&A was modified to reflect the findings from the boring logs of the two new monitoring wells. The groundwater system is now conceptualized as consisting of four major units: 1) saturated alluvium, 5-15 feet thick; 2) a unit consisting of interbedded blue, red and green shales, sandy shales and sandstone, 25-50 feet thick (low permeability unit); 3) an underlying fractured sandstone unit, 100 feet thick; and 4) an interbedded sand and shale unit, at least 60 feet thick. The production and deep observation wells are open to both the low permeability unit and sandstone unit, except for well OW-9 which is open to the deeper sand and shale unit.

The low permeability unit acts as an aquitard, allowing limited vertical leakage. There is limited hydraulic connection between the alluvium and the sandstone unit. Groundwater movement occurs primarily through horizontal fractures in the sandstone unit, as a result of stress relief fracturing (Wyrick and Borchers, 1981).

The representation of the dip of geologic units in the vicinity of Rainelle, 120 feet per mile to the northwest, was not changed in the revised model. However, the strike of the geologic units was altered slightly to N70ºW to account for the findings at wells OW-8 and OW-9. As a result, the sandstone unit is now calculated to outcrop further north along Little Sewell Creek than previously thought to be the case (Figure 1).

Recharge to the aquifer occurs via the vertical fractures along the valley walls and in the areas where the sandstone unit outcrops. The vertical fractures extend all the way down to the deeper units and thus act as low permeability barriers.

Model Modification

The groundwater model grid remained unchanged horizontally, encompassing an area of approximately 50 square miles, defined by a grid of 352 rows and 152 columns of variable spacing. The vertical model discretization now includes four layers for the representation of the alluvium, the low permeability unit, the sandstone unit, and the interbedded sandstone and shale unit. The model orientation is 35 degrees east of north; which means that the model columns are oriented northeast - southwest (Figure 1).

Grid spacing also remained unchanged. Grid spacing along model rows varies between 60.625 feet and 485 feet. Grid spacing along columns varies between 88.75 feet and 355 feet. The top layer has variable thickness; a thickness of 15 feet is specified where saturated alluvium exists, elsewhere the thickness is specified as 10 feet. The second layer, which represents the low permeability unit, has a thickness of 50 feet, except underneath the alluvium, where the thickness is specified as 35 feet. The third model layer, representing the sandstone unit, has a uniform thickness of 100 feet. The fourth model layer, representing the deeper interbedded sandstone and shale unit, has a uniform thickness of 60 feet. The second layer, the low-permeability unit, was assumed to be not present in areas where the sandstone unit directly underlies the alluvium; this was simulated by specifying a very large vertical hydraulic conductivity for the middle layer in these areas.

The model boundary conditions included no-flow boundaries along the model perimeter, and river nodes in the top layer along the major streams. All river nodes were assigned a constant hydraulic head.

Different hydraulic conductivity values were specified in the upland and valley areas in all layers. However, the sandstone unit underlying the alluvium along Meadow River north of well BW-1 was assigned upland conductivities consistent with the results obtained previously from analysis of the aquifer test results from well PW-4. This suggests that stress relief fracturing is not prevalent in areas where the valleys are very narrow.

Appendix D2

Hydraulic properties of the model, including horizontal and vertical hydraulic conductivity and storage coefficient, were determined through the calibration process. Specific yield for the top layer was set equal to 0.1.

The pumping wells PW-3 and CW-1 were represented by cells in the third model layer. Well PW-1 is represented by cells in both the third and fourth model layers. The pumping rates of wells PW-1 and PW-3 during the aquifer test varied according to the values shown in Table 1. For the purposes of the groundwater flow modeling, time-averaged pumping rates were used for both wells. Well CW-1 was assigned a constant pumping rate of 150 gallons per minute (gpm), reflecting its reported pumping schedule.

Table 1 Pumping Rates for Wells PW-1 and PW-3

Date	PW-1 (gpm)		PW-3 (gpm)	
	Measured	Average over consecutive measurements	Measured	Average over consecutive measurements
10/1/2006 12:00	500		300	
10/2/2006 13:10	490	495	300	300
10/3/2006 16:40	460	475	335	317.5
10/6/2006 8:00	445	452.5	325	330
11/30/2006 12:00	409	427	308	316.5
Time Averaged Q		**430**		**315**

Model Calibration

Model calibration was facilitated through the use of PEST (Doherty, 2005), a nonlinear parameter estimation and model calibration software. Model calibration parameters included:

- Horizontal and vertical hydraulic conductivity.
- Specific storage.

The flow model calibration targets included measured drawdown at the deep observation wells during the aquifer test. Horizontal and vertical hydraulic conductivities and storage coefficients were determined through the iterative calibration procedure. The calibrated hydraulic properties are summarized in the following table:

Table 2 Calibration Results

Unit	Valley			Uplands		
	Horizontal Conductivity (ft/d)	Vertical Conductivity (ft/d)	Specific Storage (per foot)	Horizontal Conductivity (ft/d)	Vertical Conductivity (ft/d)	Specific Storage (per foot)
Alluvium	10.7	2.9×10^{-6}		-	-	-
Sandy Shale	1.8	4.5×10^{-5}	2.2×10^{-6}	1.8	6.2×10^{-3}	1.5×10^{-6}
Sandstone	70.2	4.5×10^{-5}	1.5×10^{-6}	1.8	6.2×10^{-3}	1.5×10^{-6}
Sandstone/ Shale	20.8	0.5	1.5×10^{-6}	1.8	6.2×10^{-3}	1.5×10^{-6}

Plots of calculated drawdowns and observed drawdowns from the aquifer test are shown on Figure 2. It should be noted that no recovery data are available for well CW-1, due to equipment failure.

Model Predictions

Pumping Scenarios

The calibrated model was run for a period of 25 years to simulate long-term drawdown in the groundwater system and to evaluate corresponding streamflow depletions under two scenarios. The two scenarios include combined production rates for wells PW-1 and PW-3 that reflect conditions related to the actual operation of the plant and the corresponding water demands. The scenarios considered were based on the assumption that: (a) Groundwater is the primary source of water, and (b) Surface water from Meadow River is the primary source of water, with supplemental groundwater withdrawals when the flow in the river falls below given seasonal thresholds.

The pumping rates considered for the first scenario corresponded to the annual average, maximum, and seasonal (April through September and October through March) water demand for the plant. By design, the effluent of the Rainelle Sewage Treatment Plant, which currently is being discharged to the river, will be diverted to the power plant to supply some of the water demand. Given that the treated effluent will not be contributing to streamflow, it is included in the power plant water demand considered herein, in order to assess the effects of both the water withdrawals and reduced treated water discharge to streamflow. Therefore, the pumping rates used for model predictions were:

- Average demand: 1,049 gpm.
- Maximum demand: 1,179 gpm.
- Seasonal demand: 960 gpm for the period October-March, and 1,139 gpm for the period April-September.

For the second scenario, minimum streamflow requirements for direct water withdrawals from the river imposed by the State were considered. According to these requirements, water can be withdrawn directly from the river only when the flow is higher than 118 cubic feet per second (cfs) during the winter season (October-March) and 178 cfs during the summer period (April-September). The pumping rates were calculated based on the average seasonal demand, weighted by the ratio of number of days per season when the flow is below the minimum threshold to the number of total days per season.

For the purposes of calculating the pumping rates for the second scenario, a detailed streamflow analysis was conducted. Historical streamflow data for Meadow River are available from a USGS gauge on Meadow River at McRoss, a few miles north from well BW-1, reflecting conditions nearby the well field, and for a short period of years (1979-1982). The streamflow values for this gauge are shown in Figure 3. Another USGS gauge is located at Mt. Lookout, in

Appendix D2

Nicholas County, WV, approximately 17 miles from Rainelle, with almost continuous data for the period 1966-2007. The streamflow values for this period are shown in Figure 4.

Given the short period covered by the data from the McRoss gauge, and that only the Mt. Lookout gauge provides continuous data that span a much longer period, the correlation of the data from the two gauges was examined, to provide an equivalent streamflow dataset to be used for the streamflow analysis in the model area. The drainage area corresponding to the two gauges was obtained from the USGS NWISWeb Database and is shown in the following table:

USGS Station	Drainage Area (square miles)
McRoss, USGS 03189890	163
Mt. Lookout, USGS 03190400	365

The ratio between the two drainage areas is approximately 2.2. By scaling down the data from the Mt. Lookout gauge by a factor of 2.2, the correlation coefficient between the McRoss dataset and the resulting dataset is 0.87; the average streamflow for the period 1979-1982 is 347.3 cfs and 343.9 cfs respectively; and the median streamflow is 190.0 cfs and 190.9 cfs respectively. Therefore, the resulting dataset could be considered representative of the streamflow conditions in Meadow River near the well field and for a period of more than 40 years. In addition, it is assumed that the same conditions will prevail in the next 40 years and so the same dataset can be used to evaluate the impacts of model predicted river leakage to streamflow.

The average seasonal pumping rates used in Scenario 2 were weighted to reflect the operating schedule of the wells as a function of the number of days the wells will be turned on. It was determined that the weighted seasonal pumping rates for Scenario 2 is 707 gpm (1.58 cfs) for the period April-September, and 280 gpm (0.62 cfs) for the period October-March. Figure 5 illustrates the number of days per season per year that the wells will have to be operating due to low flow conditions in Meadow River. The values in this Figure represent the percentage of days of operation against the total number of days per season. The results of this analysis are tabulated in the following Table:

Year	# of Days Apr-Sep	# of Days Flow > 178 cfs	# of Days Flow < 178 cfs	Average Pumping Rate Apr-Sep (cfs)	Annual Pumping Rate Streamflow Apr-Sep (cfs)	# of Days Oct-Mar	# of Days Flow > 118 cfs	# of Days Flow < 118 cfs	Average Pumping Rate Mar-Oct (cfs)	Annual Average Pumping Rate Mar-Oct (cfs)
1966	30	6	24	2.03	**1.58**	92	66	26	0.60	**0.62**
1967	183	64	119	1.65		182	146	36	0.42	
1968	183	71	112	1.55		183	124	59	0.69	
1969	183	74	109	1.51		182	119	63	0.74	
1970	183	59	124	1.72		182	133	49	0.58	
1971	183	87	96	1.33		182	149	33	0.39	
1972	183	100	83	1.15		183	173	10	0.12	
1973	183	97	86	1.19		182	152	30	0.35	
1974	183	73	110	1.53		182	145	37	0.43	
1975	183	82	101	1.40		182	144	38	0.45	
1976	183	30	153	2.12		183	177	6	0.07	
1977	183	44	139	1.93		182	136	46	0.54	
1978	183	54	129	1.79		182	107	75	0.88	
1979	183	128	55	0.76		182	162	20	0.24	
1980	183	70	113	1.57		183	108	75	0.88	
1981	183	92	91	1.26		182	117	65	0.76	
1982	183	74	109	1.51		182	131	51	0.60	
1983	183	81	102	1.41		182	131	51	0.60	
1984	183	47	136	1.89		183	61	122	1.43	
1985	183	0	183	2.54		182	48	134	1.57	
1986	183	44	139	1.93		182	140	42	0.49	
1987	183	44	139	1.93		182	115	67	0.79	
1988	183	57	126	1.75		183	119	64	0.75	
1989	183	104	79	1.10		182	156	26	0.31	
1990	183	73	110	1.53		182	157	25	0.29	
1991	183	38	145	2.01		182	124	58	0.68	
1992	183	80	103	1.43		183	108	75	0.88	
1993	183	56	127	1.76		182	132	50	0.59	
1994	183	72	111	1.54		182	109	73	0.86	
1995	183	59	124	1.72		182	133	49	0.58	
1996	183	103	80	1.11		183	171	12	0.14	
1997	183	65	118	1.64		182	90	92	1.08	
1998	183	80	103	1.43		182	102	80	0.94	
1999	183	32	151	2.09		182	120	62	0.73	
2000	183	109	74	1.03		183	89	94	1.10	
2001	183	66	117	1.62		182	79	103	1.21	
2002	183	64	119	1.65		182	143	39	0.46	
2003	183	130	53	0.73		182	153	29	0.34	
2004	183	87	96	1.33		183	172	11	0.13	
2005	183	67	116	1.61		182	140	42	0.49	
2006	183	52	131	1.82		182	136	46	0.54	
2007						46	36	10	0.46	

Model Results – Drawdown

The results of the model run using the parameters obtained from calibration to aquifer test results are shown in Figure 6, for the combined annual average pumping rate of 1,049 gpm. The calculated drawdown after 25 years of pumping at well CW-1 is approximately 53 feet. The calculated drawdown at production well PW-1 is approximately 59 feet and the calculated drawdown at production well PW-3 is approximately 53 feet.

The results of the model run for the combined annual maximum pumping rate of 1,179 gpm are shown in Figure 7. The calculated drawdown after 25 years of pumping at well CW-1 is approximately 62 feet. The calculated drawdown at production well PW-1 is approximately 69 feet and the calculated drawdown at production well PW-3 is approximately 64 feet.

The results of the model run for the combined seasonal pumping rate of 1,139 gpm during the summer period and 960 gpm during the winter period are shown in Figure 8. The calculated drawdown after 25 years of pumping at well CW-1 is approximately 56 feet. The

calculated drawdown at production well PW-1 is approximately 64 feet and the calculated drawdown at production well PW-3 is approximately 60 feet.

For Scenario 2, with groundwater being the supplemental source of water, the results of the model run for the combined weighted annual seasonal pumping rate of 707 gpm during the summer period and 280 gpm during the winter period are shown in Figure 9. The calculated drawdown after 25 years of pumping at well CW-1 is approximately 33 feet. The calculated drawdown at production well PW-1 is approximately 36 feet and the calculated drawdown at production well PW-3 is approximately 33 feet.

As discussed in the previous modeling report (S.S. Papadopulos and Associates, Inc., 2005), in order to address concerns regarding short-term drought periods, an analysis of available data from observation wells in Greenbrier, Fayette, and Nicholas Counties, which encompass the drainage basin of Rainelle, was performed. The data were downloaded from the USGS NWISWeb Database. Water level data were considered only for wells with available data spanning more than one year and with sufficient number of measurements each, regardless of the formation in which they were completed. The maximum water level fluctuation for all wells did not exceed 12 feet, which could be considered as additional drawdown to reflect short-term drought conditions.

Drawdowns at the monitoring wells measured during a period of 35 days prior to the aquifer test are shown in Figure 10. The drawdowns indicate no long-term upward or downward trend during that period. However, during the pumping phase the drawdowns exhibit a downward trend. The trend is not considered significant and the calibration results are satisfactory.

A conservative estimate of the total potential drawdown at wells CW-1, PW-1, and PW-3 could be expressed as the sum of the predicted drawdown and the maximum water level fluctuation corresponding to possible drought conditions (12 ft). Well construction data and the range of potential groundwater elevations at wells CW-1, PW-1, and PW-3 are shown in the following table:

Well	Casing Elevation (ft amsl)	Well Depth (ft)	Groundwater Elevation prior to Aquifer Test (ft amsl)	Range of Drawdown (ft)	Groundwater Elevation after 25 years (ft amsl)
CW-1	2,392	200	2,376	33-62	2,331-2,302
PW-1	2,400	220	2,373	36-69	2,325-2,292
PW-3	2,388	168	2,372	33-64	2,327-2,296

It should also be noted that, based on information obtained from the Rainelle Water Department, the pump in well CW-1 is set at 180 ft below ground surface (approximately 2,212 ft above mean sea level). This suggests that the city well will be capable of meeting the city

water demands. Similarly, the estimated drawdowns at wells LW-1 and BW-1 (26-55 ft and 23-46 ft respectively) suggest that those wells will also be capable of meeting their corresponding demands.

The pumping rates considered under Scenario 1 are higher than the maximum pumping rate during the 60-day aquifer test. Although the aquifer response was evaluated under lower pumping conditions, it is common hydrologic practice to extrapolate given that in most aquifer systems the response is proportional to the stress.

Model Results – Streamflow Depletion

An analysis of the sources of the pumped water during the 25-year simulations was conducted to determine the amount of water coming from reduced discharge to the rivers and the amount coming from aquifer storage depletion. The relationships of aquifer storage depletion over time and reduced river discharge over time were examined for the cases of continuous pumping at 1,049gpm, 1,179 gpm, seasonal pumping at 1,139 gpm/960 gpm, and the weighted seasonal pumping at 707 gpm/280 gpm. The results of this analysis are shown in Figures 11, 12, 13, and 14 respectively. The impact from pumping to streamflow increases with time to a total of approximately 1.8 to 2.2 cfs, for the various cases under Scenario 1. The impact of pumping to streamflow for Scenario 2 increases with time to a total of approximately 1.0 cfs. It should be noted that this impact includes a baseline river leakage induced by pumping at well CW-1. The relationship of aquifer storage depletion over time and reduced river discharge over time for CW-1 is illustrated in Figure 15. It is estimated that the impact of well CW-1, when pumping 150 gpm for 25 years approaches 0.2 cfs. Therefore, the impact to streamflow from pumping at wells PW-1 and PW-3 is approximately 1.6 to 2.0 cfs for Scenario 1 and 0.8 cfs for Scenario 2.

In all cases, initially most of the pumped water comes from aquifer storage depletion; only after approximately 8 to 9 years of pumping does the amount of water coming from reduced river discharge equal the amount coming from aquifer storage depletion. However, when groundwater is the primary source of water, and therefore constant pumping occurs throughout the entire 25-year period, the amount of water coming from reduced river discharge is higher than when weighted seasonal pumping is considered.

The results demonstrate the limited hydraulic connection between the alluvium and the sandstone unit. Storage depletion is immediate when pumping begins and remains significant throughout the entire pumping period. River leakage increases gradually but it never equals the pumped water volume.

Figure 16 shows the annual minimum streamflow value for the adjusted dataset for McRoss and the calculated expected annual minimum streamflow value, when the weighted seasonal pumping of Scenario 2 is considered.

Appendix D2

Section 3
Summary and Conclusions

The groundwater flow model was revised and recalibrated based on the lithologic logs from two new monitoring wells and a long-term aquifer pump test. These new data have greatly improved our understanding of the aquifer system and the modified model better incorporates more regional hydrogeologic conditions. Simulations of long-term pumping at combined rates were conducted considering groundwater as primary source of water (Scenario 1) and surface water from Meadow River as primary source of water, with supplemental withdrawals for groundwater (Scenario 2).

Our analysis shows that it is feasible to meet the seasonal water demand with groundwater as the primary source of water (Scenario 1) and with surface water as the primary source of water and supplemental groundwater withdrawals during a 25 year period (Scenario 2). In addition, the city well will still be capable of meeting the city water demand. The analysis also shows that the impact of pumping to streamflow at the end of the same period is approximately 1.6-2.0 cfs for Scenario 1 and approximately 0.8 cfs for Scenario 2.

Section 4
References

Doherty, J. 2005. PEST Version 9 User's Guide. Brisbane, Queensland, Australia: Watermark Numerical Computing.

S.S. Papadopulos and Associates, Inc., 2005. Evaluation of Groundwater Pumping in Rainelle, West Virginia. Prepared for Potomac-Hudson Engineering, Bethesda, Maryland. December 2005.

Price, P.H. 1937. *General and Economic Map of Greenbrier County.* West Virginia Geological Survey.

Wyrick, G.G., and J.W. Bochers. 1981. *Hydrologic Effects of Stress-Relief Fracturing in an Appalachian Valley*. U.S. Geological Survey. Water-Supply Paper 2177.

Appendix D2

FIGURES

S.S. PAPADOPULOS & ASSOCIATES, INC.

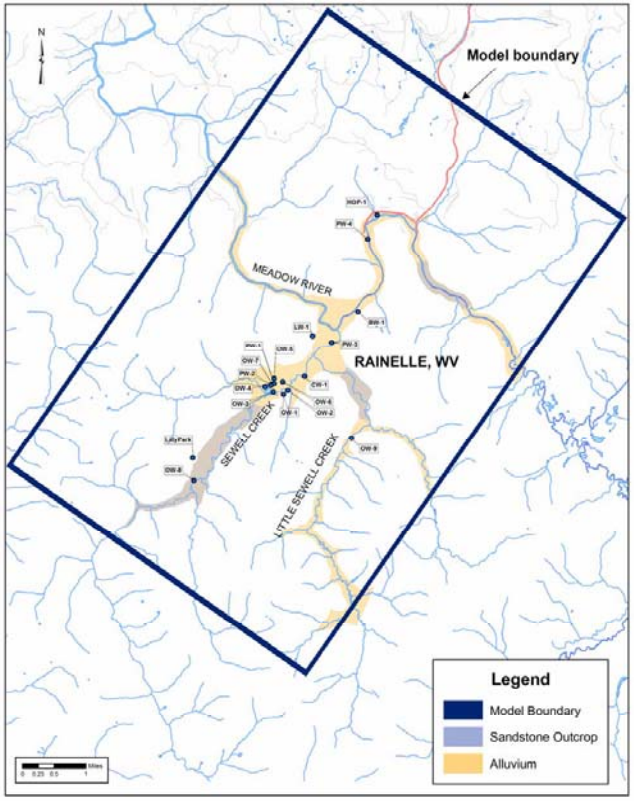


Figure 1 Location Map.

Appendix D2

S.S. PAPADOPULOS & ASSOCIATES, INC.

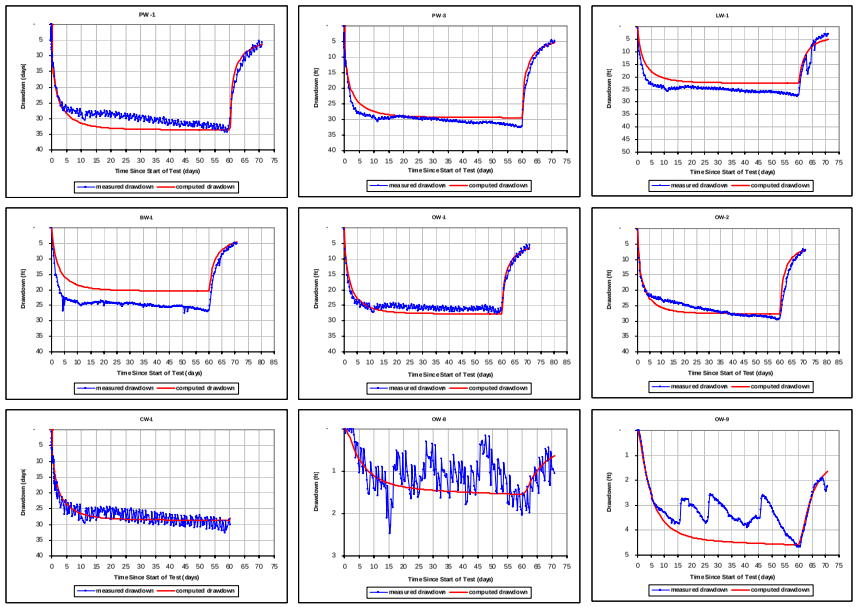


Figure 2 Observed versus Simulated Drawdown.

S.S. PAPADOPULOS & ASSOCIATES, INC.

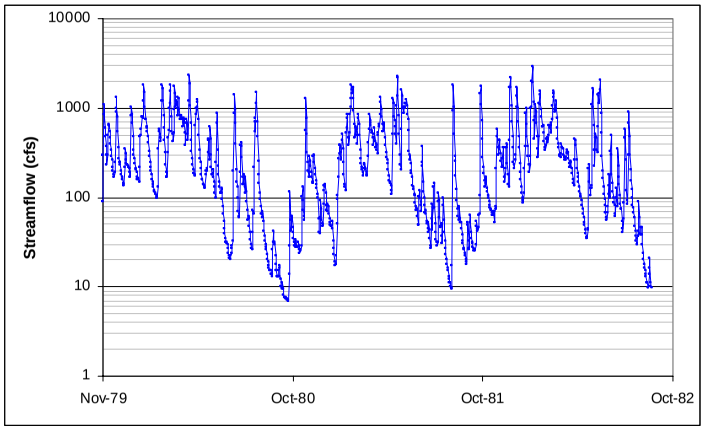


Figure 3 Streamflow Data for Meadow River (USGS 03189890, McRoss WV).

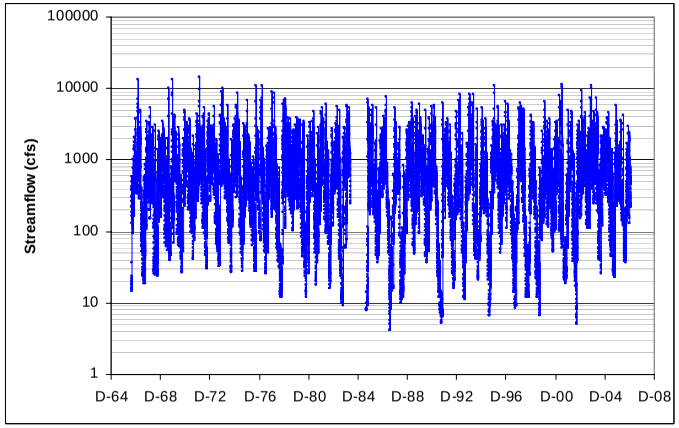


Figure 4 Streamflow Data for Meadow River (USGS 03190400, Mt. Lookout WV).

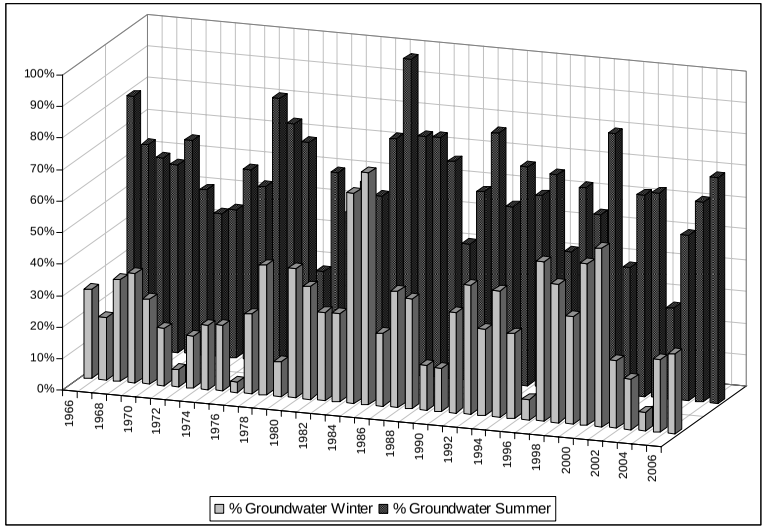


Figure 5 Annual Number of Days per Season for Groundwater Pumping

S.S. PAPADOPULOS & ASSOCIATES, INC.

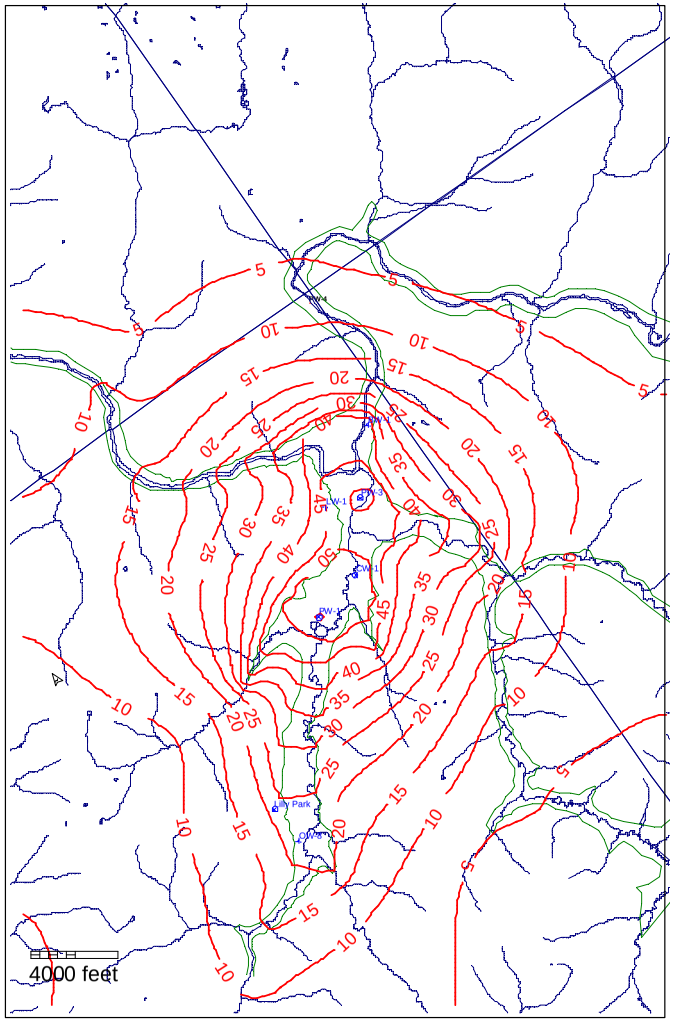


Figure 6 Simulated Drawdown after 25 years (Q=1,049 gpm).

Appendix D2

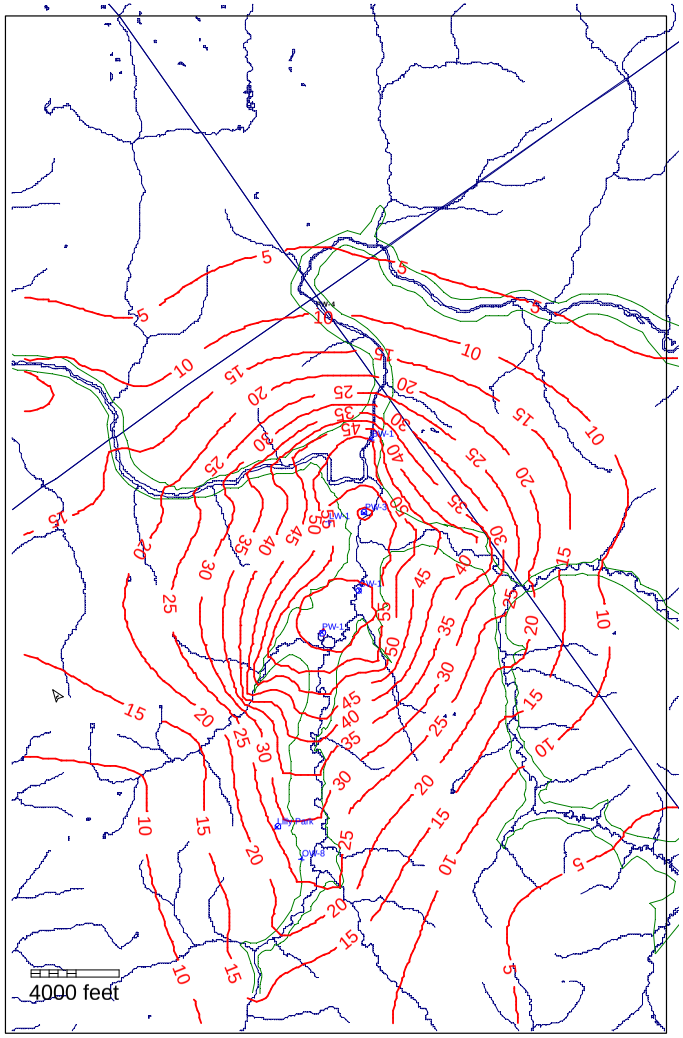


Figure 7 Simulated Drawdown after 25 years (Q=1,179 gpm).

S.S. PAPADOPULOS & ASSOCIATES, INC.

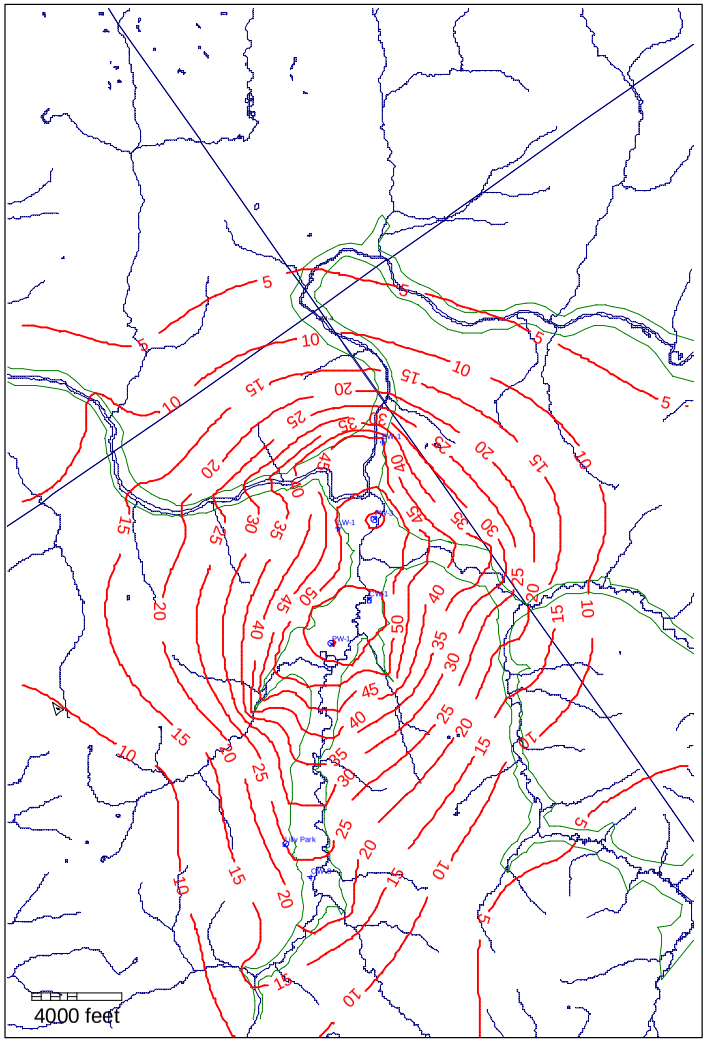


Figure 8 Simulated Drawdown after 25 years (Q=960 gpm Winter – 1,139 gpm Summer).

Appendix D2

S.S. PAPADOPULOS & ASSOCIATES, INC.

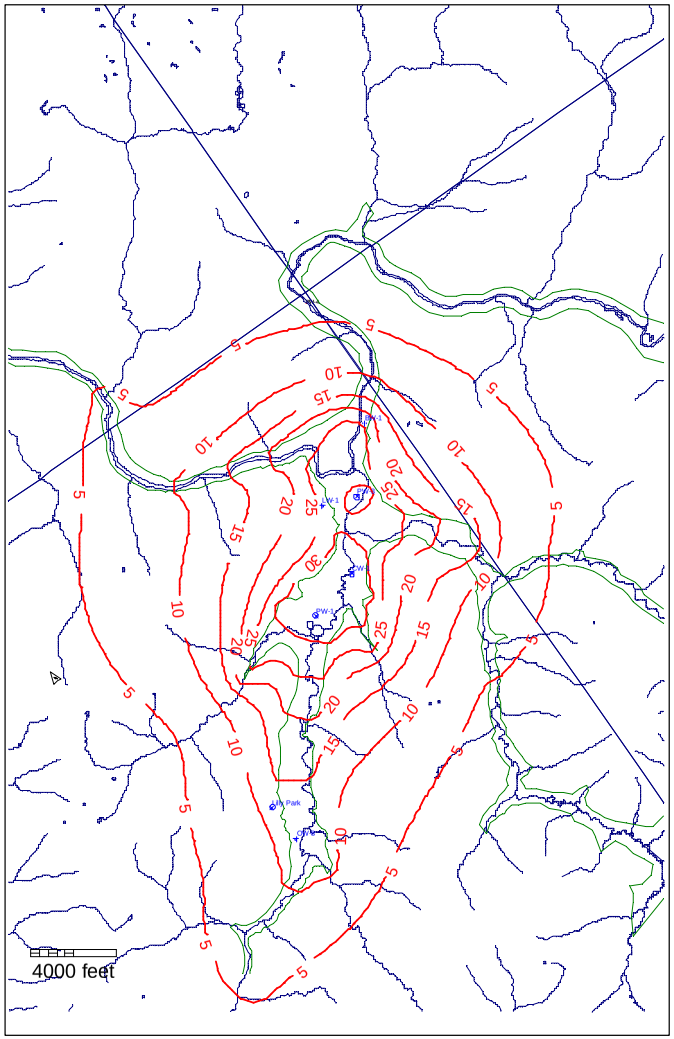
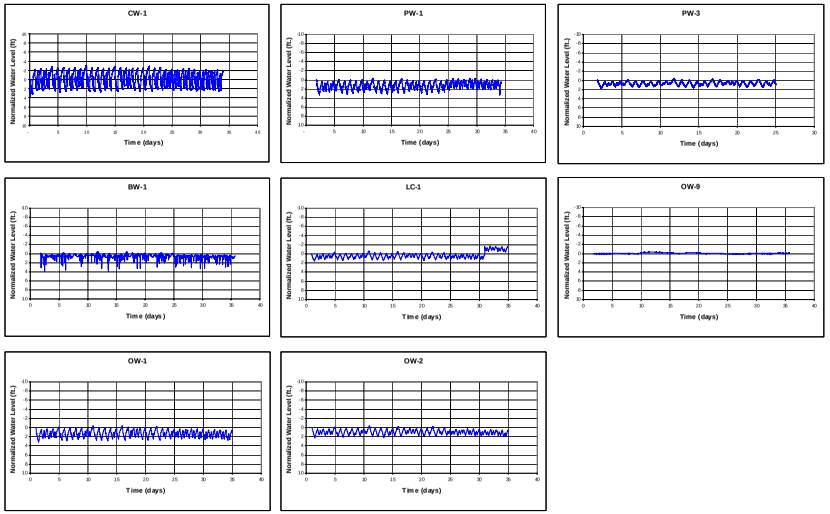


Figure 9 Simulated Drawdown after 25 years
(Weighted Q=707 gpm Winter – 280 gpm Summer).

S.S. PAPADOPULOS & ASSOCIATES, INC.



Water level data normalized to initial water levels measured at each well.

Figure 10 Observed Water Levels prior to Aquifer Test.

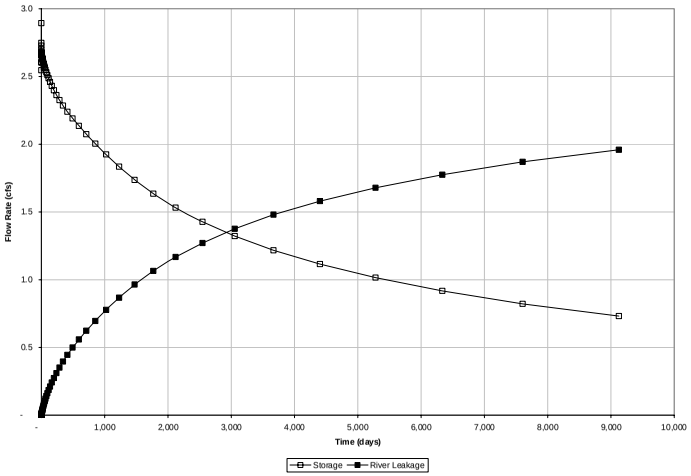


Figure 11 Storage Depletion versus River Leakage over a 25 Year Period (Q=1,049 gpm)

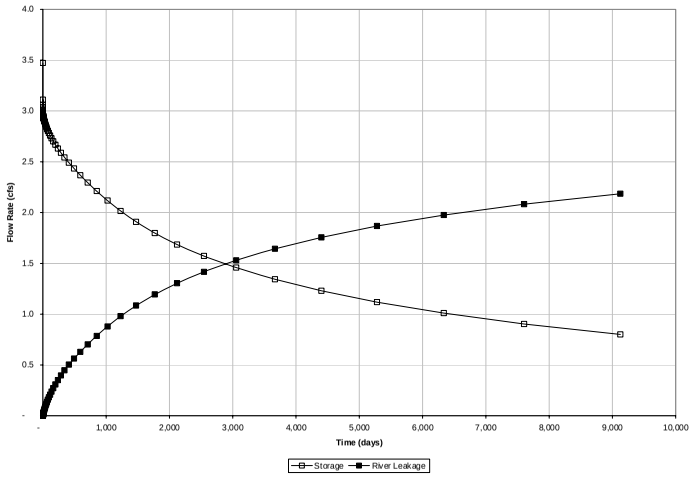


Figure 12 Storage Depletion versus River Leakage over a 25 Year Period (Q=1,179 gpm)

S.S. PAPADOPULOS & ASSOCIATES, INC.

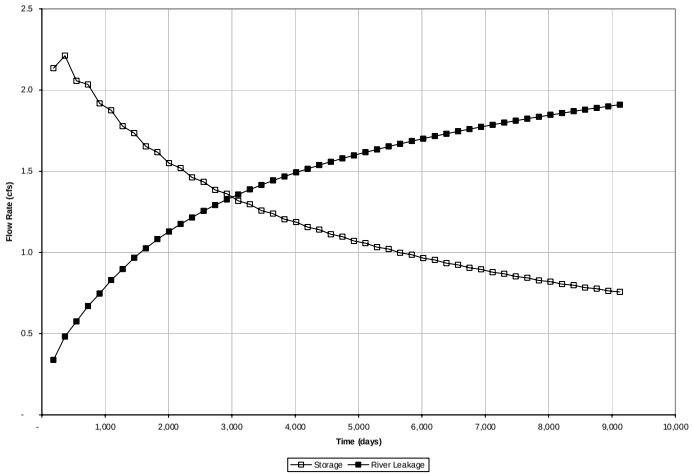


Figure 13 Storage Depletion versus River Leakage over a 25 Year Period (Q=960 gpm Winter – 1,139 gpm Summer)

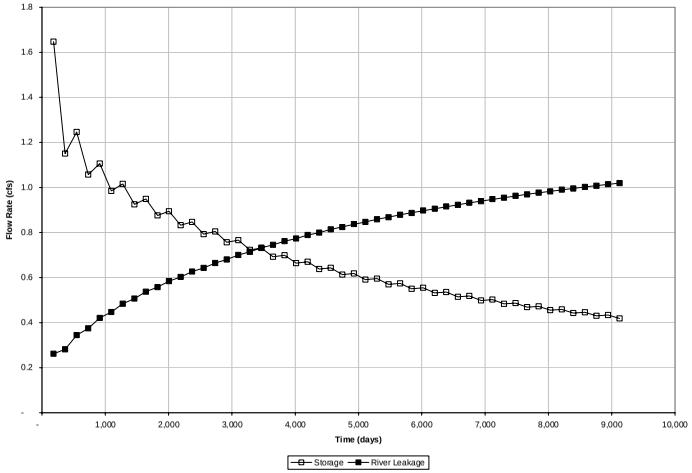


Figure 14 Storage Depletion versus River Leakage over a 25 Year Period (Weighted Q=707 gpm Winter – 280 gpm Summer)

Appendix D2

S.S. PAPADOPULOS & ASSOCIATES, INC.

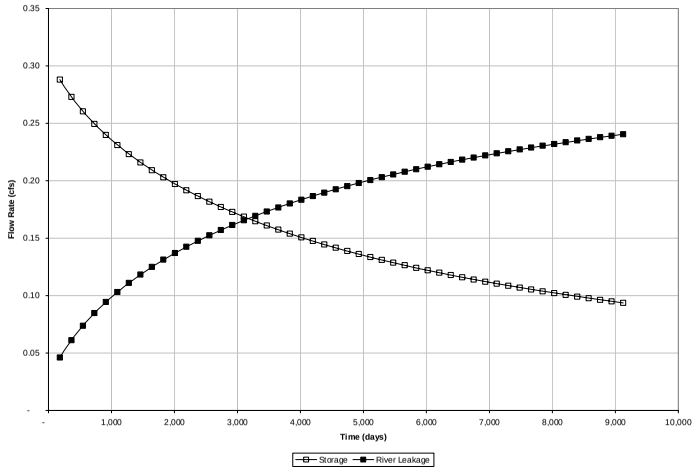


Figure 15 Storage Depletion versus River Leakage over a 25 Year Period, CW-1 (Q=150 gpm)

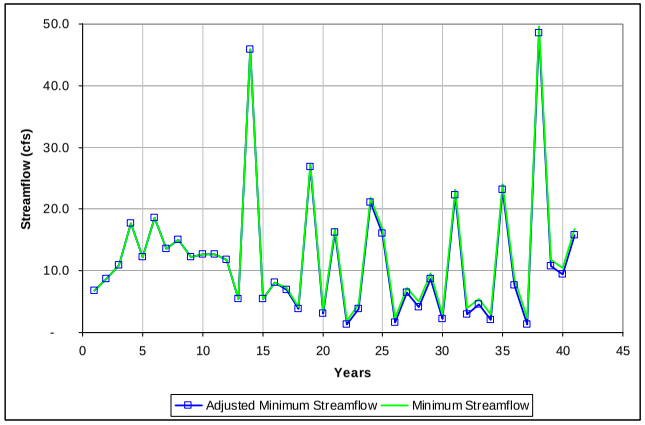


Figure 16 Minimum and Adjusted Minimum Streamflow Values for Meadow River.

Log of PW-1 based on geophysical log and video by Ed Custer, Jr

Top Elevation: 2,400.29 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	45.00	45.00	Casing or surface matter	
45.00	66.00	21.00	Shale, sandy, red, with sandstone streaks	
66.00	71.00	5.00	Shale, red, with interbedded sandstone	
71.00	89.00	18.00	Shale, sandy, red, with sandstone streaks	
89.00	90.00	1.00	Sandstone, gray	
90.00	91.00	1.00	Shale, sandy, red, with sandstone streaks	
91.00	126.00	35.00	Sandstone, gray	
126.00	150.00	24.00	Shale, sandy, red, with sandstone streaks	

Log of PW-3 based on geophysical log and video by Ed Custer, Jr

Top Elevation: 2,388.95 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	52.00	52.00	Casing	
52.00	54.30	2.30	Sandstone, gray crossbedded	Horizontal fracture at base no H20 or iron staining
54.30	77.00	22.70	Shale, sandy, red and green	Annealed 45-75 degree fractures
77.00	87.45	10.45	Sandstone, gray crossbedded	
87.45	92.35	4.90	Sandstone, gray crossbedded	Horizontal Broken Zones and fractures H20, iron staining on fractures
92.35	110.00	17.65	Sandstone, gray crossbedded	
110.00	111.00	1.00	Conglomerate, gray	Pebbles and Cobbles
111.00	114.00	3.00	Sandstone, gray crossbedded	Fracture At 113.55 some iron staining
114.00	146.00	32.00	Shale, sandy, red and green	
146.00	148.50	2.50	Sandstone, gray with shale streaks	Near horizontal Fracture at 147 iron staining
148.50	168.44	19.94	Sandstone, gray crossbedded	

Log of PW-4 based on geophysical log and video by Ed Custer, Jr

Top Elevation: 2,446.88 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	39.00	39.00	Casing	H20 9.5 Rock reported at 22.5 ft by driller
39.00	43.00	4.00	Sandstone, gray, crossbedded	
43.00	46.50	3.50	Sandy Shale	
46.50	66.00	19.50	Sandstone, gray, crossbedded	
66.00	67.00	1.00	Sandy Shale	
67.00	81.75	14.75	Sandstone, gray, crossbedded	H20 horizontal bedding fracture 80.5'
81.75	92.00	10.25	Sandy Shale, light grey green, ripple bedded	Horizontal bedding fractures @86, 88.5
92.00	126.00	34.00	Sandy Shale,red & green	
126.00	136.00	10.00	Shale,red & green, interbedded sandstone beds	
136.00	139.00	3.00	Sandstone, gray, crossbedded	
139.00	212.50	73.50	Sandy Shale,red & green	
212.50	215.00	2.50	Sandstone, gray, crossbedded	
215.00	226.50	11.50	Sandy Shale,red & green	
226.50	234.00	7.50	Shale,red & green, interbedded sandstone beds	
234.00	247.32	13.32	Sandy Shale,red & green	

Log of OW-1A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)
Top Elevation: 2,397.51 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	4.50	4.50	CL, Clay, Red Brown, sandstone gravel	Moist
4.50	5.00	0.50	CH, Dark gray, medium plastic	Moist
5.00	6.50	1.50	CH, Gray, sandy, plastic	Moist
6.50	10.00	3.50	CH, Gray, slightly silty,medium plastic	Water 9 feet
10.00	11.50	1.50	CH, Gray, trace silt and organics, plastic	Wet
11.50	15.00	3.50	CH, Gray, trace silt and organics, plastic	Wet
15.00	16.50	1.50	10" SP, Sand, Gray 6" CL, Clay, Gray, sandy 2" SP, Sandy, Gray	Wet
16.50	17.50	1.00	SP, Sand, Gray	Wet
17.50			Did not go to auger refusal	

Log of OW-1B (Earl Tuckwiller, Tuckwiller Well Drilling)
Top Elevation: 2,397.29 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	2.00	2.00	Fill	
2.00	5.00	3.00	Clay/silt	
5.00	19.00	14.00	Sand	
19.00	30.00	11.00	Shale, Red	
30.00	35.00	5.00	Sandstone	
35.00	81.00	46.00	Shale, Sandy, Red	Water at 81 feet
81.00	96.00	15.00	Sandstone	
96.00	98.00	2.00	Shale, Sandy, Red	
98.00	100.00	2.00	Sandstone	
100.00	104.00	4.00	Shale	
104.00	121.00	17.00	Sandstone	
121.00	138.00	17.00	Shale, Sandy, Red	Water at 138 feet
138.00	148.00	10.00	Sandstone	Fractured at 148 feet
148.00	160.00	12.00	Shale, Sandy, Blue	

Log of OW-2A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)
Top Elevation: 2,391.50 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	0.25	0.25	Top Soil	
0.25	2.50	2.25	CL, Clay, Red Brown, weathered shale chips	Moist
2.50	3.50	1.00	CH, Clay, Gray, medium plastic	Moist
3.50	5.00	1.50	CH, Clay, Tan, medium plastic	Moist
5.00	6.50	1.50	CH, Clay, Gray, plastic	Moist
6.50	9.00	2.50	CH, Clay, Gray, plastic	Moist
9.00	10.00	1.00	SP, Sand, Gray, clayey	Water 9 feet
10.00	11.50	1.50	5" SP, Sand, Gray, medium grained 1.5" SP, Sand, Gray, clayey, orgaincs 11.5" SP, Sand, Gray, clayey	Wet
11.50	15.00	3.50	SP, Sand, Gray, clayey	Wet
15.00	16.50	1.50	SP, Sand, Gray, medium to fine grained, This material probably was from material that flowed into the auger	Wet
15.50			Auger Refusal	

Log of OW-2B (Earl Tuckwiller, Tuckwiller Well Drilling)

Top Elevation: 2,393.19 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	3.00	3.00	Fill	
3.00	18.00	15.00	Sand	
18.00	32.00	14.00	Shale, Red	
32.00	40.00	8.00	Sandstone	
40.00	50.00	10.00	Shale, Sandy, Red	Water at 50 feet
50.00	71.00	21.00	Sandstone	Hard
71.00	87.00	16.00	Shale, Sandy, Red	Water at 87 feet
87.00	96.00	9.00	Sandstone	
96.00	128.00	32.00	Shale, Sandy, Red	Water at 128 feet
128.00	135.00	7.00	Sandstone	
135.00	140.00	5.00	Shale, Sandy, Red	
140.00	160.00	20.00	Shale, Sandy, Blue	

Log of OW-3A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)

Top Elevation: 2,394.39 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	0.50	0.50	Top Soil, Clay, Dark Brown, with organics	
0.50	5.00	4.50	CL, Clay, Tan, silty	Moist
5.00	6.50	1.50	3" SP, Sand, Tan, Moist 2" Clay, Black, Moist 13" SP, Sand, Tan, fine grained, clayey, Wet	
6.50	10.00	3.50	SP, Sand, Tan, clayey	Wet
10.00	11.50	1.50	5 SP, Sand, Tan, clayey, 13" SP, Sand, Gray, medium-fine grained	Wet
11.50	12.25	0.75	SP, Sand, Gray	Wet
12.25			Auger Refusal	

Log of OW-3B (Earl Tuckwiller, Tuckwiller Well Drilling)

Top Elevation: 2,393.66 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	2.00	2.00	Fill	
2.00	18.00	16.00	Sand	
18.00	20.00	2.00	Clay and Wood	
20.00	50.00	30.00	Shale, Sandy, Red	Water at 38 feet
50.00	65.00	15.00	Shale, Sandy, Blue	
65.00	95.00	30.00	Sandstone, white	
95.00	113.00	18.00	Shale, Sandy, Blue	
113.00	128.00	15.00	Shale, Sandy, Red	
128.00	134.00	6.00	Shale, Sandy, Blue	
134.00	138.00	4.00	Shale, Sandy, Red	
138.00	160.00	22.00	Shale, Sandy, Blue	

Log of OW-4A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)
Top Elevation: 2,402.57 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	0.25	0.25	Top Soil	
0.25	1.50	1.25	Fill, CL, Clay, Green Gray, silty	Moist
1.50	2.50	1.00	Fill, CL, Clay, Tan, coal chips	Hard Augering
2.50	3.50	1.00	Fill, Clay, coal and rock chips	
3.50	5.00	1.50	CL, Clay, Black, Fill?	
5.00	6.50	1.50	Fill, Clay, silt, wood chips	Moist
6.50	7.50	1.00	Fill, Clay, silt, wood chips	Moist
7.50	10.00	2.50	CL, Clay, Black, slightly plastic	Moist
10.00	11.50	1.50	CH, Clay, Gray, plastic	Moist
11.50	13.00	1.50	CH, Clay, Gray, plastic	Moist
13.00	15.00	2.00	SP/CH, Sand, Gray, Clayey	Wet
15.00	16.50	1.50	SP/CH, Sand, Gray, Clayey	Wet
15.00			Did not go to auger refusal	

Log of OW-4B (Earl Tuckwiller, Tuckwiller Well Drilling)
Top Elevation: 2,403.17 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	2.00	2.00	Fill	
2.00	18.00	16.00	Clay, sandy	
18.00	48.00	30.00	Shale, Red	
48.00	61.00	13.00	Sandstone	Water at 50 feet
61.00	88.00	27.00	Shale, Sandy, Red	
88.00	91.00	3.00	Shale, Sandy, Blue	
91.00	121.00	30.00	Sandstone	Water at 91 and 121 feet
121.00	138.00	17.00	Shale, Sandy, Blue	
138.00	148.00	10.00	Shale, Sandy, Red	
148.00	160.00	12.00	Shale, Sandy, Blue	

Log of OW-5A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)
Top Elevation: 2,415.29 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	0.50	0.50	Top Soil	
0.50	2.00	1.50	Fill, CL, Clay, Black, slightly plastic	Moist
2.00	3.50	1.50	CL, Clay, Dark Gray to Tan	Moist
3.50	5.00	1.50	CH, Clay, Tan, plastic	Moist
5.00	6.50	1.50	5" CH, Clay, Dark Gray, organics, plastic 10" CH, Clay, Tan, plastic	Moist
6.50	8.00	1.50	CH, Clay, Tan, plastic	Moist Water at 8 feet
8.00	10.00	2.00	SP, Sand, Gray, clayey, fine-medium grained	Wet
10.00	11.50	1.50	2" CH, Clay, Gray, plastic, Wet 6" SP, Sand, Tan, Wet 10" MH, Silt, Gray, very fine sandy, moist to wet	Wet
11.50	13.00	1.50	MH, Silt, Gray, sandy,	
13.00			Did not go to auger refusal	

Log of OW-5B (Earl Tuckwiller, Tuckwiller Well Drilling)
Top Elevation: 2,413.62 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	2.00	2.00	Fill	
2.00	15.00	13.00	Clay, sandy	
15.00	28.00	13.00	Shale, Soft	
28.00	51.00	23.00	Shale, Red	
51.00	54.00	3.00	Shale, Red, Hard	
54.00	58.00	4.00	Sandstone, Hard	
58.00	71.00	13.00	Shale, Red	
71.00	76.00	5.00	Shale, Red, Hard	
76.00	85.00	9.00	Shale, Sandy, Red	
85.00	91.00	6.00	Sandstone	Water 85-91 Feet
91.00	108.00	17.00	Sandstone	
108.00	109.00	1.00	Sandstone	Water 108-109 feet
109.00	121.00	12.00	Sandstone	
121.00	137.00	16.00	Sandstone	Water at 137 feet
137.00	144.00	7.00	Shale, Sandy, Blue	
144.00	160.00	16.00	Shale, Sandy, Red	

Log of OW-6A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)
Top Elevation: 2,400.83 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	0.25	0.25	Top Soil	
0.25	3.50	3.25	Fill, Clay, gravel, pieces of concrete	
3.50	5.00	1.50	CL, Clay, Black, sandy, fill?	Moist
5.00	6.50	1.50	12" CL, Gray, sandy, fine grained, Wet 6" CH, Clay, Gray, Organics	Wet/Moist
6.50	10.00	3.50	CH, Clay, Gray, plastic	Water at 7 feet
10.00	11.50	1.50	8" MH, Silt, tan/brown, clayey, sticky 10" CH, Clay, Tan and Gray, Plastic	Moist/Wet
11.50	15.00	3.50	CH, Clay, Tan and Gray, Plastic	Wet, Slow Augering
15.00	16.50	1.50	CH/MH, Clay and Silt, Tan and Gray, Plastic, Trace of coal and sand	
16.50	20.00	3.50	CH, Clay, silty, dark gray, sticky	Wet, Slow Augering
20.00	25.00	5.00	CH/MH, Clay, silty, sandy, dark gray, sticky	Water at 21 feet
25.00			No Auger Refusal	

Log of OW-6B (Earl Tuckwiller, Tuckwiller Well Drilling)
Top Elevation: 2,401.34 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	3.00	3.00	Fill	
3.00	24.00	21.00	Clay, silty	
24.00	70.00	46.00	Shale, Red	
70.00	92.00	22.00	Sandstone, Hard, Red	Water 92 Feet
92.00	125.00	33.00	Sandstone, Hard, salt and pepper	
125.00	135.00	10.00	Shale, Sandy	
135.00	160.00	25.00	Shale, Red	

Log of OW-7A (Danny McCoy, Rob Ridgeway, Engineering & Testing 2000, Inc.)
Top Elevation: 2,403.76 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	9.00	9.00	Clay, Tan/Dark Brown	Moist
9.00	12.00	3.00	SP - Sand, gray, medium grained, Wet	Water at 9 feet
12.00			Auger Refusal	Water at 2.5 feet after drilling

Log of OW-8 (Earl Tuckwiller, Tuckwiller Well Drilling)
Top Elevation: 2,410.75 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	40.00	40.00	Overburden	
40.00	60.00	20.00	Blue sand shale (little water encountered at 51 feet)	
60.00	98.00	38.00	White sand rock (water encountered at 89 feet)	
98.00	100.00	2.00	Blue and black rock with sulphur odor	
100.00	120.00	20.00	White sandstone	
120.00	147.00	27.00	Blue and white sand stone	
147.00	200.00	53.00	Red shale	

Log of OW-9 (Earl Tuckwiller, Tuckwiller Well Drilling)
Top Elevation: 2,413.38 ft amsl

Top_Depth	Bot_Depth	Thickness (ft)	Lithologic_Description	Comments
0.00	14.00	14.00	Overburden	
14.00	34.00	20.00	Red shale	
34.00	60.00	26.00	Reddish-blue shale	
60.00	80.00	20.00	Blue Shale	Little water at 60 ft.
80.00	99.00	19.00	Blue sandy shale	
99.00	100.00	1.00	Red shale	
100.00	120.00	20.00	Blue shale with little red shale	15 gpm of water at 110 ft.
120.00	125.00	5.00	Blue shale	
125.00	140.00	15.00	Red shale	More water encountered at 135 ft.
140.00	160.00	20.00	Red Shale	