#98

Hydrologic Properties of Aquifers in the Central Savannah River Area

Volume Two

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Executive Summary

The hydrologic properties of selected aquifer systems underlying the Milhaven and Girard sites in Georgia were determined through a series of aquifer performance tests performed from October, 1994 to January, 1995. At the Milhaven site, the systems under investigation consisted of the upper, middle and lower components of the Upper Floridan, the lower Dublin, and the lower Midville aquifers. At the Dublin site, only the lower Dublin and lower Midville aquifers were tested. In addition, the hydrologic properties of the lower Midville aquifer underlying the P, B and D Areas at the Savannah River Site were determined by a series of aquifer tests conducted in 1993 and 1994. The tests generally consisted collecting water level and atmospheric data for 24 hours followed by a 72 hour pump test and a subsequent 72 hour recovery period. These tests were designed to determine the aquifer properties over a large area, to determine whether any hydrologic boundaries existed in the area, and to find out if leakance could be induced through the confining units which separated the aquifer units.

Introduction

This investigation is part of a larger project entitled, "The Trans-River Project", which is managed by John Clarke of the U. S. Geological Survey (USGS). It is a cooperative project with the USGS, the U. S. Department of Energy (USDOE), the Westinghouse Savannah River Company (WSRC), the Georgia Geological Survey, and other agencies. The initial work plan entailed performing approximately 40 pump tests, analyzing the data, and reporting the results to the USGS, USDOE, and WSRC. The results of the pump tests are to be utilized by the USGS to assist them in the development of a model to investigate the possibility of contamination of regional water supplies because of ground-water underflow from SRS beneath the Savannah River into Georgia.

Acknowledgments

The funding for this project was provided by the Department of Energy and the Westinghouse Savannah River Company through the South Carolina Universities Research and Education Foundation Task Order #94 and #29-94.

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The Milhaven Tests

AQUIFER PERFORMANCE TEST REPORT

Millhaven Well TW1, Screven County, Georgia

October 3-10, 1994

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July 12, 1995

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Funds for this investigation were provided in part by SCUREF TASK ORDER #94 (Van Price, Jr., WSRC, Subcontract Technical Representative) and SCUREF TASK ORDER #29-94 (Thomas Temples, U. S. DOE, Technical Representative)

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ABSTRACT

As part of the USGS Trans-River Project, the Department of Earth Sciences at Clemson University conducts pump tests at selected localities in South Carolina and Georgia near or on the United States Department of Energy's Savannah River Site (U. S. DOE/SRS). The test at Millhaven, located in Screven County, Georgia, was conducted from October 3 through 10, 1994 using the USGS's TW1 well as the pumping well and three other wells from the cluster (TW2, TW3, and the core hole) as observation wells. The pumping well (TW1) is screened in the upper zone of the Upper Floridan Aquifer. Since none of the monitoring wells were screened over the same hydrogeologic interval as the pumping well, a storativity of 0.001 was estimated from Hodges (1994, written communication) and historical data of the region. A transmissivity of 172.8 m2/day (1,860 ft2/day) was calculated from TW1 data. The 21.33 meter thickness of the upper zone of the upper Floridan at Millhaven yields a hydraulic conductivity of 8.1 m/day (27 ft/day) from the TW1 data. The specific capacity of the well was 2.12 gpm/ft. Other observation wells screened in successively deeper zones (TW2 in the middle zone of the Upper Floridan, TW3 in the lower zone of the Upper Floridan, and the core hole in the Meyers Branch Confining Unit) were monitored to detect vertical leakage across confining layers. Water level changes directly related to pumping were observed in the TW2 well, indicating leakage across the confining unit separating the upper and lower zones of the Upper Floridan. No water level changes directly related to pumping were observed in well TW3 or the core hole, indicating no detectable leakage from the lower zone of the Upper Floridan or across the Meyers Branch confining interval at the flow rate of 53 gpm.

1.0 INTRODUCTION

The format of this report is modified from Clarke (U. S. Geological Survey, written communication, 1993).

1.1 Purpose of the Millhaven Aquifer Performance Tests

The United States Geological Survey (USGS) is creating a model to predict the rate and direction of groundwater flow in the vicinity of the United States Department of Energy's Savannah River Site (U. S. DOE/SRS). The model will incorporate the hydraulic properties determined from aquifer performance tests at Millhaven. This is part of an overall effort to investigate the possibility of groundwater flow and contaminant migration beneath the Savannah River from SRS in South Carolina to Georgia (Trans-River Project).

The USGS is continuing to drill well clusters in Georgia where aquifer performance tests (pump tests) will be conducted by the faculty and students of the Department of Earth Sciences at Clemson University. The data will be analyzed to estimate hydraulic properties of aquifers and confining units on the Georgia side of the Savannah River. The hydraulic property information available to the model on the South Carolina side of the Savannah River consists of data published by Siple (1967), South Carolina Water Resources Commission (SCWRC) reports (Logan, 1987; Logan and Euler, 1989), unpublished SRS reports, and ongoing research by Clemson University Hydrogeology faculty and graduate students. The Georgia side of the river has been studied by Brooks and others (1985), Clarke and others (1985) and Faye and McFadden (1986); however, the volume of data is not as extensive as the South Carolina side for the region, and thus, new well sites such as Millhaven must be completed and tested in order to make the model more comprehensive.

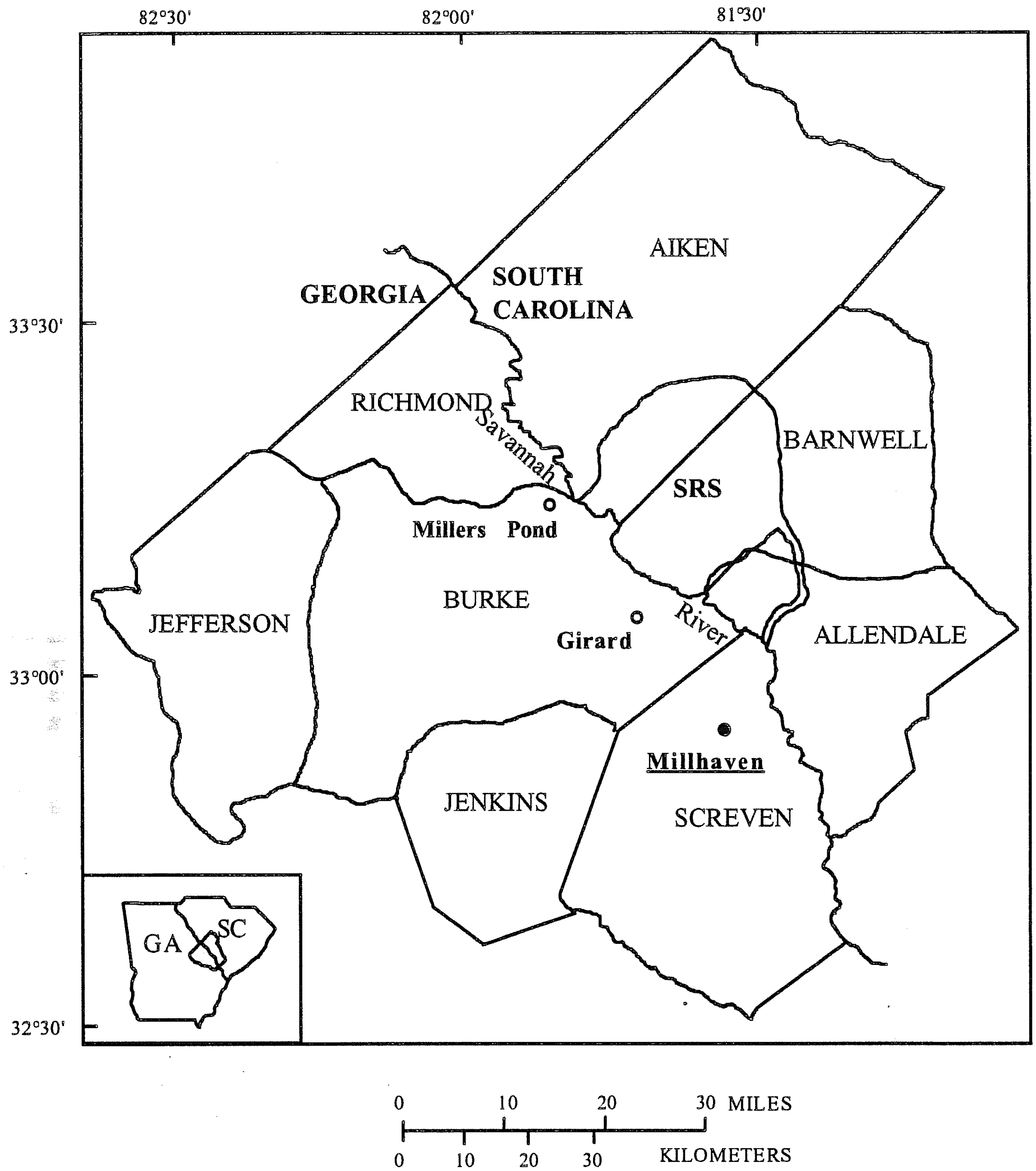

Figure 1. Map showing the location of Millhaven, Screven County, Georgia (Modified from Clarke and others, 1994, in press).

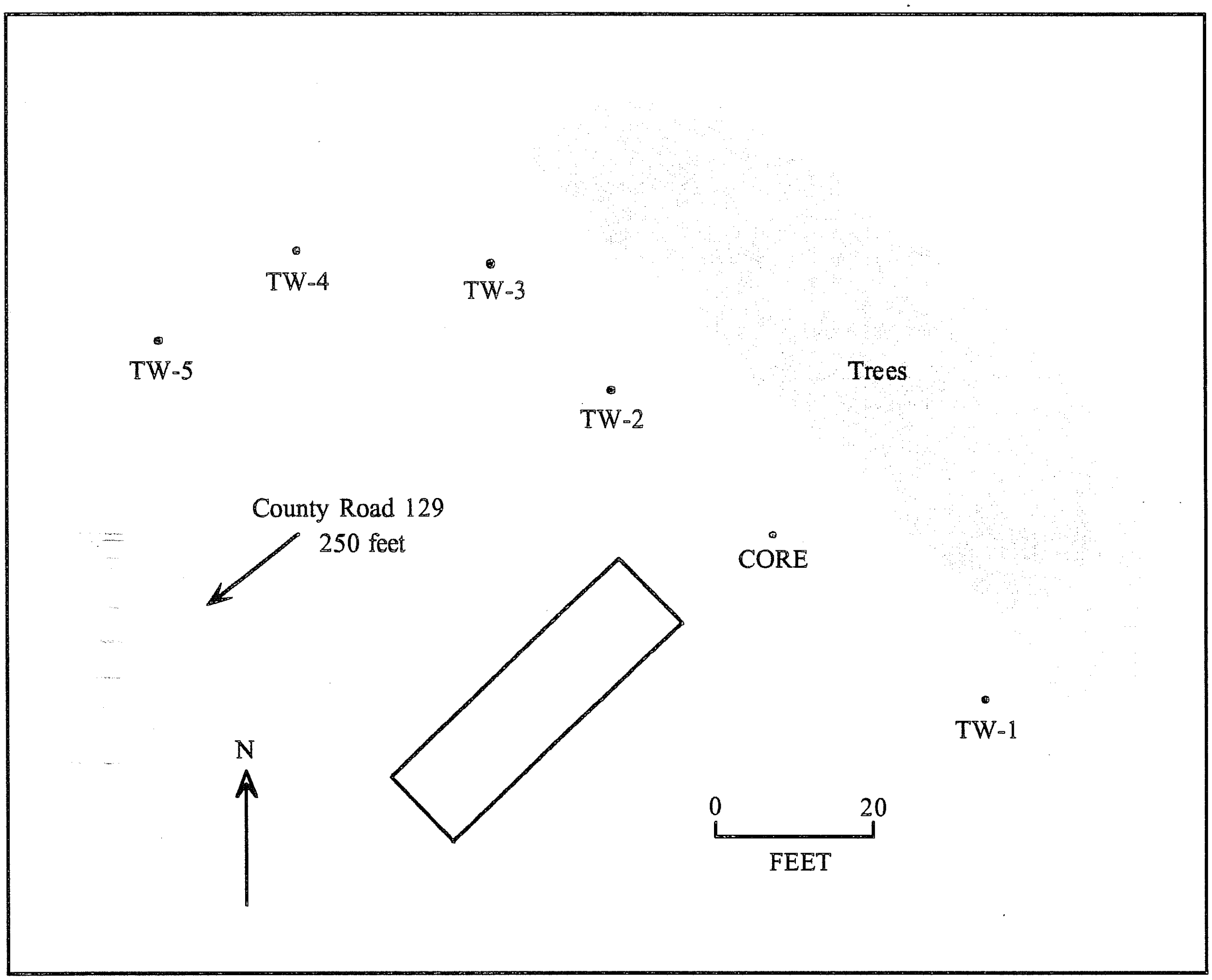

Figure 3. Map showing the location of the wells at Millhaven (Modified from Clarke, written communication, 1995).

2.2.1 Pumping Well Data Acquisition Methods

The pumping well, TW1, is screened in the upper part of the Upper Floridan Aquifer from 18.30 to 9.16 m (30.04 to 60.04 ft) MSL (**Figure 2**). A 7 1/2 hp submersible pump was set at a depth of 12.80 m (42 ft). Because of the depth at which the pump was set, a 100 psi transducer (chamber #4) was positioned at a depth of approximately 16.1 m (52.82 ft).

2.2.2 Observation Well Data Acquisition Methods

There were no observation wells screened in the same aquifer zone (upper zone of the Upper Floridan) as the pumping well. Three other wells screened in successively deeper zones were monitored to detect vertical leakage, if present. Well TW2 is screened in the middle zone of the Upper Floridan from -13.37 to -28.61 m (-43.87 to -93.87 ft) MSL, and TW3 is screened in the lower zone of the Upper Floridan from -34.72 to -51.64 m (-113.92 to -169.42 ft) MSL. The core hole cased to a depth of 174.64 m (573 ft), below which no steps were taken to maintain an open hole. The relative screen positions are shown in **Figure 2**. The transducers for wells TW2, TW3, and the core hole were placed at 8.32 m (27.31 ft), 3.89 m (12.75 ft), and 2.60 m (8.54 ft) below the water table in each respective well.

well	transducer #	transducer psi rating
TW1	4	100
TW2	1	45
TW3	2	45
CH	3	45

2.3 **Analysis Methods**

The initial analysis step is to correct the raw pressure data from the wells for changes in atmospheric pressure. These variations can mask the small response of an aquifer in an observation well. Removal of atmospheric pressure changes makes it easier to detect water level changes that result from pumping.

Barometric corrections are made by subtracting atmospheric pressure changes muliplied by the Barometric Efficiency (BE). The BE of an aquifer is the ratio of the change in hydraulic head in an aquifer (due to atmospheric changes) to the actual change in atmospheric pressure. A BE of 1 indicates that 100% of the atmospheric pressure changes have been transmitted to the aquifer. A BE of 0 would indicate that none of the atmospheric pressure changes have been transmitted to the aquifer.

2.3.1 Observation Well Analysis Method

Data from an observation well screened in the same aquifer as the pumping well can be analyzed to calculate the storativity and transmissivity of the aquifer; however, there were no observation wells screened in the pumped interval at the Millhaven site. Therefore, this technique could not be used to determine the aquifer's physical parameters at this particular site. The observation wells used for the test were screened in successively deeper hydrologic units and qualitatively detect leakage, if present, by water level changes that result from pumping.

2.3.2 Pumping Well Analysis Method

Data from the pumping well is governed by three variables: the transmissivity and storativity of the aquifer, and the skin factor of the pumping well. If one of the three variables is known or can be estimated, the other two can be calculated. The skin factor of the pumping well is unknown and could be

The change in water level vs. time plot for TW1 (**Figure 4**) is a good graphical representation of the flow history for the test.

3.2.2 Water Level Readings

During the test, 1670 water level data points were recorded in the pumping and monitoring wells by the data acquisition system. Data points were recorded as frequently as every 5 seconds at times of rapidly changing water levels, decreasing to every 5 minutes when water level changes were relatively small. **Figures 4** and **5** show plots of change in water level vs. time for the pumping and observation wells, respectively.

The background data for the TW1 test was studied for possible water level trends or fluctuations which may have affected the drawdown data during the pumping phase of the test. The pumping well showed a slight upward trend; however, the trend correction to be applied was miniscule when compared to the drawdown in the well. Thus, no correction was performed on the well test data. The observation well plots, however, showed a distinct trend over the duration of the test. The TW2 and TW3 wells showed a recovery caused by a rain event preceding the TW1 test. The core hole also exhibited similar behavior, but the depth of the monitored interval makes it difficult to determine whether this phenomenon is caused by recharge to the Meyer's Branch unit or by some sort of interaquifer communication beneath the Meyer's Branch.

3.2.3 Maximum Water Level Change (meters) During the Test

A drawdown of about 7.82 meters (25.6 ft) was observed in TW1 during the 66 hour pumping period. The observation well screened in the lower zone of the Upper Floridan, TW2, drew down 0.02 meters, indicating a hydraulic connection between TW1 and TW2 (**figure 5**). Well TW3, screened in the lower zone of the Upper Floridan, and the core hole, completed in the Meyers Branch, showed no changes related to pumping well TW1.

- Static water levels were measured by USGS personnel prior to Clemson's pumping tests.

well	hydrogeologic screened zone	static WL	WL change
TW1	upper part of the Floridan	4.11 m	7.82 m
TW2	middle part of the Floridan	4.61 m	0.02 m
TW3	lower part of the Floridan	4.42 m	0.00 m
Core hole	Meyers Branch Confining	unknown	0.00 m

3.3 Data Analysis Results

3.3.1 Barometric Corrections

Water level pressure data was corrected for the variations in atmospheric pressure by subtracting atmospheric pressure changes multiplied by the barometric efficiency. Pressure data from the pumping well and monitor wells were corrected for atmospheric pressure changes using the following barometric efficiencies.

Well	Barometric Efficiency
TW1	0.75
TW2	0.60
TW3	0.40
CH	0.60

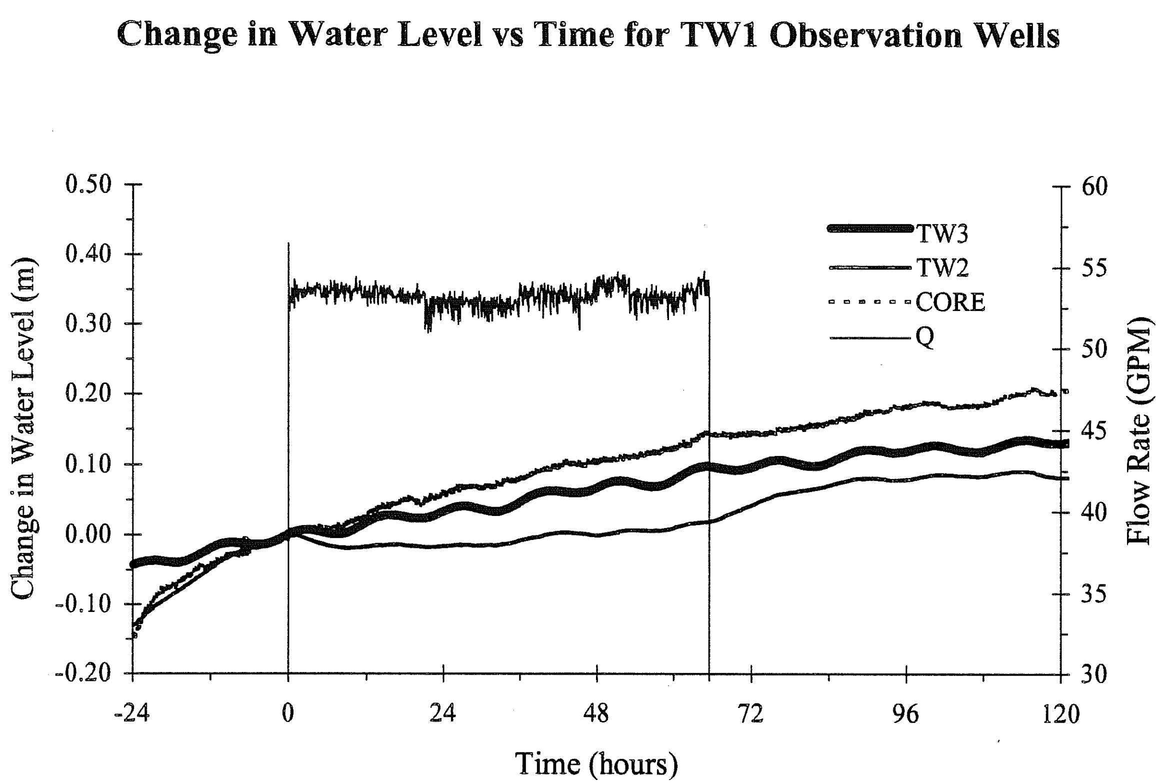

Figure 5. Change in water level vs. time for observation wells (TW2, TW3, and the core hole). The pumping rate for the test is shown in relation to the changing water levels.

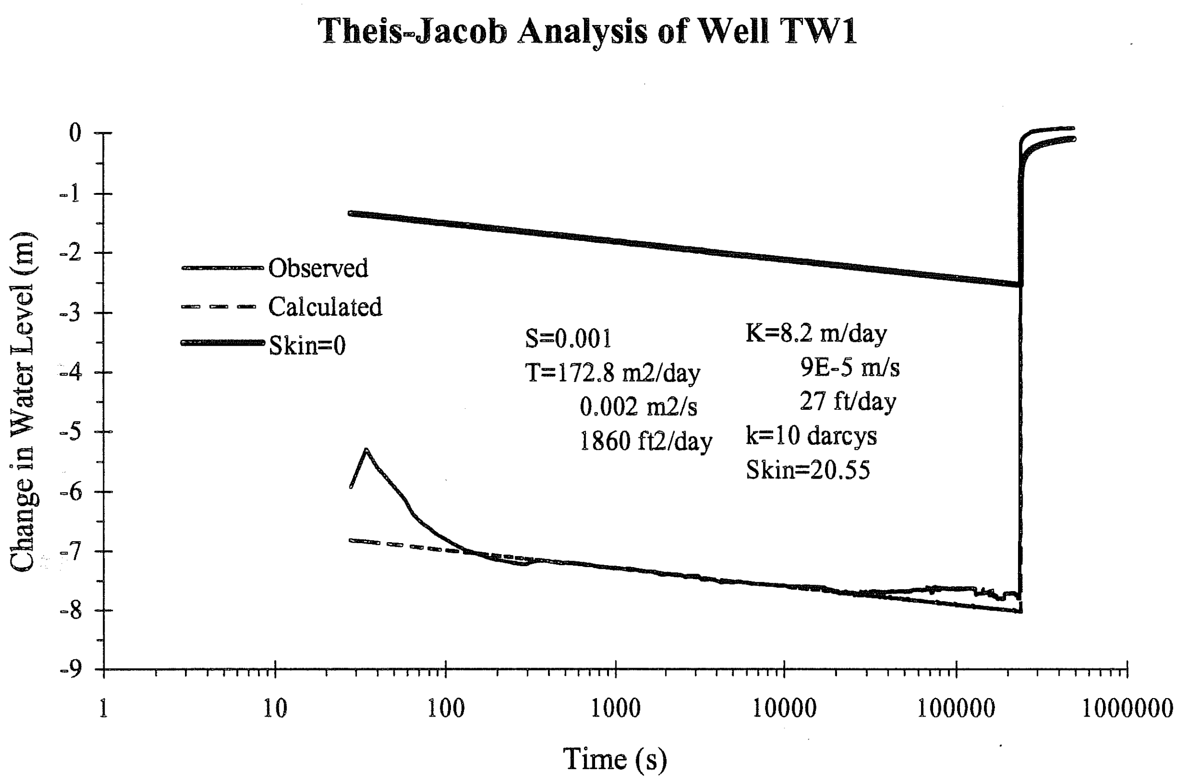

Figure 6. Theis-Jacob analysis (curve match) for well TW1.

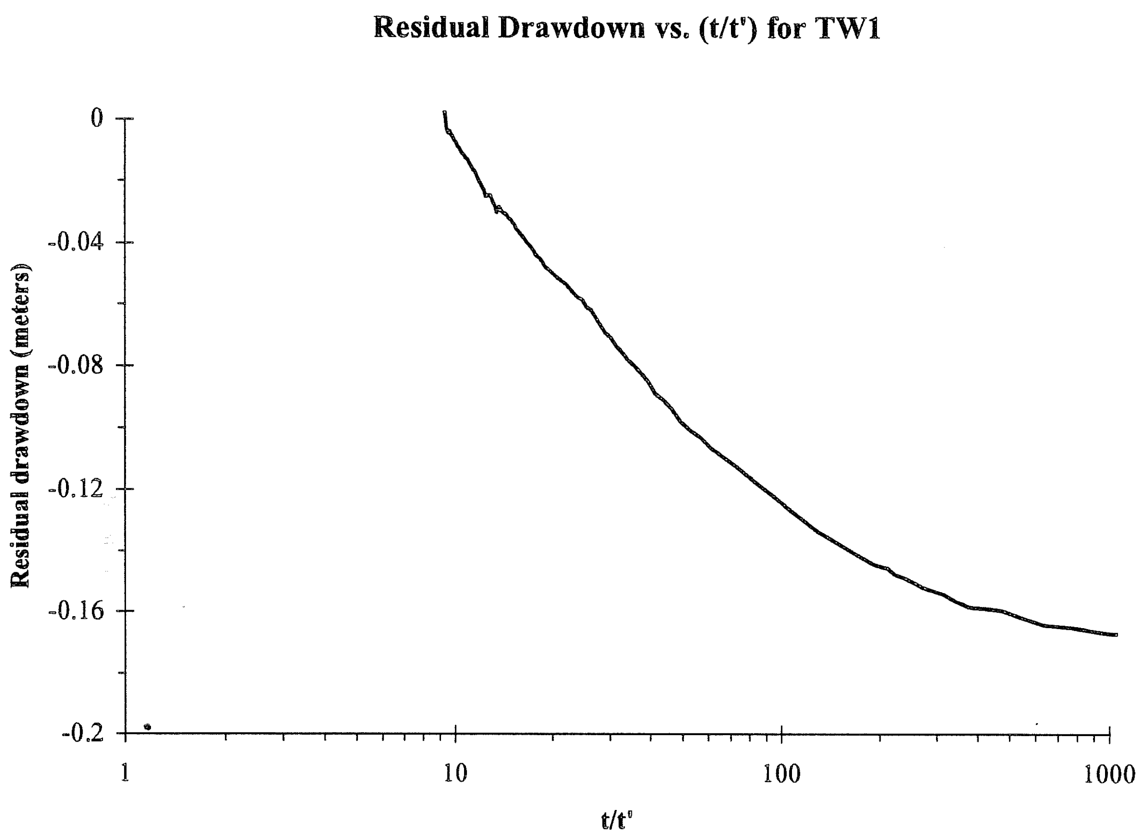

Figure 8. Recovery data plot for the TW1 test. The portion of the recovery curve used to compute the transmissivity of the aquifer lies between the t/t' values of 10 and 100.

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ACKNOWLEDGMENTS

The authors would like to thank John Clarke (USGS) for reviewing this report and making suggestions for its improvement. We are, however, responsible for any mistakes contained in this document.

1.2 Site Conditions

1.2.1 Location

The Millhaven site is located in the north-central portion of Screven County, Georgia, approximately 4.75 miles (7.6 km) west of the Savannah River (**Figure 1**).

1.2.2 Hydrogeologic Setting

The Millhaven well cluster is drilled into Coastal Plain sediments ranging in age from Late Cretaceous to late Eocene. The sediments, interbedded sands, shales, and carbonates, were deposited over Paleozoic crystallines and Triassic red beds exposed by Late Cretaceous erosion. Regional dip is to the southeast and decreases upward from 48 ft/mi (9m/km) at the base of the section to 15 ft/mi (3 m/km) at the top of the middle Eocene beds (Snipes and others, 1993). At Millhaven, the thickness of the sediments is at least 1450 ft (442 m). The hydrostratigraphy of the site is comprised of the Midville, Dublin, Miller's Pond, and Upper Floridan aquifers, the Appleton Confining Unit, and the Meyers Branch and Allendale Confining Systems. The major aquifer systems and confining units are shown in **Figure 2**.

1.2.3 Description of Wells Used for the Test

The TW2 well was used as the pumping well. Three other wells at the site (TW1, TW3, and the core hole) were used as observation wells for the test. **Figure 2** relates the wells to the subsurface hydrogeology of the site. **Figure 3** is a simplified site map showing the location of wells used for the test. The construction specifications of each well are given below:

Pumping Well (TW2):	Coordinates =	Latitude	32°53'25"
		Longitude	81°35'43"
	Elevation (ground) =	33.87 m (111.13 ft) MSL	
	Elevation (TOC) =	34.44 m (112.99 ft) MSL	

Total Depth (from ground):	64.61 m (212 ft)
Effective Well Depth (from ground):	64.00 m (210 ft)
Construction Date:	13 April 1993
Depth Screened Interval:	47.24 to 62.48 m (155 to 205 ft)
Elevation Total Depth:	-30.74 m (-100.87 ft) MSL
Elevation Effective Well Depth:	-28.61 m (-93.87 ft) MSL
Elevation Screened Interval:	-13.37 to -28.61 m (-43.87 to -93.87 ft) MSL
Diameter (casing):	0.152 m (6") from 0 to 64.00 m (0 to 210')
Screened Geologic Unit:	Barnwell Group
Screened Hydrogeologic Unit:	Upper Floridan (middle zone)
Depth Static Water Level:	4.61 m (15.13 ft) on 06/21/93

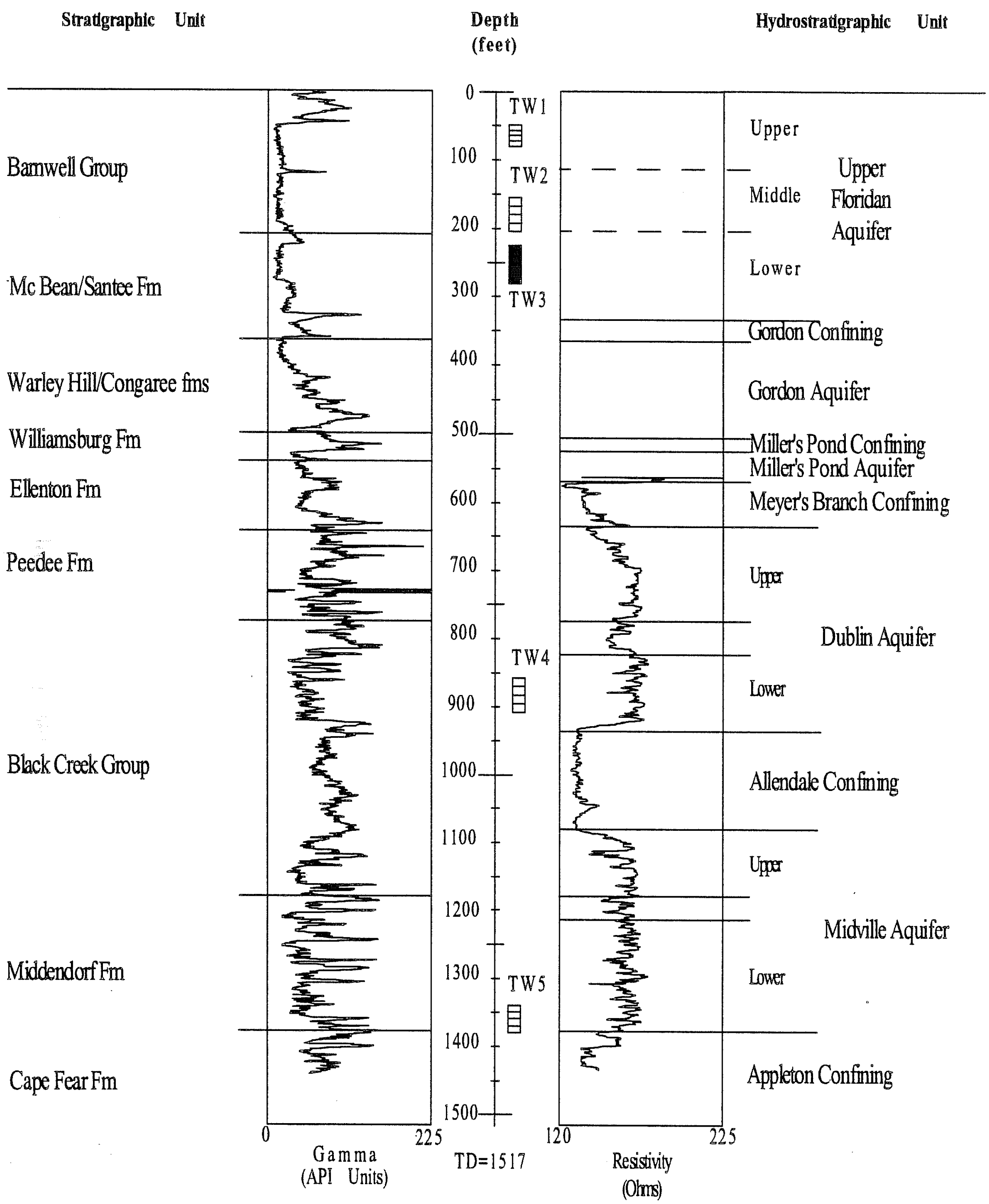

Figure 2. Hydrostratigraphy of the Millhaven site. Locations of well screens and open hole sections are shown.

Observation Well (TW1):	Elevation (ground) =	33.54 m (110.04 ft) MSL
	Elevation (TOC) =	34.10 m (111.88 ft) MSL

Effective Depth: 24.38 m (80 ft)
Elevation Screened Interval: 18.30 to 9.16 m (60.04 to 30.04 ft) MSL
Diameter (casing): 0.152 m (6") from 0 to 26.82 m (0 to 88 ft)
Screened Geologic Unit: Barnwell Group
Screened Hydrogeologic Unit: Upper Floridan (upper zone)
Depth Static Water Level: 4.11 m (13.49 ft) on 06/21/93
Distance from Pumping Well: 25.14 m (82.5 ft)

Observation Well (TW3):	Elevation (ground) =	33.86 m (111.08 ft) MSL
	Elevation (TOC) =	34.42 m (112.92 ft) MSL

Effective Depth: 85.49 m (280.5 ft)
Elevation Screened Interval: -34.72 to -51.64 m (-113.92 to -169.42 ft) MSL
Diameter (casing): 0.152 m (6") from 0 to 68.58 m (0 to 225 ft)
Screened Geologic Unit: McBean/Santee
Screened Hydrogeologic Unit: Upper Floridan (lower zone)
Distance from Pumping Well: 6.86 m (22.5 ft)

2.0 METHODS

2.1 Test Logistics

Ideally, a pump test is composed of three periods of data collection: background, pumping, and recovery. Background data is used to determine if the aquifer is in an equilibrium condition and the extent to which it is being affected by inconsistent external forces. It is also used to determine the barometric efficiency of the monitored aquifers so test data can be corrected for changes in atmospheric pressure. The aquifer is then pumped, creating a pressure drawdown cone extending radially from the pumping well. After pumping stops, the aquifer is allowed to recover to pre-test conditions.

Each of the Millhaven aquifer tests was originally scheduled to be conducted over a period of seven days. Clemson University Earth Sciences Department personnel transported the SCUREF Data Acquisition Facility to each well site and set up equipment to monitor the well during the pump test. During this test, background data were collected for 26.2 hours, followed by 37.0 hours of pumping and 34.9 hours of recovery data.

2.2 Data Acquisition Methods

Water level readings are recorded as pressure changes in meters of water relative to an initial equilibrium static water level condition. For the duration of a pump test (background through recovery), quartz crystal transducers monitor and record water level changes in the pumping well and observation wells. Relative water level changes are recorded automatically on the computer data acquisition system at operator specified intervals ranging from 5 seconds to 5 minutes throughout the test. An additional transducer monitors and records changes in atmospheric pressure which are removed from the well data prior to aquifer parameter analysis. The transducers are calibrated to a maximum of 0.005% of full scale (1.5 mm for a 45 psi transducer) for repeatability and hysteresis. The resolution of a 45 psi transducer is normally about 0.2 mm.

transmissivity and is estimated as the storativity calculated from a nearby observation well. Since there was no observation well screened in the same hydrogeologic unit for this test, a value for storativity was estimated as 0.0001 (Hodges, written communication, 1994). Curve matching of drawdown data yields a transmissivity value for the aquifer and a skin factor for TW2 using superposition of the Theis solution (1935) or Jacob straight-line method (Cooper and Jacob, 1946) for variable flow rates modified for the skin factor analysis of Van Everdingen (1953) for confined aquifers with fully penetrating wells. Once a value for the transmissivity had been obtained, the hydraulic conductivity of the aquifer may be determined by dividing the value for transmissivity by the aquifer thickness. The hydraulic conductivity is then multiplied by 104,000 m/s to obtain the permeability of the aquifer media in darcys (Freeze and Cherry, 1979).

The aquifer test data were entered into a Microsoft Excel spreadsheet designed to graphically estimate the aquifer transmissivity and skin factor for the well, using the modified Theis solution of van Everdingen (1953). The values for transmissivity and skin factor were iteratively changed until the slope and position of the theoretical drawdown plot matched a plot generated from the actual data collected from the test. The hydraulic characteristics for the aquifer were then taken directly from the spreadsheet. The validity of the spreadsheet used to generate these values was verified by Moore (1994).

2.3.3 Recovery Data Analysis Methods

Changes in water level recorded during the recovery period of an aquifer test may be used to determine the transmissivity and storativity values for the aquifer. Since no wells were screened in the same interval as the pumping well at Millhaven, only a transmissivity value may be calculated from the recovery data. The transmissivity is determined by plotting the residual drawdown (the difference between the static water level and the amount of recovery since shutting the pump downj) against the logarithm of the ratio (t/t'), where t is the time since pumping began and t' is the time since pumping stopped. The transmissivity is calculated by using the Jacob equation: $T=0.183Q/ds'$, where Q is the pumping rate (m3/day) and *d*s' is the slope of a "best-fit" straight line drawn between two consecutive logarithmic cycles on the s' vs. t/t' plot. The values obtained from this analysis may then be compared to the pumping phase analysis. Theoretically, the drawdown and recovery analyses should be identical if the aquifer conditions conform to the basic assumptions of the Theis (1935) equation (Driscoll, 1986).

3.0 RESULTS

3.1 Duration of the Test

The pump test took place over a four day span in the middle of November, 1994. Specific times for each phase of the test are given below:

Background Data	26.2 hours	(16:47 11/11/94 to 19:00 11/12/94)
Pump On	37.0 hours	(19:00 11/12/94 to 07:57 11/14/94)
Recovery (pump off)	34.9 hours	(07:57 11/14/94 to 18:52 11/15/94)
Total test time	98.1 hours	(16:47 11/11/94 to 18:52 11/15/94)

- The pumping phase of the aquifer test lasted only 37 hours because the TW2 well had to be retested due to difficulties encountered with an earlier 72-hour test. The data from the first test were unable to be analyzed.

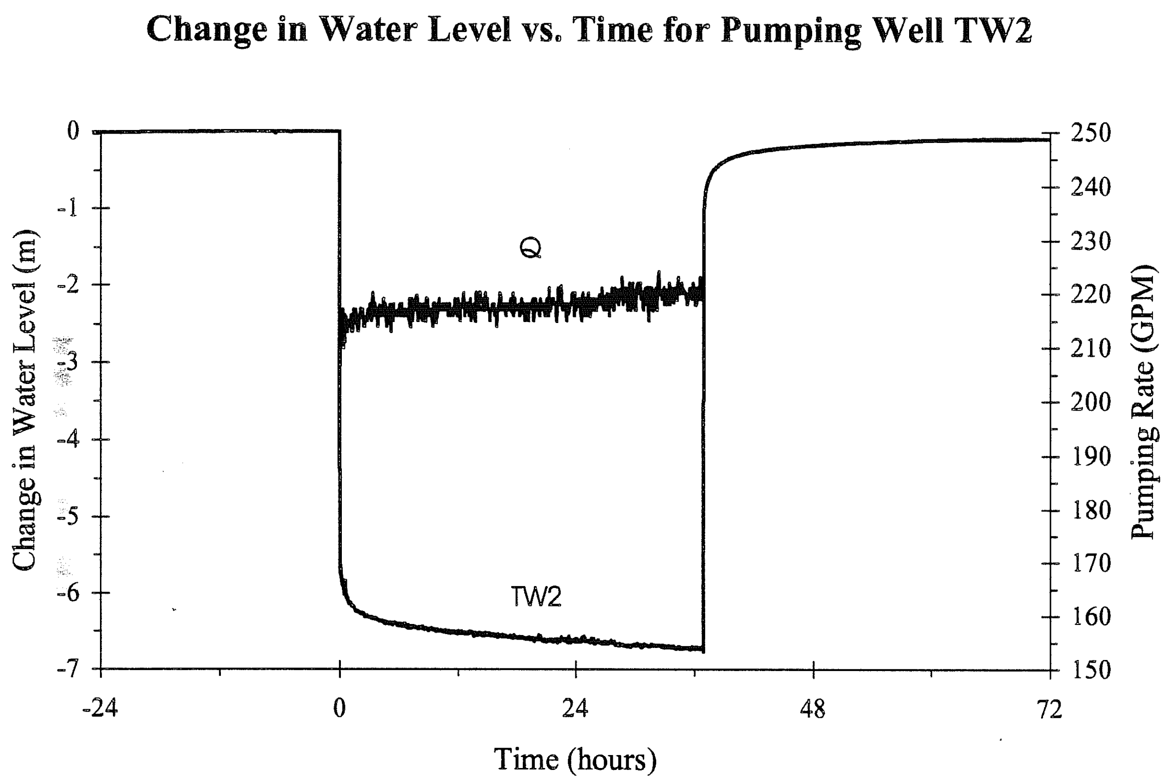

Figure 4. Change in water level vs. time for pumping well TW2.

Well	Barometric Efficiency
TW1	0.80
TW2	0.55
TW3	0.35
CH	0.50

3.3.2 Calculated Aquifer Properties

- A Theis-Jacob curve match for TW2 is shown in **Figure 6**.
- An enlarged portion of the curve match is shown in **Figure 7**.
- Hydraulic conductivity and permeability calculations are based on an effective aquifer thickness of 24.38 meters (80 ft) for the middle zone of the Upper Floridan Aquifer (**Figure 2**).
- A plot of the recovery data obtained during the TW2 test is shown in **Figure 8**. A transmissivity of 789 m2/day (8,494 ft2/day) was calculated from the recovery analysis. The portion of the recovery curve used in the analysis lies between the t/t' values of 10 and 100.

		TW2 (PW)
Storativity		0.0001 (estimated)
Transmissivity	(pumping)	518.3 m2/day (5,580 ft2/day)
	(recovery)	789 m2/day (8,494 ft2/day)
Hydraulic Conductivity		21.3 m/day (70 ft/day)
Permeability		25 darcys

3.3.3 Calculated Skin Factor and Well Efficiency

A pseudo skin factor (does not consider effects of partial penetration) of 7.7 was calculated for the pumping well.

The well efficiency for the TW2 test was calculated by dividing the theoretical drawdown after 24 hours (3.90 m) by the actual drawdown after the same amount of time (6.65 m). This equates to a well efficiency of 59%.

3.3.4 Specific Capacity

A flow rate of 217 gpm resulted in a 6.65 meter (21.81 ft) water level change after 24 hours in well TW2. This equates to a specific capacity of approximately 9.97 gpm/ft.

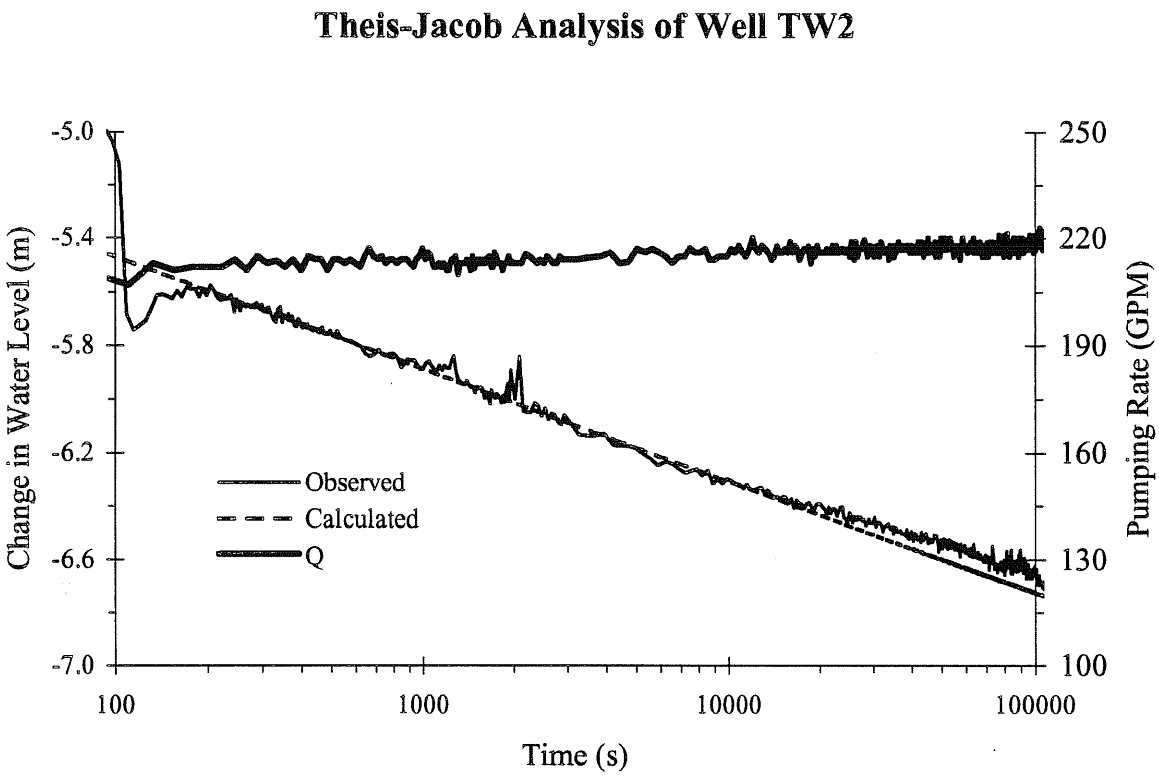

Figure 7. Enlargement of figure 6, showing greater detail of the curve matched portion of the well test data.

4.0 DISCUSSION

4.1 Leakage

Leakage was detected between the upper and middle zones of the Upper Floridan Aquifer. Water level changes in the upper zone of the Upper Floridan Aquifer (**Figure 5**, TW1) can be directly related to pumping of the middle zone of the Floridan. Additionally, the drawdown in the middle zone is less than expected at late pumping times (**Figure 6**). Observation wells screened in adjacent parts of the section, TW3 (lower zone of the Upper Floridan) and the core hole, exhibited no water level changes during pumping of the upper zone of the Upper Floridan. The relationship of changing water levels to changing flow rates for all observation wells is shown in **Figure 5**.

4.2 Comments

- In a subsequent report, data from the test will be numerically modeled using MODFLOW (USGS) to determine a vertical hydraulic conductivity for the leaky confining unit within the Upper Floridan Aquifer.

- Tidal effects on water levels (earth tides) were detected with the high resolution transducers. A small "wave" of approximately 0.01 to 0.05 m is seen in water level data for all wells (**Figure 5**).

- Unfortunately, there was no observation well screened in the same zone as the pumping well and aquifer storativity had to be estimated.

- The recovery data analysis produced a value for the transmissivity of the middle zone of the Upper Floridan that was approximately 52% higher than the pumping data analysis. A possible explanation for this difference is that when the pump was shut down at the end of the pumping phase of the test, the water remaining in the vertical piping to the surface was instanteously reintroduced into the well. This effect produced an artificial recharge event, distorting the recovery of the well. For this reason, the transmissivity obtained from the pumping analysis is considered more valid.

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ABSTRACT

As part of the USGS Trans-River Project, the Department of Earth Sciences at Clemson University conducts pump tests at selected localities in South Carolina and Georgia near or on the United States Department of Energy's Savannah River Site (U. S. DOE/SRS). The test at Millhaven, located in Screven County, Georgia, was conducted from November 3 through 11, 1994 using the USGS's TW3 well as the pumping well and three other wells from the cluster (TW2, TW4, and the core hole) as observation wells. The pumping well (TW3) is completed as an open hole in the limestone of the lower part of the Upper Floridan Aquifer. Since none of the monitoring wells were screened over the same hydrogeologic interval as the pumping well, a storativity of 0.0001 was estimated from Hodges (1994, written communication) and historical data of the region. A transmissivity of 121 m2/day (1,302 ft2/day) was calculated from TW3 data. The 30.48 meter thickness of the lower zone of the Upper Floridan at Millhaven yields a hydraulic conductivity of 3.96 m/day (13 ft/day) from the TW3 data. The specific capacity of the well was 4.14 gpm/ft. Other observation wells screened in adjacent zones (TW2 in the middle zone of the Upper Floridan, TW4 in the lower Dublin, and the core hole in the Meyers Branch Confining Unit) were monitored to detect vertical leakage across confining layers. No water level changes directly related to pumping were observed in any of the observation wells, indicating no detectable leakage to the lower zone of the Upper Floridan Aquifer at a flow rate of 207.5 gpm.

1.0 INTRODUCTION

The format of this report is modified from Clarke (U. S. Geological Survey, written communication, 1993).

1.1 Purpose of the Millhaven Aquifer Performance Tests

The United States Geological Survey (USGS) is creating a model to predict the rate and direction of groundwater flow in the vicinity of the United States Department of Energy's Savannah River Site (U. S. DOE/SRS). The model will incorporate the hydraulic properties determined from aquifer performance tests at Millhaven. This is part of an overall effort to investigate the possibility of groundwater flow and contaminant migration beneath the Savannah River from SRS in South Carolina to Georgia (Trans-River Project).

The USGS is continuing to drill well clusters in Georgia where aquifer performance tests (pump tests) will be conducted by the faculty and students of the Department of Earth Sciences at Clemson University. The data will be analyzed to estimate hydraulic properties of aquifers and confining units on the Georgia side of the Savannah River. The hydraulic property information available to the model on the South Carolina side of the Savannah River consists of data published by Siple (1967), South Carolina Water Resources Commission (SCWRC) reports (Logan, 1987; Logan and Euler, 1989), unpublished SRS reports, and ongoing research by Clemson University Hydrogeology faculty and graduate students. The Georgia side of the river has been studied by Brooks and others (1985), Clarke and others (1985) and Faye and McFadden (1986); however, the volume of data is not as extensive as the South Carolina side for the region, and thus, new well sites such as Millhaven must be completed and tested in order to make the model more comprehensive.

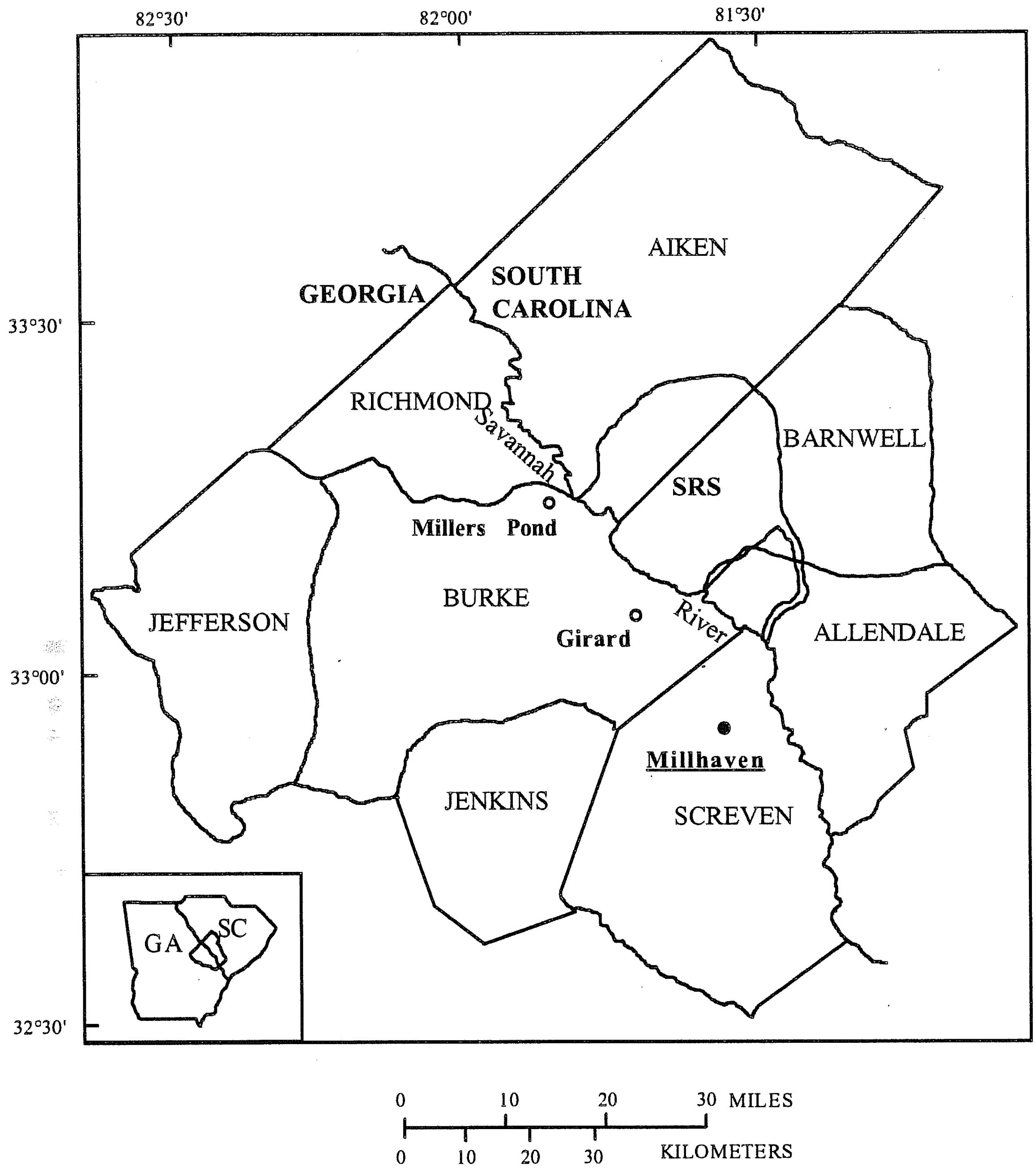

Figure 1. Map showing the location of Millhaven, Screven County, Georgia (Modified from Clarke and others, 1994, in press).

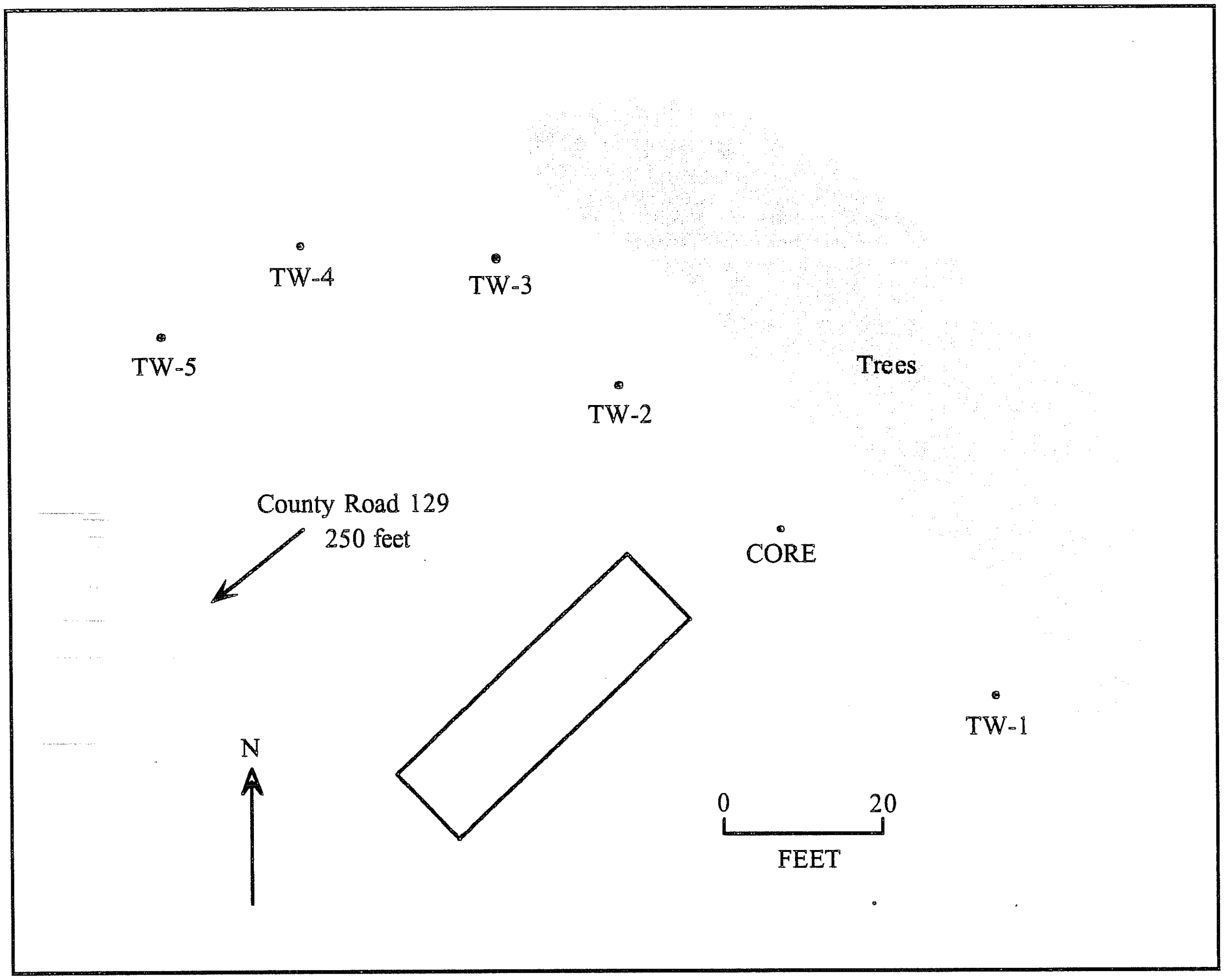

Figure 3. Map showing the location of the wells at Millhaven (Modified from Clarke, written communication, 1995).

2.2.1 Pumping Well Data Acquisition Methods

The pumping well, TW3, is completed in the lower zone of the Upper Floridan from -34.72 to -51.64 m (-113.92 to -169.42 ft) MSL (**Figure 2**). A 25 hp submersible pump was selected and set at a depth of 57.60 m (189 ft). A 200 psi transducer (chamber #4) was positioned approximately 6.46 m (21.20 ft) below the pump in the well.

2.2.2 Observation Well Data Acquisition Methods

There were no observation wells screened in the same aquifer zone (lower zone of the Upper Floridan) as the pumping well. Three other wells screened in adjacent zones were monitored to detect vertical leakage, if present. Well TW2 is screened in the middle zone of the Upper Floridan from -13.37 to -28.61 m (-43.87 to -93.87 ft) MSL, and TW4 is screened in the lower Dublin from -227.39 to -242.63 m (-746.07 to -796.07 ft) MSL. The core hole is cased from the surface to a depth of 573 ft, below which no steps were taken to maintain an open hole. The relative screen positions are shown in **Figure 2**. The transducers for well TW2, TW4, and the core hole were placed at 2.83 m (9.29 ft), 11.48 m (37.67 ft), and 2.77 m (9.10 ft) below the water table in each respective well.

well	transducer #	transducer psi rating
TW2	2	45
TW3	4	200
TW4	1	45
CH	3	45

2.3 Analysis Methods

The initial analysis step is to correct the raw pressure data from the wells for changes in atmospheric pressure. These variations can mask the small response of an aquifer in an observation well. Removal of atmospheric pressure changes makes it easier to detect water level changes that result from pumping.

Barometric corrections are made by subtracting atmospheric pressure changes muliplied by the Barometric Efficiency (BE). The BE of an aquifer is the ratio of the change in hydraulic head in an aquifer (due to atmospheric changes) to the actual change in atmospheric pressure. A BE of 1 indicates that 100% of the atmospheric pressure changes have been transmitted to the aquifer. A BE of 0 would indicate that none of the atmospheric pressure changes have been transmitted to the aquifer.

2.3.1 Observation Well Analysis Method

Data from an observation well screened in the same aquifer as the pumping well can be analyzed to calculate the storativity and transmissivity of the aquifer. The wells at Millhaven were screened in adjacent aquifer zones, therby not allowing observation well analysis for transmissivity and storativity. The observation wells screened in adjacent hydrologic units qualitatively detect leakage, if present, by water level changes that result from pumping.

2.3.2 Pumping Well Analysis Method

Data from the pumping well is governed by three variables: the transmissivity and storativity of the aquifer, and the skin factor of the pumping well. If one of the three variables is known or can be estimated, the other two can be calculated. The skin factor of the pumping well is unknown and could be highly variable, depending on well installation. The storativity of the aquifer is less sensitive than the

The change in water level vs. time plot for TW3 (**figure 4**) is a good graphical representation of the flow history of the test.

3.2.2 Water Level Readings

During the test, 2467 water level data points were recorded in the pumping and monitoring wells by the Clemson system. Data points were recorded as frequently as every 5 seconds at times of rapidly changing water levels, decreasing to every 5 minutes when water level changes were relatively small. **Figures 4** and **5** show plots of change in water level vs. time for the pumping and observation wells, respectively.

The background data for the TW3 test was studied for possible water level trends or fluctuations which may have affected the drawdown data during the pumping phase of the test. The pumping well showed no noticeable trend. The observation well plots, however, showed distinct trends over the duration of the test. The TW2 and TW4 wells exhibited a downward trend unrelated to pumping during the TW3 test. The core hole showed an upward trend, but the depth of the monitored interval makes it difficult to determine whether this phenomenon is caused by a recharge event or by some sort of interaquifer communication beneath the Meyer's Branch.

3.2.3 Maximum Water Level Change (meters) During the Test

A drawdown of about 15.91 meters (52.19 ft) was observed in TW3 during the 53.6 hour pumping period. The observation wells used for the test, TW2 (middle zone of the Upper Floridan), TW4 (lower Dublin), and the core hole (Meyers Branch), showed no water level changes related to pumping well TW3.

- Static water levels were measured by USGS personnel prior to Clemson's pumping tests.

well	hydrogeologic screened zone	static WL	WL change
TW2	middle part of the Floridan	4.61 m	0.08 m
TW3	lower part of the Floridan	4.42 m	15.91 m
TW4	lower part of the Dublin	-12.35 m*	0.00 m
Core hole	Meyers Branch Confining	-2.78 m*	0.00 m

* Denotes artesian head above land surface

3.3 Data Analysis Results

3.3.1 Barometric Corrections

Water level pressure data was corrected for the variations in atmospheric pressure by subtracting atmospheric pressure changes multiplied by the barometric efficiency. Pressure data from the pumping well and monitor wells were corrected for atmospheric pressure changes using the following barometric efficiencies.

Well	Barometric Efficiency
TW2	0.65
TW3	0.35
TW4	0.60
CH	0.65

Change in Water Level vs Time for TW3 Observation Wells

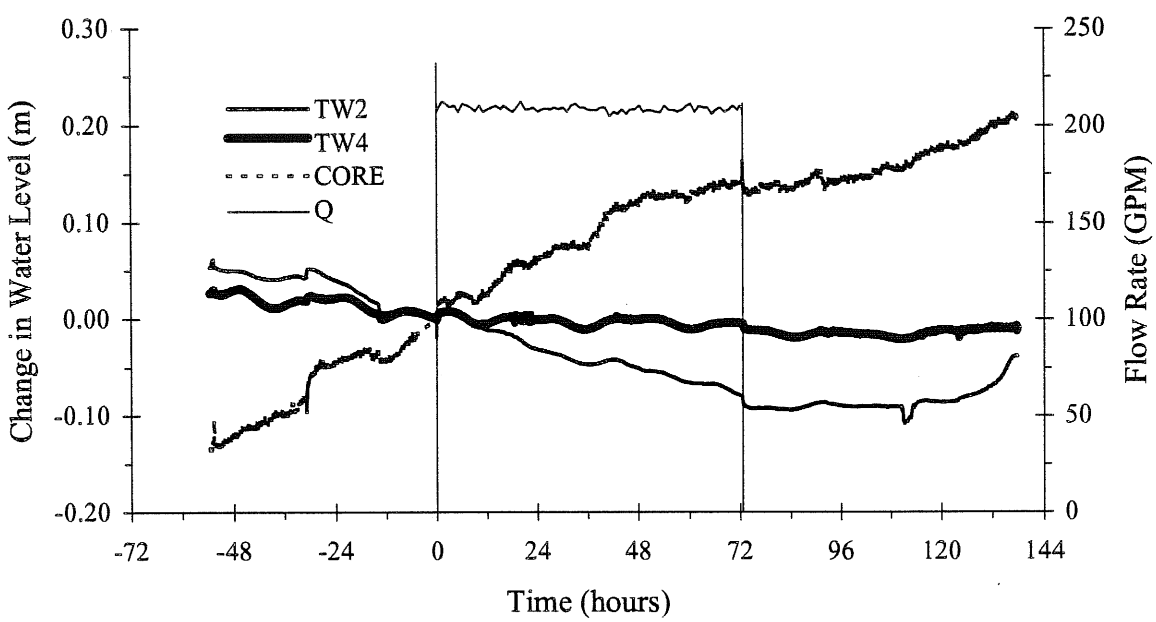

Figure 5. Change in water level for TW3 observation wells (TW2, TW4, and the core hole).

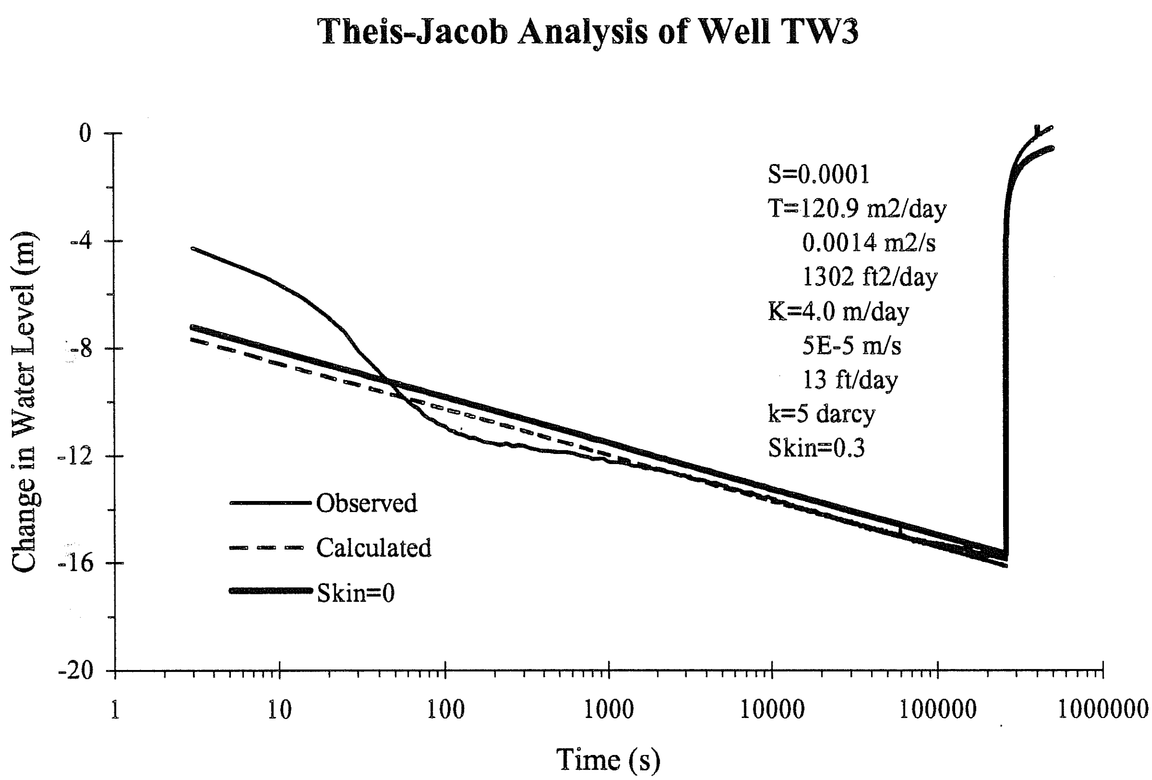

Figure 6. Theis-Jacob analysis (curve match) for well TW3.

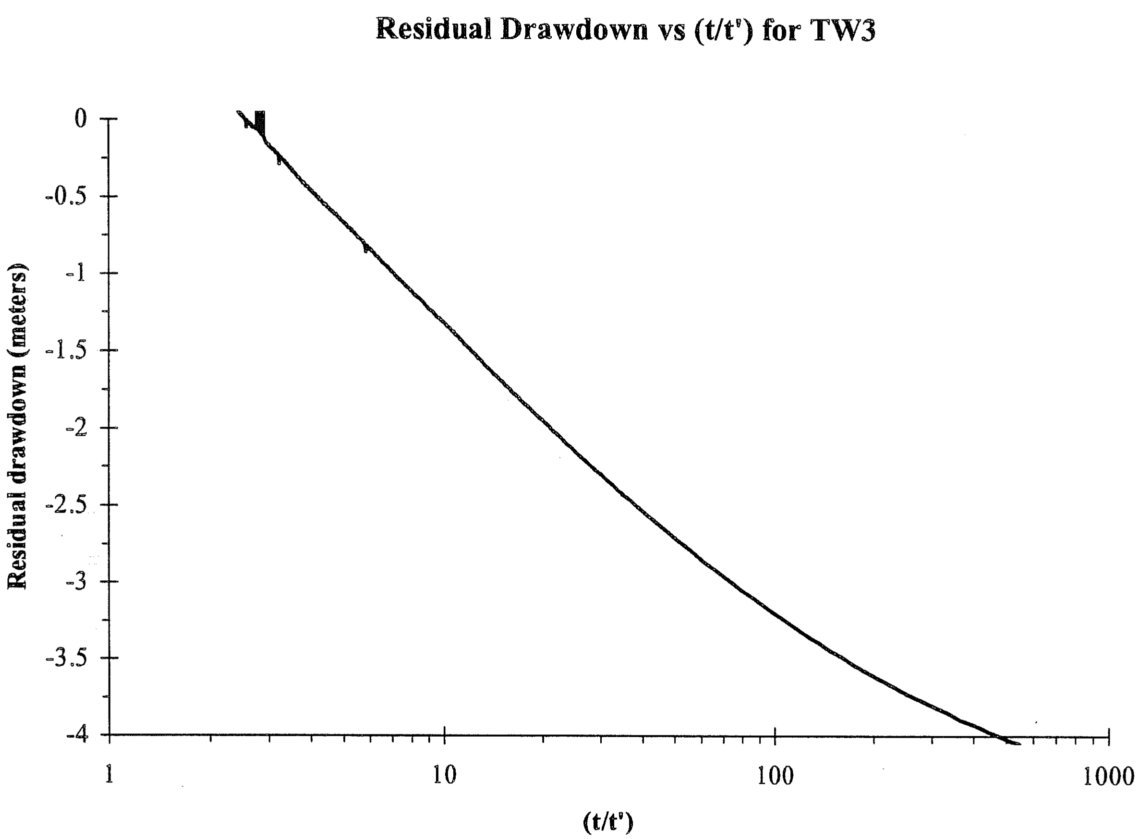

Figure 8. Recovery data plot for the TW3 test. The portion of the recovery curve used to compute the transmissivity of the aquifer lies between the t/t' values of 10 and 100.

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ACKNOWLEDGMENTS

The authors thank John Clarke (USGS) for reviewing this report and making suggestions for its improvement. We are, however, responsible for any mistakes contained in this document.

1.2 Site Conditions

1.2.1 Location

The Millhaven site is located in the north-central portion of Screven County, Georgia, approximately 4.75 miles (7.6 km) west of the Savannah River (**Figure 1**).

1.2.2 Hydrogeologic Setting

The Millhaven well cluster is drilled into Coastal Plain sediments ranging in age from Late Cretaceous to late Eocene. The sediments, interbedded sands, shales, and carbonates, were deposited over Paleozoic crystallines and Triassic red beds exposed by Late Cretaceous erosion. Regional dip is to the southeast and decreases upward from 48 ft/mi (9m/km) at the base of the section to 15 ft/mi (3 m/km) at the top of the middle Eocene beds (Snipes and others, 1993). At Millhaven, the thickness of the sediments is at least 1450 ft (442 m). The hydrostratigraphy of the site is comprised of the Midville, Dublin, Miller's Pond, and Upper Floridan aquifers, the Appleton Confining Unit, and the Meyers Branch and Allendale Confining Systems. The major aquifer systems and confining units are shown in **Figure 2**.

1.2.3 Description of Wells Used for the Test

The TW4 well was used as the pumping well. Three other wells at the site (TW3, TW5, and the core hole) were used as observation wells for the test. **Figure 2** relates the wells to the subsurface hydrogeology of the site. **Figure 3** is a simplified site map showing the location of wells used for the test. The construction specifications of each well are given below:

Pumping Well (TW4):	Coordinates =	Latitude	32°53'25"
		Longitude	81°35'43"
	Elevation (ground) =	33.81 m (110.93 ft) MSL	
	Elevation (TOC) =	34.42 m (112.93 ft) MSL	

Total Depth (from ground):	277.96 m (912 ft)
Effective Well Depth (from ground):	276.44 m (907 ft)
Construction Date:	01 September 1993
Depth Screened Interval:	261.20 to 276.44 m (857 to 907 ft)
Elevation Total Depth:	-244.15 m (-801.07 ft) MSL
Elevation Effective Well Depth:	-242.63 m (-796.07 ft) MSL
Elevation Screened Interval:	-227.39 to -242.63 m (-746.07 to -796.07 ft) MSL
Diameter (casing):	0.152 m (6") from 0 to 277.96 m (0 to 912')
Screened Geologic Unit:	Black Creek Group
Screened Hydrogeologic Unit:	Dublin (lower zone)
Depth Static Water Level:	-12.35 m (-40.51 ft) on 09/21/93*

* A negative value for water level indicates artesian head above the ground surface

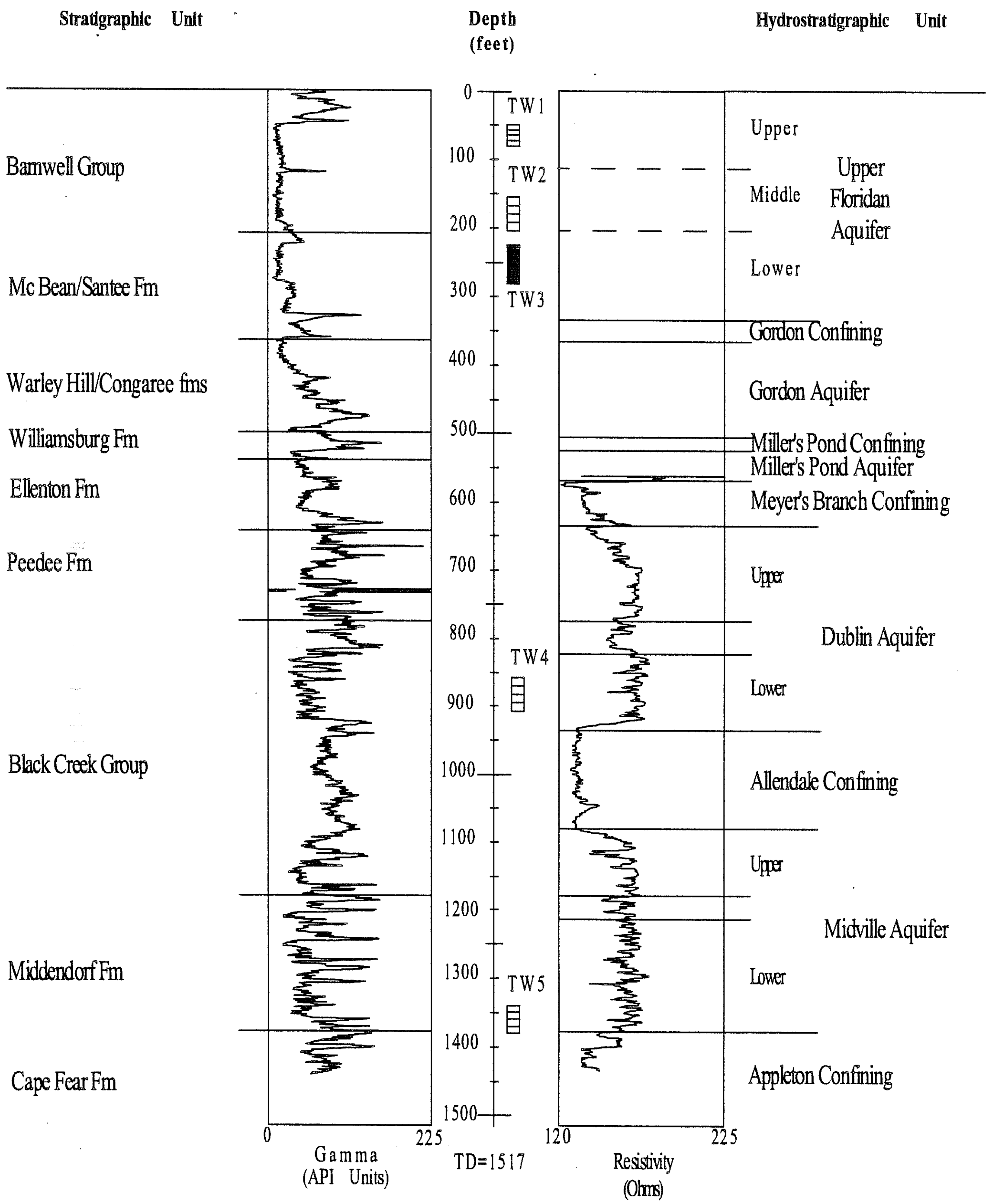

Figure 2. Hydrostratigraphy of the Millhaven site. Locations of well screens and open hole sections are shown.

Observation Well (TW3):	Elevation (ground) =	33.86 m (111.08 ft) MSL
	Elevation (TOC) =	34.42 m (112.92 ft) MSL

Effective Depth:	85.49 m (280.5 ft)
Elevation Open Interval:	-34.72 to -51.64 m (-113.92 to -169.42 ft) MSL
Diameter (casing):	0.152 m (6") from 0 to 68.58 m (0 to 225 ft)
Screened Geologic Unit:	McBean/Santee
Screened Hydrogeologic Unit:	Upper Floridan (lower zone)
Distance from Pumping Well:	13.15 m (43.13 ft)

Observation Well (TW5):	Elevation (ground) =	33.53 m (110 ft) MSL
	Elevation (TOC) =	33.83 m (111 ft) MSL

Effective Depth:	420.60 m (1380 ft)
Elevation Screened Interval:	-374.89 to -387.08 m (-1230 to -1270 ft) MSL
Diameter (casing):	0.152 m (6") from 0 to 393.17 m (0 to 1290 ft)
	0.102 m (4") from 393.17 to 425.18 (1290 to 1395 ft)
Screened Geologic Unit:	Middendorf
Screened Hydrogeologic Unit:	Midville (lower zone)/Appleton Confining Unit
Distance from Pumping Well:	6.48 m (21.25 ft)

2.0 METHODS

2.1 Test Logistics

Ideally, a pump test is composed of three periods of data collection: background, pumping, and recovery. Background data is used to determine if the aquifer is in an equilibrium condition and the extent to which it is being affected by inconsistent external forces. It is also used to determine the barometric efficiency of the monitored aquifers so test data can be corrected for changes in atmospheric pressure. The aquifer is then pumped, creating a pressure drawdown cone extending radially from the pumping well. After pumping stops, the aquifer is allowed to recover to pre-test conditions.

Each of the Millhaven aquifer tests was originally scheduled to be conducted over a period of seven days. Clemson University Earth Sciences Department personnel transported the SCUREF Data Acquisition Facility to each well site and set up equipment to monitor the well during the pump test. During this test, background data were collected for 64.3 hours, followed by 72.0 hours of pumping and 51.1 hours of recovery data.

2.2 Data Acquisition Methods

Water level readings are recorded as pressure changes in meters of water relative to an initial equilibrium static water level condition. For the duration of a pump test (background through recovery), quartz crystal transducers monitor and record water level changes in the pumping well and observation wells. Relative water level changes are recorded automatically on the computer data acquisition system at operator specified intervals ranging from 5 seconds to 5 minutes throughout the test. An additional transducer monitors and records changes in atmospheric pressure which are removed from the well data prior to aquifer parameter analysis. The transducers are calibrated to a maximum of 0.005% of full scale (1.5 mm for a 45 psi transducer) for repeatability and hysteresisThe resolution of a 45 psi transducer is normally about 0.2 mm.

transmissivity and is estimated as the storativity calculated from a nearby observation well. Since there was no observation well screened in the same hydrogeologic unit for this test, a value for storativity was estimated as 0.0001 (Hodges, written communication, 1994). Curve matching of drawdown data yields a transmissivity value for the aquifer and a skin factor for TW4 using superposition of the Theis solution (1935) or Jacob straight-line method (Cooper and Jacob, 1946) for variable flow rates modified for the skin factor analysis of Van Everdingen (1953) for confined aquifers with fully penetrating wells. Once a value for the transmissivity had been obtained, the hydraulic conductivity of the aquifer may be determined by dividing the value for transmissivity by the aquifer thickness. The hydraulic conductivity is then multiplied by 104,000 m/s to obtain the permeability of the aquifer media in darcys (Freeze and Cherry, 1979).

The aquifer test data were entered into a Microsoft Excel spreadsheet designed to graphically estimate the aquifer transmissivity and skin factor for the well, using the modified Theis solution of van Everdingen (1953). The values for transmissivity and skin factor were iteratively changed until the slope and position of the theoretical drawdown plot matched a plot generated from the actual data collected from the test. The hydraulic characteristics for the aquifer were then taken directly from the spreadsheet. The validity of the spreadsheet used to generate these values was verified by Moore (1994).

2.3.3 Recovery Data Analysis Methods

Changes in water level recorded during the recovery period of an aquifer test may be used to determine the transmissivity and storativity values for the aquifer. Since no wells were screened in the same interval as the pumping well at Millhaven, only a transmissivity value may be calculated from the recovery data. The transmissivity is determined by plotting the residual drawdown (the difference between the static water level and the amount of recovery since shutting the pump downj) against the logarithm of the ratio (t/t'), where t is the time since pumping began and t' is the time since pumping stopped. The transmissivity is calculated by using the Jacob equation: $T=0.183Q/ds'$, where Q is the pumping rate (m3/day) and *d*s' is the slope of a "best-fit" straight line drawn between two consecutive logarithmic cycles on the s' vs. t/t' plot. The values obtained from this analysis may then be compared to the pumping phase analysis. Theoretically, the drawdown and recovery analyses should be identical if the aquifer conditions conform to the basic assumptions of the Theis (1935) equation (Driscoll, 1986).

3.0 RESULTS

3.1 Duration of the Test

The pump test took place over a nine day span in early December, 1994. Specific times for each phase of the test are given below:

Background Data	64.3 hours	(16:42 11/30/94 to 08:59 12/03/94)
Pump On	72.0 hours	(08:59 12/03/94 to 09:00 12/06/94)
Recovery (pump off)	51.1 hours	(09:00 12/06/94 to 12:08 12/08/94)
Total test time	187.4 hours	(16:42 11/30/94 to 12:08 12/08/94)

3.2 Data Acquisition Results

3.2.1 Pumping Rates

A time-weighted average of flow rate measurements was determined based on values obtained from an Omega digital flow meter. The average flow rate for the TW4 test was 76 gpm.

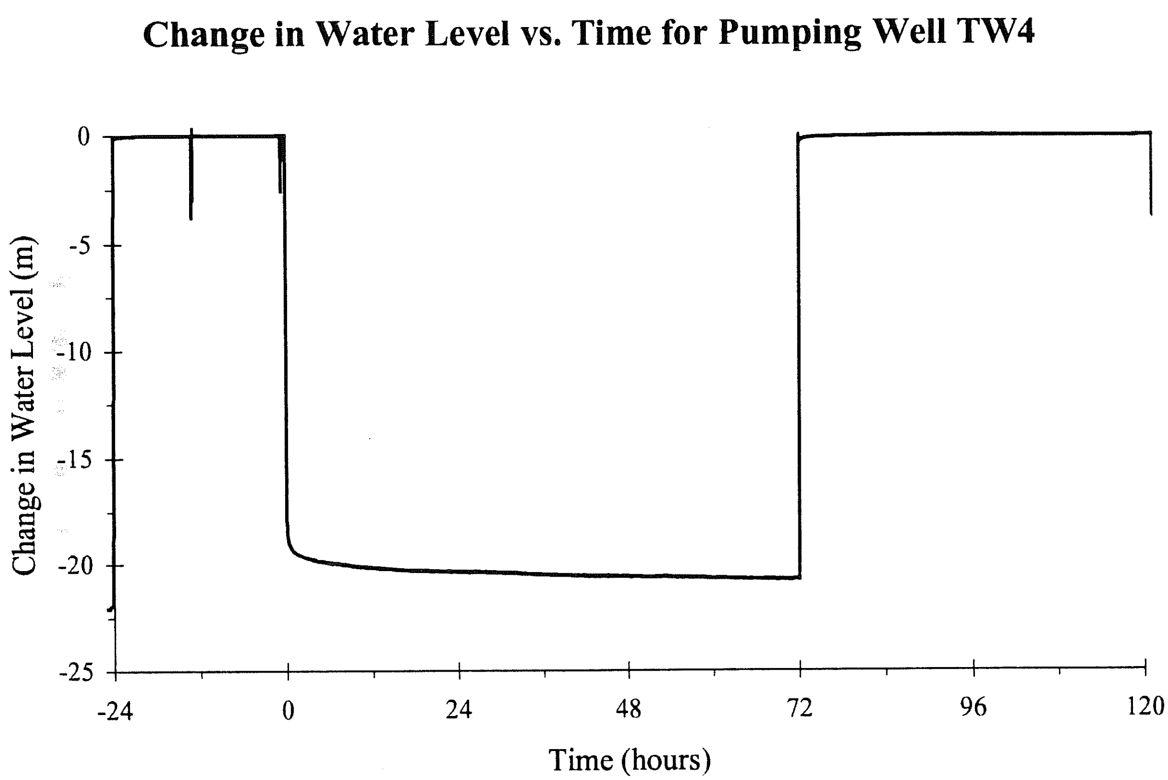

Figure 4. Change in water level vs. time for pumping well TW4 showing the pumping rate for the duration of the test. A time weighted average of 76 gpm was estimated for the test.

3.3.2 Calculated Aquifer Properties

- A Theis-Jacob curve match for TW4 is shown in **Figure 6**.
- An enlarged portion of the curve match is shown in **Figure 7**.
- Hydraulic conductivity and permeability calculations are based on an effective aquifer thickness of 35.05 meters (115 ft) for the lower Dublin Aquifer (**Figure 2**).
- A plot of the recovery data obtained during the TW4 test is shown in **Figure 8**. A transmissivity of 653 m2/day (7,030 ft2/day) was calculated from the recovery analysis. The portion of the recovery curve used in the analysis lies between the t/t' values of 10 and 100.

		TW4 (PW)
Storativity		0.0001 (estimated)
Transmissivity	(pumping)	103.7 m2/day (1,116 ft2/day)
	(recovery)	653 m2/day (7,030 ft2/day)
Hydraulic Conductivity		3.05 m/s (10 ft/day)
Permeability		3 darcys

3.3.3 Calculated Skin Factor and Well Efficiency

A pseudo skin factor (does not consider effects of partial penetration) of 22.15 was calculated for the pumping well.

The well efficiency for the TW4 test was calculated by dividing the theoretical drawdown after 24 hours (6.30 m) by the actual drawdown after the same amount of time (20.37 m). This equates to a well efficiency of 31%.

3.3.4 Specific Capacity

A flow rate of 76 gpm resulted in a 20.37 meter (66.85 ft) water level change after 24 hours in well TW4. This equates to a specific capacity of approximately 1.14 gpm/ft.

4.0 DISCUSSION

4.1 Leakage

Observation wells screened in adjacent portions of the section, TW3 (lower zone of the Upper Floridan), TW5 (Midville/Appleton) and the core hole (Meyers Branch), exhibited no water level changes during the pumping of the lower Dublin. The relationship of changing water levels to changing flow rates for all observation wells is shown in **Figure 5**.

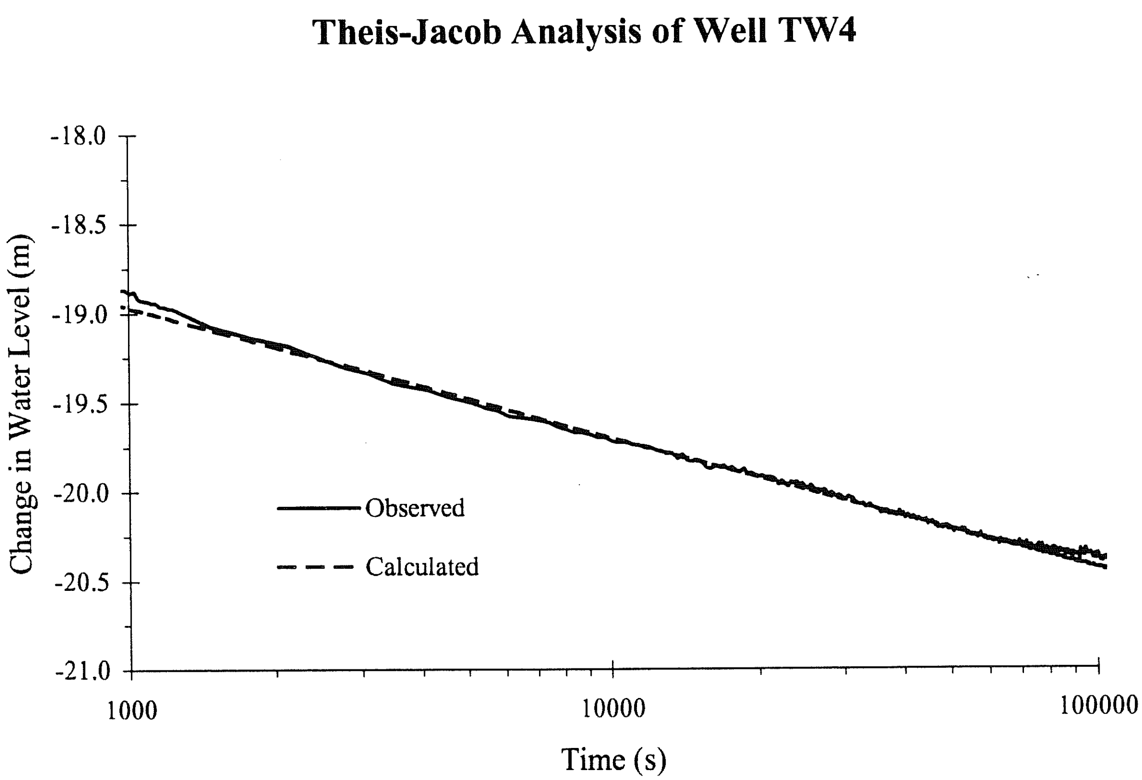

Figure 7. Enlargement of figure 6, showing greater detail of the curve matched portion of the well test data. The flow history of the test is shown for reference.

4.2 Comments

- Tidal effects on water levels (earth tides) were detected with the high resolution transducers. A small "wave" of approximately 0.01 to 0.05 m is seen in water level data for all wells (**Figure 5**).

- Unfortunately, there was no observation well screened in the same zone as the pumping well and aquifer storativity had to be estimated.

- The Omega flow meter connection to the computer data acquisition system was disrupted during the early portion of the aquifer test. In order to protect the test data from further disturbance by electrical surges, flow measurements were taken manually from the flow meter.

- The recovery data analysis produced a value for the transmissivity of the lower Dublin that was approximately 530% higher than the pumping data analysis. A possible explanation for this difference is that when the pump was shut down at the end of the pumping phase of the test, the water remaining in the vertical piping to the surface was instanteously reintroduced into the well. This effect produced an artificial recharge event, distorting the recovery of the well. For this reason, the transmissivity obtained from the pumping analysis is considered more valid.

The Girard Tests

AQUIFER PERFORMANCE TEST REPORT

Girard Dublin Well (TW2), Burke County, Georgia

December 27, 1994 - January 4, 1995

Prepared by

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and

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April 21, 1995

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Funds for this investigation were provided in part by SCUREF TASK ORDER #94 (Van Price, Jr., WSRC, Subcontract Technical Representative) and SCUREF TASK ORDER #29-94 (Thomas Temples, U. S. DOE, Technical Representative)

ACKNOWLEDGMENTS

Funding for this project was provided through SCUREF Task Order #94 and SCUREF Task Order #29-94. John Clarke (USGS) and Van Price, Jr. (WSRC) coordinated logistical arrangements with Clemson University Earth Sciences Department Personnel to conduct the Girard aquifer performance tests.

Resources Commission (SCWRC) reports (Logan, 1987; Logan and Euler, 1989), unpublished SRS reports, and ongoing research by Clemson University Hydrogeology faculty and graduate students. The Georgia side of the river has been studied by Brooks and others (1985), Clarke and others (1985) and Faye and McFadden (1986); however, the volume of data is not as extensive as the South Carolina side for the region, and thus, new well sites such as Girard must be completed and tested in order to make the model more comprehensive.

1.2 Site Conditions

1.2.1 Location

The Girard site is located in the northeastern portion of Burke County, Georgia, approximately 4 miles (6.4 km) west of the Savannah River (**Figure 1**).

1.2.2 Hydrogeologic Setting

The Girard well cluster is drilled into Coastal Plain sediments ranging in age from Late Cretaceous to late Eocene. The sediments, interbedded sands, shales, and carbonates, were deposited over Paleozoic crystallines and Triassic red beds exposed by Late Cretaceous erosion. Regional dip is to the southeast and decreases upward from 50 ft/mi (9.5m/km) at the base of the section to 15 ft/mi (3 m/km) at the top of the middle Eocene beds (Snipes and others, 1993). Based on the field geologic log prepared by W. Fred Falls (USGS), the thickness of the sediments at Girard is approximately 1376 ft (419 m). The hydrostratigraphy of the site is comprised of the Midville and Dublin aquifer systems, Millers Pond Aquifer, the Gordon Aquifer, Upper Three Runs Aquifer, the Appleton Confining Unit, and the Meyers Branch and Allendale Confining Systems. The major aquifer systems and confining units are shown in **Figure 2**.

1.2.3 Description of Wells Used for the Test

The Dublin well (TW2) was used as the pumping well and the Midville well (TW3) served as the observation well for the test. **Figure 2** relates the wells to the subsurface hydrogeology of the site. **Figure 1** is a simplified site map showing the location of wells used for the test. The construction specifications of each well are given below:

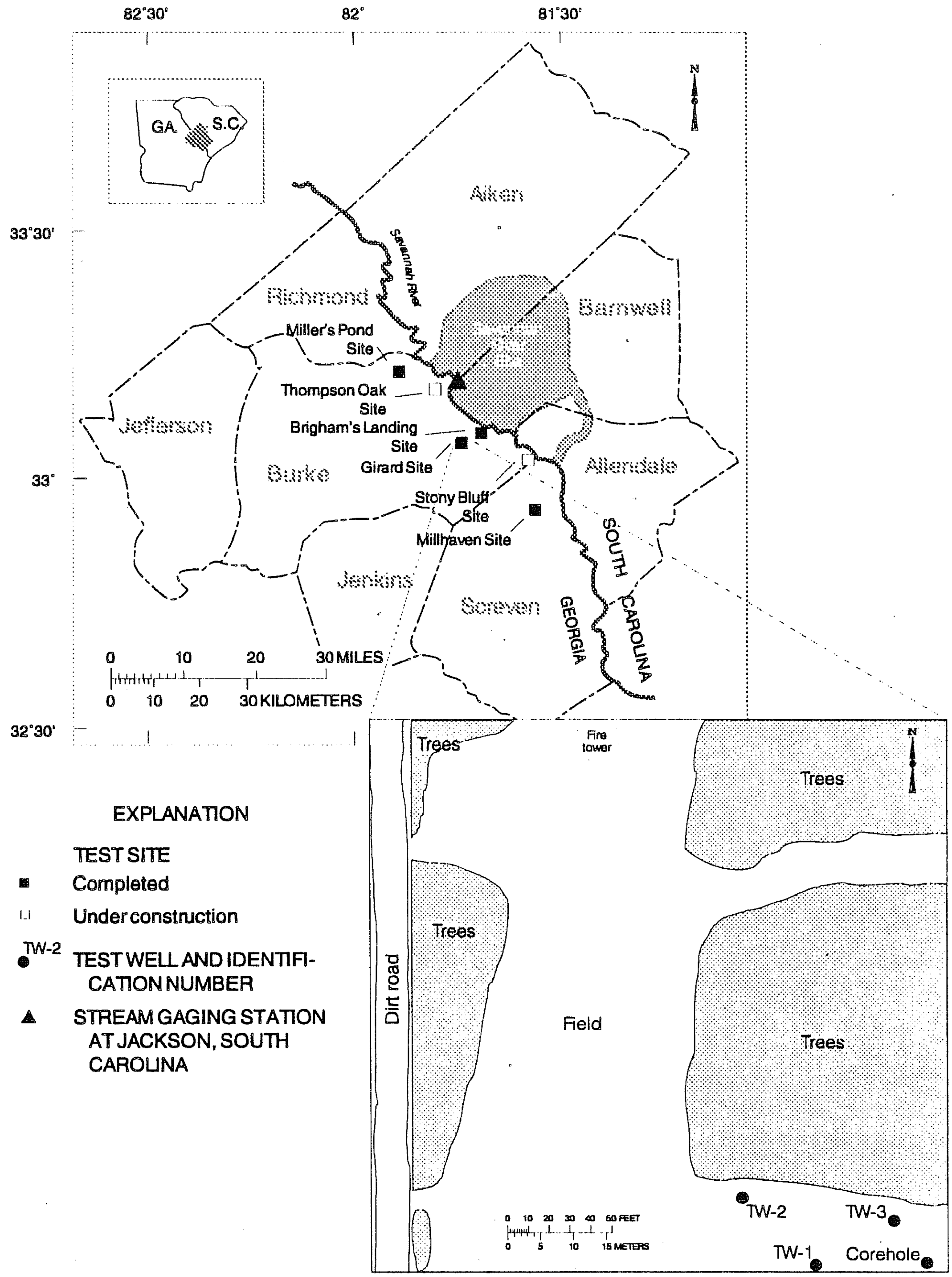

Figure 1. Map showing the location of the Girard site, Burke County, Georgia, and well locations.

2.0 METHODS

2.1 Test Logistics

Ideally, a pump test is composed of three periods of data collection: background, pumping, and recovery. Background data is used to determine if the aquifer is in an equilibrium condition and the extent to which it is being affected by inconsistent external forces. It is also used to determine the barometric efficiency of the monitored aquifers so test data can be corrected for changes in atmospheric pressure. The aquifer is then pumped, creating a pressure drawdown cone extending radially from the pumping well. After pumping stops, the aquifer is allowed to recover to pre-test conditions.

Each of the Girard aquifer tests was originally scheduled to be conducted over a period of seven days. Clemson University Earth Sciences Department personnel transported the SCUREF Data Acquisition Facility to the well site and set up the equipment to monitor the well during the pump test. During this test, background data were collected for 49.5 hours, followed by 72 hours of pumping and 68 hours of recovery data.

2.2 Data Acquisition Methods

Water level readings are recorded as pressure changes in meters of water relative to an initial equilibrium static water level condition. For the duration of a pump test (background through recovery), quartz crystal transducers monitor and record water level changes in the pumping well and observation well. Each transducer is protected in a stainless steel housing measuring 0.07 m (2.75 in); therefore, they cannot be used in less than three-inch diameter wells. Relative water level changes are recorded automatically on the computer data acquisition system at operator specified intervals ranging from 5 seconds to 5 minutes throughout the test. An additional transducer monitors and records changes in atmospheric pressure which are removed from the well data prior to aquifer parameter analysis. The transducers are calibrated to a maximum of 0.005% of full scale (1.5 mm for a 45 psi transducer) for repeatability and hysteresis. The resolution of a 45 psi transducer is normally about 0.2 mm.

2.2.1 Pumping Well Data Acquisition Methods

The pumping well, TW2, is screened in the lower part of the Dublin Aquifer System from -149.0 to -158.2 m (-489 to -519 ft) MSL (**Figure 2**). A 5 hp submersible pump was set at a depth of 51.2 m (168 ft). A 100 psi transducer (chamber #3) was positioned approximately 3.05 m (10 ft) below the pump.

2.3.3 Pumping Well Analysis Method

Data from the pumping well is governed by three variables: the transmissivity and storativity of the aquifer, and the skin factor of the pumping well. If one of the three variables is known or can be estimated, the other two can be calculated. The skin factor of the pumping well is unknown and could be highly variable depending on well installation. The storativity of the aquifer is less sensitive than the transmissivity and is estimated as the storativity calculated from a nearby observation well. Since there were no observation wells screened in the same hydrogeologic unit for this test, a value for storativity was estimated as 0.0001 (Hodges, written communication, 1994). Curve matching of drawdown data yields a transmissivity value for the aquifer and a skin factor for the Dublin well (TW2) using superposition of the Theis solution (1935) or Jacob straight-line method (Cooper and Jacob, 1946) for variable flow rates modified for the skin factor analysis of Van Everdingen (1953) for confined aquifers with fully penetrating wells.

The hydraulic conductivity is determined by dividing the transmissivity by the effective aquifer thickness. Permeability can then be estimated by multiplying the hydraulic conductivity in m/sec by a factor of 104,000 to convert to darcys (Freeze and Cherry, 1979).

The aquifer test data are entered into a Microsoft Excel spreadsheet designed to graphically estimate the aquifer transmissivity and skin factor for the well, using the modified Theis solution of van Everdingen (1953). The values for transmissivity and skin factor are iteratively changed until the slope and position of the theoretical drawdown plot match a plot generated from the actual data collected from the test. The hydraulic characteristics for the aquifer are then taken directly from the spreadsheet. The validity of the spreadsheet used to generate these values was verified by Moore (1994).

2.3.4 Recovery Analysis Methods

Change in water level measurements taken during the recovery period of a pump test can also be analyzed to calculate transmissivity and storativity values. However, since no observation wells were screened in the same zone as the pumping well at the Girard site, only transmissivity values can be calculated from time-recovery data. To determine transmissivity, residual drawdown (the difference between pre-pumping static water level and the amount of recovery after pump off) is plotted against the logarithm of t/t', where t is time since pump started and t' is time since pump stopped. Transmissivity can then be calculated using the following Jacob straight line equation: **T=0.183Q/*ds*'** where Q is the pumping rate (m^3/day) and *d*s' is the slope of the line from the s' vs. t/t' plot taken between two consecutive t/t' logarithmic cycles. The values obtained from analyzing the recovery data can then be compared to the values obtained from time-drawdown analysis. Theoretically, the drawdown and recovery analyses should be identical if the aquifer conditions conform to the basic assumptions of the Theis concept (Driscoll, 1986).

3.2.3 Maximum Water Level Change (meters) During the Test

A drawdown of about 6.7 meters (22 ft) was observed in the Dublin well (TW2) during the 72 hour pumping period. TW2 also showed an decreasing water level trend of approximately 0.13 m (0.43 ft) occuring through all phases of the pump test. This trend was corrected by adding a factor equal to the slope of the trend from the BE corrected drawdown data.

The observation well screened in the lower Midville (TW3) showed no observable drawdown related to pumping during the pump test. A decreasing water level trend of approximately 0.065 m (0.21 ft) appeared in the observation well (TW2) data (**Figure 4**). This trend was not pumping related because it began during background data collection and continued through the recovery portion of the test. The trend was corrected by adding a factor equal to the slope of the trend from the BE corrected data. The TW3 recovery water level data ends at the 94 hour mark in **Figure 4** because the pressure transducer was removed from the well to allow the drillers to continue developing TW3.

The effects of earth tides appear in **Figure 4** as the cyclic 2.0 to 4.0 cm fluctuations from 0 through 94 hours.

- Static water levels were measured from top of casing for the observation well and the pumping well.
- Static water levels were taken on 12/27/94 prior to starting the test.

well	hydrogeologic screened zone	Static WL	WL change
TW2	lower part of the Dublin	92.5 ft (28.2 m)	22.01 ft (6.7 m)
TW3	lower part of the Midville	76.1 ft (23.2 m)	0.00 ft (0.0 m)

3.2.4 Remarks

3.3 Data Analysis Results

3.3.1 Barometric Corrections

Water level pressure data from the pumping well and monitor well were corrected for atmospheric pressure changes using the following barometric efficiencies. The barometric efficiencies were calculated using the method described in section **2.3.1.**

Well	Barometric Efficiency
TW2 - Dublin	0.58
TW3 - Midville	0.55

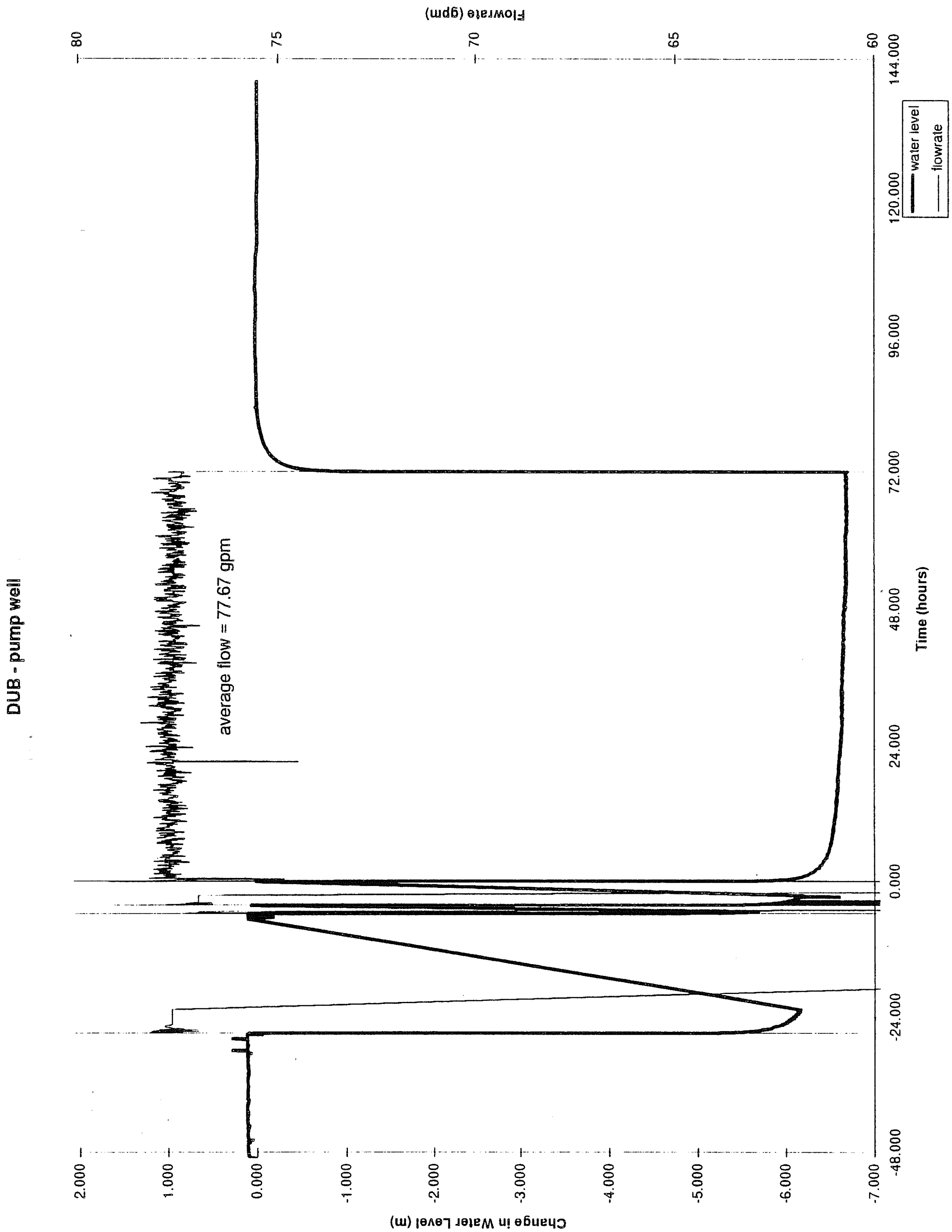

Figure 3. Flowrate & Change in water level vs. time for TW2 Dublin (pumping) well.

4.0 DISCUSSION

4.1 Leakage

No leakage was detected at Girard across the confining layers that separate the Dublin and Midville aquifers.

- TW2 and TW3 are screened in the lower Dublin and lower Midville aquifers respectively, separated by the upper Midville aquifer (**Figure 2**). Pumping the lower Dublin aquifer would not likely cause water level changes in the lower Midville.

- The late time pumping data from the lower Dublin does not suggest leakage across confining layers separating it from the upper Dublin and lower Midville aquifers. (**Figure 5**).

- The difference in static water levels between the lower Dublin and lower Midville (16 ft) suggests no communication between the two zones.

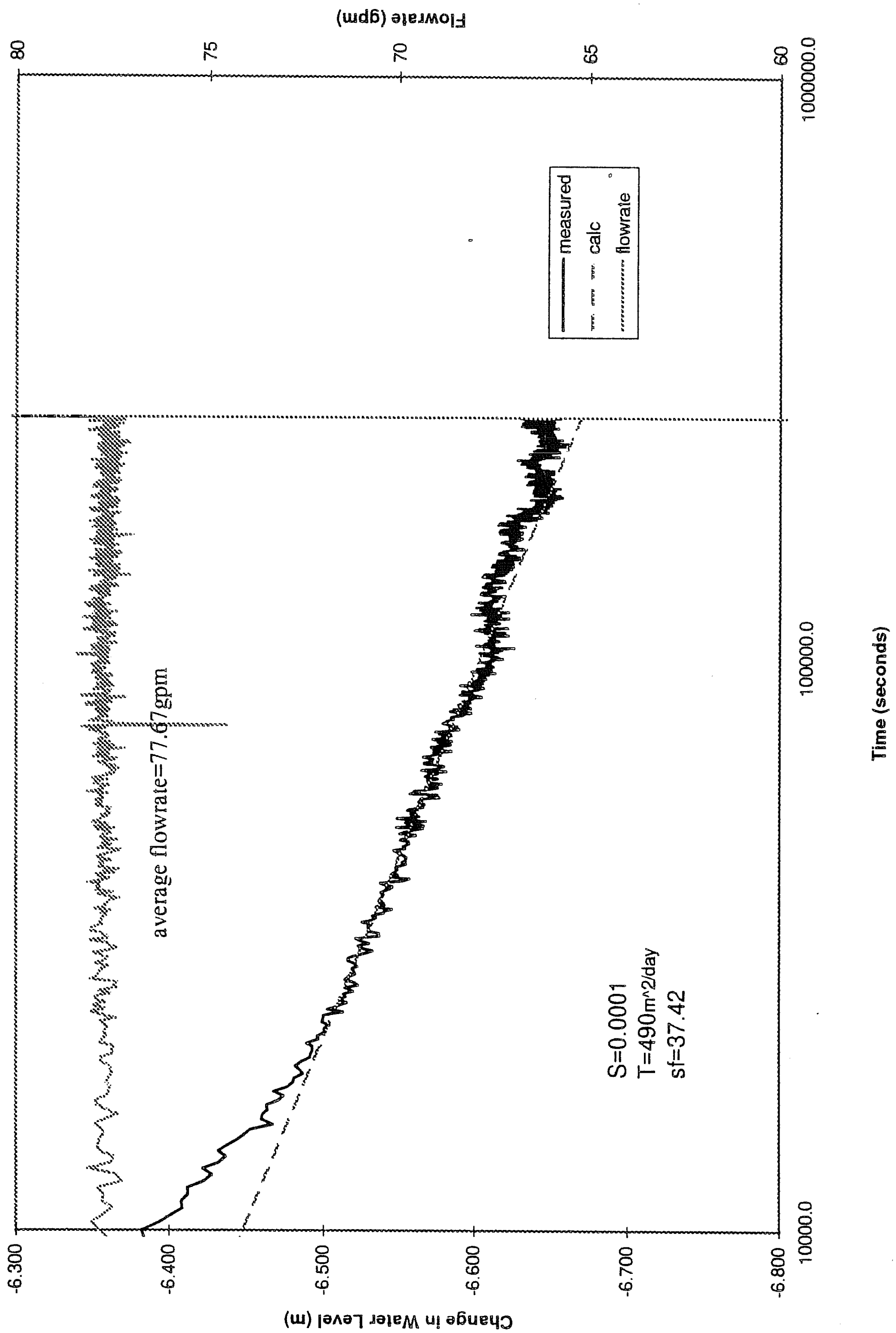

Figure 6. Enlargement of Figure 5, showing greater detail of the curve matched portion of the well test data.

4.2 Comments

- The transducer placed in the observation well: TW3 (Midville), had to be removed during the recovery portion of the TW2 pump test to allow the drillers to develop the well. Prior to the removal of the transducer, no hydraulic connection between the Dublin and Midville aquifer systems was observed at the Girard site.

- A storativity value had to be estimated for this pump test due to the fact that no observation wells were completed in the same aquifer zone as the pumping well.

- Tidal effects on water levels (earth tides) were detected with the high resolution transducers. A small "wave" of approximately 0.01 - 0.04 m is seen in water level data for the observation well (**Figure 4**).

- Well TW1 was not monitored because it is a 2 inch diameter well; the 2.75 inch diameter transducer chamber could not be lowered into the well.

- The Dublin (TW2) recovery analysis for transmissivity does not match the drawdown analysis for transmissivity. One explanation for the difference between the results of drawdown and recovery analysis is that water in the riser pipe during pumping is immediately reinjected to the well at pump-off time. This produces an artificial recharge event and therefore distorts the recovery of the well. For this reason we believe the pumping analysis is more valid.

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ABSTRACT

As part of the USGS Trans-River Project, the Department of Earth Sciences at Clemson University conducts pump tests at selected localities in South Carolina and Georgia near or on the United States Department of Energy's Savannah River Site (U. S. DOE/SRS). The test at Girard, located in eastern Burke County, Georgia, was conducted from January 14 through January 21, 1995 using the USGS's Midville well (TW3) as the pumping well and the Dublin well (TW2) as the single observation well. The pumping well, TW3, is screened in the lower Midville aquifer. Since none of the monitoring wells were screened over the same hydrogeologic interval as the pumping well, a storativity of 0.0001 was estimated from Hodges (1994, written communication) and historical data of the region. A transmissivity of 105.4 m^2/day (1134.5 ft^2/day) was calculated from the Midville pump test data. The 39.6 meter (130 ft) effective aquifer thickness of the lower Midville at Girard yields a hydraulic conductivity of 2.7 m/day (8.9 ft/day) from the Midville pump test data. The effective aquifer thickness of the lower Midville was determined by subtracting the combined thicnesses of the major shale breaks from the entire thickness of the lower Midville aquifer on the gamma ray log. The specific capacity of the well was 1.85 gpm/ft. The Dublin observation well (TW2) was monitored to detect vertical leakage across confining layers. No water level changes directly related to pumping were observed in TW2, indicating no leakage across the confining unit separating the Dublin and Midville aquifers at an average flow rate of 76.5 gpm (0.29 m^3/min.).

1.0 INTRODUCTION

The format of this report is modified from Clarke (U. S. Geological Survey, written communication, 1993).

1.1 Purpose of the Girard Aquifer Performance Tests

The United States Geological Survey (USGS) is creating a model to predict the rate and direction of groundwater flow in the vicinity of the United States Department of Energy's Savannah River Site (U. S. DOE/SRS). The model will incorporate the hydraulic properties determined from aquifer performance tests at the Girard site. This is part of an overall effort to investigate the possibility of groundwater flow and contaminant migration beneath the Savannah River from SRS in South Carolina to Georgia (Trans-River Project).

The USGS is continuing to drill well clusters in Georgia where aquifer performance tests (pump tests) will be conducted by the faculty and students of the Department of Earth Sciences at Clemson University. The data will be analyzed to estimate hydraulic properties of aquifers and confining units on the Georgia side of the Savannah River. The hydraulic property information available to the model on the South Carolina side of

Pumping Well (TW3 - Midville):	Coordinates =	Latitude	33°13'48"
		Longitude	81°52'44"
	Elevation (ground) =	77.4 m (254 ft) MSL	
	Elevation (TOC) =	(not available)	

Construction Date:	not available
Total Depth (from ground):	358.1 m (1,175 ft)
Elevation Total Depth:	-280.7 m (-921 ft) MSL
Effective Well Depth (from ground):	341.99 m (1,122 ft)
Elevation Effective Well Depth:	-264.6 m (-868 ft) MSL
Depth Screened Interval:	326.1 to 342.0 m (1,070 to 1,122 ft)
Elevation Screened Interval:	-248.7 to -264.6 m (-816 to -868 ft) MSL
Diameter (casing):	0.152 m (6") from 0 to 304.8 m (0 to 1,000 ft) 0.102 m (4") from 304.8 to 348.60 m (1,000 to 1,143.7 ft)
Screened Geologic Unit:	Middendorf
Screened Hydrogeologic Unit:	Midville (lower zone)
Depth Static Water Level:	23.20 m (76.10 ft) on 12/27/94

Observation Well (TW2 - Dublin):	Elevation (ground) =	77.4 m (254 ft) MSL
	Elevation (TOC) =	(not available)

Construction Date:	not available
Total Depth (from ground):	238.96 m (784 ft)
Elevation Total Depth:	-161.5 m (-530 ft) MSL
Effective Well Depth (from ground):	235.61 m (773 ft)
Elevation Effective Well Depth:	-158.2 m (-519 ft) MSL
Depth Screened Interval:	226.47 to 235.61 m (743 to 773 ft)
Elevation Screened Interval:	-149.0 to -158.2 m (-489 to -519 ft) MSL
Diameter (casing):	0.102 m (4") from 222.5 to 238.96 m (730' to 784') 0.152 m (6") from 0 to 222.5 m (0 to 730')
Screened Geologic Unit:	Black Creek
Screened Hydrogeologic Unit:	Dublin (lower zone)
Depth Static Water Level:	28.19 m (92.50 ft) on 12/27/94
Distance from Pumping Well	22.56 m (74 ft)

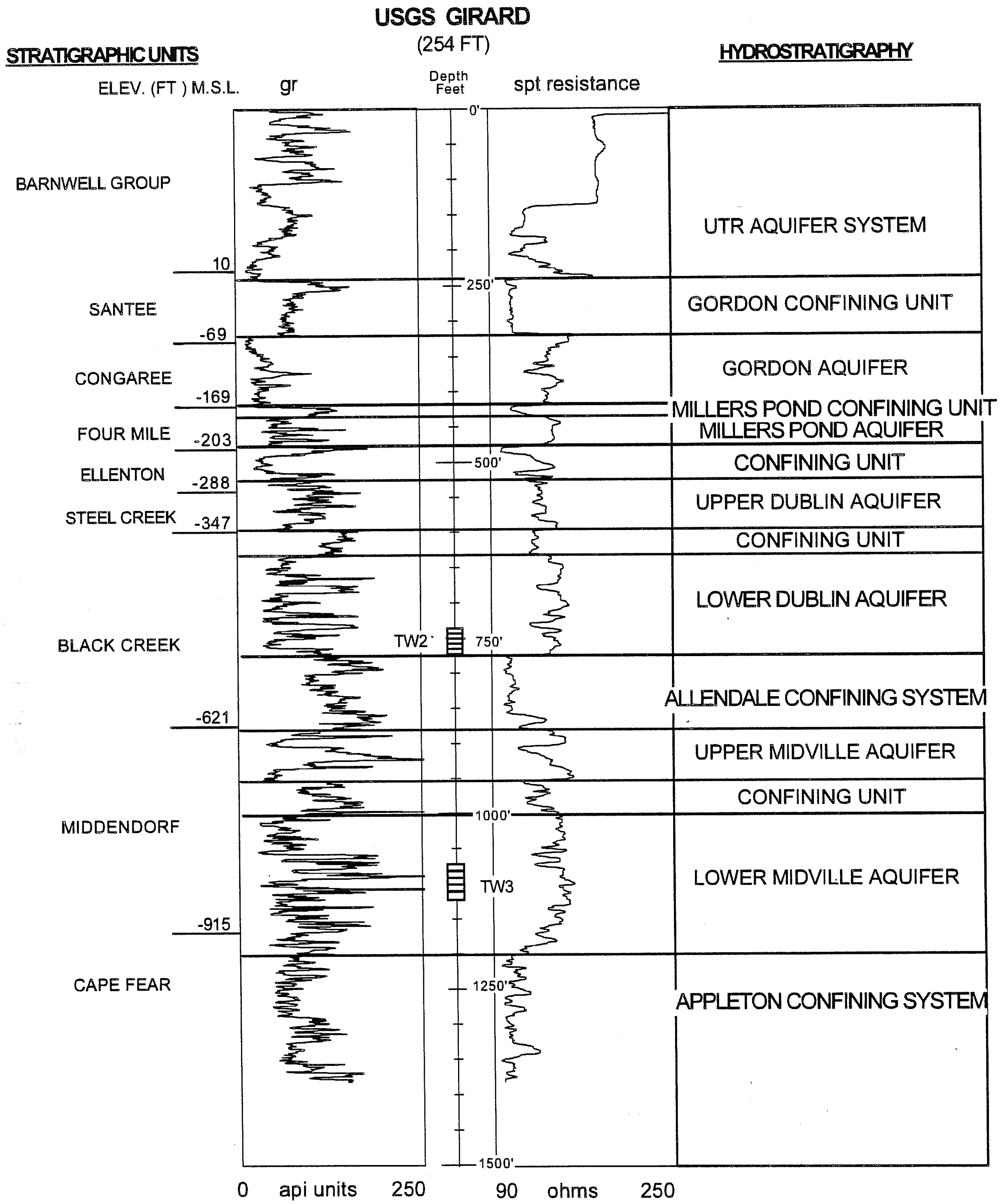

Figure 2. Hydrostratigraphy of the Girard site. Locations of well screens are shown.

2.2.2 Observation Well Data Acquisition Methods

There were no observation wells screened in the same aquifer zone (lower Midville) as the pumping well, TW3. The Dublin well (TW2) was monitored to detect vertical leakage, if present, between the Dublin and Midville aquifer systems. TW2 is screened in the lower Dublin from -150.27 to -159.41 m (-493 to -523 ft) MSL. The relative screen positions are shown in **Figure 2**. A transducer was placed approximately 3.05 m (10 ft) below the water table in the TW2.

well	transducer #	transducer psi rating
TW3 (Midville)	3	100
TW2 (Dublin)	2	45

2.3 Analysis Methods

2.3.1 Atmospheric Pressure Corrections

The initial analysis step is to correct the raw pressure data from the wells for changes in atmospheric pressure. These variations can mask the small response of an aquifer in an observation well. Removal of atmospheric pressure changes makes it easier to detect water level changes that result from pumping.

Barometric corrections are made by subtracting atmospheric pressure changes multiplied by the barometric efficiency (BE). The BE of an aquifer is the ratio of the change in hydraulic head in an aquifer (due to atmospheric changes) to the actual change in atmospheric pressure. A BE of 1 indicates that 100% of the atmospheric pressure changes have been transmitted to the aquifer. A BE of 0 would indicate that none of the atmospheric pressure changes have been transmitted to the aquifer.

2.3.2 Observation Well Analysis Method

Data from an observation well screened in the same aquifer as the pumping well can be analyzed to calculate the storativity and transmissivity of the aquifer (see **2.1 Test Logistics** and **3.2.1 Pumping Rates**). The wells at Girard are screened in separate aquifer systems, making observation well analysis impossible. However, an observation well screened in a deeper or shallower hydrologic unit qualitatively detects leakage, if present, by water level changes that result from pumping.

3.0 RESULTS

3.1 Duration of the Test

The pump test took place over a seven day span in the middle of January, 1995. The specific times for each phase of the test are given below:

Background Data	23.70 hours	(16:20 01/14/95 to 16:00 01/15/95)
Pump On	72.00 hours	(16:00 01/15/95 to 16:00 01/18/95)
Recovery (pump off)	73.50 hours	(16:00 01/18/95 to 17:30 01/21/95)
Total test time	169.20 hours	(16:20 01/14/95 to 17:30 01/21/95)

3.2 Data Acquisition Results

3.2.1 Pumping Rates

A time-weighted average of flow rate measurements was determined based on values obtained from an Omega digital flow meter. The average flow rate for the TW3 (Midville) pump test was 76.5 gpm (0.29 m^3/min.). **Figure 3** is a plot of the change in water level and flow rate versus time for the pumping well TW3.

3.2.2 Water Level Readings

During the test, 2381 water level data points were recorded in the pumping and monitoring wells by the data aquisition system. Data points were recorded as frequently as every 5 seconds at times of rapidly changing water levels, decreasing to every 5 minutes when water level changes were relatively small. **Figures 3** and **4** show plots of change in water level vs. time for the pumping and observation wells, respectively.

3.3.2 Calculated Aquifer Properties

- A Theis-Jacob curve match for TW3 Midville well is shown in **Figure 5**.
- An enlarged portion of the curve match is shown in **Figure 6**.
- Hydraulic conductivity and permeability calculations are based on drawdown transmissivity and an effective aquifer thickness of 39.6 meters (130 ft) for the lower aquifer of the Midville System (**Figure 2**).

	TW3 (PW)
Storativity	0.0001 (estimated)
Transmissivity (drawdown analysis)	105 m^2/day (1130 ft^2/day)
Transmissivity (recovery analysis)	425 m^2/day (4574 ft^2/day)
Hydraulic Conductivity	2.7 m/day (8.9 ft/day)
Permeability	3.25 darcys

3.3.3 Calculated Skin Factor

A pseudo skin factor (does not consider effects of partial penetration) of 9.15 was calculated for the pumping well, TW3. This skin factor corresponds to a well efficiency of 49%. A well with zero-skin factor would be a 100% efficient well. The well efficiency was determined by producing theoretical drawdown data based on zero skin factor and then dividing that theoretical data by the measured drawdown data after 24 hours of pumping and multiplying by 100%.

3.3.4 Specific Capacity

A flow rate of 76.5 gpm (0.29 m^3/min) created a 12.6 meter (41.3 ft) water level change after 72 hours in well TW3 (Midville). This equates to a specific capacity of approximately 1.85 gpm/ft.

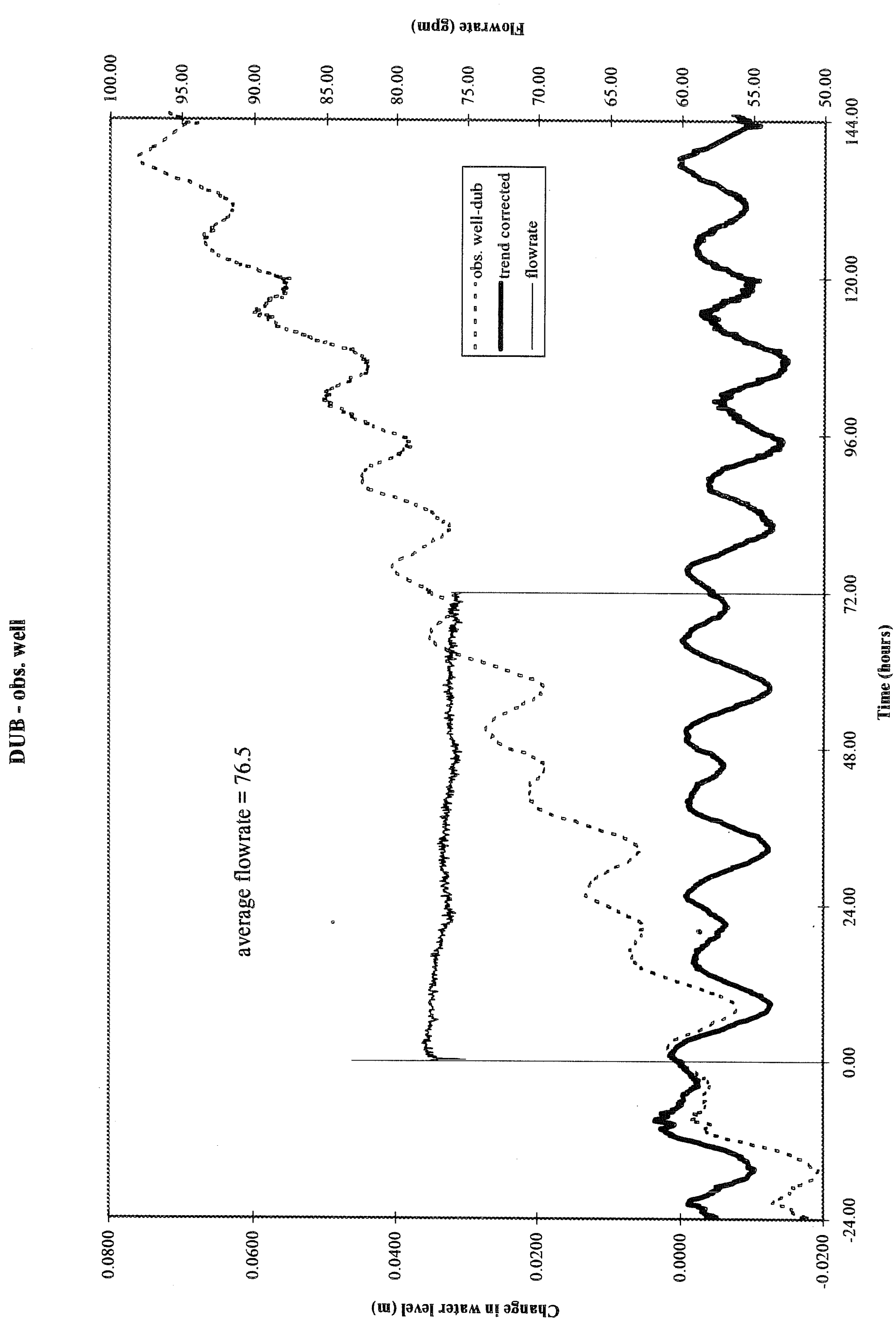

Figure 4. Flow rate & Change in water level vs. time for observation well TW2

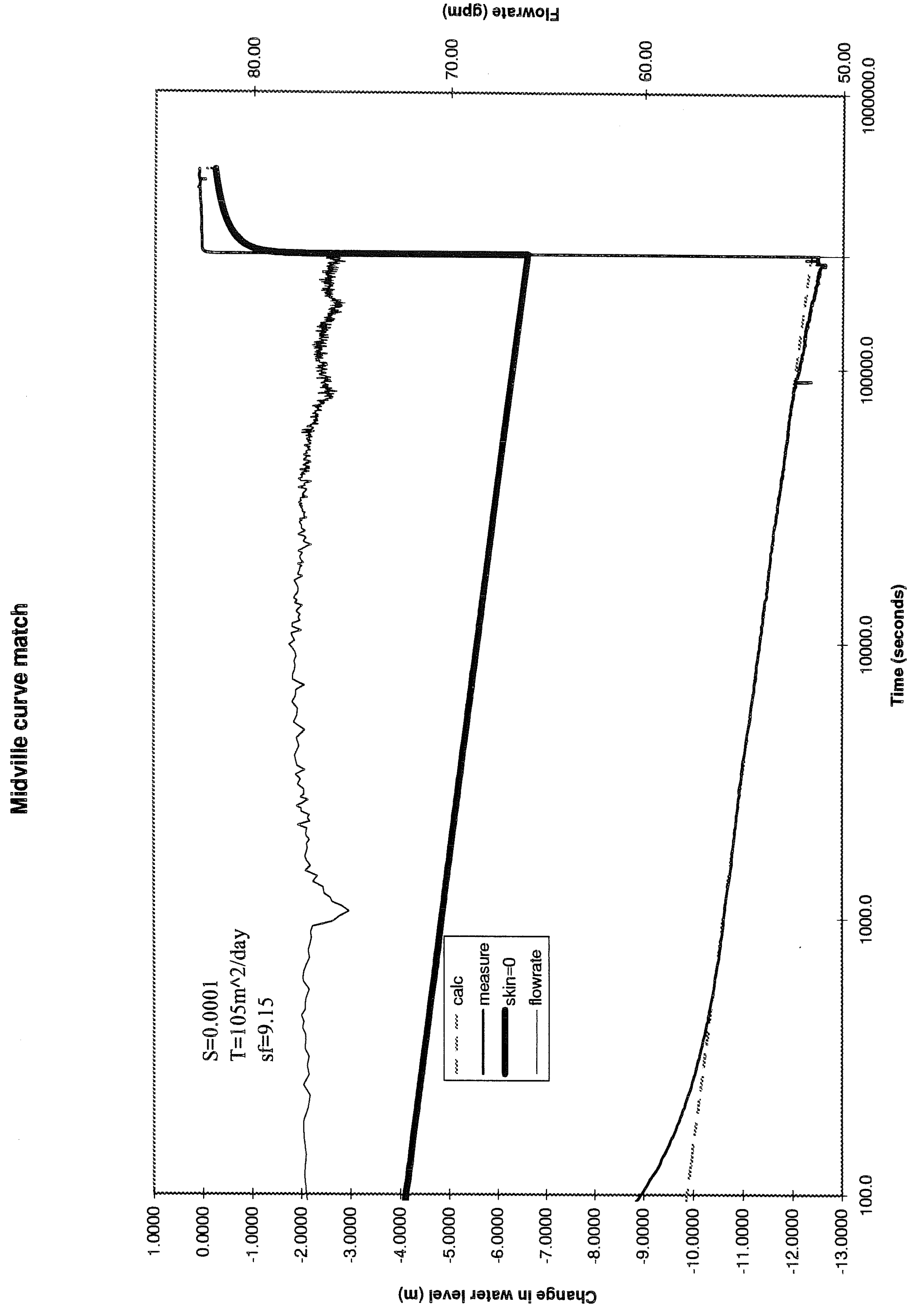

Figure 5. Theis-Jacob analysis (curve match) for TW3 Midville well.

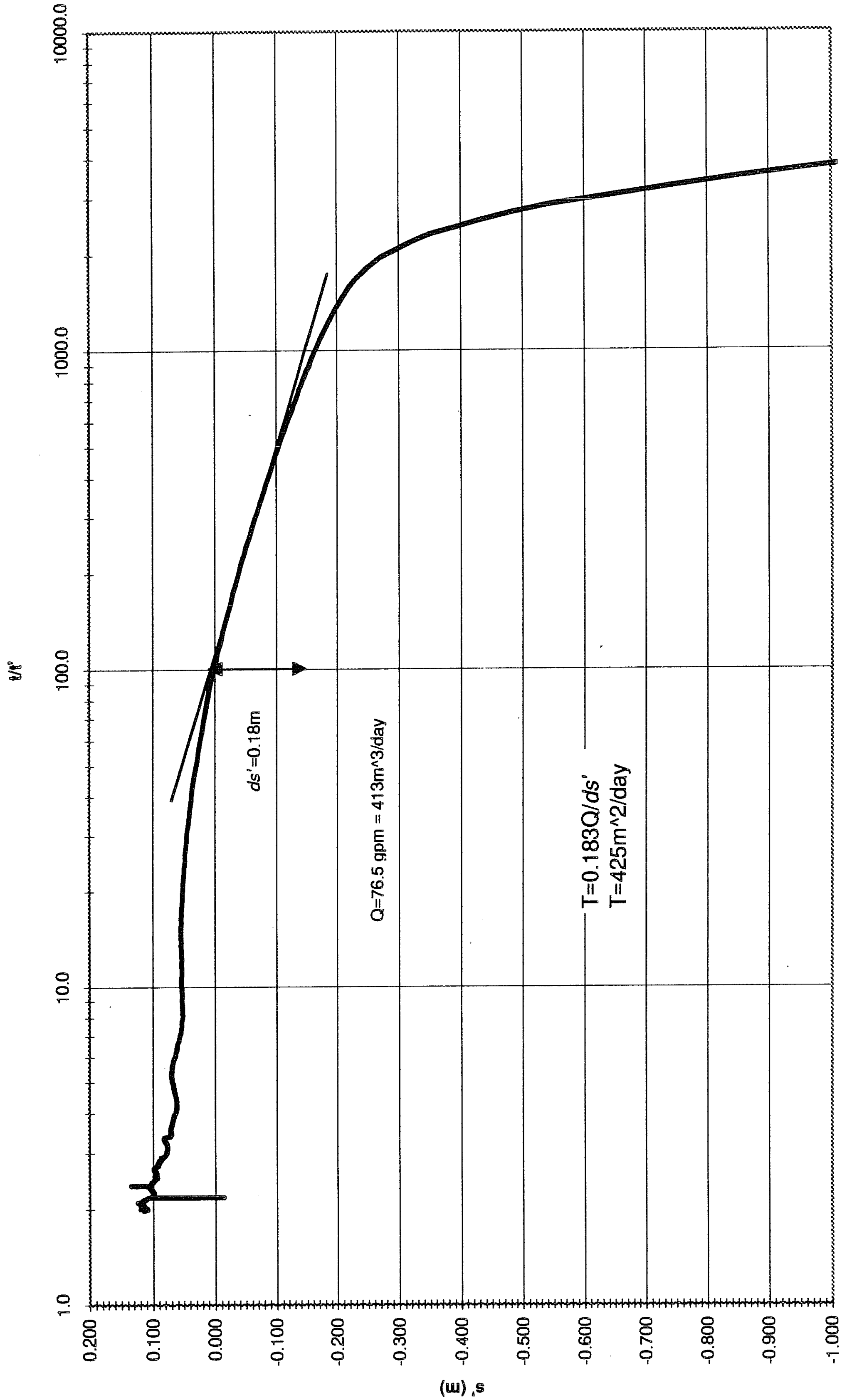

Figure 7. Residual Drawdown vs. t/t' for Midville (TW3) pumping well.

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The P, B and D Area Tests

AQUIFER PERFORMANCE TEST REPORT

P Area, SRS

June 24-28, 1993

Prepared by

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February 16, 1994

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ABSTRACT

As part of the USGS Trans-River Project, the Department of Earth Sciences at Clemson University conducts pump tests at selected localities in South Carolina and Georgia near or on the Savannah River Site (SRS). The test at P Area, centrally located within SRS, was conducted from June 24 to June 28 of 1993 using a water supply well (PW120P) as the pumping well and four wells from a nearby monitor well cluster P24 (TA,TB,TC,TD) as observation wells. The pumping well (PW120P) and one observation well (P24-TA) are screened over the same zone in the lower Midville aquifer. A transmissivity of 0.0165 m^2/s (15,300 ft^2/day) and a storativity of 0.9 E-4 were calculated from P24-TA data. A transmissivity of 0.0180 m^2/s (16,500 ft^2/day) was calculated from PW120P data. The 30 meter thickness of the lower Midville at P Area yields hydraulic conductivities of 0.00054 m/s (500 ft/day) from P24-TA data and 0.00059 m/s (550 ft/day) from PW120P data. Other observation wells screened in successively shallower zones (P24-TB in the upper Midville, P24-TC in the lower Dublin, P24-TD in the upper Dublin) were monitored to detect vertical leakance across confining layers. Water level changes directly related to pumping were observed in the P24-TB well, indicating leakance across the confining unit separating the lower and upper Midville. No pumping related water level changes were observed in the Dublin, indicating no detectable leakance across the Allendale Confining Unit which separates the Midville and Dublin Aquifer Systems.

1.0 INTRODUCTION

The format of this report is modified from Clarke (U. S. Geological Survey, written communication, 1993).

1.1 Purpose of the P Area Aquifer Performance Test

The United States Geological Survey (USGS) is creating a model to predict the rate and direction of groundwater flow in the vicinity of the Westinghouse Savannah River Site (SRS). The model will incorporate the hydraulic properties determined from the aquifer performance test at P area. This is part of an overall effort to investigate the possibility of groundwater flow and contaminant migration beneath the Savannah River from SRS in South Carolina to Georgia (Trans-River Project).

The USGS is drilling well clusters in Georgia where aquifer performance tests (pump tests) will be conducted by the faculty and students of the Department of Earth Sciences at Clemson University. The data can be analyzed to estimate hydraulic properties of aquifers and confining units on the Georgia side of the Savannah River. The hydraulic property information available to the model on the South Carolina side of the Savannah River is comprised of historical estimates made at SRS and of estimates made from well data held by the South Carolina Water Resources Commission (SCWRC). By performing pump tests at water supply (production) well and monitor well cluster sites at SRS facilities, the amount and quality of information available to the model on the South Carolina side of the Savannah River can be substantially increased. This information can be acquired economically by testing existing production wells without the expense of drilling and then testing new wells. The aquifer performance test at P area is the first in a series of pump tests to be conducted on SRS production wells.

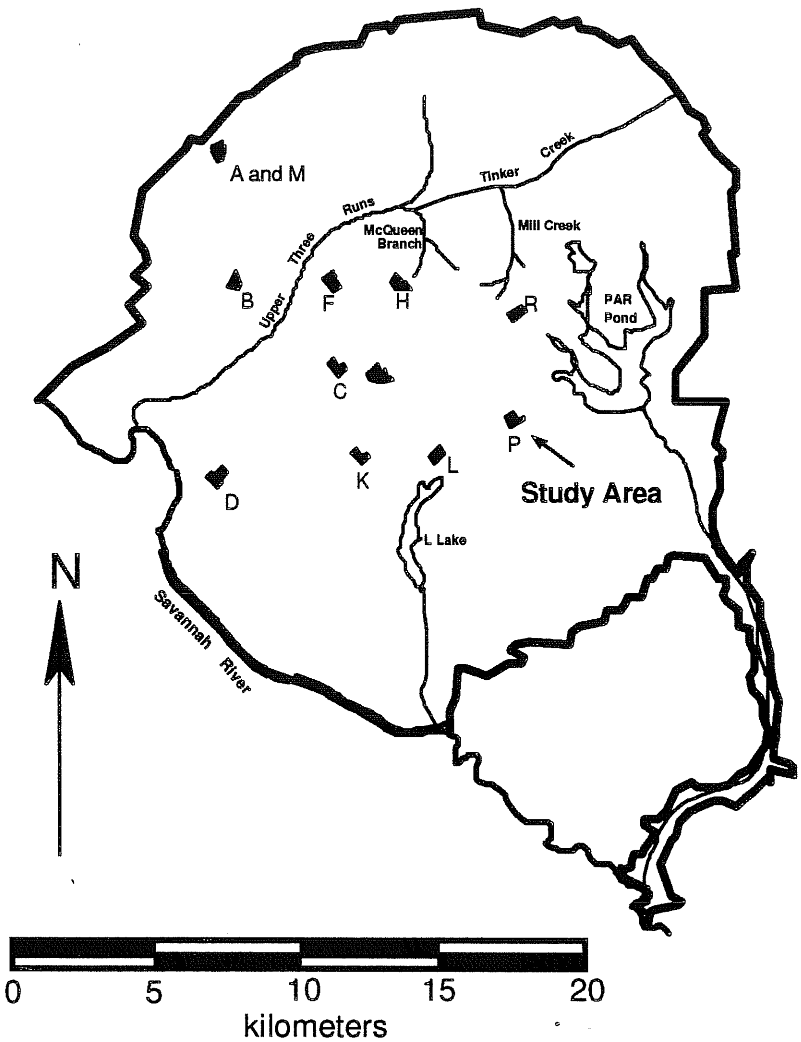


Figure 1. Map showing the location of P Area within the SRS.

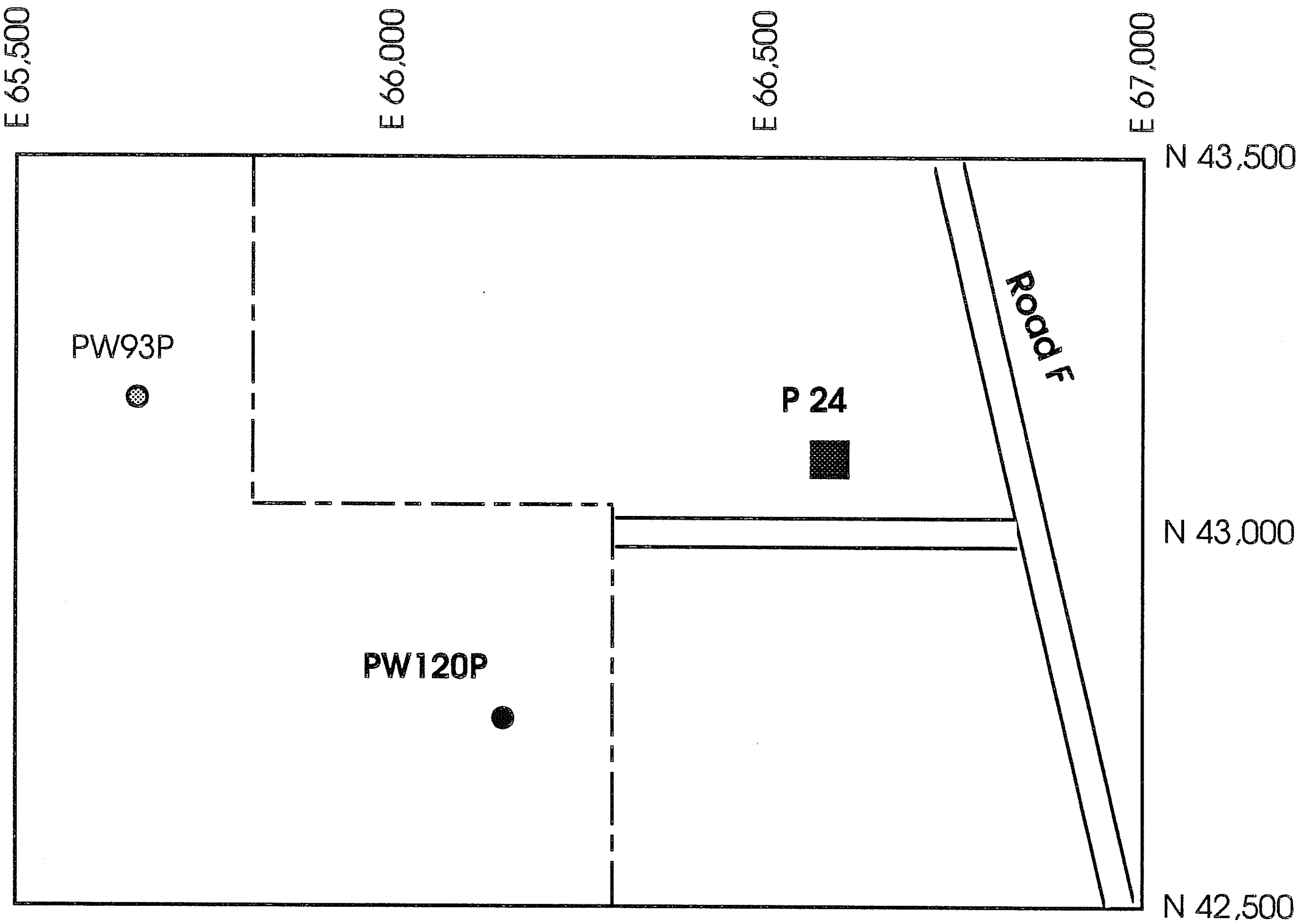


Figure 3. Map showing the location of the wells at P Area, SRS.

2.0 METHODS

2.1 Test Logistics

Ideally, a pump test is composed of three periods of data collection: background, pumping, and recovery. Background data is used to determine if the aquifer is in an equilibrium condition and the extent to which it is being affected by inconsistent external forces. It is also used to determine the barometric efficiency of the monitored aquifers so test data can be corrected for changes in atmospheric pressure. The aquifer is then pumped, creating a pressure drawdown cone extending radially from the pumping well. After pumping stops, the aquifer is allowed to recover to pre-test conditions.

Pump tests performed using supply wells require coordination with site engineers to accomplish our objectives within the restrictions imposed by site water demand. At P Area we were restricted to no more than 24 hours of continuous pump-off time for the supply well (PW120P). According to P Area engineers, the PW120P has pumped continuously for at least the past 2 years at 455-460 gpm. In order to perform a conventional pump test, the supply well would have to be shut-in twice, once to allow the aquifer to return to a pre-pumping non-drawdown condition, and a second time to collect recovery data after pumping. To minimize our impact on site water supply, the decision was made to use the continuous pumping of the supply well to our advantage. Because PW120P had been pumped at a constant rate for over 2 years, it can be assumed that the well and aquifer has achieved an equilibrium condition within our study area. Background data was recorded as the supply well continued pumping (the normal condition in the area). Pumping was stopped and recovery ("pumping") data was recorded for 24 hours. Pumping was then resumed and "recovery" data was recorded as the aquifer returned to a pre-test drawn down condition. This strategy limited our impact on site water supply to one 24 hour pump-off period.

2.2 Data Acquisition Methods

Water level readings are recorded as pressure changes in meters of water relative to an initial equilibrium static water level condition. For the duration of a pump test (background through recovery), transducers monitor and record water level changes in the pumping well and observation wells. Relative water level changes are recorded automatically on the computer data acquisition system at operator specified intervals ranging from 5 seconds to 5 minutes throughout the test. An additional transducer monitors and records changes in atmospheric pressure to be removed from the well data prior to aquifer parameter analysis. The transducers are calibrated to a maximum of 0.005% of full scale (1.5 mm for a 45 psi transducer) for repeatability and hysteresis. Typical field resolution values for a 45 psi transducer are 0.2 mm.

2.2.1 Pumping Well Data Acquisition Methods

The pumping well, PW120P, is screened in the lower part of the Midville Aquifer System from -187.3 to -202.5 m (-614.5 to -664.5 ft MSL) see **Figure 2**. Well PW120P is equipped with a 150 hp turbine pump that produces about 458 gpm on a continuous basis and is capable of producing over 500 gpm for short periods. A digital flow meter installed at the well head continuously registers the flow rate. All flow measurements made during the test were manually taken from the digital flow meter.

The observation wells screened in successively shallower hydrologic units qualitatively detect leakance, if present, by water level changes that result from pumping.

2.3.2 Pumping Well Analysis Method

Data from the pumping well is governed by three variables: the transmissivity and storativity of the aquifer, and the skin factor of the pumping well. If one of the three variables is known or can be estimated, the other two can be calculated. The skin factor of the pumping well is unknown. The storativity of the aquifer is less sensitive than the transmissivity and is estimated as the storativity calculated from a nearby observation well. The storativity value calculated from P24-TA was used for analysis of PW120P. Variable rate curve matching of drawdown data yields a transmissivity value for the aquifer and a skin factor for PW120P using the superposition of the Theis solution (1935) or Jacob straight-line method (Cooper and Jacob, 1946) for variable flow rates modified for the skin factor analysis of Van Everdingen (1953) for confined aquifers with fully penetrating wells. Because PW120P is screened over only the bottom 50 ft of the lower Midville (100 ft thick), the data was also analyzed using the Hantush (1961, 1964) solution for partially penetrating wells modified to account for the Van Everdingen (1953) skin factor. The Hantush solution is used to calculate the transmissivity of the aquifer and the skin factor of the well, while correcting for vertical flow within the aquifer. The well efficiency of the pumping well is calculated by taking the ratio of the theoretical drawdown of the well with a skin factor of zero and the actual measured drawdown.

3.0 RESULTS

3.1 Duration of the Test

The pump test took place over a four day span in late June, 1993 during the Clemson University Hydrogeology Summer Field Camp. The specific times for each phase of the test are given below:

Background Data (pumping)	24.94 hours	(6/24 at 1504 to 6/25 at 1600)
Pump Off	24 hours	(6/25 at 1600 to 6/26 at 1600)
Recovery (pump on)	43.17 hours	(6/26 at 1600 to 6/28 at 1110)
Total test time	92.11 hours	(6/24 at 1504 to 6/28 at 1110)

3.2 Data Acquisition Results

3.2.1 Pumping Rates

Well PW120P was pumped at a constant rate of 458 gpm prior to the test for over 2 years. For the test, the pump was shut off for 24 hours and then re-started. Flow rates during the test were modeled relative to the 458 gpm pre-test condition. Relative discharge (Q) is shown followed by the actual flow rate. All flow measurements were made using the digital flow meter installed at the pumping well.

Figure 4. Pumping well (PW120P): water level change vs time.

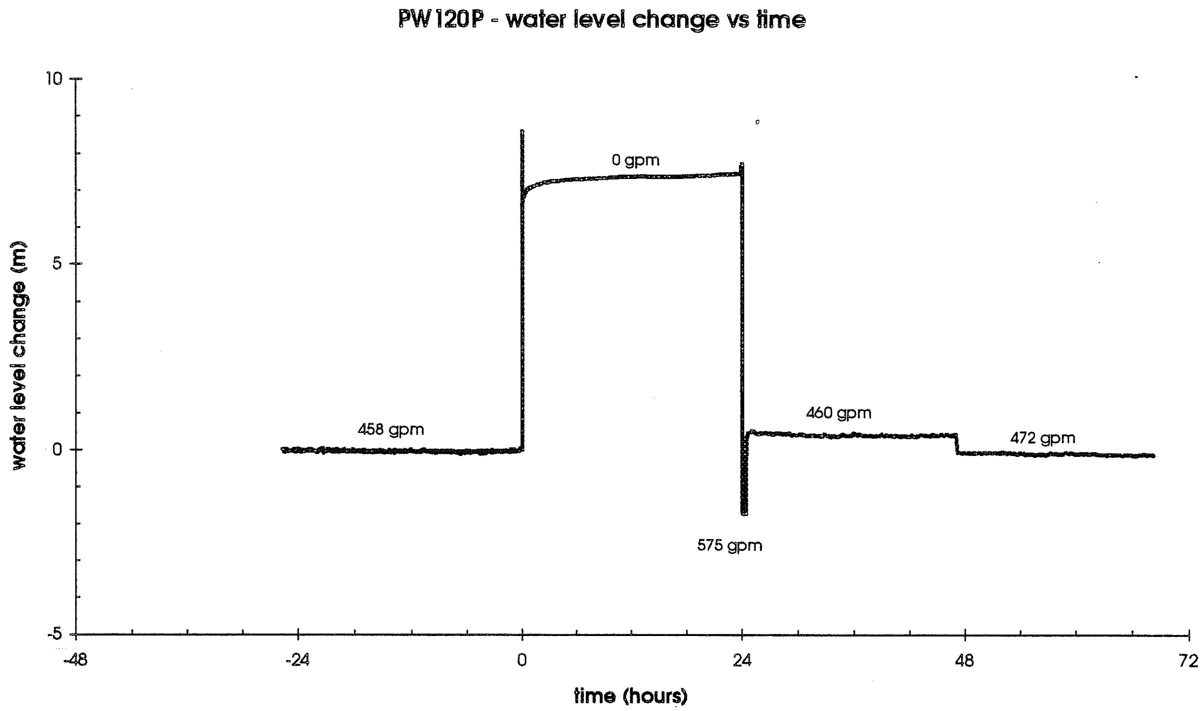
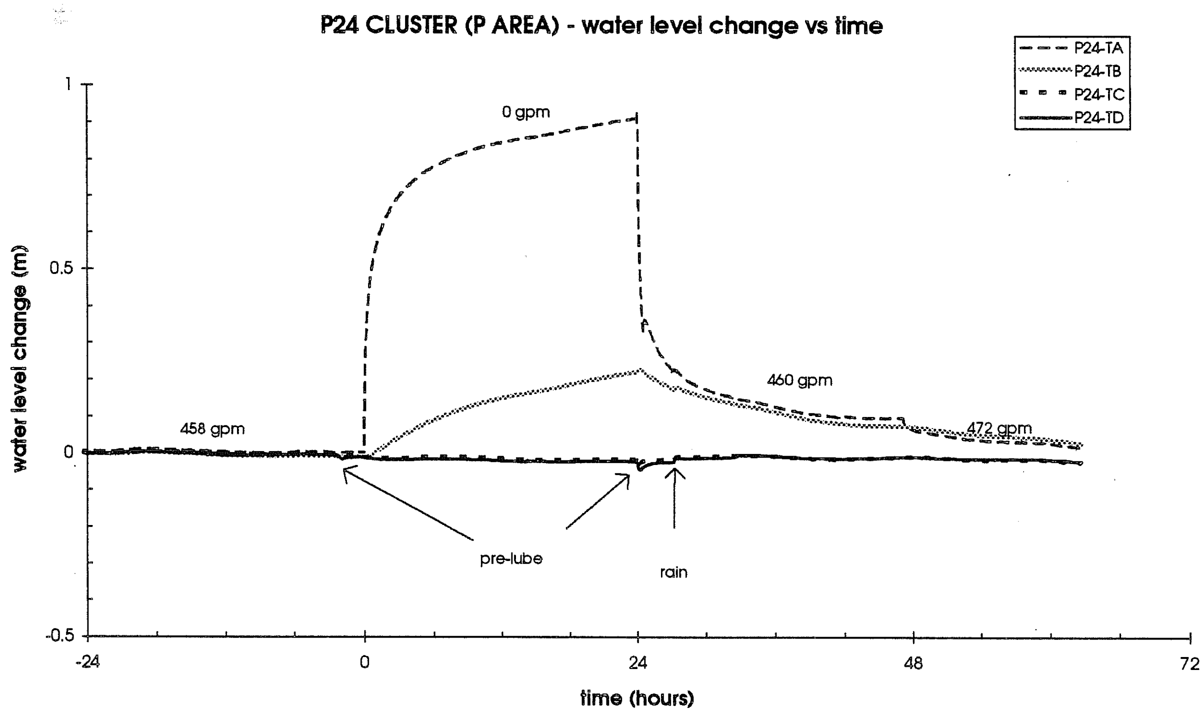
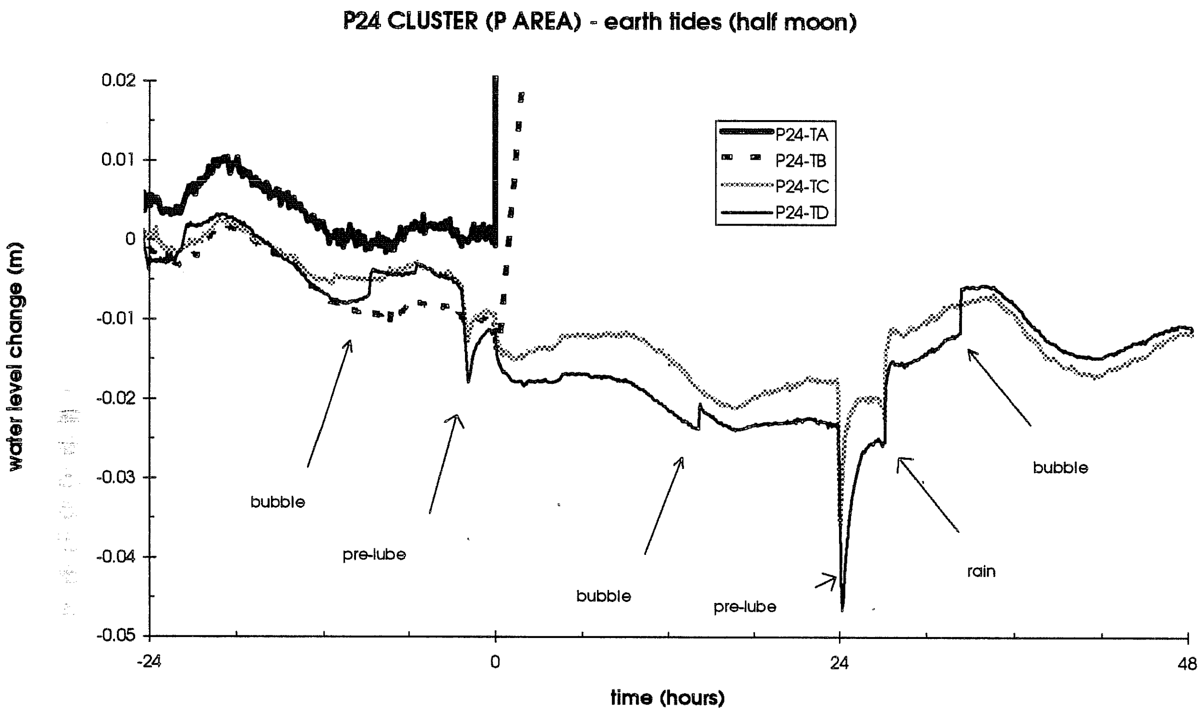


Figure 5. Observation wells (P24-TA, TB, TC, TD): water level change vs time.



well	barometric efficiency
PW120P	0.83
P24-TA	0.83
P24-TB	0.80
P24-TC	0.82
P24-TD	0.78

Figure 6. Plot of drawdown data at a limited scale to show wave effect of earth tides.



3.3.2 Calculated Aquifer Properties

- Curve matches for P24-TA and PW120P are shown in **Figure 7** and **Figure 8.**
- Hydraulic conductivity and permeability calculations are based on an effective aquifer thickness 30 meters (100 ft) for the lower aquifer of the Midville System (**Figure 2**).

	P24-TA (OW)	**PW120P (PW)**
Storativity	0.9 E-4	0.9 E-4
Transmissivity	0.0165 m^2/s (15,300 ft^2/day)	0.0180 m^2/s (16,700 ft^2/day)
Hydraulic Conductivity	0.00055 m/s (156 ft/day)	0.00060 m/s (170 ft/day)
Permeability	55 darcys	60 darcys

Figure 8. Semi-log analysis (curve match) of pumping well PW120P.

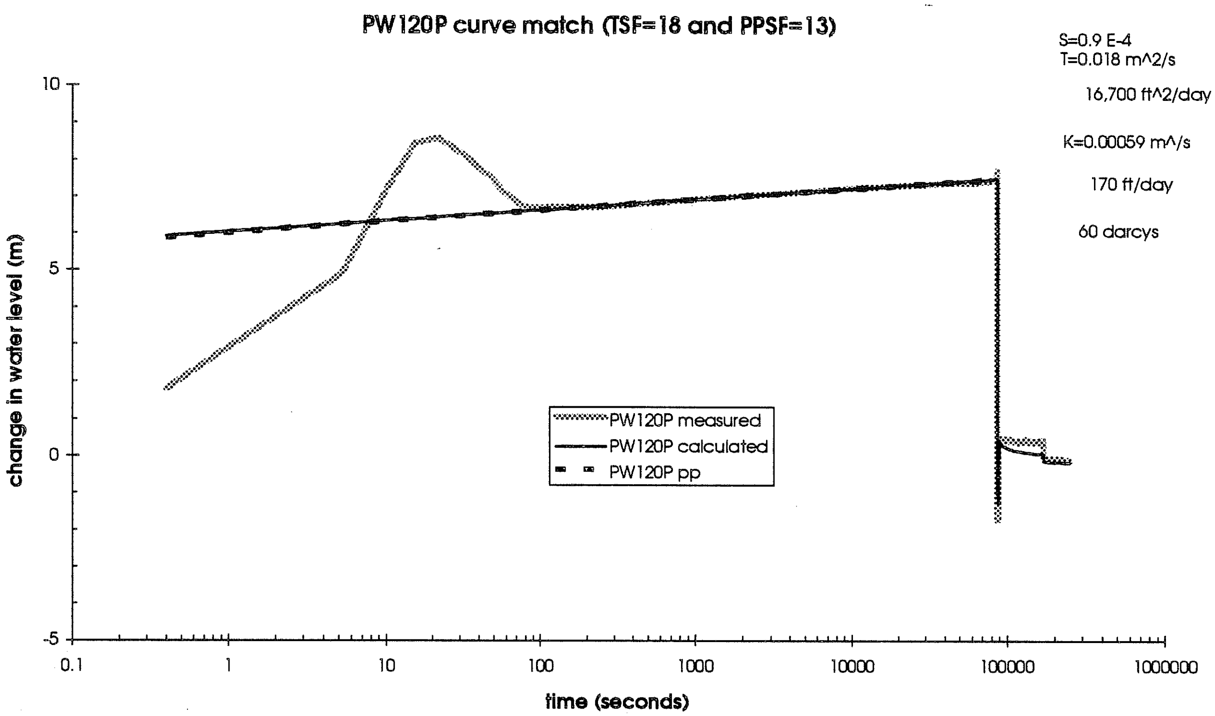
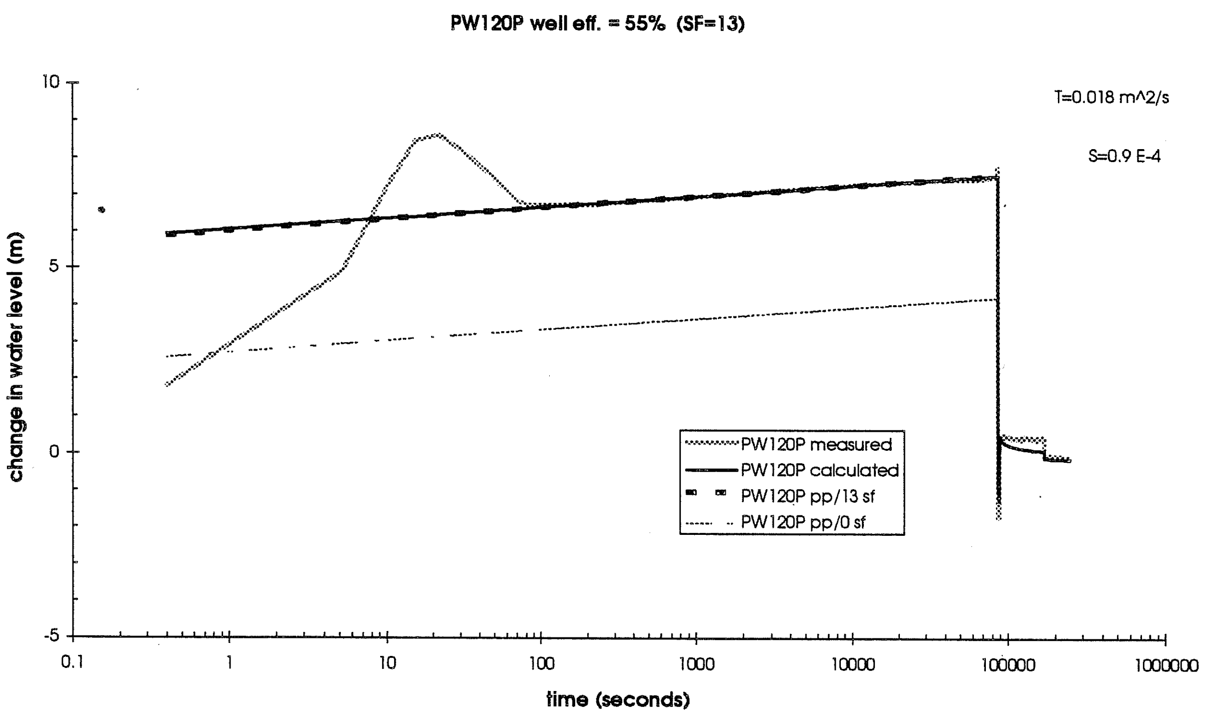


Figure 9. Well efficiency analysis of PW120P: Plot of theoretical water level change for a perfectly efficient well (skin factor = 0) with actual drawdown of PW120P (skin factor = 13).



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ACKNOWLEDGMENTS

Buford Beavers (WSRC), coordinated logistical arrangements with site personnel and Clemson University. Robert Hunter and Dan Wells (WSRC), assisted with the pump test. Van Price (WSRC), Tommy Temples (US DOE) and Richard Strom (SRTC) assisted with logistical arrangements. Larry Harrelson (USGS), originally suggested using SRS water supply wells for pump tests and monitor well clusters as observation wells.

1.2 Site Conditions

1.2.1 Location

B Area is located in the northwest section of the WSRC Savannah River Site (**Figure 1**).

1.2.2 Hydrogeologic Setting

The Savannah River Site is located on Coastal Plain sediments ranging in age from Miocene to Late Cretaceous. The sediments, interbedded sands and shales, were deposited over Paleozoic crystallines and Triassic red beds exposed by Late Cretaceous erosion. Regional dip is to the southeast and decreases upward from 48 ft/mi (9m/km) at the base of the section to 15 ft/mi (3 m/km) at the top of the middle Eocene beds (Snipes, 1993). Across SRS, the thickness of the sediments ranges from 700 ft (210 m) in the northwest to 1400 ft (430 m) in the southeast. At B Area, the sediments are about 720 ft (220 m) thick. The Midville Aquifer System is the deepest in the section and is separated from the overlying Dublin Aquifer System by the Allendale Confining Unit. The Meyers Branch Confining Unit separates the Dublin from the overlying Gordon Aquifer The major aquifer systems and confining units are shown in **Figure 2**.

1.2.3 Description of Wells Used for the Test

The site water supply well, PW67B, was used as the pumping well. Four wells at the P29 monitor well cluster (P29-TA, P29-TC, P29-TD, P29-A) were used as observation wells for the test. **Figure 2** relates the wells to the subsurface hydrogeology in a cross sectional view. **Figure 3** is a simplified site map showing the location of wells used for the test. **Figure 4** is a schematic of the well construction diagram of PW67B. Note that the static water levels of the pumping well and to a lesser degree of the observation wells are affected by intermittent pumping prior to the test. For this reason, water levels taken in July 1990 were used. The specifics of each well are given below:

Pumping Well (PW67B):	SRS coordinates =	N 86693 E 42622
	Elevation (ground) =	81.99 m (269.00 ft) MSL (est.)
	Elevation (TOC) =	82.84 m (271.80 ft) MSL

Total Depth (from TOC):	not available
Effective Well Depth (from TOC):	221.82 m (727.8 ft)
Completion Date:	15 October 1963
Depth Screened Interval:	188.30 to 221.82 m (617.8 to 727.8 ft)
Depth Gravel Pack:	not available
Elevation Total Depth:	not available
Elevation Effective Well Depth:	-138.98 m (-456 ft MSL)
Elevation Screened Interval:	-105.46 to -138.98 m (-346 to -456 ft MSL)
Elevation Gravel Pack:	not available
Diameter (casing):	0.25 m (10")
Screened Geologic Unit:	Middendorf
Screened Hydrogeologic Unit:	Midville
Depth Static Water Level:	30.39 m (99.7 ft) July 1990

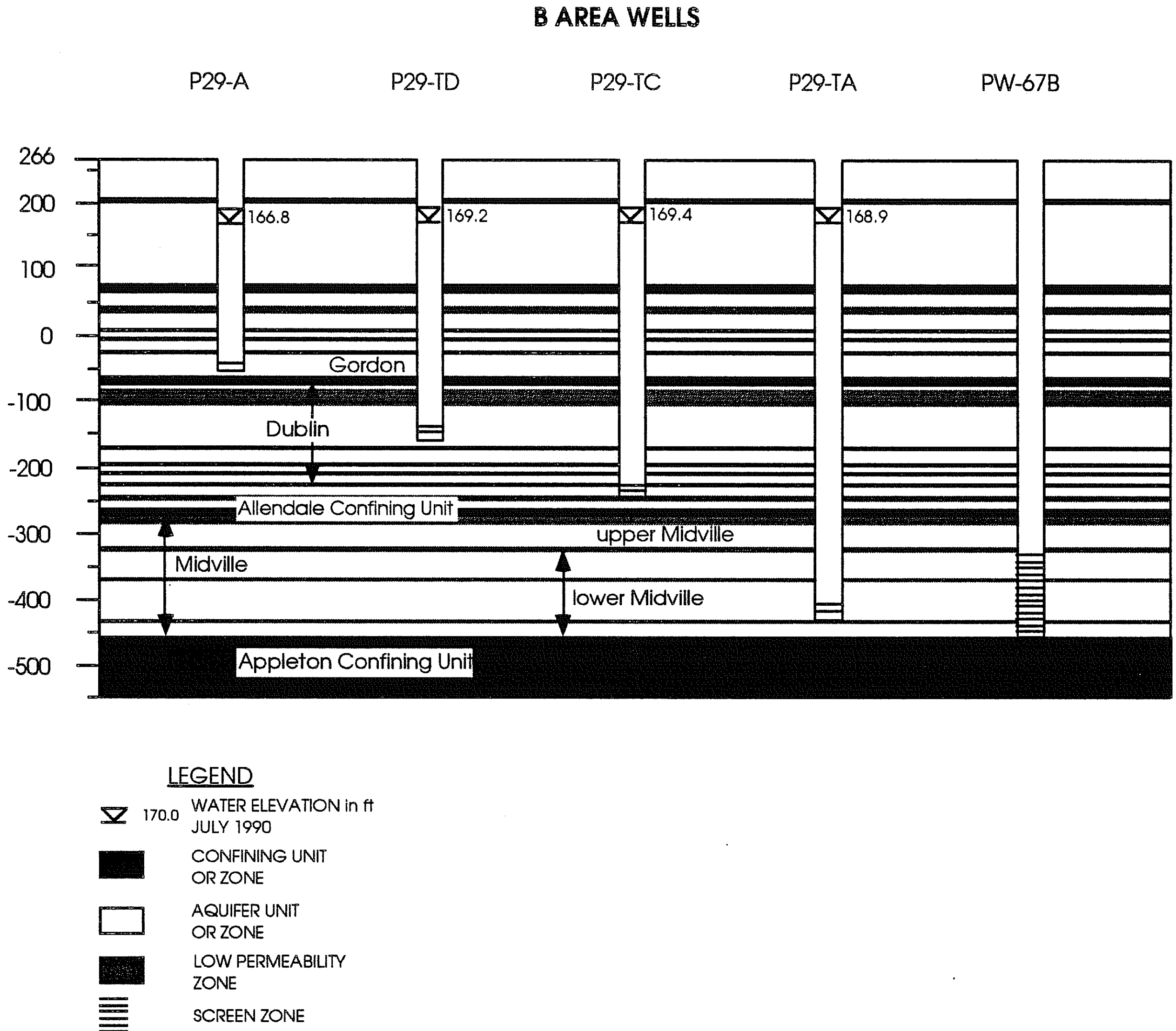


Figure 2. Schematic stratigraphic cross section at the B Area study site. Locations of the well screens are shown.

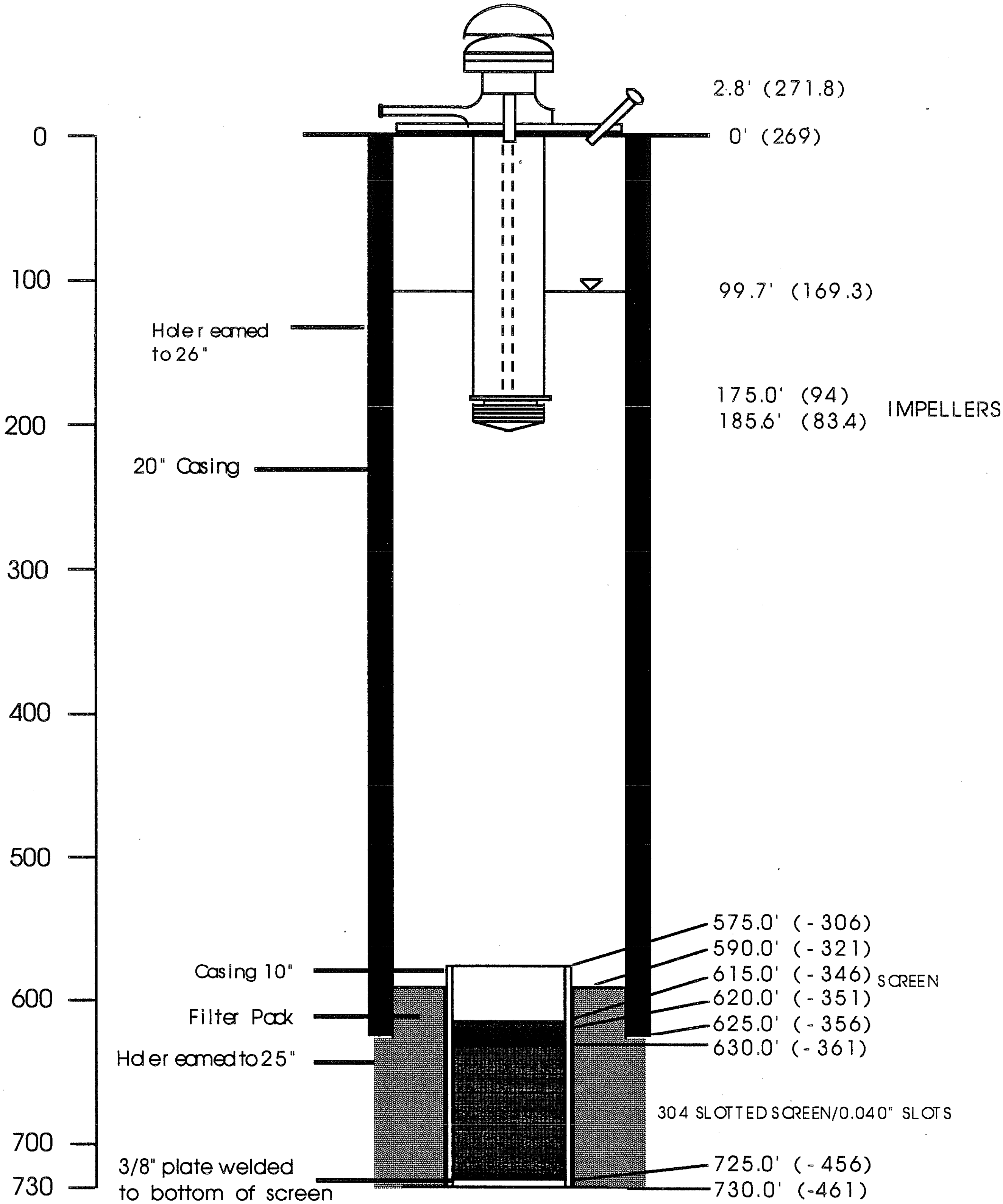


Figure 4. Construction diagram of pumping well PW67B.

2.0 METHODS

2.1 Test Logistics

Ideally, a pump test is composed of three periods of data collection: background, pumping, and recovery. Background data is used to determine if the aquifer is in an equilibrium condition and the extent to which it is being affected by inconsistent external forces. It is also used to determine the barometric efficiency of the monitored aquifers so water level test data can be corrected for changes in atmospheric pressure. The aquifer is then pumped, creating a pressure drawdown cone extending radially from the pumping well. After pumping stops, the aquifer is allowed to recover to pre-test conditions.

Pump tests performed using supply wells require coordination with site engineers to accomplish our objectives within the restrictions imposed by site water demand. At B Area, PW67B is pumped intermittently at about 1000 gpm to fill the water supply tank. The pump is automatically activated when the water level in the supply tank drops below a pre-determined limit. The pump automatically turns off when the tank is full, usually after 10 to 20 minutes of pumping. The period between pumping events (normally 2.5 to 3 hours) is dependent on site water usage and is shown by plots of water level change vs time, **Figures 5** and **6**. Continuous pump-off time for PW67B was restricted to about 12-15 hours to maintain adequate water supply in case of fire. To control pumping times for the test, WSRC engineers changed the pump control from automatic to manual mode.

Background data collection began as the supply well continued intermittent pumping (the normal practice in the area). Pumping was stopped for 13.45 hours to allow the aquifer to recover as much as possible under the time constraints. For the discharge period of the test, at least 24 hours of continuous pumping was desired to provide the maximum opportunity to detect leakance through confining units. When pumping began, the storage tank was filled until it overflowed. Flow was then diverted to a discharge ditch. After 7 hours, it was necessary to refill the storage tank by diverting flow from the discharge ditch to the tank and then back to the discharge ditch after the tank was filled. At the end of the 24 hour pumping period, the tank was again filled prior to turning the pump off. Flow was restricted to 500-600 gpm during the pumping period of the test to limit run-off. Recovery data was taken for 10.25 hours before automatic pumping at the site resumed.

2.2 Data Acquisition Methods

Water level readings are recorded as pressure changes in meters of water relative to an initial equilibrium static water level condition. For the duration of a pump test (background through recovery), transducers monitor and record water level changes in the pumping well and observation wells. Relative water level changes are recorded automatically on the computer data acquisition system at operator specified intervals ranging from 5 seconds to 5 minutes throughout the test. An additional transducer monitors and records changes in atmospheric pressure to be removed from the well data prior to aquifer parameter analysis. The transducers are calibrated to a maximum of 0.005% of full scale (1.5 mm for a 45 psi transducer) for repeatability and hysteresis. Typical field values for a 45 psi transducer are 0.2 mm.

2.2.1 Pumping Well Data Acquisition Methods

The pumping well, PW67B, is screened in the lower part of the Midville Aquifer System from -105.46 to -138.98 m (-346 to -456 ft MSL) see **Figure 2.** Well PW67B is equipped with a 150 hp turbine pump that normally produces about 1000 gpm on an intermittent basis to fill the water supply tank at B Area. For the test, flow was restricted to about 500-600 gpm. Flow measurements taken during the test were made using an orifice weir provided by WSRC.

Access to PW67B is limited by the well head design. A 2 inch diameter pipe used for taking water level measurements provides the only access to the well, short of removing the pump. The transducers employed by the Clemson high resolution system are protected by a stainless steel encasement 2.75 inches in diameter, making the pumping well practically inaccessible. The alternative was to use a smaller transducer for the pumping well that is not a standard part of the Clemson system. Personnel in the drilling department at WSRC provided an Instrumentation Northwest PS9000 piezometric quartz crystal transducer system. It uses transducers only slightly larger (0.840" OD and 9.125" in length) than a standard water level tool (0.5" OD and 9" in length) and that easily fit into the 2" diameter access pipe of the pumping well. The PS9000 does not have the resolution (typical repeatability/hysteresis is 0.1% of the transducer psi rated span) of the Clemson system. For the 20 psi span transducer used for the test, the resolution is about +/- 15 mm. However, for the large water level changes that occur in a pumping well, precise resolution is not as critical.

2.2.2 Observation Well Data Acquisition Methods

Observation well P29-TA is screened from -122.77 to -129.35 m (-402.8 to -424.4 ft). This is in the same lower Midville zone as pumping well PW67B. Three other wells screened in successively shallower zones were monitored to detect vertical leakance if present. Well P29-TC is screened in the lower Dublin from -67.81 to -74.40 m (-222.5 to -244.1 ft), P29-TD is screened in the upper Dublin from -43.40 to -49.98 m (-142.4 to -164.0 ft), and P29-A is screened in the Upper Dublin from -11.52 to -14.81 m (-37.8 to -48.6 ft). No well was completed in the upper Midville (P29-TB) at the P29 cluster due to mechanical problems while drilling. The relative screen positions are shown in **Figure 2**. The monitor wells are permanently equipped with sample pumps which were pulled for the test. The wells are 4 inches in diameter, large enough for the high resolution transducers used by the Clemson system.

well	transducer #	transducer psi rating
PW67B	WSRC	20
P29-TA	4	100
P29-TC	1	45
P29-TD	2	45
P29-A	3	45

3.0 RESULTS

3.1 Duration of the Test

The pump test took place over a four day span in early July, 1993 during the Clemson University Hydrogeology Summer Field Camp. The specific times for each phase of the test are given below:

Background Data (intermittent pumping at 1000 gpm)	31.90 hours	(7/1 at 1223 to 7/2 at 2018)
Background Data pump off	13.45 hours	(7/2 at 2018 to 7/3 at 0945)
Pumping (pump on)	25.00 hours	(7/3 at 0945 to 7/4 at 1045)
rate prior to tank refill	(7.15 hrs) @ 572 gpm	(7/3 at 0945 to 7/3 at 1654)
tank refill rate	(0.43 hrs) @ 613 gpm	(7/3 at 1654 to 7/3 at 1720)
rate after refill	(17.42 hrs) @ 565 gpm	(7/3 at 1720 to 7/4 at 1045)
Recovery (pump off)	10.25 hours	(7/4 at 1045 to 7/4 at 2100)
Total test time	80.60 hours	(7/1 at 1223 to 7/4 at 2100)

3.2 Data Acquisition Results

3.2.1 Pumping Rates

The discharge rate for PW67B ranged from 565-613 gpm during the continuous pumping portion of the test. Flow rate variations occurred when flow was diverted from the discharge ditch to fill the storage tank. Flow rates during the test were modeled relative to the 0 gpm pre-pumping recovered condition. All flow measurements were made using the orifice weir provided by WSRC. Relative discharge (Q) is shown followed by the actual flow rate:

Q_0: 0.0000 m^3/s (time averaged rate)
pump off (0 gpm) for 13.45 hours, 7/2 at 2018 to 7/3 at 0945

Q_1: 0.0361 m^3/s (time averaged rate)
pump at 572 gpm for 7.15 hours, 7/3 at 0945 to 7/3 at 1654

Q_2: 0.0387 m^3/s (time averaged rate)
pump at 613 gpm for 0.43 hours, 7/3 at 1654 to 7/3 at 1720

Q_3: 0.0356 m^3/s (time averaged rate)
pump at 565 gpm for 17.42 hours, 7/3 at 1720 to 7/4 at 1045

Q_4: 0.0000 m^3/s (time averaged rate)
pump off(0 gpm) for 10.25 hours, 7/4 at 1045 to 7/4 at 2100

The water level change vs time plot for PW67B (**Figure 5**) is a good graphical representation of the flow history for the test.

3.3.2 Calculated Aquifer Properties

- Curve matches for P29-TA and PW67B are shown in **Figure 7** and **Figure 8**.
- Hydraulic conductivity and permeability calculations are based on an effective aquifer thickness 40 meters (130 ft, see section 4.2 Comments) for the lower aquifer of the Midville System (**Figure 2**).

	P29-TA (OW)	PW67B (PW)
Storativity	1.2 E-4	1.2 E-4
Transmissivity	0.0090 m^2/s (8,400 ft^2/day)	0.010 m^2/s (9,300 ft^2/day)
Hydraulic Conductivity	0.00023 m/s (65 ft/day)	0.00025 m/s (71 ft/day)
Permeability	23 darcys	26 darcys

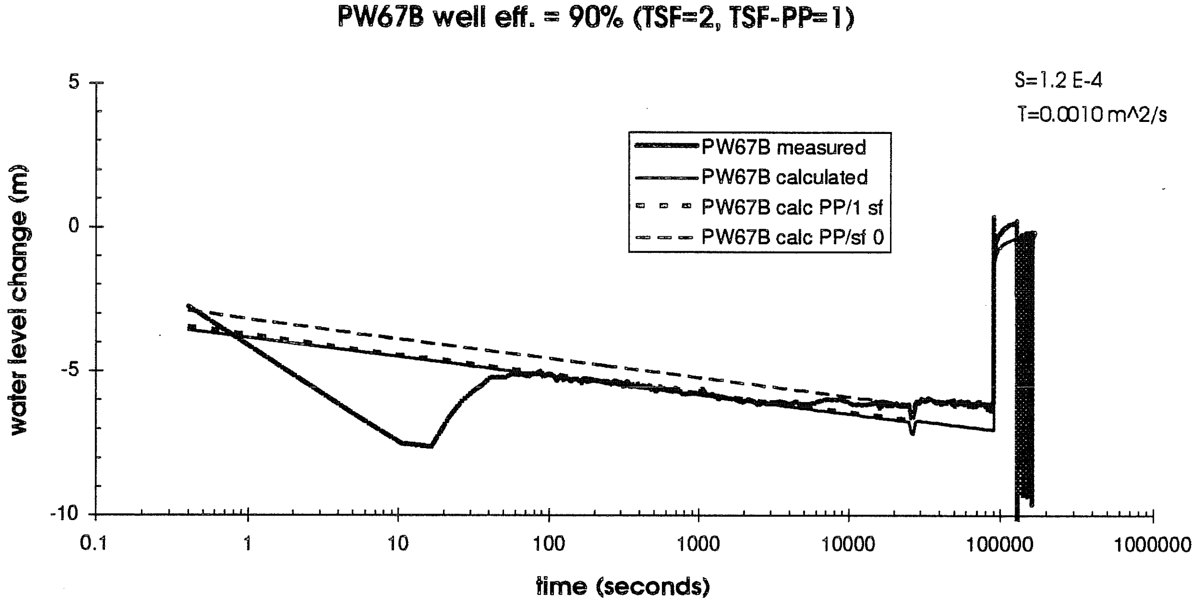
3.3.3 Calculated Skin Factor and Pumping Well Efficiency

A pseudo skin factor (does not consider effects of partial penetration) of 2 was calculated for the pumping well. This yielded a well efficiency of 80%. Well PW67B is screened over 110 ft of the 130 ft thickness of the lower Midville aquifer at B Area (**Figure 2**). When the effect of partial penetration is considered, a skin factor of 1 was calculated, yielding a well efficiency of 90% (**Figure 9**).

3.3.4 Specific Capacity

A flow rate change of 565 gpm created a 6.35 meter (20.8 ft) water level change after 25 hours in PW67B. This result equates to a specific capacity of 27 gpm/ft which is close to the specific capacity of 28.7 gpm/ft determined in the original test conducted on this well in 1963 (Buford Beavers, personal communication, 1994). A one hour test performed in May of 1993 calculated a specific capacity of 30.3 gpm.

Figure 9. Well efficiency analysis of PW67B: Plot of theoretical water level change for a perfectly efficient well (skin factor = 0) with actual drawdown of PW67B (pseudo skin factor = 2, skin factor = 1)



4.0 DISCUSSION

4.1 Leakance

At B Area, drawdown in the lower Midville (pumped aquifer) was less than expected at late pumping times (**Figure 8**), suggesting leakance across confining units separating the lower Midville from other aquifers in the section. Without data from observation wells screened in other aquifers, however, this finding could be attributed to causes other than leakance, for example a discharge boundary. Leakance was confirmed by water level changes in the lower Dublin (P29-TC) and upper Dublin (P29-TD, P29-A) aquifers directly related to pumping of the lower Midville aquifer. The relationship of changing water levels to changing flow rates for all observation wells is shown in **Figure 6**.

4.2 Comments

- The historical static water levels in 3 of the observation wells were within 6 inches, suggesting communication (leakance) between the Midville (P29-TA, screened in the same zone as the pumping well) and the Dublin Aquifer Systems (P29-TC and P29-TD) prior to the test. The static water level in the other observation well, P29-A (screened in the uppermost Dublin Aquifer), was about 2-3 ft below that of the other monitor wells. The relatively high flow rates during the test produced significant water level changes in all observation wells, including the P29-A well, clearly demonstrating the presence of leakance within the hydrogeologic section as high as the Upper Dublin aquifer.

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performing pump tests at water supply (production) well and monitor well cluster sites at SRS facilities, the amount and quality of information available to the model on the South Carolina side of the Savannah River can be substantially increased. This information can be acquired economically by testing existing production wells without the expense of drilling and then testing new wells.

1.2 Site Conditions

1.2.1 Location

D Area is located on the western side of the WSRC Savannah River Site (**Figure 1**).

1.2.2 Hydrogeologic Setting

The Savannah River Site is located on Coastal Plain sediments ranging in age from Miocene to Late Cretaceous. The sediments, interbedded sands and shales, were deposited over Paleozoic crystallines and Triassic red beds exposed by Late Cretaceous erosion. Regional dip is to the southeast and decreases upward from 48 ft/mi (9m/km) at the base of the section to 15 ft/mi (3 m/km) at the top of the middle Eocene beds (Snipes, 1993). Across SRS, the thickness of the sediments ranges from 700 ft (210 m) in the northwest to 1400 ft (430 m) in the southeast. At D Area the sediments are about 900 ft (275 m) thick. The Midville Aquifer System is the deepest aquifer in the section and is separated from the overlying Dublin Aquifer System by the Allendale Confining Unit.

1.2.3 Description of Wells Used for the Test

The primary water supply well for D area, PW905-3D, was used as the pumping well. Two wells (PW905-136D and PW-2D) were used as observation wells for the test. **Figure 2** relates the wells to the subsurface hydrogeology in a cross sectional view. **Figure 3** is a simplified site map showing the location of wells used for the test. **Figures 4 and 5** are schematics of the well construction diagram for PW905-3D and PW905-136D respectively. The specifics of each well are given below:

Pumping Well (PW905-3D):	SRS coordinates (ft) = N 66150 E 19820 Elevation (ground) = 40.84 m (134.00 ft) MSL Elevation (TOC) = 41.15 m (135.00 ft) MSL
<u>Total Depth (from TOC)</u>:	224.32 m (736 ft)
<u>Effective Well Depth (from TOC)</u>:	222.49 m (730 ft)
<u>Completion Date</u>:	1 September 1993

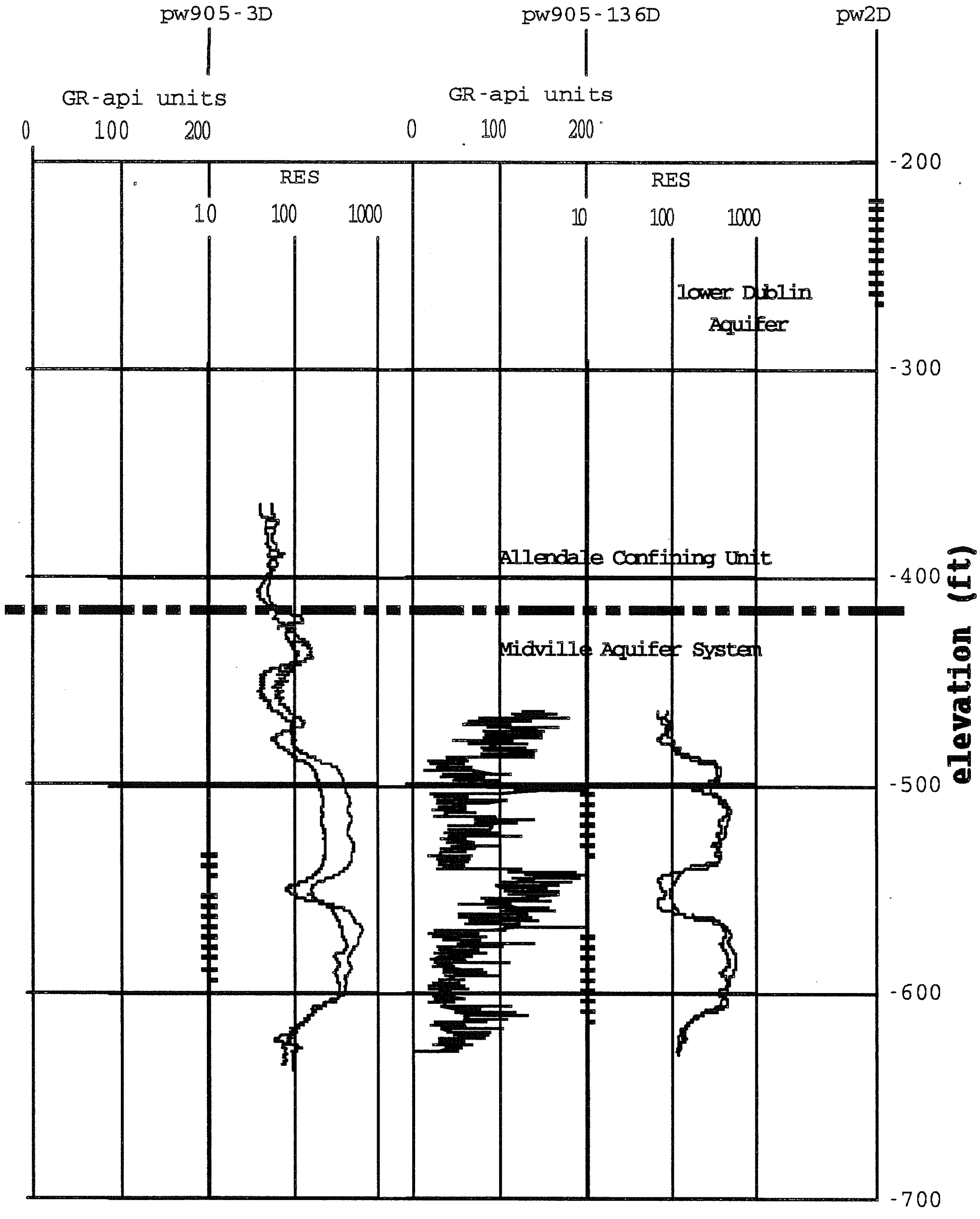


Figure 2. Schematic cross section at the D Area study site. Locations of the well screens are shown for each well.

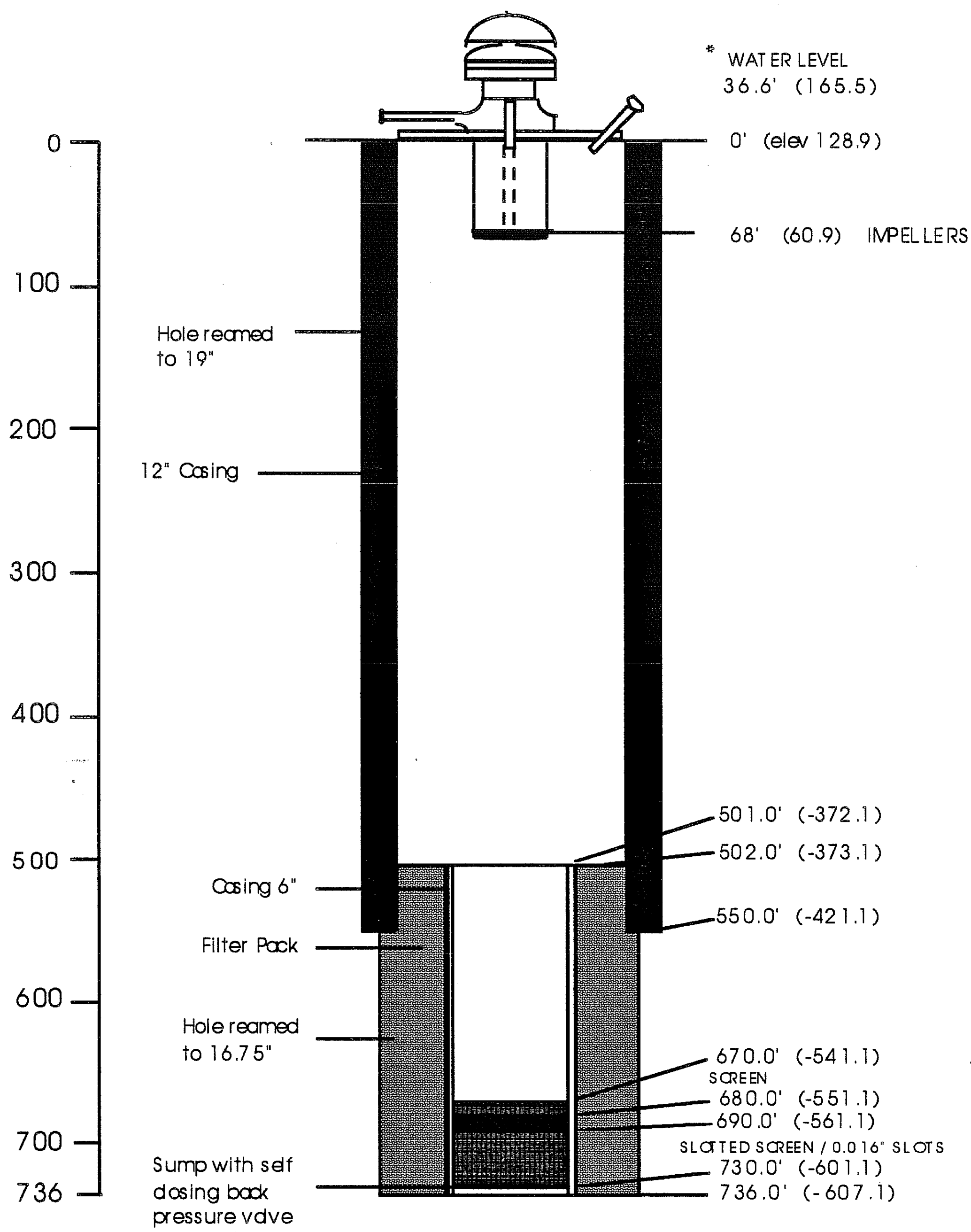


Figure 4. Well construction diagram of pumping well PW905-3D.

Observation Well (PW905-136D):	SRS coordinates (ft) = N 66180 E 20588 Elevation (ground) = 40.84 m (132.5 ft) MSL Elevation (TOC) = 41.15 m (135.0 ft) MSL
Effective Depth:	228.59 m (750 ft)
Elevation First Screened Interval:	-153.92 to -163.06 m (-505.0 to -535.0 ft) MSL
Elevation Second Screened Interval:	-175.25 to -187.44 m (-575.0 to -615.0 ft) MSL
Diameter (casing):	0.457 m (18") from 0 to 173.73 m (570 ft), 0.153m (6") from 173.73 to 231.64 m (570 to 760 ft)
Screened Geologic Unit:	Middendorf
Screened Hydrogeologic Unit:	lower Midville
Depth Static Water Level:	9.8 m (32.1 ft) **artesian**
Distance from Pumping Well	234.25 m (768.59 ft)

Observation Well (PW-2D):	SRS coordinates (ft) = N 65804 E 20126 Elevation (ground) = 39.84 m (130.7 ft) MSL Elevation (TOC) = 40.60 m (133.2 ft) MSL
Effective Depth:	122.52 m (402 ft)
Elevation First Screened Interval:	-13.35 to -14.87 m (-43.8 to -48.8 ft) MSL
Elevation Second Screened Interval:	-66.69 to -81.93 m (-218.8 to -268.8 ft) MSL
Diameter (casing):	0.203 m (8")
Screened Geologic Unit:	Upper Black Creek
Screened Hydrogeologic Unit:	Dublin (lower part)
Depth Static Water Level:	8.5 m (27.9 ft) **artesian**
Distance from Pumping Well	140.78 m (461.90 ft)

2.0 METHODS

2.1 Test Logistics

Ideally, a pump test is composed of three periods of data collection: background, pumping, and recovery. Background data is used to determine if the aquifer is in an equilibrium condition and the extent to which it is being affected by inconsistent external forces. It is also used to determine the barometric efficiency of the monitored aquifers so test data can be corrected for changes in atmospheric pressure. The aquifer is then pumped, creating a pressure drawdown cone extending radially from the pumping well. After pumping stops, the aquifer is allowed to recover to pre-test conditions. At D Area, background data was collected during regular intermittent pumping conditions as well as a 12 hour period during which pumping was stopped to allow for recovery of the aquifer.

2.2.2 Observation Well Data Acquisition Methods

Observation well PW905-136D is screened from -153.92 to -163.06 m and -175.25 to -187.44 m (-505.0 to -535.0 ft and -575.0 to -615.0 ft MSL). This is in the same lower Midville zones as pumping well PW905-3D. One other well screened in a shallower zone was monitored to detect vertical leakage if present. Well PW-2D is screened in the lower Dublin from -66.69 to -81.93 m (-218.8 to -268.8 ft MSL). The relative screen positions are shown in **Figure 2**.

well	transducer #	transducer psi rating
PW905-3D	1	45
PW905-136D	3	45
PW-2D	2	45
atmos		15

2.3 Analysis Methods

The initial analysis step is to correct the raw water level pressure data from the wells for changes in atmospheric pressure. These variations can mask the small response of an aquifer in a distant observation well or a well monitoring a different aquifer to detect vertical leakance. Removal of atmospheric pressure changes makes it easier to detect changes in water level that result from pumping. The correction is made using a barometric efficiency factor that is determined for each aquifer. Water level data is corrected by subtracting the relative change in atmospheric pressure multiplied by the barometric efficiency of the aquifer. The barometric efficiency numerically represents the magnitude to which changes in atmospheric pressure are transmitted to an aquifer. If the full magnitude of atmospheric pressure change is seen in an aquifer, a barometric efficiency correction factor of 1 is used (removes the full magnitude of relative atmospheric pressure changes from the water level pressure data). If an aquifer shows no response to changes in atmospheric pressure, a barometric efficiency of 0, there would be no need to correct for atmospheric pressure changes. Most aquifers in the study area have barometric efficiencies ranging from 0.5 to 0.9.

2.3.1 Observation Well Analysis Method

Data from an observation well screened in the same aquifer as the pumping well can be analyzed to calculate the storativity and transmissivity of the aquifer. Observation well PW905-136D is screened in the same zones as PW905-3D. The transmissivity and storativity of the aquifer is calculated by variable flow rate curve matching of observation well drawdown data using the superposition of the Theis solution (1935) or Jacob straight-line method (Cooper and Jacob, 1946) for variable flow rates. The

3.2 Data Acquisition Results

3.2.1 Pumping Rates

Well PW905-3D was pumped at 190 and 200 gpm during the test. The time intervals of relative discharge rates (Q) are shown followed by the actual flow rate. All flow measurements were made using the digital flow meter installed at the pumping well.

Q_0: 0.000 m^3/s

Q_1: 0.011989 m^3/s (time averaged rate) 190 gpm
pump on (190 gpm) for 1.25 hours, 12/11 at 1957 to 12/11 at 2112

Q_2: 0.01262 m^3/s (time averaged rate)
pump on (200 gpm) for 24.16 hours, 12/11 at 2112 to 12/12 at 2121:34

Q_3: 0.000 m^3/s (time averaged rate)

The water level change vs time plot for PW905-3D (**Figure 6**) is a good graphical representation of the flow history for the test.

3.2.2 Water Level Readings

During the test, 937 water level data points were recorded in the monitor wells by the Clemson system. Data points were recorded as frequently as every 5 seconds at times of rapidly changing water levels, decreasing to every 5 minutes when water level changes were relatively small. **Figures 6** and **7** show plots of change in water level vs time for the pumping well and observation wells.

3.2.3 Maximum Water Level Change During the Test

A drawdown of 2.47 meters (8.10 ft) was observed in PW905-3D during the pumping period of the test. Observation well PW905-136D, screened in the same Midville Aquifer zones as PW905-3D, had a drawdown of 0.32 meters. Observation well PW-2D, screened in the Dublin Aquifer, did not show pumping related water level changes.

- static WL's (artesian) were calculated from transducer pressure readings taken during background data collection.

well	aquifer	static WL (elevation)	WL change
PW905-3D	lower Midville	11.0 m (50.30 m AMSL)	2.47 m
PW905-136D	lower Midville	9.8 m (50.17 m AMSL)	0.32 m
PW-2D	lower Dublin	8.5 m (48.37 m AMSL)	0.03 m

3.2.4 Remarks

- Low temperatures during the early morning hours of 12/13/94 caused the water in the Tygon tubing connected to PW-2D to freeze. The freezing caused a large increase in pressure on the transducer (**Figure 8**). This occurred during the recovery phase near the end of the test.

3.3 Data Analysis Results

3.3.1 Barometric Corrections

Water level pressure data can vary as a direct response to changes in atmospheric pressure (due to changing weather conditions). At D area, the Midville and Dublin Aquifers were determined to have barometric efficiencies of 0.60 (60% of the relative atmospheric pressure changes were seen in the water level data).

Pressure data from the pumping well and monitor wells were corrected for atmospheric pressure changes using the following barometric efficiencies.

well	barometric efficiency
PW905-3D	0.60
PW905-136D	0.60
PW-2D	0.60

3.3.2 Calculated Aquifer Properties

- Curve matches for PW905-136D and PW905-3D are shown in **Figure 9** and **Figure 10.**

- Hydraulic conductivity and permeability calculations are based on an effective aquifer thickness of 40 meters (130 ft) for the lower aquifer (both lobes) of the Midville System (**Figure 2**).

Figure 9. Semi-log analysis (curve match) of observation well PW905-136D.

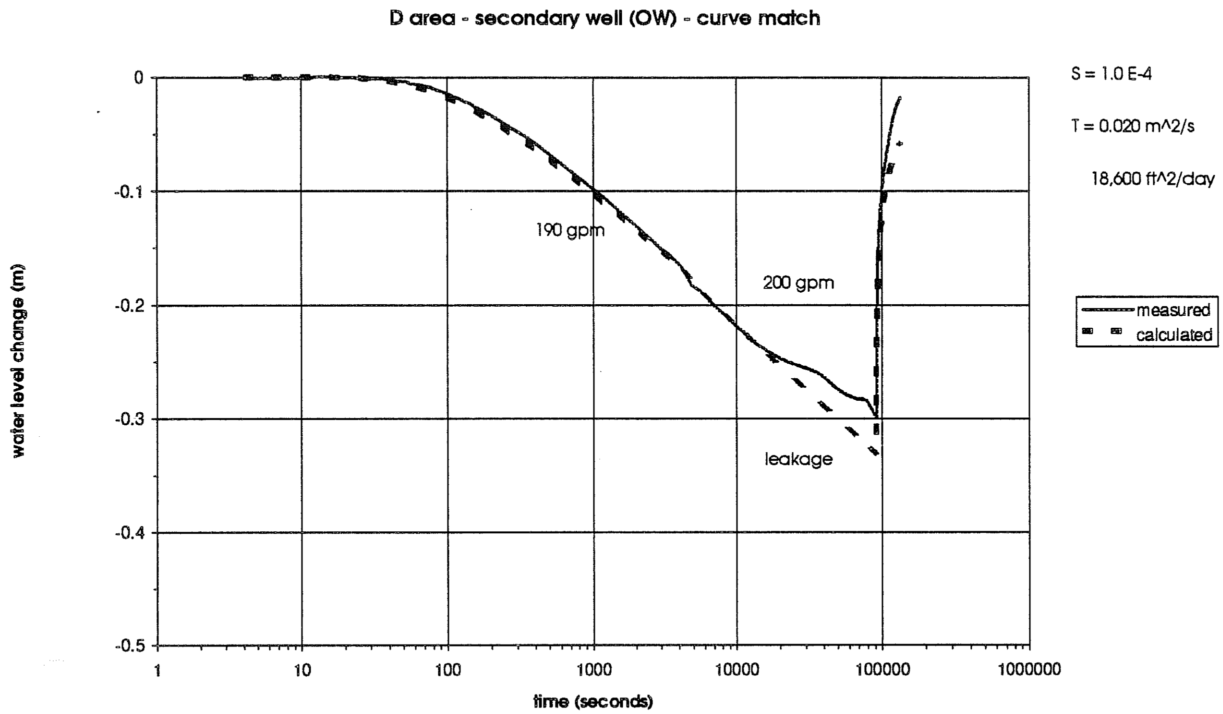


Figure 10. Semi-log analysis (curve match) of pumping well PW905-3D.

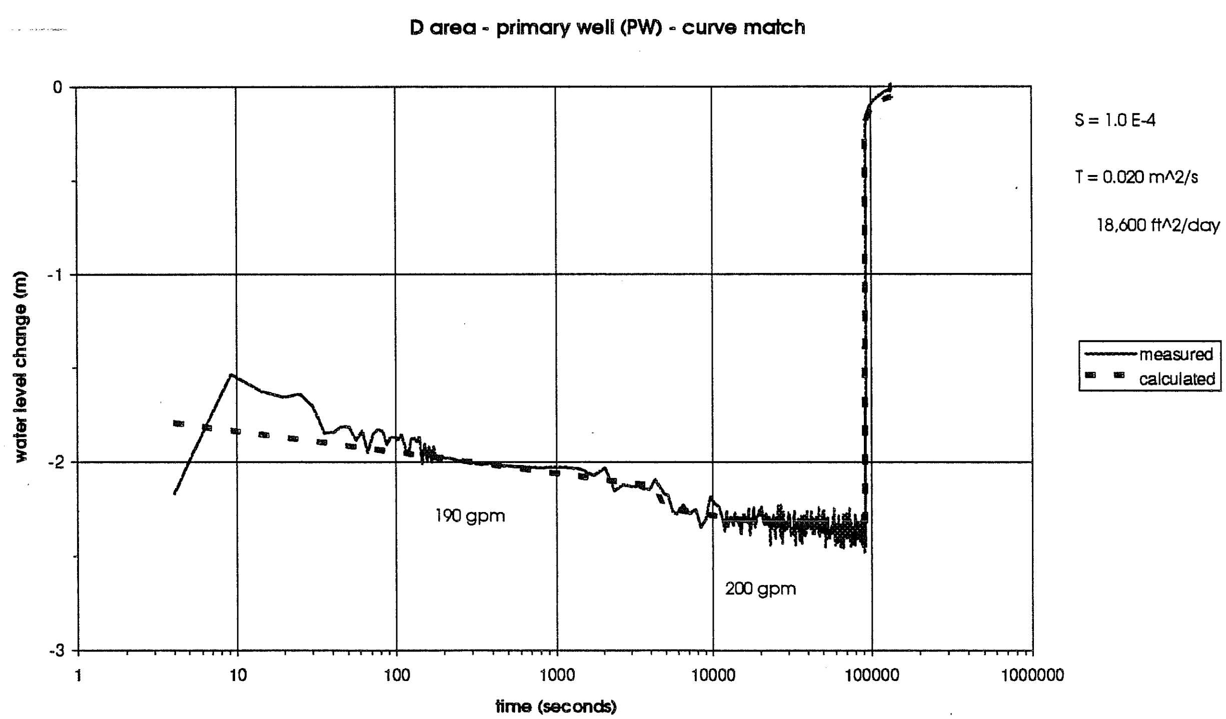
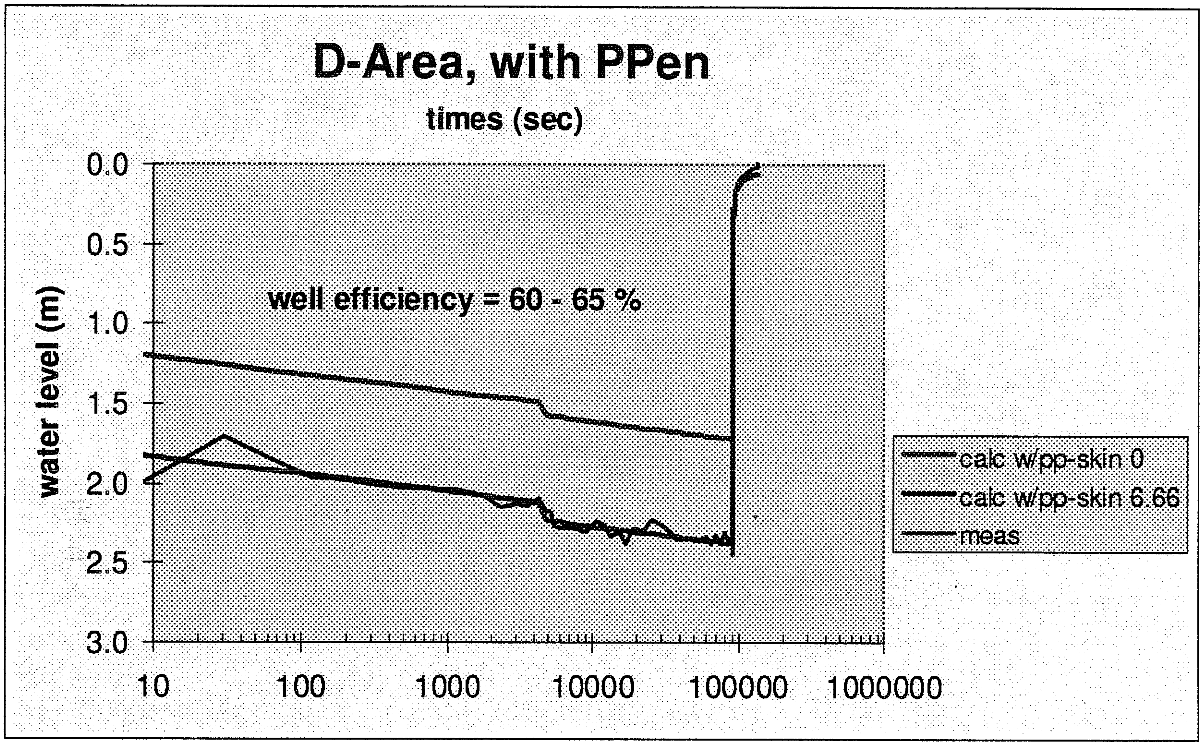


Figure 12. Well efficiency analysis of PW905-3D: Plot of theoretical water level change for a perfectly efficient well (skin factor = 0) accounting for partial penetration effects with actualdrawdown of PW905-3D. A skin factor of 6.6 (accounts for partial penetration) was calculated for the well.



4.0 DISCUSSION

4.1 Leakage

Leakage across the Allendale Confining System (separating the Midville from the overlying Dublin Aquifer System) was not detected at D Area during the test. Observation well PW-2D (lower Dublin), exhibited no water level changes directly related to pumping of the lower Midville by well PW-3D. Though, a pumping well located in the upper Midville or higher flow rates would have been a better test of the Allendale.

5.0 REFERENCES

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