May 21, 2009

Paul Pogorzelski, PE
Township Administrator/Engineer
Hopewell Township
201 Washington Crossing-Pennington Rd
Titusville, 08560-1410

Re: Aquifer Testing Results and Hydrogeologic Evaluation of the Pennytown Site, Block 33 Lot 1, in Hopewell Township, Mercer County, New Jersey.

Dear Mr. Pogorzelski:

M^2 Associates has completed the evaluation of the groundwater resources at the Pennytown site with respect to meeting water-supply demands of residential units to be constructed by Hopewell Township. These units will be constructed to satisfy a portion of the affordable housing requirements imposed on the township by the Council for Affordable Housing (COAH). Since the water-supply demands of the proposed project will be less than 100,000 gallons per day, the Township will not be required to obtain a New Jersey Department of Environmental Protection (NJDEP) water allocation permit.

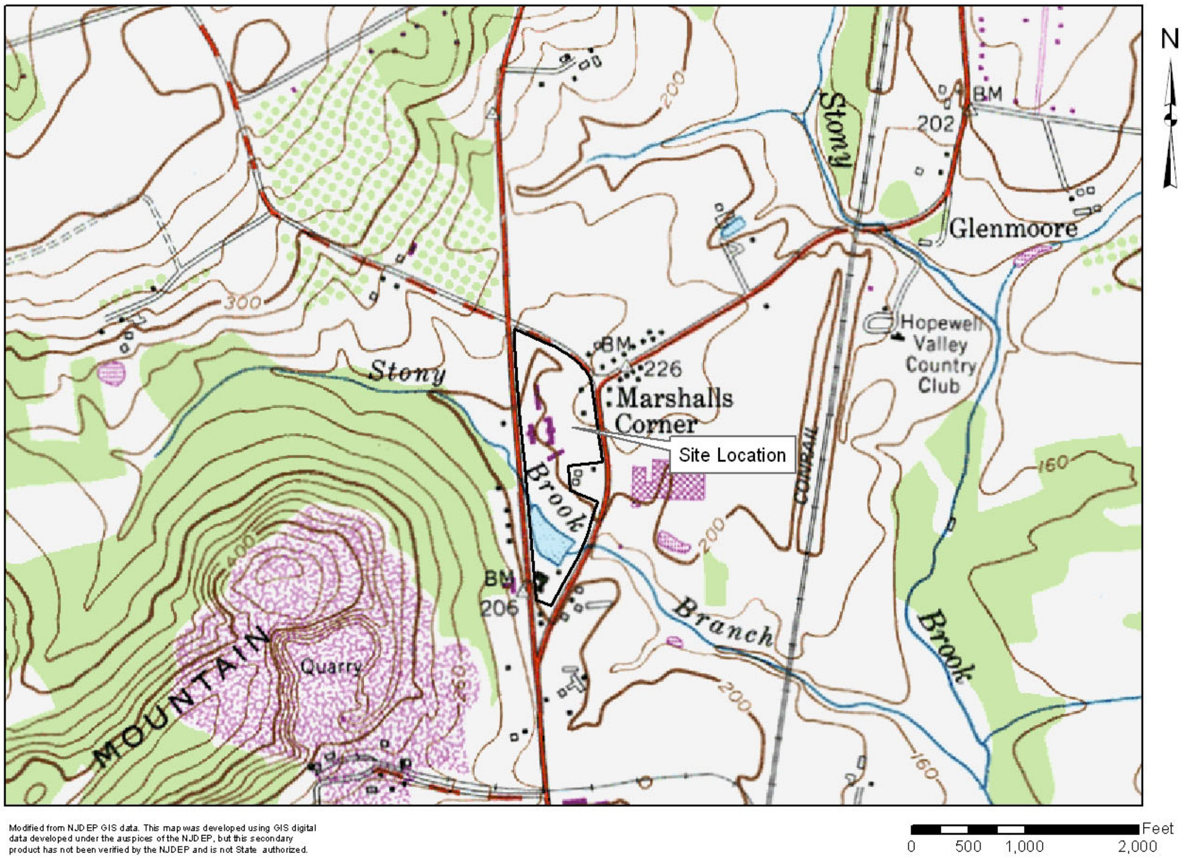
Based on information provided by the current property owner, it was assumed for this hydrogeologic evaluation that the site wastewater treatment plant and disposal fields have the capacity to treat and dispose 14,000 gallons per day (gpd). Therefore, this treatment/disposal rate was assumed to serve as the daily water-supply demand rate. Later testing by Alliance Environmental, LLC of the wastewater treatment/disposal operations indicate that the system is not capable of disposing 14,000 gpd and therefore, water-supply demands may be lower than the daily demand used in this evaluation. If the daily demand is lower than 14,000 gpd, then additional safety factor has been included in calculations herein.

SITE CONDITIONS

LOCATION

The location of the Pennytown site is shown on Figure 1. The site is bounded to the west by New Jersey State Highway 31, to the north by Marshalls Corner-Woodsville Road and to the east by Pennington-Hopewell Road (a.k.a. Marshalls Corner-Hopewell Road).

Figure 1: Location of Pennytown Site in Hopewell Township, New Jersey.



Geology

The bedrock geology beneath the site is shown on Figure 2. The entire Pennytown site is underlain by the Passaic Formation. Gray beds, which are members of the Passaic Formation, have been mapped along the eastern side of the site and the more classic red beds of this formation are mapped to the west and east of the gray beds. The difference between the beds is occasionally relevant with respect to hydrogeology. The gray beds were formed from sediments deposited in lakes, which were often very fine-grained silts and clays. Beds formed from these sediments may not yield or transmit water as readily as the red beds. Beneath the Pennytown site, results of well drilling indicate that the gray beds are lower yielding and less capable of transmitting water than the red beds further east.

Mapping of the bedrock geology as shown on Figure 2 and completed jointly by the United States Geological Survey (USGS) and New Jersey Geological Survey (NJGS) indicate that the beds are dipping relatively steeply at an angle of 32º to the southwest and striking North 11º West. Groundwater is often transmitted more readily in the direction of bedding strike and to a lesser extent, perpendicular to strike.

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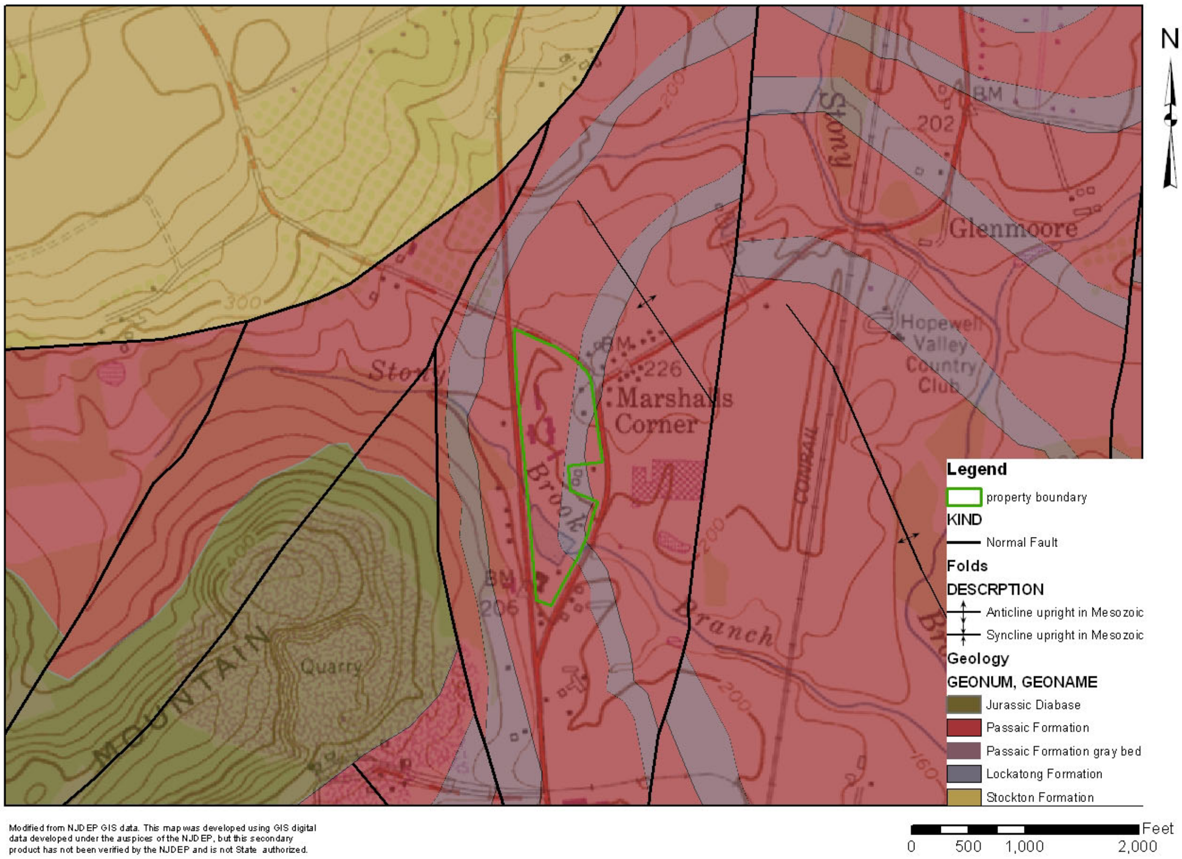
Figure 2: Bedrock Geology Beneath and Near Pennytown Site in Hopewell Township, New Jersey.



Modified from NJDEP GIS data. This map was developed using GIS digital data developed under the auspices of the NJDEP, but this secondary product has not been verified by the NJDEP and is not State authorized.

The USGS/NJGS mapping of the bedrock geology near the Pennytown site also shows that the property is located within a fault-bound block formed by a series of splays from the interbasinal Hopewell Fault. Since groundwater is transmitted and stored in bedrock aquifers in fractures and openings between blocks of rock, the presence of these faults indicates a significant potential for highly fractured bedrock beneath the site. For the faults depicted on Figure 2, the eastern block has moved downward with respect to the western block as the Newark Basin opened. Some estimates developed by USGS indicate that movement along the Hopewell Fault exceeded 10,000 feet, which suggests extensive fracturing and breaking of bedrock near this fault.

In summary, the location of the site in a fault bound block formed by splays of the interbasinal Hopewell Fault indicates a high potential for development of groundwater resources beneath the site. This potential is lowered by the presence of gray beds and the steep dip of bedding beneath the site. Beds encountered in wells at a depth of 200 feet below ground surface, would be exposed at ground surface at a distance of 320 feet east of the well location. Typically, the Passaic Formation beds dip at a much lower angle (10 to 15 degrees) and therefore, have a much larger potential horizontal extent.

WELL LOCATIONS

Bedrock geology and a fracture trace analyses of aerial photographs were used to identify potential well locations. Information provided by Hopewell Township Health Department with respect to historic and current wastewater disposal fields at the site, and other potential environmental concerns were used to refine the well locations. Based on this information and additional data obtained from the first two wells, a total of three new wells were installed to evaluate site hydrogeologic conditions. These wells were designed and located such that if Hopewell Township proceeds with construction of residential units, then one or more of the wells will serve as water-supply wells for the housing units. The locations of the wells are shown on Figure 3 and were located on this figure based on survey information provided by Hopewell Valley Engineering, PC.

Figure 3: New Well Locations at Pennytown Site in Hopewell Township, New Jersey.

At the request of the Hopewell Township Health Department, 30 to 32 feet of extra well casing was installed in each well. The wells are all constructed with the well casing extending to depths ranging from 80 to 82 feet below ground surface. The wells are all constructed as open holes in the bedrock from the bottom of the casing to the depth of 350 feet below ground surface.

Well 1 was the first well installed. Although the geologic mapping indicated the presence of the red beds at this location, gray beds were quickly encountered. The yield was measured at 12 gallons per minute (gpm), which while sufficient for meeting the needs of the proposed homes, was not sufficient for the required aquifer testing. Most of the yield in this well was encountered at 300 feet below ground surface.

Given the low yield of Well 1 and historic wastewater disposal to the west and south of this well location, the next well installed was Well 3 in the front yard of a former residence along Pennington-Hopewell Road. This location was the furthest eastern location on the site not located near a wastewater disposal zone. Based on the mapped dipping of bedding beneath the site, it was intended that by moving 100 feet up-dip of Well 1, that the fractured red beds providing water to Well 1 would be encountered at a shallower depths in Well 3. It also expected that additional water-bearing fractures would be encountered. The drilling at this up-dip location provided more than twice the yield reported for Well 1. The estimated yield of Well 3 is 25 gpm.

Since the yield of Well 3 was sufficient for meeting the demands of the proposed residential units, Well 2 was located to the northwest of Well 3 along the line of bedding strike. Well 2 was also located up-dip of Well 1 along a line perpendicular to strike. Siting the wells along strike and perpendicular to strike is in accordance with Hopewell Township Land Use Code Section 17-149 and general practice requirements of New Jersey Department of Environmental Protection (NJDEP) with respect to requests for major water withdrawals from the Passaic Formation. It was intended for Well 2 to serve as the pumping well and Wells 1 and 3 to serve as observation wells located perpendicular and along strike to evaluate anisotropic behavior of the aquifer. During the drilling of Well 2, the yield was estimated at 60 gpm or more than twice the yield of Well 3 and five times the yield of Well 1.

AQUIFER TESTING

STEP-DRAWDOWN TEST

A step-drawdown test was conducted in Well 2 to assess well efficiency and to determine a pumping rate that would be sustained for the longer-term aquifer test. The step-drawdown test was conducted at the following pumping rates 15, 32, 46, and 62 gpm and the duration of each step was 60 minutes. Figure 4 shows changes in water levels at each pumping rate.

The results of the step-drawdown test indicate that at 15 gpm, Well 2 could be pumped for several days if not months to years, with little change in water levels or drawdown in the well. As the rate increased, the ability of the aquifer to transmit additional water decreased slightly as indicated by the increased rate of drawdown in the well. The data indicate that Well 2 has the potential to be continuously pumped at a rate of 62 gpm for a week and that drawdown would be approximately 160 feet after 7 days of pumping.

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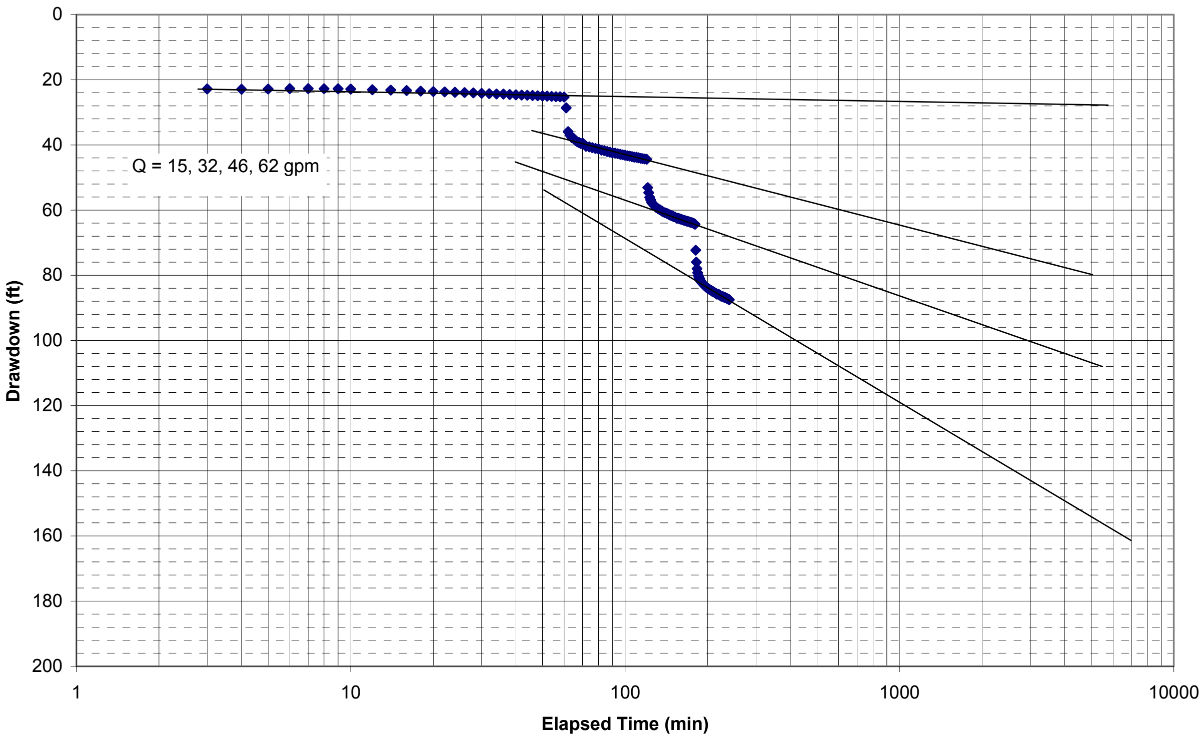
Figure 4: Step-Drawdown Test of Well 2 at Pennytown Site



Based on the step-drawdown test, a pumping rate of approximately 50 gpm was selected for the constant-rate testing of the aquifer. The step-drawdown test results indicated that 50 gpm would provide adequate stress to the aquifer to affect water levels in the observation wells, which is necessary to accurately determine aquifer characteristics. Water levels from non-pumping observation wells provide the most reliable data for calculating aquifer characteristics and therefore, for evaluating potential impacts to neighboring properties and natural resources. The rate of 50 gpm is five times the average daily rate of 10 gpm required to provide 14,000 gpd and 2.5 times the peak-day demand for the proposed housing project.

AQUIFER TEST PLAN/NEIGHBOR NOTIFICATION

After completing the step-drawdown test, an aquifer test plan was submitted to Hopewell Township Health Department and this department notified neighbors located within 500 feet of the Pennytown site boundaries of the test. Based on information provided by the Health Department, three neighbors requested monitoring of their wells during the constant-rate test. Based on information provided by two of these property owners, the wells on Block 34 Lots 12 and 13 could not be located.

The third property owner requesting monitoring was Pennwell Holdings/Kooltronics. Based on NJDEP mapping of the wells for Pennwell Holdings/Kooltronics, these wells

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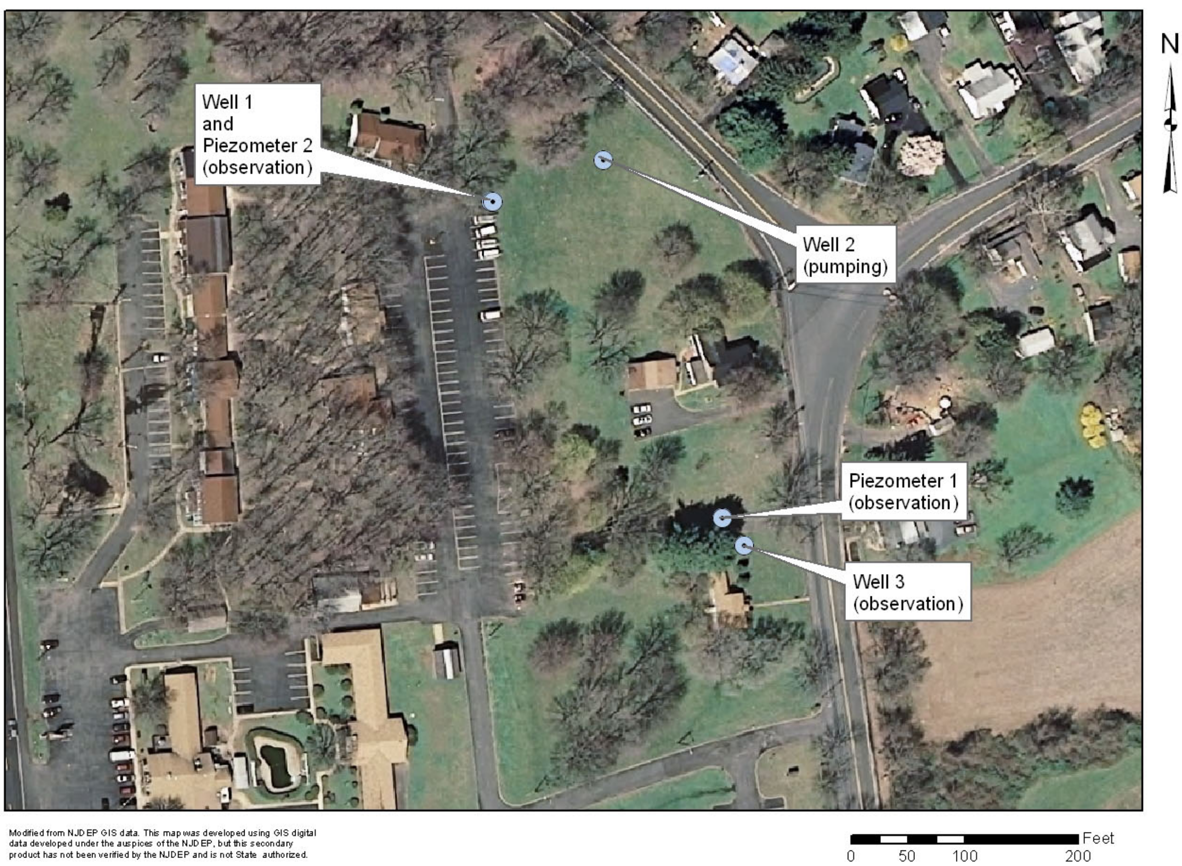
are located approximately 2400 feet southeast of Well 2. Given this distance, to observe any drawdown influence from the pumping of Well 2, it would be necessary for Pennwell Holdings/Kooltronics to shutdown their wells for a minimum period of four days. Since Pennwell Holdings/Kooltronics needs the wells to meet the water-supply demands of their operations and because Well 3 was located much closer to Well 2 and would provide more reliable data with respect to pumping influences to the southeast, the Pennwell Holdings/Kooltronics wells were not monitored during aquifer testing at the Pennytown site.

WELL LOCATIONS

Aquifer testing was conducted at the site using the three new wells and two nearby piezometers installed by Alliance Environmental. This testing was conducted to determine aquifer characteristics, calculate the long-term yields and radii of influences, and evaluate potential adverse impacts to wells on neighboring properties and natural resources. The locations of the wells and piezometers monitored during the testing are shown on Figure 5.

Figure 5: Pumping and Observation Well Locations for Aquifer Test at Pennytown Site in Hopewell Township, New Jersey.



Modified from NJDEP GIS data. This map was developed using GIS digital data developed under the auspices of the NJDEP, but this secondary product has not been verified by the NJDEP and is not State authorized.

As discussed above, Wells 1, 2, and 3 are all completed in the deeper bedrock aquifer encountered from approximately 80 to 350 feet below ground surface. The two piezometers were installed by Alliance Environmental in the shallow water-table aquifer beneath the site to 27 feet below ground surface. While the two piezometers were installed to evaluate aquifer characteristics of the water-table aquifer with respect to wastewater disposal, M^2 Associates monitored water levels in these piezometers to evaluate the hydraulic connection, if any, between the shallow water-table aquifer and the deeper bedrock aquifer. In some areas underlain by Passaic Formation rocks, confining layers can separate the shallow system from the deeper bedrock aquifer and provide additional protection from contaminants introduced near the ground surface.

The locations of Piezometer 1 and 2 also afforded an evaluation of the anisotropic nature of the hydraulic connection between the water-table aquifer and deeper bedrock aquifer. Piezometer 1, similar to Well 3 is located nearly along strike of bedding with respect to Well 2. Piezometer 2, similar to Well 1 is located perpendicular to strike. The distances between the pumping well and the observation wells and piezometers are summarized as follows:

Distance between Well 2 and Observation Point

Well 1	106
Well 3	362
Piezometer 1	333
Piezometer 2	104

PHASES/PRECIPITATION

The aquifer test was conducted in three phases. The background phase was extended to evaluate influences from precipitation. A total of 0.26-inch of precipitation was measured at the site during the last 24 hours of the background phase and no precipitation was measured during the pumping and recovery phases. A National Weather Service acceptable rain gauge was used at the site to measure precipitation. Given the extended background phase, the influence of precipitation on water levels is definable with water levels increasing in the three wells.

The background phase of water level monitoring in the three site wells and two shallow piezometers was conducted to evaluate antecedent trends. In the three wells and Piezometer 1, the background phase was started at 14:00 on April 9, 2009 and concluded at 9:52 on April 22, 2009. The background phase in Piezometer 2 started at 14:00 on April 13, 2009 and concluded at the same time as in the other wells. This phase was conducted to assess antecedent trends.

The pumping phase started at 9:53 on April 22, 2009 and continued for 24 hours. During this phase, water was withdrawn from Well 2 at a constant rate of 50 gpm and water levels were measured in the pumping well, two observation wells and two piezometers to evaluate pumping influences.

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The recovery phase started at 9:53 on April 23, 2009 and continued for 48 hours. This phase was conducted to determine the aquifer response to the cessation of pumping and evaluate potential for dewatering/mining of the aquifer.

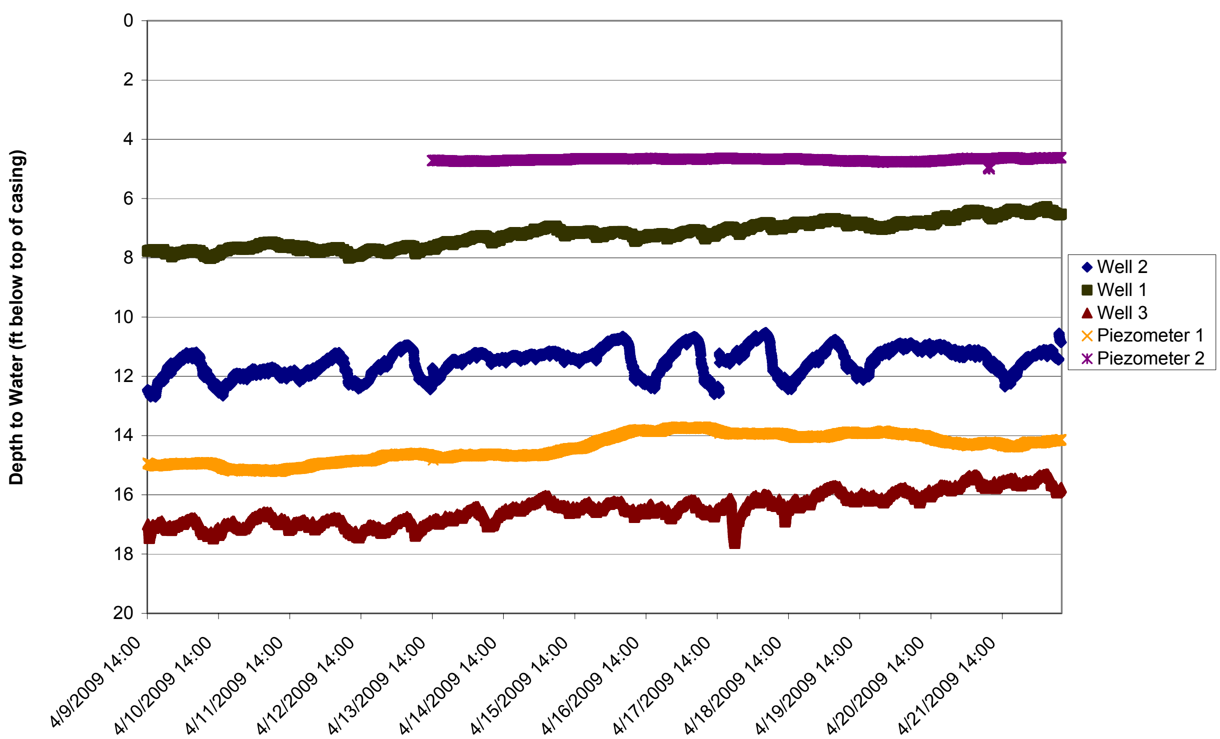
During all three phases of testing, water levels were measured and recorded in the three site wells and two piezometers every minute with pressure transducers and datalogging devices.

RESULTS

Background Phase

The depth to groundwater in the three site wells and two piezometers are shallow. Figure 6 shows the depth to groundwater as measured from the top of casing in the three wells and two piezometers. The top of casing ranged from 1.7 to 2.3 feet above ground surface in these five measuring points. Groundwater was encountered within 16 feet of ground surface in all five monitoring locations.

Figure 6: Depth to Water in Wells During Background Phase at Pennytown Site



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With the exception of Piezometer 2, water levels beneath the site increased during the background phase. Water levels in Piezometer 2 fluctuated slightly during the nine days of background monitoring but remained relatively unchanged from the initial static level made at the beginning of the phase.

After subtracting the influence of daily fluctuations, water levels increased approximately 1.3 feet in Wells 1, 2, and 3 during the nearly 13 days of background monitoring. Water levels in Piezometer 1 increased nearly 0.8-foot during the background phase. Nearly two inches of precipitation were measured between April 9 and 21, 2009. The background phase data indicate that the deep bedrock aquifer and the shallow water-table aquifer intersected by Piezometer 1 are replenished by precipitation. Given the steep dip of bedrock beds beneath the site as measured by USGS/NJGS, it is likely that the precipitation must infiltrate near the site to result in such quick increases in water levels.

The data from Wells 2 and 3, and to a much lesser extent the data from Well 1, indicate daily fluctuations in water levels. These data indicate that water levels are at highest point during early morning hours (before 6:00AM), then decline in the later morning hours before increasing in the early afternoon hours. Water levels then decline again during the late afternoon/early evening hours. This pattern is indicative of off-site water use. Some of these fluctuations can range from a few tenths of a foot to more than 1.5-feet. The larger fluctuations suggest nearby pumping influences.

It is highly unlikely that the water-level fluctuations are a result of pumping at the Pennwell Holdings/Kooltronics site, the only high volume water user near the site, since the fluctuations are more noticeable during the weekends and are not as noticeable during long week day periods such as April 14 through 15 and 20 through 21. Furthermore, the fluctuations are more evident in Well 2 than in Well 3. Well 3 is approximately 360 feet nearer the Pennwell Holdings wells than Well 2.

It is very likely that the fluctuations in the deep bedrock wells are a result of residential water use in the homes of nearby Marshalls Corner. Water levels in Well 2 can fluctuate more than 1.5 feet over a period of a few hours from off-site pumping. In addition, some of the fluctuations in Well 3 do not correspond to changes in Well 2. The background phase data indicate that some of the residential wells in Marshalls Corner are hydraulically connected to the site wells.

Pumping Phase

Well 2 was pumped continuously for 1440 minutes (24 hours) at an average rate of 50.1 gpm. The rate fluctuated only slightly during the test with a total of 72,114 gallons of water withdrawn. The total volume of water is more than five times the average daily demand of 14,000 gallons initially anticipated for this site. The volume of water was more than 2.5 times the peak-day demand as determined with the procedures outlined in Hopewell Township Land Use Code Section 17-149.

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Water levels in the three site wells and Piezometer 1 were influenced by the pumping of Well 2 at this rate. Water levels in Piezometer 2 were significantly less affected by the pumping in the deeper bedrock aquifer approximately 104 feet to the east. Water levels measured in the wells and piezometers within the minute prior to the start of pumping and drawdown after 24 hours of continuous pumping are summarized as follows:

Pre-Pumping Water Levels and Drawdown

Monitoring Point	Pre-Pumping Water Level (ft below the top of casing)	Total Drawdown (ft)
Well 2	10.86	74.62
Well 1	6.52	36.40
Well 3	15.75	14.03
Piezometer 1	14.14	5.00
Piezometer 2	4.62	0.11

Drawdown is the measure of the distance water levels are lowered as a result of pumping. Therefore, at the end of the pumping phase, the water level in Well 2 was 85.48 feet below the top of casing. Water level changes in the three site wells and two piezometers are shown on Figures 7 through 11.

Figure 7: Drawdown in Well 2 While Pumping Well 2

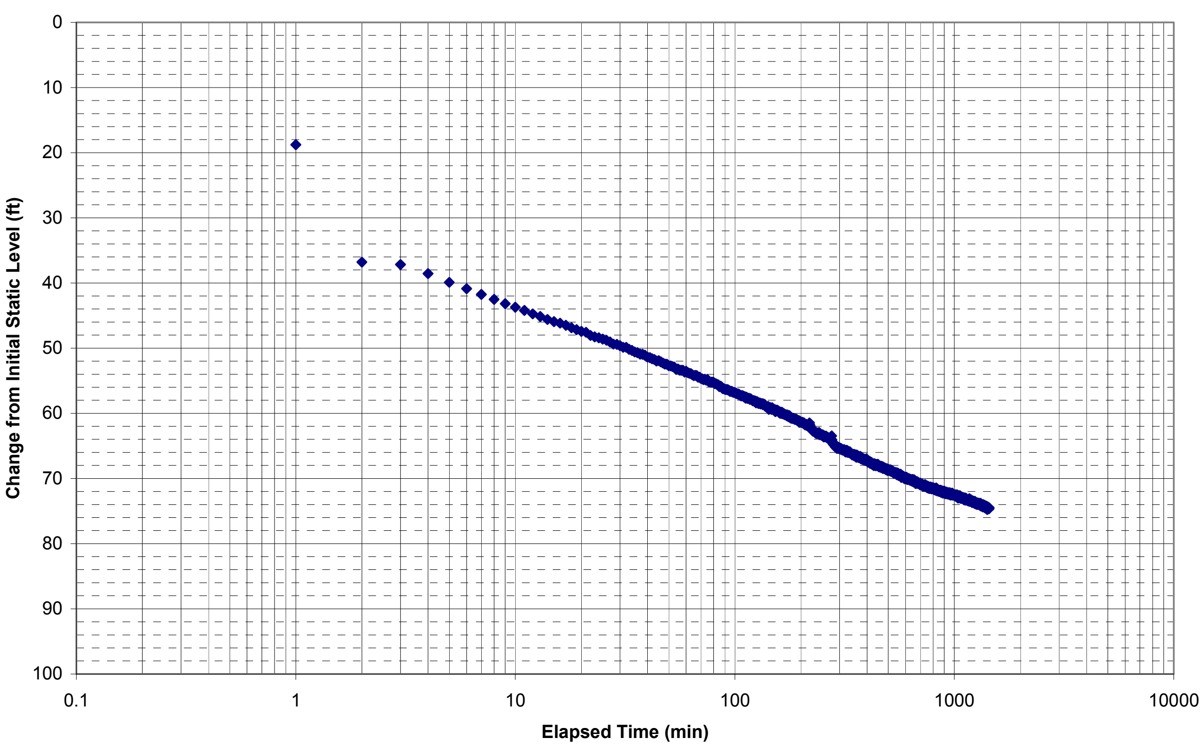

Figure 8: Drawdown in Well 1 While Pumping Well 2

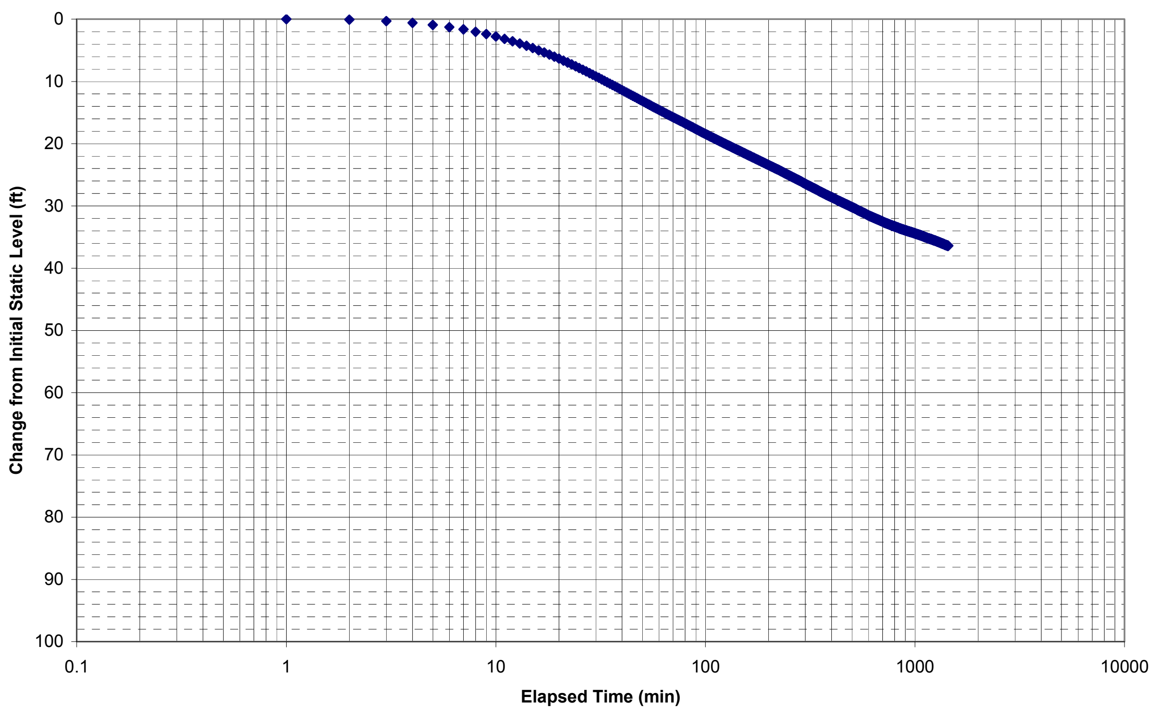

Figure 9: Drawdown in Well 3 While Pumping Well 2

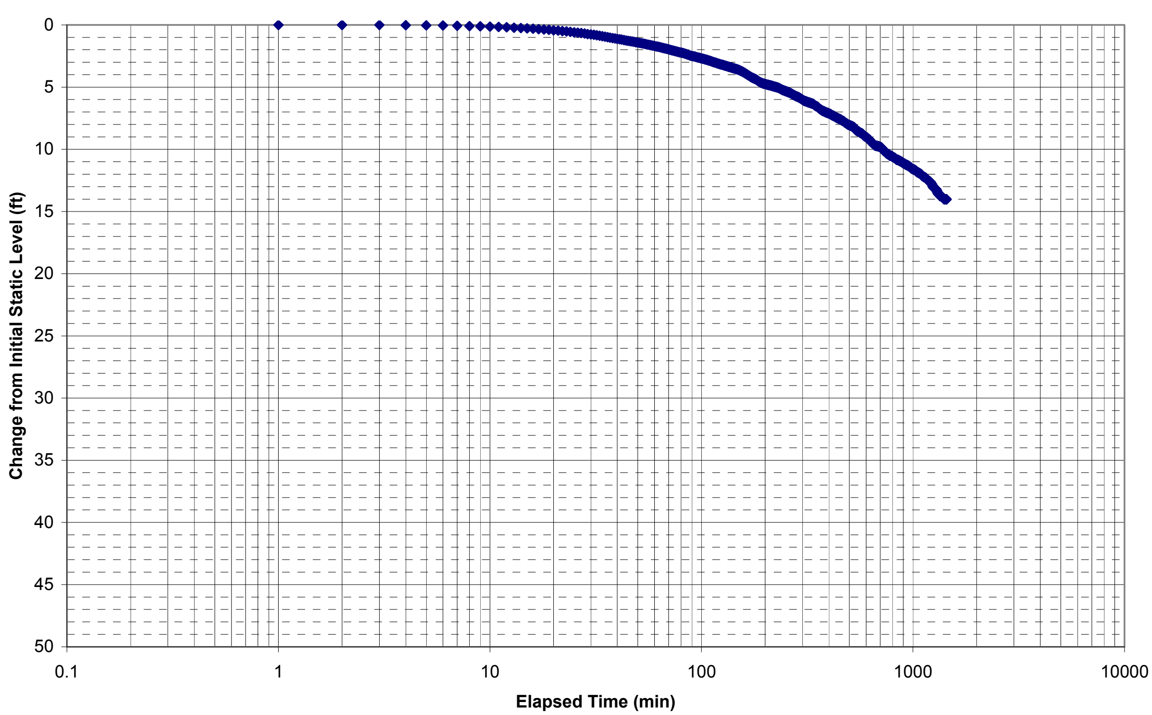

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Figure 10: Drawdown in Piezometer 1 While Pumping Well 2

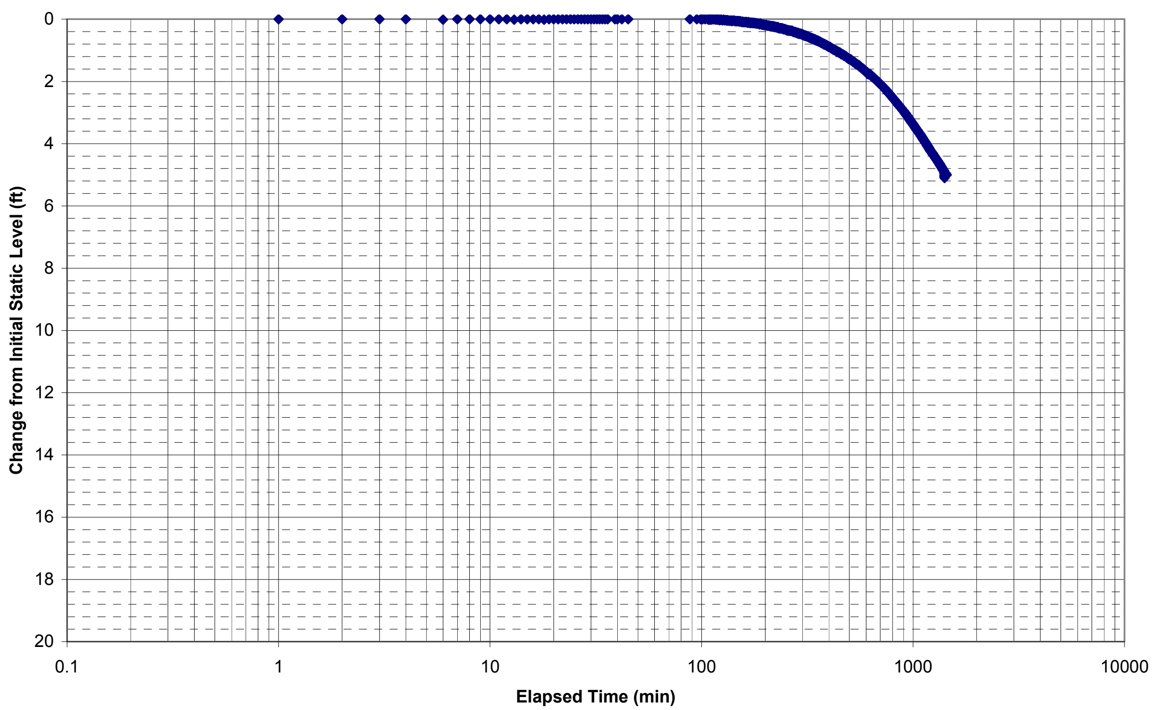
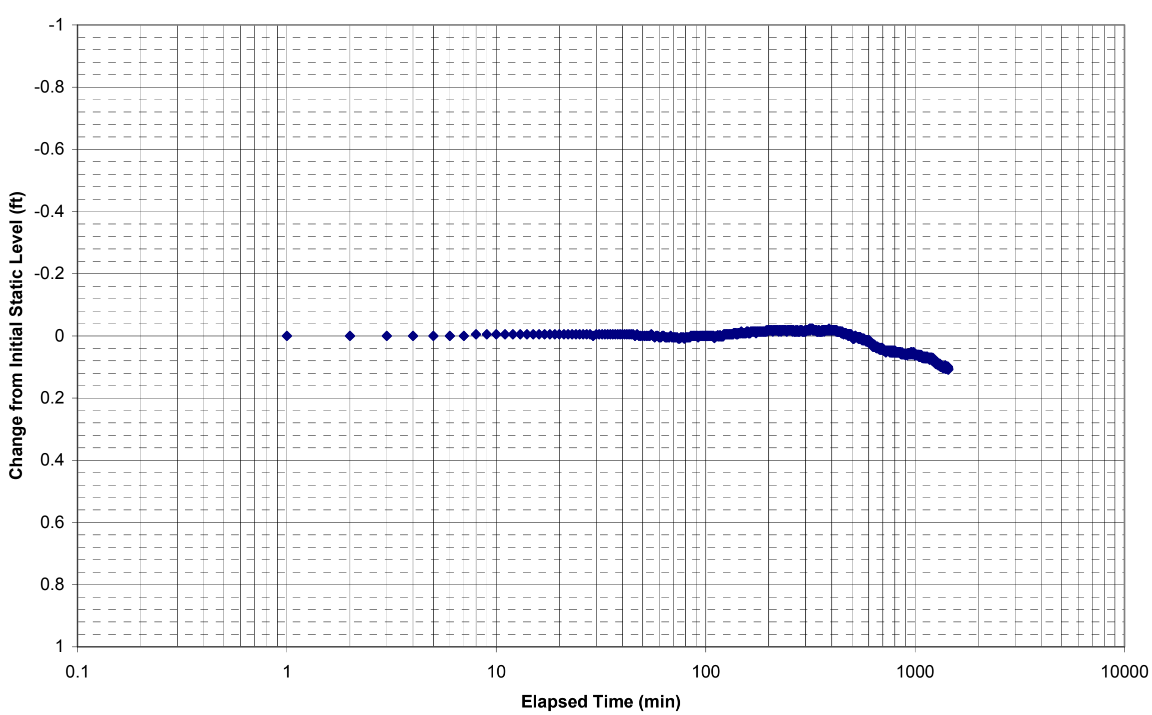


Figure 11: Drawdown in Piezometer 2 While Pumping Well 2



The rate of drawdown in Wells 1 and 2 is linear indicating no significant boundary conditions were encountered. If the slopes of lines drawn through the data from the Wells 2 and 1 flattened, it would indicate replenishment at a rate greater than the pumping rate. If the slopes steepened, it would indicate shallow fracture dewatering.

The data from Well 3 indicate increased rates of drawdown after approximately 1200 minutes of pumping, which suggests that water in shallow fractures along strike is draining to deeper fractures. The data from Piezometer 1 indicate drainage of shallow water-bearing fractures and a significant hydraulic connection along strike between the shallow water-table aquifer intersected by this piezometer and the deeper bedrock aquifer intersected by Wells 2 and 3. The data from Piezometer 2 also indicate increasing rates of drawdown as shallow water-bearing zones are drained into the deeper bedrock aquifer but to a much lesser extent than Piezometer 1.

The pumping phase data indicate that the deep bedrock aquifer intersected by Wells 1, 2, and 3 is hydraulically connected to the water-table zone intersected by Piezometers 1 and 2. The data from Piezometer 2 (after 520 minutes) show a slightly delayed response to pumping in comparison to Piezometer 1 (after 120 minutes). The data from these two piezometers indicate the hydraulic connection. The difference in delayed responses indicates anisotropic behavior with greater tendency to lower water levels in the shallow zone along strike than down dip. The data indicate that discharges to the shallow zone can infiltrate to the deeper bedrock aquifer and affect the quality of water withdrawn from Wells 1, 2, and 3.

Figure 12: Distance versus Drawdown at Pennytown Site

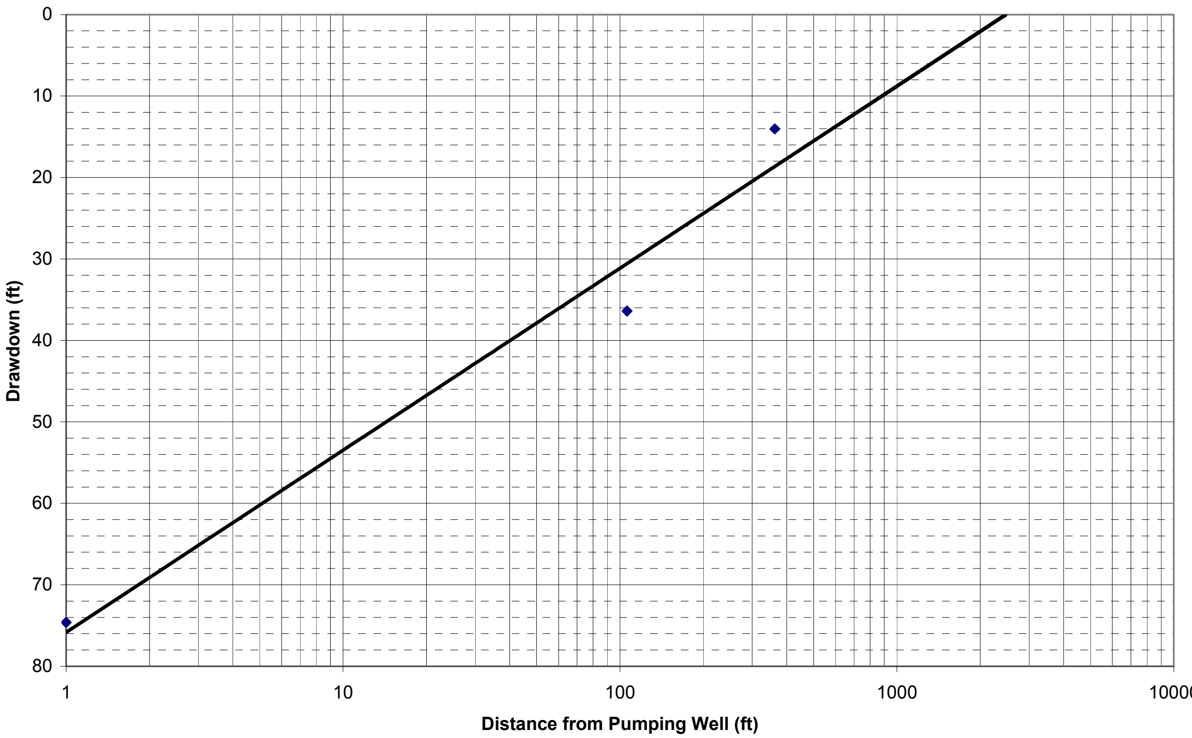


Figure 12 depicts the distance versus drawdown relationship for the three bedrock wells. The result of this analysis indicates that the radius of influence from the pumping of Well 2 at a rate of 50 gpm extends approximately 2500 feet from the pumping well. The data indicate a slightly anisotropic influence with greater drawdown than expected from the linear relationship in Well 1 and less drawdown than anticipated from this relationship in Well 3. Since drawdown is inversely related to transmissivity, the data would indicate a greater transmissivity along strike toward Well 3 and less aquifer transmission capacity in the direction perpendicular to strike.

Approximately 21 hours after the pump was started in Well 2, the owner of Block 34 Lot 13, Alexa Udy, notified on-site personnel that the pump in her well was running constantly. Prior to pumping, Mrs. Udy was not sure of the location of her well but when the problem occurred, the well was located by a representative of Samuel Stothoff Company in the basement of the house. This representative turned the pump off until the well and pump could be later examined by a licensed pump installer and a representative of M^2 Associates. It was determined by M^2 Associates based on water-level measurements in Mrs. Udy's well that the pumping of Well 2 had affected water levels in her well and lowered the water level below the pump intake. The licensed pump installer examined the pump and concluded that the pump was operating.

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The Udy well is approximately 58 feet deep and the water level in this well was lowered below the intake point at approximately 41 to 45 feet below the basement floor. Upon the cessation of pumping of Well 2, water levels in Mrs. Udy's well recovered and within three hours, the pump and well returned to normal operation. The data from the Udy well taken in conjunction with the data from the background, pumping, and recovery phases indicate that pumping at the Pennytown site will affect water levels in nearby residential wells. The extent of these impacts is directly dependent on the rate of withdrawals at the Pennytown site.

Recovery Phase

For the 48-hour period after the pump was turned off in Well 2, water levels in this well, the two observation wells and the two piezometers continued to be measured and recorded every minute. Water levels as measured before the start of pumping, 48-hours after pumping stopped, and residual drawdown in the wells and piezometers are summarized as follows:

Monitoring Point	Pre-Pumping Water Level (ft below the top of casing)	Water Level after 48 Hours of Recovery (ft below the top of casing)	Residual Drawdown (ft)
Well 2	10.86	15.58	-4.72
Well 1	6.52	11.52	-5.00
Well 3	15.75	20.71	-4.96
Piezometer 1	14.14	21.05	-6.91
Piezometer 2	4.62	4.79	-0.17

Water levels in the wells and piezometers did not return to the levels measured prior to the start of pumping. Water levels in the bedrock aquifer were approximately 5 feet lower 48-hours after pumping stopped than they were before pumping. Water levels in Piezometers 1 and 2 continued to decline after pumping stopped and were lower 48-hours after pumping stopped than immediately after pumping stopped. These data indicate that the shallow water-bearing zones continued to drain into the deeper bedrock aquifer to replace groundwater withdrawn from this aquifer during the pumping phase. Water level responses to the cessation of pumping in the three bedrock wells and two shallow piezometers are shown on Figures 13 through 17.

Figure 13: Water Levels in Well 2 After Pumping Well 2

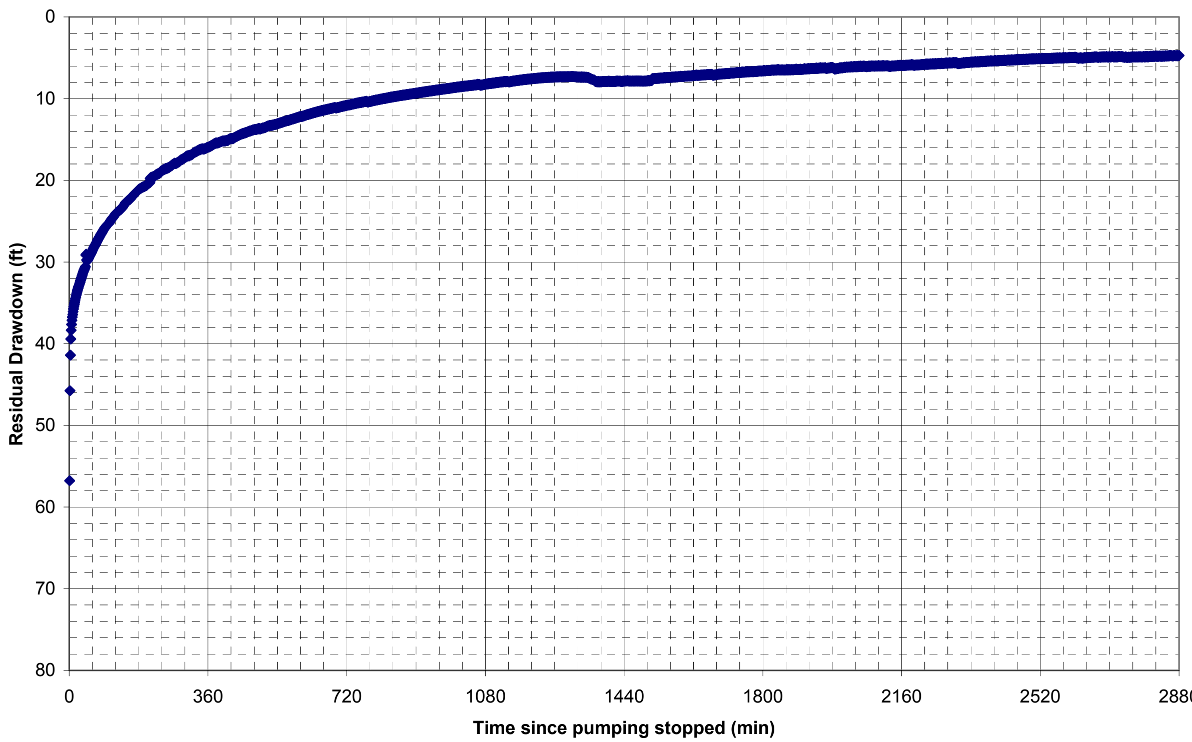

Figure 14: Water Levels in Well 1 After Pumping Well 2

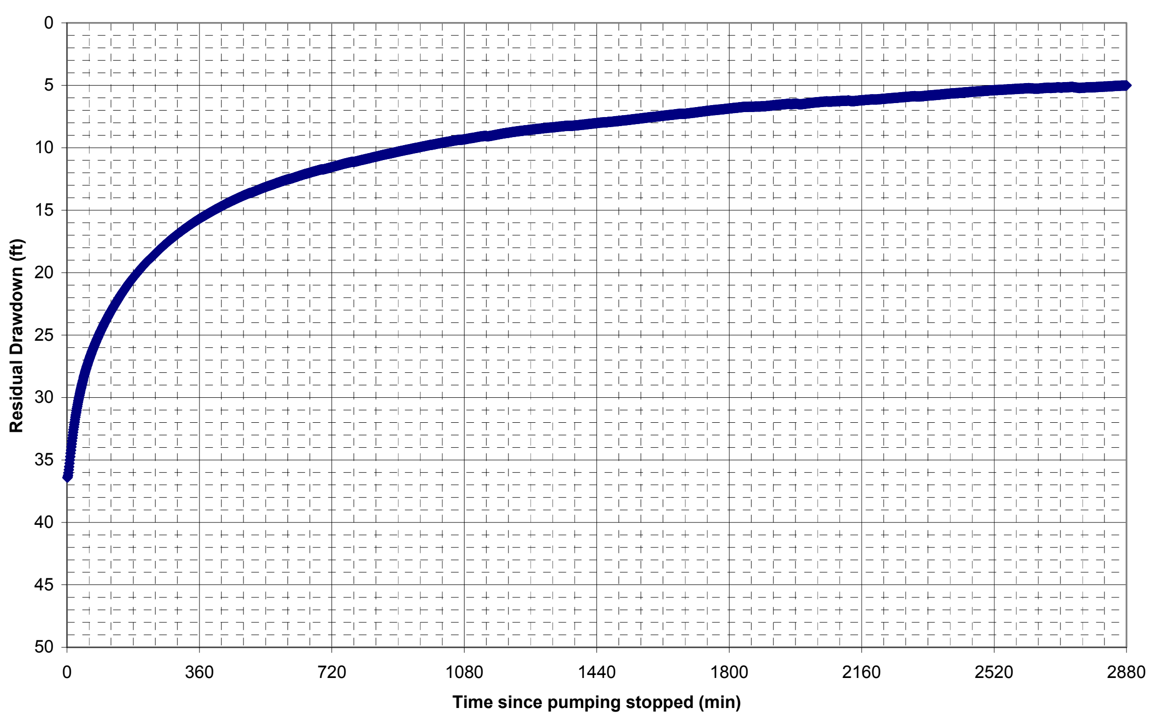

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Figure 15: Water Levels in Well 3 After Pumping Well 2

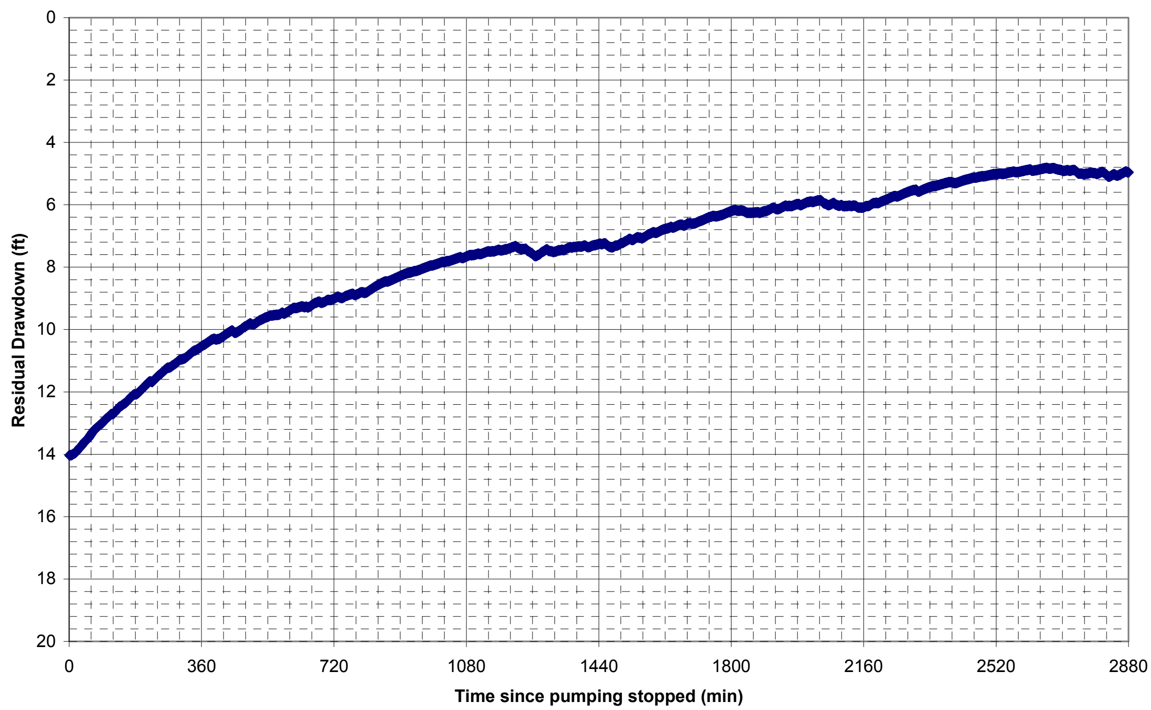


Figure 16: Water Levels in Piezometer 1 After Pumping Well 2

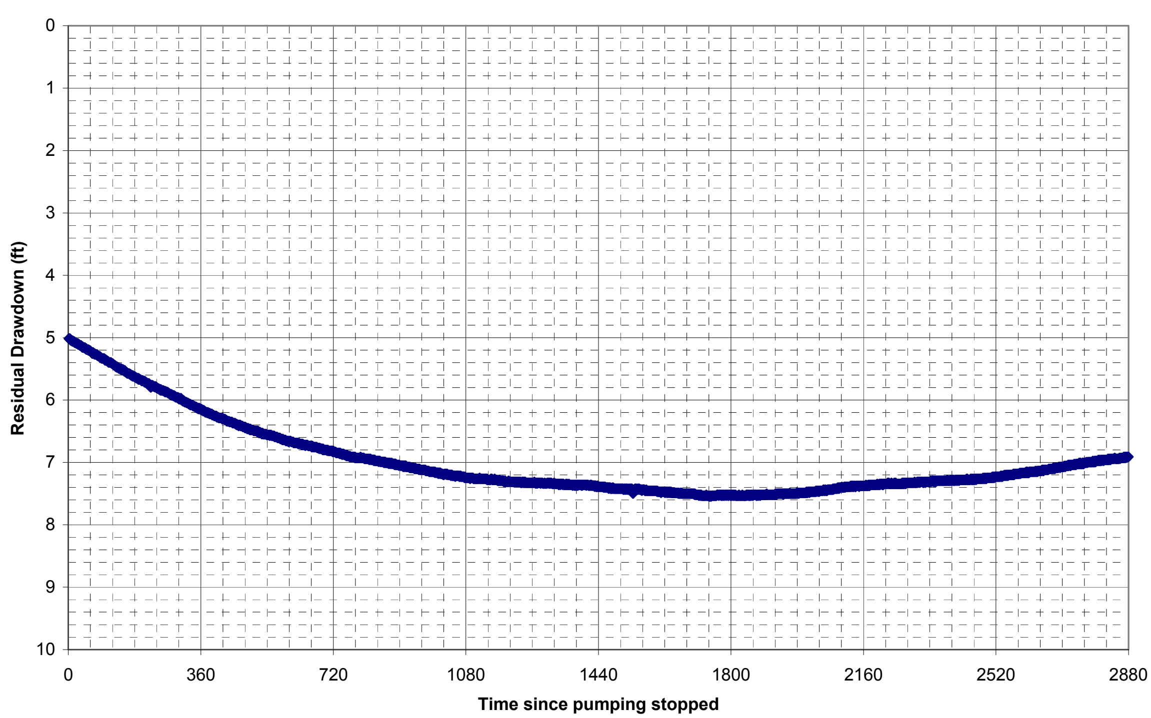
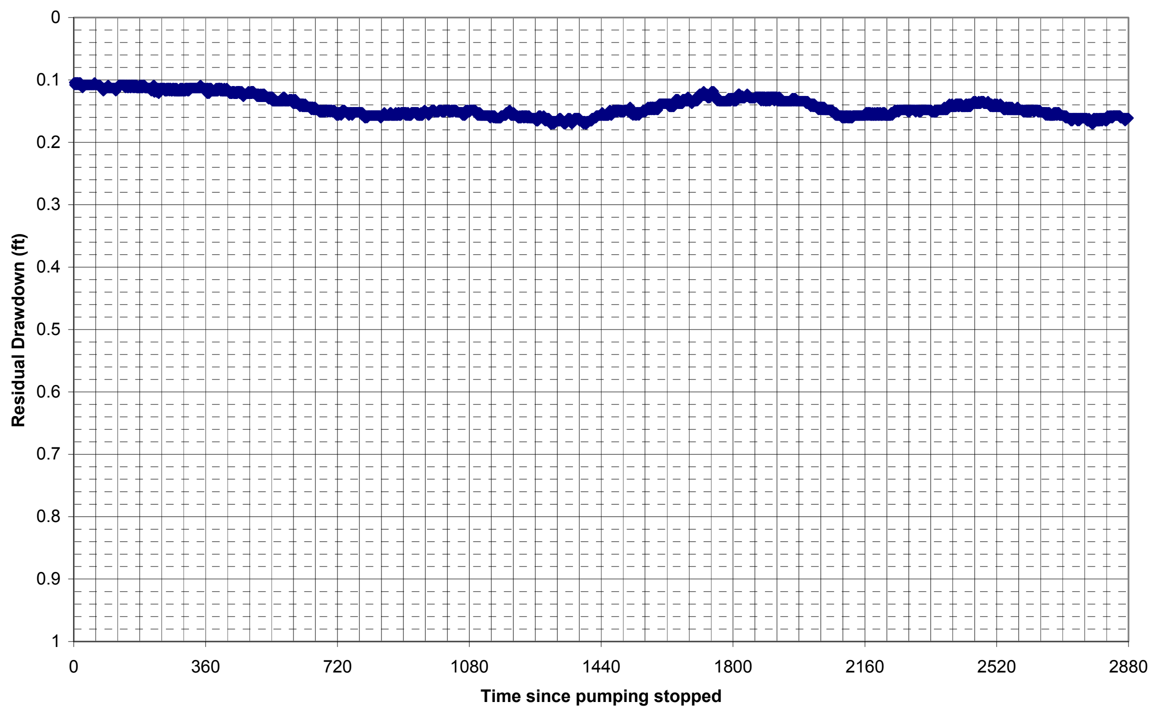


Figure 17: Water Levels in Piezometer 2 After Pumping Well 2



The recovery phase data indicate that initially, the deep bedrock aquifer responds quickly to the cessation of pumping but then the rate of recovery slows substantially as water infiltrates from shallow water-bearing zones downward to the deeper bedrock zones. A full analysis of the recovery phase data indicates that the deep bedrock aquifer will recover to pre-pumping water levels but that recovery is dependent on the availability of water in shallow fractures and the rate at which, groundwater can migrate vertically. The data further indicate that recovery is dependent on precipitation. During prolonged drought, recovery in the site wells will be slowed as less water is available in shallow zones. Shallow wells at nearby residences will likely be affected.

The data from the recovery phase were analyzed with the Theis (1935) residual drawdown method to determine aquifer response to pumping. The data from the three wells are depicted graphically on Figures 18, 19, and 20. These plots of residual drawdown versus the ratio of the time since pumping started to the time since pumping stopped indicate that the aquifer was trending to full recovery. The data indicate an aquifer of limited extent but do not indicate the potential for significant mining or dewatering. The recovery phase data indicate that the aquifer is dependent on replenishment from precipitation infiltrating to the shallow water-table aquifer and ultimately, draining to the deeper water-bearing zones. The data further indicate that rates of withdrawals should be balanced with rates of infiltrating water.

Figure 18: Residual Drawdown in Well 2 After Pumping Well 2

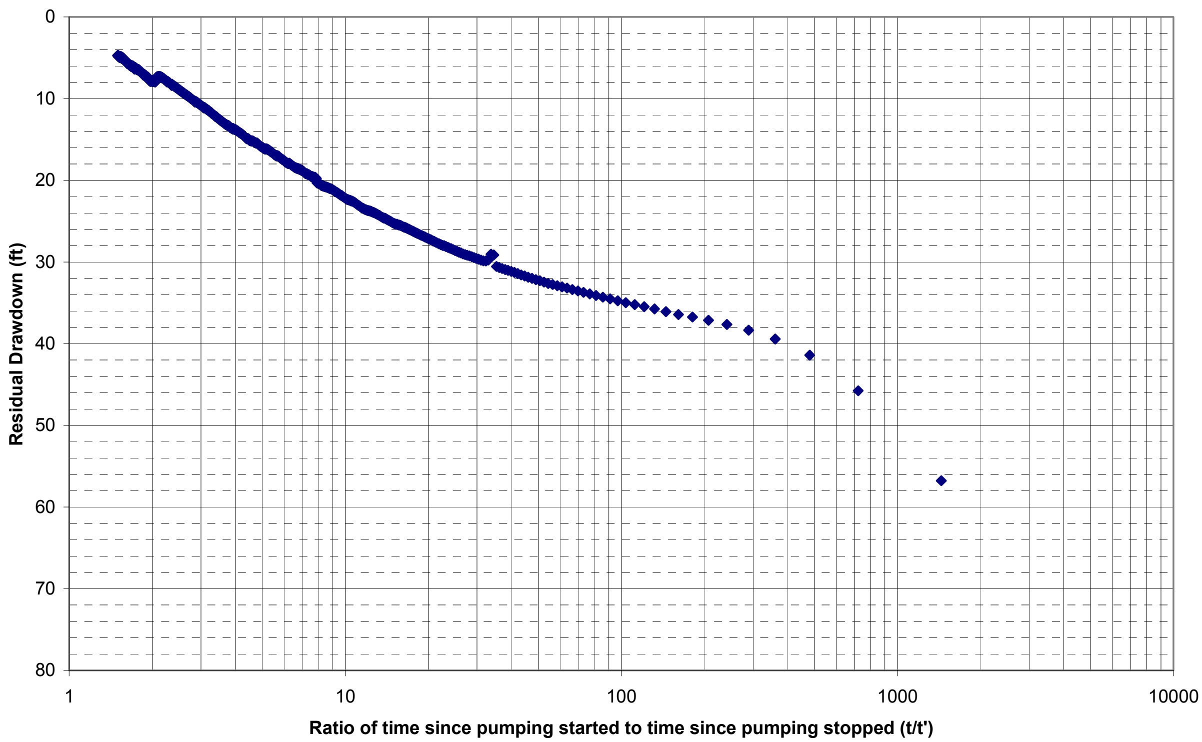


Figure 19: Residual Drawdown in Well 1 After Pumping Well 2

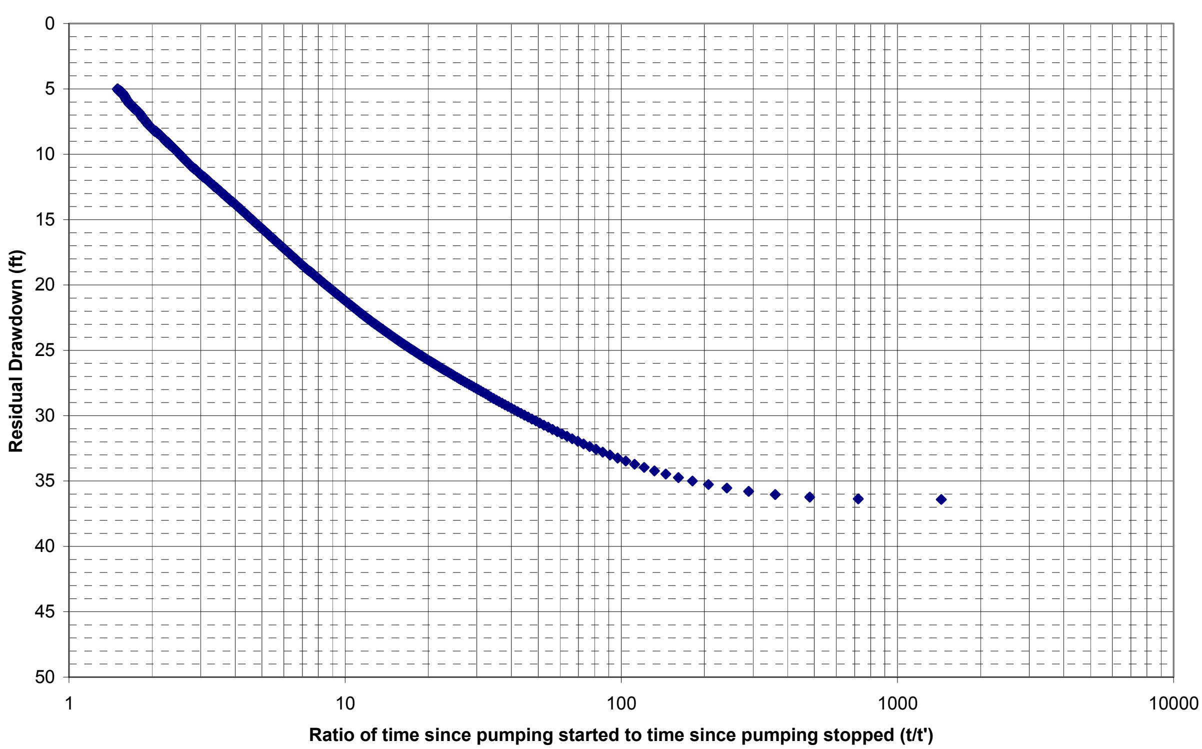


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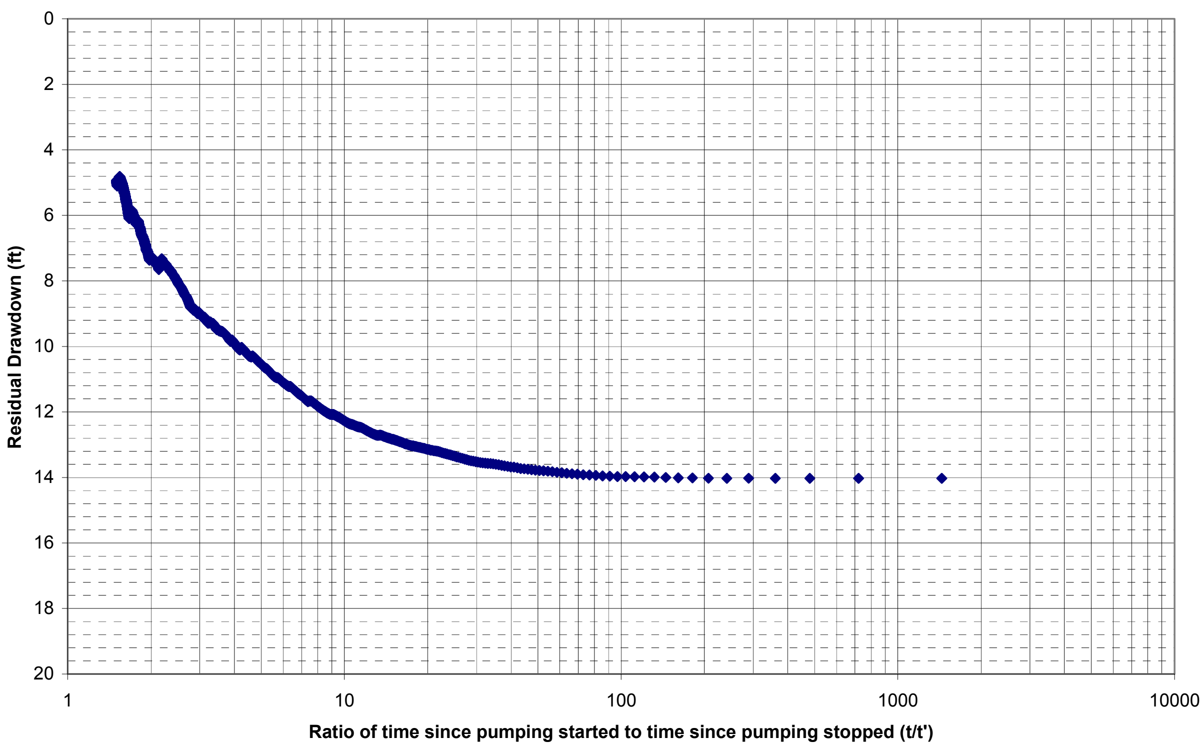
Figure 20: Residual Drawdown in Well 3 After Pumping Well 2



Aquifer Characteristics

The data from the three wells collected during the pumping and recovery phases were analyzed with standard text-book procedures to determine aquifer characteristics of transmissivity and storage coefficient. The data from the pumping phase as depicted on Figures 7 through 9, were analyzed with the Theis (1935) and Cooper-Jacob (1946) methods for confined aquifers. The data were further evaluated using the Hantush-Jacob (1955) method for leaky aquifers with no storage in the aquitard. The recovery phase data depicted on Figures 18 through 20 were analyzed with the Theis (1935) Residual Drawdown Method to further assess aquifer transmissivity.

The geology and aquifer testing data indicate a multi-layered aquifer system with hydraulic connection between deeper bedrock aquifer and the shallow water-table aquifer encountered in the weathered bedrock nearer ground surface. It is likely that one or more beds comprised of weakly to poorly fractured rock separate the shallow water-table aquifer from the deeper bedrock aquifer and that these beds of competent rock have little storage. Vertical fractures resulting from faulting likely connect these zones. Leakage from the shallow zone to the deeper zone is apparent in the data from the three wells and two piezometers.

AQTESOLV for Windows (Version 3.01-Professional) developed by HydroSOLVE™ of Reston, Virginia was used to complete the analyses. The Theis (1935) Non-Equilibrium Well Equation and the Cooper-Jacob (1946) modification are detailed in Driscoll (1986) and Kruseman and de Ridder (1994). The Hantush-Jacob (1955) method is discussed in Kruseman and de Ridder (1994).

The Theis (1935) method is perhaps the most widely used and tested tool for analyses of pumping-phase data and serves as the general foundation for most other methods of analyzing these types of data. The Theis (1935) method typically provides very good approximations for aquifer characteristics. Other methods may improve the estimates made with the Theis (1935) method if boundary conditions are encountered or the aquifer receives leakage. Given the limitations on accuracy associated with natural systems, especially fractured bedrock aquifer systems, the approximations of aquifer characteristics made with the Theis (1935) method are reliable. For these analyses, we also used the Hantush-Jacob (1955) method for assessing leakage.

The analytical results for the pumping phase data are summarized as follows:

	Transmissivity (ft^2/day)			Storage Coefficient		
Monitored Well	Theis (1935)	Cooper-Jacob (1946)	Hantush-Jacob (1955)	Theis (1935)	Cooper-Jacob (1946)	Hantush Jacob (1955)
Well 2	117	117	111			
Well 1	109	114	89	1.1E-04	9.6E-05	1.6E-04
Well 3	144	167	144	2.0E-04	1.5E-04	2.0E-04

The analytical results from the pumping well are included in the above table simply to show that the analyses were completed. However, the data and analyses for the two observation wells are significantly more reliable since water levels in these wells are not affected by pump and pumping well inefficiencies. The data from the observation wells indicate an aquifer transmissivity range from 89 to 167 square feet per day (ft^2/day). These values indicate an aquifer with limited transmission capacity but one that can sufficiently transmit water to meet the needs of the proposed residential units. Storage coefficients also indicate a narrow range 9.6×10^{-5} to 2.0×10^{-4} and indicate confined aquifer conditions. Given the leakage observed in the data, the layers of rock separating the deep bedrock aquifer from the shallow water-table aquifer should be assumed to serve as semi-confining layers and not true confining layers. Impacts to shallow water-quality could affect the quality of water withdrawn from the deep bedrock aquifer.

The slightly higher transmissivity values for Well 3 in comparison to Well 1 indicate that the bedrock aquifer has a slightly greater capacity to transmit water along strike than perpendicular to strike. The Hantush-Jacob (1955) method to include leakage indicates that withdrawals from the deeper bedrock aquifer can be sustained by water draining from the shallow water-table aquifer. However, long-term reliance on water in the

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shallow zone to sustain withdrawals from the deep zone is likely to result in impacts to nearby residential wells completed in the shallow zone.

The Theis (1935) residual drawdown method as outlined in Driscoll (1986) and Kruseman and de Ridder (1994) was used to evaluate the recovery phase data. This method is perhaps the most widely used analytical method for evaluating recovery phase data (Kruseman and de Ridder 1994). The water-level data for this phase were analyzed with the Theis (1935) method to determine the aquifer transmission capability. These results indicate that the bedrock aquifer has a slightly lower capacity to transmit water than suggested by the pumping phase data. The residual drawdown analyses indicate aquifer transmissivity values at the lower-end of the range determined from the pumping phase and are summarized as follows:

Residual Drawdown Analyses

Monitored Well	Transmissivity (ft^2/day)
Well 2	80
Well 1	89
Well 3	89

The Theis (1935) Non-Equilibrium Well Equation was used to calculate theoretical drawdown in Wells 1 and 3 after pumping 24-hours at a rate of 50.1 gpm to determine which, of the four analytical solutions for transmissivity and storage coefficient most closely simulate actual drawdown during the pumping phase. Since the Theis (1935) residual drawdown method does not calculate a storage coefficient, the coefficient determined with the Theis (1935) method from the pumping phase was used in the calculations. The results of these calculations are as follows:

Calculated Drawdown Versus Actual Drawdown

Well	Radial Distance (ft)	Analytical Method	Transmissivity (ft^2/day)	Storage Coefficient	Calculated Drawdown (feet)	Actual Drawdown (feet)
Well 3	362	Theis (1935)	144	2.0E-04	13.58	14.03
		Cooper-Jacob (1946)	167	1.5E-04	13.75	14.03
		Hantush-Jacob (1955)	144	2.0E-04	13.58	14.03
		Theis (1935) Recovery	89	2.0E-04	18.10	14.03
Well 1	106	Theis (1935)	109	1.1E-04	37.35	36.40
		Cooper-Jacob (1946)	114	9.6E-05	36.74	36.40
		Hantush-Jacob (1955)	89	1.6E-04	40.59	36.40
		Theis (1935) Recovery	89	1.1E-04	43.82	36.40

The calculations of theoretical drawdown versus actual drawdown indicate that the aquifer characteristics determined with the Cooper-Jacob (1946) analyses most closely simulate in the two site wells. The Cooper-Jacob (1946) analyses indicated the highest transmissivity values. The calculated drawdown values are within 2 percent of actual drawdown in these two wells.

Radius of Influence

A transmissivity value of 167 ft^2/day and storage coefficient of 1.5×10^{-4} were used to calculate the radius of influence in the direction of bedding strike beneath the site. A transmissivity of 114 ft^2/day and storage coefficient of 9.6×10^{-5} were used to evaluate the radius of influence perpendicular to strike or in the direction of bedding dip. In these calculations, the pumping rate equals 10 gpm or the equivalent of 14,400 gallons per day. The time of pumping equals 30 days. The Theis (1935) Non-Equilibrium Well Equation was used to complete the calculations. Using the approach employed by NJDEP-Bureau of Water Allocation and NJGS, the radius of influence is established at the point where drawdown in the aquifer equals 1-foot.

These calculations indicate a radius of influence of 5600 feet in the direction of strike to the northwest-southeast and 7200 feet in the direction of dip to the northeast-southwest. These calculations are conservative as they are based on the assumption that the aquifer will not receive recharge from precipitation or any other source during the 30 days. The calculations assume all water is withdrawn from aquifer storage and not replaced or replenished including with the treated wastewater discharged to trenches beneath the site.

The wells at the two nearest homes (Block 34 Lots 13 and 12) in Marshalls Corner are located approximately 140 and 190 feet up dip from Well 2. The water levels in these two residential wells after 30 days of pumping Well 2 without aquifer replenishment would likely be lowered 10 to slightly more than 11 feet. The furthest home from Well 2 in Marshalls Corner is also located up dip at an approximate distance of 840 feet. After pumping Well 2 for 30 days at a rate of 10 gpm, the water level in the well on this property 840 feet to the northeast would likely be lowered 6.4 feet.

The Pennwell Holdings/Kooltronics wells are located approximately along strike at a distance of 2400 feet from Well 2. If Well 2 were pumped for 30 consecutive days at a rate of 10 gpm and the aquifer was not replenished, the water level in the Pennwell Holdings/Kooltronics wells would likely be lowered 2.4 feet as a result of the Well 2 pumping.

WATER QUALITY

At the conclusion of the pumping phase, a representative of New Jersey Analytical Laboratories, a NJDEP certified laboratory, collected a water sample to be analyzed for the parameters listed in the Township Land Use Code Section 17-149 as well as those listed by United States Environmental Protection Agency (USEPA) as Primary and Secondary Drinking Water Standards. Copies of the original laboratory report are on file with the Hopewell Township Health Department.

The analytical results for the water sample do not indicate the presence of any contaminants, either natural or man-made, at concentrations exceeding NJDEP or USEPA water-quality criteria, other than total dissolved solids. Dissolved solids can be reduced with standard treatment technologies. The measure of hardness was high, albeit at a concentration below the USEPA secondary drinking water standard. Hardness can be reduced with the same treatment methods used to lower dissolved solids concentrations. The water-quality data do not indicate the presence of any contaminants that would limit the use of this resource for drinking water purposes.

CONCLUSIONS

Based on the hydrogeologic evaluation, the following conclusions are made:

1. Three wells were installed at the Pennytown site to evaluate aquifer characteristics and potential impacts to existing neighboring wells and other natural resources. The data from these wells indicate that yields increase to the east as additional red beds are encountered.

2. While published geologic maps would suggest a highly fractured and therefore, productive bedrock aquifer, empirical data from aquifer testing shows that these resources have limited extent. Furthermore, the data indicate that the aquifer systems beneath the property and Marshalls Corner is highly dependent on precipitation.

3. Aquifer testing data indicate a poorly transmissive bedrock aquifer that is hydraulically connected to the shallow water-table aquifer. Leakage from the shallow zone to the deep bedrock aquifer was necessary to sustain withdrawals from the pumping well during the test.

4. Impacts to the Udy well during the pumping phase taken in conjunction with the data from site wells for the background, pumping, and recovery phases indicate that pumping at the Pennytown site will affect water levels in nearby residential wells. The extent of these impacts is directly dependent on the rate of withdrawals at the Pennytown site.

5. A full analysis of the recovery phase data indicates that the deep bedrock aquifer will recover to pre-pumping water levels but that recovery is dependent on the availability of water in shallow fractures and the rate at which, groundwater can migrate vertically. The data further indicate that recovery is dependent on precipitation. During prolonged drought, recovery in the site wells will be slowed as less water is available in shallow zones.

6. Pumping of the aquifer for long periods of time without replenishment from other water resources will result in a large zone of influence. Under these conditions, water levels in residential wells located in nearby Marshalls Corner will be drawn down by the pumping at the Pennytown site. The empirical data from the aquifer test indicated that the draw down could adversely affect some of the nearest residential wells.

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7. Given the potential for adverse impacts to water levels in nearby wells, it will likely be necessary for the homes in Marshalls Corner to be connected to the same public water supply as developed at the Pennytown site or for the wells on some of these properties to be sufficiently deepened or pump intakes lowered, such that the Well 2 pumping will not limit the use of these residential wells.

8. Analytical data for a water sample collected at the conclusion of the pumping phase do not indicate the presence of any contaminants that would preclude the use of these groundwater resources for drinking water purposes. However, given the hydraulic connection between the shallow water-table aquifer and the deeper bedrock aquifer, the potential exists for impacts to the drinking water resources if contaminants are discharged at or near the ground surface.

9. Given the limited groundwater resources beneath the site and the dependence on precipitation or other forms of replenishment, monitoring of water levels in the shallow and deep bedrock aquifer systems should be considered, especially for periods of prolonged dry weather. It may be advisable to modify pumping patterns such that Well 2 and 3 are alternated or influences are dispersed over a larger portion of the site under these conditions.

If you have any questions, please call Matt Mulhall at (908) 238-0827.

Respectfully submitted,
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