GROUNDWATER RESOURCE INVESTIGATION
NEW BALTIMORE SERVICE DISTRICT
New Baltimore, Virginia

RESULTS OF PUMPING TESTS
on WELLS E-1, E-6, E-7 and M-6a

Submitted to

COUNTY OF FAUQUIER
and
FAUQUIER COUNTY
WATER AND SANITATION AUTHORITY

VOLUME I -- REPORT

April, 1995

Presented by

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April 17, 1995

Mr. David Binning
Director
Fauquier County Water & Sanitation Authority
Rt. 3, Box 239BB, Meetze Road
Warrenton, VA 22186

Dear Dave,

Emery & Garrett Groundwater, Inc. (EGGI) is pleased to submit to you our summary report describing the results of our Phase II groundwater resources investigation recently completed in the New Baltimore study area.

As you are aware, we believe our findings are very favorable relative to the development of new groundwater resources to serve the public water supply needs of the New Baltimore Service Area. Enclosed within this technical report are descriptions of our approach to this groundwater testing program, methods of investigation, conclusions, and recommendations.

I hope you find this document responsive to your needs. If you have any questions, please do not hesitate to contact me.

Best regards,

James M. Emery
President

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I. INTRODUCTION / BACKGROUND

A. Background of the Project

Groundwater resources have historically been, and still remain today, the exclusive sources of water serving the public needs of Fauquier County. In 1964, Fauquier County created the Fauquier County Water and Sanitation Authority (FCWSA) as a public utility to furnish water to selected service districts, one of which includes the community of New Baltimore, Virginia. New Baltimore is located in the east-central portion of Fauquier County, approximately three miles west of Prince William County (Figure 1a). The New Baltimore Service District has experienced increased residential development and associated growth along the Route 29 corridor east of Warrenton, Virginia. This growth has increased the demand for potable water resources within the New Baltimore Service District.

Emery & Garrett Groundwater Inc. (EGGI) was retained by the County of Fauquier in a joint effort with the FCWSA to conduct a phased comprehensive groundwater resource investigation of the New Baltimore water service area. The goals of this project were several fold:

- **Phase IA** -- To assess the availability of groundwater resources within the New Baltimore Service District and to identify "areas" (zones) considered favorable for groundwater development.
- **Phase IB** -- To specifically locate test well drilling targets within selected groundwater development "areas" through the use of geophysical surveys.
- **Phases II** -- To conduct test well drilling, yield testing, and water quality analyses sufficient to confirm the "best" sources of groundwater available within the New Baltimore Service District.

The results of this investigation are intended to provide critically needed hydrogeologic data enabling the County and the FCWSA to proceed in developing new sources of groundwater resources to meet *existing* and *future* water demands, *protect* future water supplies, and to establish a means to better *manage* groundwater resources within the New Baltimore Service area. To that end, EGGI conducted an extensive groundwater exploration program (Phase IA and IB) which delineated ten *primary* favorable zones for groundwater development. The primary zones are identified as Zones A, B, C, D, E, G, H, J, L, and M (Figure 1b). In addition to these primary zones, EGGI also selected four *secondary* zones that are considered good candidate areas for developing groundwater resources but are less favorable than the primary zones. The approach, methods of investigation, and results of Phases IA and IB of this groundwater exploration program are presented in EGGI's previously submitted report entitled, *Groundwater Resource Investigation, New Baltimore Service District, New Baltimore, Virginia* submitted to the FCWSA in July of 1992.

Upon the completion of Phases IA and IB, the FCWSA chose Zones E, D, G, H, and a portion of Zone M for further investigation (Phase II). These groundwater development zones represented those areas which would be most cost effective to integrate into the existing distribution system. It is anticipated that other remaining zones will be studied further in future years.

The contents of this report serve to present collected hydrogeologic data related to Phase II of this groundwater investigation as conducted in Zones D, E, G, H, and M. Furthermore, this report documents the installation of thirteen test wells, conversion of several test wells to production wells, completion of pumping tests, and water quality analyses. All supporting data is included in a series of appendices (Volume II of this report). The conclusions and findings of this study have also been illustrated on a colored plate (Plate 1) to help with the interpretation of the collected hydrogeological data and the implementation of the proposed recommendations.

B. Hydrogeologic Considerations for Developing Additional Groundwater Resources in the New Baltimore Service District

The New Baltimore study area, as established by the Fauquier County Planning Department and the FCWSA, encompasses approximately 30 square miles and surrounds the existing public water distribution system available in this region. The study area is evenly divided into two distinct geologic provinces: the western portion is known as the Blue Ridge province and the eastern portion is referred to as the Culpeper Basin (Figure 1a).

The underlying rocks of the Blue Ridge geologic province are made up predominantly of igneous and metamorphic rocks known as greenschists, quartz-rich schists, and quartzites. The Culpeper Basin is quite different and is made up of sedimentary rocks (i.e., sandstone, siltstone, conglomerate) and intrusive igneous rocks (i.e., basalt and diabase). Separating the Blue Ridge province and the Culpeper Basin is one of the largest faults known to exist in northern Virginia -- the Western Border Fault.

Regional stresses have caused the bedrock in the New Baltimore service area to be greatly disturbed. The rocks of the Blue Ridge Province have been deformed (faulted, folded, and arched up) and metamorphosed during the Paleozoic tectonic period which formed the Appalachian Mountains. In addition, the rocks within the Culpeper Basin (eastern portions of New Baltimore study area) were impacted by basin subsidence, volcanoes spilling large flows of lava (i.e., basalt), faulting, folding, and intrusions of mafic dikes (diabase). Erosion of these faulted and folded rock units exposes the complex bedrock geology observed at ground surface today. Such geologic environments greatly complicate the occurrence and availability of groundwater resources and demands that hydrogeologic investigations be made concurrently at both detailed and regional scales.

Inasmuch as bedrock is generally impermeable in an undisturbed state, its water-bearing properties are dependent upon the occurrence of discontinuities (contact surfaces between different rock types, fracture systems, etc....) which provide pathways for the transmission of groundwater resources. Where these water-bearing characteristics occur in laterally-extensive zones, bedrock aquifers can be predictably located which can often yield substantial supplies of groundwater. It is these types of groundwater supplies which were the targets for development within the New Baltimore service district.

As many as twenty-eight (28) wells have historically been used in New Baltimore to supply potable water to the local community (see EGGI July, 1992 report). Seventeen of these wells yielded less than 50 gallons per minute (gpm) and one yielded as little as 6 gpm (i.e., Meadowvale Well #1). Some of those wells are still in use, but many have been discontinued due to low yields and poor quality. The operation and maintenance of these low-yield wells was extremely costly and inefficient. Well failure due to poor construction or insufficient yield have caused at least eleven of these wells to be permanently abandoned. Therefore, an important goal of this exploration program was to develop *high-yielding* wells which also contained the best water quality available.

II. TEST WELL DRILLING IN FAVORABLE ZONES D, E, G, H, and M

A. Test Well Drilling Program

A total of thirteen wells were drilled in the five Favorable Zones identified in EGGI's Phase I Report (July, 1992). This included three wells in Zone D (D-1a, D-1b, and D-2), five wells in Zone E (E-1, E-3, E-4, E-6 and E-7), two wells in Zone G (G-1 and G-3), two wells in Zone H (H-1 and H-3), and one well in Zone M (M-6a) (Figures 1 and 2, Table I). The seven test wells installed in Zones D, G, and H penetrated rocks of the Mesozoic Culpeper Basin or the Border Fault separating the Culpeper Basin from the rocks of the Blue Ridge Province. The remaining six wells drilled in Zones E and M all penetrated rocks of the Pre-Mesozoic Blue Ridge Province.

All test wells were drilled by Singhas and Michael Corporation of Berryville using air rotary methods and were 6 inches in diameter. A minimum of 20 feet of temporary steel casing was installed from the ground surface into bedrock and was used to stabilize the test well while drilling. Samples of rock fragments in each well were collected every 10 feet and cataloged for rock type, mineralization along fractures, effects due to contact metamorphism, and degree of fracturing. An EGGI geologist supervised the drilling of all test wells and recorded variations in bedrock lithology and location of fractures which were intercepted during the drilling program. Total depths of test wells ranged from 300 to 700 feet, with an average of 474 feet (Table I). Detailed geologic logs for all test wells were prepared and are presented in Appendix A.

Water samples were collected at each water-bearing fracture zone encountered during drilling and at the bottom of each well. These water samples were tested for sulfate, dissolved iron, manganese, hardness, and specific conductivity in the field (Table II). In addition, water samples, taken at the conclusion of drilling each test well, were sent to WaterCheck, a division of National Testing Laboratories, Inc. in Cleveland, Ohio, for complete chemical analyses

(Appendix B). Water chemistry variations observed in each well were used to determine the final depth and construction (i.e., casing depth) for each of the test wells.

"Blow tests" (air lift yield) of each test well were measured at each water-bearing fracture zone, where substantial increases in yield had occurred, and at the conclusion of drilling (Table I). "Blow tests" involve using the drilling rig to air lift the water out of the well so that a volumetric measurement of yield can be made. Blow test results indicate the *potential* yield of a test well and provide a means of comparing the productivity of each test well and identifying those wells which deserved further testing.

Cumulative "blow test" yields measured from the thirteen test wells drilled produced 1438 gpm (2.07 million gallons per day [gpd]) (Table I). Final air-lift yields from *test* wells ranged from 15 to 300+ gpm, with nine of the thirteen wells yielding in excess of 50 gpm. Based upon average well yields in the New Baltimore area, these test well yields are considered to be exceptional. All of the wells were completed with locking caps to help prevent future vandalism of the boreholes.

B. Water Quality of Test Wells

1. Variations in Groundwater Chemistry with Depth Observed During Drilling

Groundwater samples were collected from each water-bearing fracture zone as drilling proceeded in each borehole. A continuous log of water chemistry with depth provided a clearer understanding of the vertical distribution of water chemistry in each well; this data was useful in determining the final construction specifications of production wells (i.e., the length of casing or total depth of the well).

Vertical changes in groundwater chemistry varied significantly among the thirteen test wells (Table II). The total number of water samples collected from a single test well ranged from one (for wells with little yield) to six for high yielding wells containing several water-bearing zones. Wells in the pre-Mesozoic rocks of Zones E and M had more instances of iron and manganese exceeding secondary drinking water standards. In contrast, the wells in Zones D, G, and H, in the Culpeper Basin rocks, were much more likely to have zones with high hardness and sulfate values. Water in most wells became more mineralized with depth, however, both E-6 and M-6a encountered water with reduced concentrations of iron at depth after penetrating zones nearer to the surface with undesirable levels of iron.

2. Resultant Water Chemistry Observed After Completing the Drilling of Test Wells

Groundwater samples were collected from nine of the thirteen test wells at the conclusion of drilling and submitted to National Testing Laboratories, Inc. of Cleveland, Ohio. These water samples were analyzed to determine the concentration of all the regulated drinking water parameters, including inorganics, metals and volatile organic compounds (Appendix A). Four of the wells, D-1a, D-2, D-2b and E-4, were not sampled for complete drinking water tests because the limited yields of these wells did not justify further investigation.

Manganese was the most common parameter to exceed its recommended secondary drinking water standard of 0.05 milligrams per liter (mg/l). Wells E-1, E-6, G-1, G-3 and M-6a had concentrations of manganese ranging from 0.054 to 0.23 mg/l (Appendix A). Well G-1 and Well E-6 were the only wells which exceeded the 0.3 mg/l secondary standard for iron. Most of the water from the nine wells sampled had hardness values which are considered moderate to very hard, ranging from 80 to 295 mg/l, with an average of 150 mg/l.

Wells G-1 and G-3 had sulfate levels of 293 and 327, respectively, exceeding the current recommended secondary standard of 250 mg/l. However, the secondary standard for sulfate is likely to change, according to pending EPA legislation, to a level of 500 mg/l. Well H-3 exceeded the secondary level for aluminum (0.2 mg/l) at the conclusion of drilling with a concentration of 0.3 mg/l. EGGI has observed elevated levels of aluminum to diminish after extended pumping periods and, therefore, a pumping test should be conducted on this well to assess final water quality.

C. Results of Test Well Drilling

Based upon the results of test well drilling, it was apparent that test Wells E-1, E-3, E-6, E-7, M-6a, G-1, G-3, H-1, and H-3 could be successfully converted to production wells. The yield of these test wells ranged from 75 gpm to 300+ gpm with an average of 160 gpm. Test Wells E-1 and E-6 yielded the most water (300+ gpm each) and Wells E-1, E-7, and H-1 produced water with the best quality. The FCWSA chose to convert only E-1, E-3, E-6, E-7, and M6-a at this time, leaving Zones G and H to be further studied at a later date.

III. CONVERSION OF TEST WELLS TO PRODUCTION WELLS

The construction of large diameter production wells (i.e., 8-inch) are more desirable for permanent use than smaller diameter test wells (i.e., 6-inch) for the following reasons:

- The larger diameter well provides greater flexibility in pump selection (i.e., large diameter pumps with slower rotation speeds can be used, thereby minimizing wear on the pump and pumping equipment).
- Increased drilling diameter often leads to increased well capacity and efficiency of well performance.
- The larger-diameter wells reduce the entrance velocity of water entering the borehole from fracture zones, thereby reducing the degree to which mineral precipitates will form on the pump and borehole surface.

- Larger-diameter wells provide for greater clearance between the pump and the borehole wall, reducing the potential for pumps to become lodged in the well.

Five of the thirteen test wells installed during the test well drilling program were deemed sufficiently favorable for use as production wells or backup production wells; these included: Wells E-1, E-3, E-6, E-7 and M-6a.[1] Each of these wells was reamed to 8-inches in diameter to a depth below the major water-bearing bedrock fractures (Table I, Appendix A). During the reaming, an upper portion of each well was drilled to 12 inches in diameter to allow for permanent, 8-inch, heavy-wall steel casing to be installed according to Virginia Waterworks Regulations (Table I). A Portland cement, pressure-grout seal was installed for the entire length of the 8-inch casing to ensure that no leakage could occur around the outside of the casing. A Fauquier County Health Department representative inspected each of the wells to ensure that the grouting process met Virginia Waterworks Regulations. The final air-lift capacities (blow test yields) of the five wells following reaming were >400, 100, >400, 75 and 105 gpm, for Wells E-1, E-3, E-6, E-7 and M-6a, respectively. The sum of all the air-lift yield capacities of the 8-inch production wells is 1,080 gpm (over 1.5 million gallons per day).[2]

IV. REVIEW OF PUMPING TEST PROGRAM -- WELLS E-1, E-6, E-7 AND M-6a

A. Purpose of Pumping Tests

A multiple phase pumping test was designed to evaluate the overall productivity of Zone E and the individual sustainable yields of Wells E-1, E-6, E-7 and M-6a. Well E-3, which was converted to an 8-inch production well, was not tested at this time but was utilized as a monitoring well during the pumping tests of Zone E. Later testing on Well E-3 can be completed if the FCWSA desires to use E-3 as an emergency backup groundwater supply well.

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[1] Please note: Test wells in Zones G and H may be converted to 8-inch production wells at a later date.
[2] These air lift yields do not, however, represent long-term sustainable yields. Sustainable yields were determined through the analysis of pumping test data.

Pumping tests were conducted to estimate the actual withdrawal capacity and quality of water withdrawn from each well. Therefore, the objectives of the pumping test program conducted in Favorable Zone E and partially in Zone M included the following:

- To determine the long-term sustainable pumping capacity (yield) of each well.
- To assess the quality of groundwater under long-term pumping conditions.
- To evaluate the hydraulic characteristics of the water-bearing bedrock systems.
- To assess the nature of recharge to the bedrock aquifer (i.e., rate of recovery of the local water table after pumping has ceased).
- To determine the potential impacts of pumping high capacity wells on local groundwater users.
- To develop a groundwater pumping management plan which will prolong the life of the pumping wells and maintain the integrity of the aquifer.

B. Selection of Monitoring Well Locations -- Including Local Domestic Wells

An extensive groundwater monitoring program was established to observe the potential impact that pumping high yield production wells might have on existing local users of groundwater. A total of 18 different monitoring wells were selected based on observations in the field, type of well, geologic site conditions and landowner permission. These monitoring wells included 13 domestic wells, four existing bedrock wells, and the FCWSA Snow Hill production well (Plate 1, Figures 2 and 3, and Table III).

A Letter of Intent was sent to all landowners located proximal to the proposed wells to be tested in Zone E requesting permission to install automated water level recorders in their residential wells (Appendix B). In addition, efforts were made to contact homeowners by phone and personal visits were made to individual homes to inform local groundwater users of the monitoring program. Automated water level monitoring equipment was installed in those domestic wells where authorization from the homeowners was received. (Data collected from all monitoring wells are presented in Appendix D). All the monitoring wells were secured to prevent foreign substances from entering the wells during the pumping tests.

Well M-6a is relatively isolated from existing domestic wells, with only one well identified nearby (the Fauquier Swimming Club [FSC]). This well was located approximately 1200 feet southeast of the pumping well. Due to the extraordinary efforts required to monitor the FSC well (including a disruption of service), EGGI decided to forego monitoring at this location. No other monitoring wells could be identified within a reasonable proximity to M-6a and, therefore, water level monitoring was restricted to the pumping well only.

C. Pumping Test Design

Pumping test designs vary depending on the ultimate goals of the project. For the purposes of this groundwater supply development project, a three-phase design for the pumping test program was selected. This included step tests, constant rate tests, and recovery tests. The first phase included short term "step" drawdown tests on two of the four production wells (E-1 and E-6). Step tests require that the wells be pumped at a number of incrementally higher pumping rates, each for a pre-determined amount of time (Appendix C). During each step, the pumping rate was held constant. Step tests are used to determine the efficiency of a pumping well at varying pumping rates and provide hydraulic information necessary to select a pumping rate for the long-term pumping test. Step tests also serve to check the discharge system, pumps, and power source to the pumps to ensure all is in working order for subsequent long-term pumping tests.

Short-term tests were followed by long-term (three to four-plus days) constant rate pumping tests. During long-term pumping tests, water levels in the pumping wells and the selected off-site and on-site monitoring wells were recorded to the nearest .01 foot. Throughout the pumping tests of Wells E-1, E-6, and E-7, water level data was collected for approximately three to six days prior to pumping, during the pumping period and eight to ten days after pumping was terminated. (For a total of nearly 15-20 days.) Well M-6a was not monitored prior to the testing period, but recovery water levels were monitored for three days following the termination of pumping. Water level data plotted against time of pumping provides information on the response of the bedrock aquifer to the withdrawal of groundwater from individual production wells.

All four wells (E-1, E-6, E-7, and M-6a) were pumped simultaneously. At the conclusion of pumping, recovery water levels were collected until near static (pre-pumping) water levels were reached (full recovery).

It should be noted that in Virginia, constant rate tests are required to continue for a minimum of 48 hours for public water supplies; however, for this project, pumping tests were continued for 74 hours for Well E-7, 76 hours for Well M-6a, 90.25 hours for Well E-6 and 95 hours for Well E-1. These pumping tests were extended so that the bedrock aquifer system could be fully stressed, thus allowing for a more accurate evaluation of the sustainable yield of the bedrock aquifer system.

D. Pumping Test Set-up

Wells E-1, E-6, E-7 and M-6a were tested using submersible, electric pumps powered by portable, diesel generators. Flow was restricted on the discharge line using a gate valve to control the pumping rate (Figure 5). The flow rate was monitored using an in-line flowmeter which was calibrated with volumetric measurements at the discharge point to ensure accurate yield measurements. Discharging water was carried to nearby streams and was not allowed to flow over the ground surface. A spigot was provided on each discharge line to allow for easy collection of water samples. Finally, a 1-inch diameter tube was attached to the drop pipe to allow access to the well for using water level probes during the test (Figure 5). Following the installation of all pumping equipment, chlorine tablets were added to all wells to disinfect the wells prior to starting the pumping test. All water levels were recorded to within one hundredth of a foot using both manual and automated equipment.

On-site climatic data were collected using a standard, 4-inch raingauge and a barometer attached to an automated datalogger (Figure 6). Barometric pressure is presented in units of feet of water (as opposed to inches of mercury) to show the maximum possible impact that changes in atmospheric pressure could have on groundwater levels.

V. STEP DRAWDOWN TESTS ON PUMPING WELLS E-1 AND E-6

Step drawdown tests were conducted on Wells E-1 and E-6 on August 26, 1994. Well E-6 was pumped first. The step test on Well E-1 began 35 minutes following completion of the E-6 step test. Water level data collected during the step tests are presented in Appendix C.

Wells E-7 and M-6a were pumped for short periods of time (i.e., 30 minutes) to check pump rotation and ensure that the generators, discharge lines and flowmeters were all in good working order prior to beginning the long-term constant rate tests.

A. Step Drawdown Response in Pumping Well E-1

The step drawdown test conducted on Well E-1 consisted of pumping the well at three discrete steps of incrementally increased pumping rates. Each step was 45 minutes in duration and progressed in the following manner: Step #1 -- 155 gpm, Step #2 -- 255 gpm, Step #3 -- 360 gpm (Figure 7). The specific capacity (a measure of productivity determined as the pumping rate divided by the induced water level drawdown) of the pumping well was observed to be 13.5 gpm/ft during Step #1 and decreased to 11.1 gpm/ft at the conclusion of the test. A reduction in specific capacity at higher pumping rates is expected for any pumping well; as entrance velocities increase, the efficiency of a well decreases. Losses of efficiency in Well E-1 were relatively small and changed little during the final step of the test. Such results, in addition to the availability of large amounts of drawdown and no increases in turbidity, suggest that pumping at the maximum rate of the step test is reasonable. No water-bearing fractures will be dewatered during pumping, as water levels are expected to remain inside the permanent casing (less than 95 feet from the top of casing). Therefore, it was determined that the long-term constant pumping rate for Well E-1 could be maintained between 320 to 350 gpm.

B. Step Drawdown Response in Pumping Well E-6

The step drawdown test conducted on Well E-6 was very similar to that conducted in Well E-1. Well E-6 was pumped at three discrete pumping rate increments and each step was 45 minutes in duration. Discharge rates included Step #1 -- 150 gpm, Step #2 -- 275 gpm, and Step #3 -- 400 gpm (Figure 8). The specific capacity of Pumping Well E-6 was first recorded as 12.1 gpm/ft during Step #1 and decreased to 11.1 gpm/ft at the conclusion of the test, identical to that of Well E-1. Losses of efficiency in Well E-6 were relatively small and changed little during the final step of the test. Water levels remained inside the casing throughout the test with large amounts of drawdown remaining and no increases in turbidity. Therefore, it was determined that the long-term constant pumping rate for Well E-6 could also range between 320-350 gpm, the same as for Well E-1.

Wells E-1 and E-6 both withdraw water indirectly from a similar interconnected fracture system. Evidence for this was observed during the step test when both wells responded to independent pumping. The interference between the wells was minor (about 1.2 feet was observed during the E-6 step test). However, rather than pumping both wells at maximum capacity, EGGI chose to start the pumping test at a combined rate of 640 gpm to ensure that the bedrock aquifer system could sustain the lower yield prior to increasing pumping rates to maximum capacities.

VI. LONG-TERM CONSTANT RATE PUMPING TESTS ON WELLS E-1, E-6 AND E-7: DRAWDOWN RESPONSES

A. Pumping Test Format

All four production wells began pumping on August 29, 1994 (Table IV). Since Well M-6a was located several miles away from Zone E, the long-term pumping test was started independently and began earlier in the day than the other wells for logistical reasons. M-6a was pumped at 100 gpm throughout the pumping test period with very little variation.

Based upon data collected from the initial step tests, it became apparent that Well E-7 was not interconnected with the bedrock fracture systems intercepted by Wells E-1 and E-6. Therefore, for logistical considerations, this pumping test was allowed to start at 11:00, before Wells E-1 and E-6 (Table IV). Well E-1 was then started at 13:00 and E-6 was used as a monitoring well until 17:45 that evening, when pumping at Well E-6 was initiated. Constant pumping rates of 320, 320, and 78 gpm were quickly established and maintained at Wells E-1, E-6 and E-7, respectively. Pumping rates for both E-1 and E-6 were later increased to 350 gpm for the final 67 hours of the test.

All the wells pumped uninterrupted until their designated times of shutdown. Wells E-7 and M-6a pumped until 9/1/94. Wells E-1 and E-6 continued pumping together until noon on 9/2/94. Following the termination of pumping, recovery water levels were measured from all the pumping and monitoring wells until water levels had fully (or nearly) recovered to pre-pumping levels.

One significant thunderstorm provided the only rainfall event during the pumping tests. On 9/1/94 at 19:55 to 20:20, 0.24 inches of rain fell during a heavy downpour. The stream gage installed up-gradient of Well E-6 varied little throughout the test, except for a brief increase in stream flow resulting from the sudden runoff associated with the thunderstorm. In general, seasonal low flow conditions prevailed in the area throughout the pumping tests.

B. Well E-1: Response to Pumping

1. Pumping Phase -- Well E-1

Well E-1 was pumped at an average rate of 340 gpm for 95 hours, removing a total volume of 1,938,000 gallons of groundwater from the fractured bedrock aquifer (Table IV, Appendix D). Twenty-eight hours into the pumping test, after beginning the test at a pumping rate of 320 gpm, the pumping rate was increased to 350 gpm. This was accomplished because the early aquifer response indicated that an increased rate of withdrawal could be sustained. The pumping rate remained at 350 gpm until the conclusion of the pumping period. Plots of water level versus pumping time for Well E-1 indicate that water levels declined gradually throughout the test to a water level of 57.39 feet below the top of casing (Figures 9 and 10, Plate 1). *This is equivalent to a total of only 48.93 feet of drawdown (Table IV).* At the conclusion of the test, *only 24 percent* of the available drawdown had been utilized, leaving 153 feet of drawdown still remaining above the major water-bearing fracture at 210 feet. The specific capacity at the end of pumping was 7.0 gallons per minute per each foot of induced drawdown (gpm/ft) (Table IV). The water level response related to the pumping of Well E-1 at 350 gpm is shown as a straight line on a semilogarithmic plot of water level versus time (the final 67 hours of the test). During the last four hours of the test, the water level in this well remained constant, suggesting that the cone of depression has expanded sufficiently to intercept the necessary recharge to sustain the pumping rate (Figure 10).

The transmissivity of the bedrock aquifer around E-1 was calculated to be 5,280 gallons per day per foot (gpd/ft) using the Jacob approximation of the non-equilibrium well equation. Although the aquifer in question violates several of the underlying assumptions of the Jacob model, the transmissivity value calculated in such a manner can be useful when comparing the productivity of one well to another. This value is unusually high when compared to wells in similar geologic environments suggesting that the bedrock aquifer at this location is very transmissive to groundwater flow, a favorable condition for developing and sustaining high-yield wells.

2. Recovery Phase -- Well E-1

After pumping ceased, recovery water levels were recorded for an additional 11,520 minutes in Well E-1. The water level recovery rate in Pumping Well E-1 was consistent with the pumping data, showing a pumping cone of depression re-filling in the same manner as it responded to pumping (Figure 10, Appendix D). Ninety-eight percent of the drawdown recovery occurred in 97 hours, indicating almost complete recharge to the fracture system in a time period equal to the time of pumping. The transmissivity calculated using the recovery data, 6,060 gpd/ft, agrees very closely with that calculated using pumping data (Table IV). The recovery response is very favorable as it indicates sustainable recharge to the fracture system in what is traditionally considered a dry season. If full recovery takes place in a shorter time than the pumping period, it generally indicates favorable recharge conditions; whereas, recovery times exceeding the pumping interval suggests that water is being removed from storage and fractures are not receiving the required recharge. Well E-1 exhibits a case between these extremes where recharge to the bedrock aquifer system balances the withdrawal from the aquifer system almost exactly. Full recovery at E-1 is not going to show groundwater levels returning to pre-pumping levels, because seasonal groundwater level declines were taking place throughout the test and may account for 0.5 to 1.5 feet of water level change (Plate 1). Evidence for this is seen in the pre-pumping water level data for all the wells, which shows a gradual decline of groundwater levels before the groundwater testing began.

C. Well E-6: Response to Pumping

1. Pumping Phase -- Well E-6

Wells E-1 and E-6 draw water from an interconnected fracture system which contains highly transmissive zones within that fracture system. The pumping of Well E-6 caused a water level response that was similar to the response observed in Well E-1. Well E-6 began pumping at 320 gpm for the first 23.25 hours of the test and was increased to 350 gpm for the remaining 67 hours of the test. This resulted in the removal of 1,852,000 gallons of groundwater during the pumping period. Total drawdown in Well E-6 during the test equaled 46.85 feet, with a calculated specific capacity of 7.3 gpm/ft (Table IV). Plots of water level versus time indicate a gradual lowering of the water table, but at the conclusion of pumping, only 43 percent of available drawdown was utilized (Figures 11 and 12, Appendix D). The first major water-bearing zone contributes water at 114 feet below ground. Near the end of pumping, the semi-logarithmic plot shows a very slight trend towards increased drawdown, suggesting that the bedrock fracture system is likely not capable of yielding more than 1 million gallons of water per day from both Wells E-1 and E-6 combined.

The transmissivity calculated using pumping data from Well E-6 is very similar to Well E-1, with a value of 5,450 gpd/ft. In every aspect, Wells E-1 and E-6 responded as nearly identical wells within an interconnected fracture system which is remarkably consistent over the 2,750-foot distance separating the wells. This is even more interesting when reviewing the lack of impact on local domestic wells which were drilled outside of this high-yielding linear bedrock aquifer.

2. Recovery Phase -- Well E-6

After the conclusion of pumping, the water level in Well E-6 recovered 98 percent within 5,940 minutes after pumping terminated (Figure 12, Appendix D). Similar to E-1, the recovery water levels did not quite fully reach static water levels; the remaining recovery can be attributed to seasonal groundwater level declines independent of the pumping test. Pumping test withdrawal rates appear to have matched the maximum capacity of the aquifer to provide long-term sustainable yields. The transmissivity calculated using E-6 recovery data is 5,440 gpd/ft, once again in very close agreement with the pumping values for E-6 *and* the transmissivities calculated using data from Well E-1.

D. Well E-7: Response to Pumping

1. Pumping Phase -- Well E-7

Pumping Well E-7 withdraws water from a fractured bedrock aquifer which is independent of the major water-bearing bedrock aquifer observed between E-1 and E-6. Well E-7 lies an equidistant 2800 feet from Wells E-1 and E-6; the three wells forming an almost perfect equilateral triangle (Plate 1). Well E-7 was pumped at 78 gpm for the duration of the 74 hour test with no interruptions. Total withdrawal of groundwater from this source equaled 346,000 gallons of groundwater during the pumping period.

Maximum drawdown induced during the test was 63.26 feet, which translates to a specific capacity of 1.2 gpm/ft, substantially lower than observed in Wells E-1 and E-6. The first major water-bearing zone in Well E-7 is at 80 feet below ground surface. The maximum depth to water at the conclusion of pumping was 69.58 feet below the top of casing (about 2 feet above ground). Therefore, 84 % of the recommended available drawdown was utilized during the test. For short-term pumping, drawdowns could continue below the water-bearing zone at 80 feet, but it is not recommended for longer durations. The drawdown plots for Well E-7 illustrate a "leaky recharge" situation where the cone of depression is spreading out, but over time it receives more and more recharge, resulting in a gradually flattening curve from 100 minutes until the end of the test (Figures 13 and 14, Appendix D). This type of response to pumping is favorable, because it illustrates the ability of Well E-7 to obtain recharge under pumping conditions to help balance the 100 gpm withdrawal rate. In other words, Well E-7 is approaching stabilization, where pumping withdrawals are equal to recharge to the well. The pumping transmissivity was calculated as 1,270 gpd/ft.

2. Recovery Phase -- Well E-7

Following the termination of pumping, recovery measurements continued at E-7 until full recovery was realized. Over 99.3 % of recovery occurred within the recovery time equal to the time of pumping, suggesting very favorable recharge characteristics (Figure 14, Appendix D). All available information suggests that Well E-7 can maintain a pumping rate of 78 gpm indefinitely. The recovery transmissivity was in poor agreement with the pumping value at 750 gpd/ft, which may suggest that a boundary condition (in this case, a recharge boundary) was acting as a dominant influence on the response of Well E-7 to pumping.

E. Observed Water Level Fluctuations in Local Domestic Wells and Other Monitoring Wells as a Result of Pumping Wells E-1, E-6 and E-7

Water levels in eighteen monitoring wells were recorded before, during, and after the pumping of Wells E-1, E-6 and E-7 (Appendices D and E, Plate 1). These monitoring wells included thirteen domestic wells, four existing wells, and the FCWSA Snow Hill production well. Only seven of those monitoring wells responded to the pumping test with decreased water levels. The response of domestic wells and a summary of domestic owners concerns addressed during the test is included in the following section.

1. Domestic Well Responses

Three of the thirteen domestic wells responded to pumping Wells E-1, E-6, E-7, and M-6a; these included the Gulledge Well, the Tenant Well, and the Radio Station Well (Plate 1). The Gulledge Well was the domestic well which responded with the greatest water level decline, about

10 feet over the course of the pumping test (Figure 15). According to state records (GW-2 Form -- Appendix B), the Gulledge Well is 250 feet deep with water-bearing zones intercepted at 150-155 feet and 220-225 feet below ground surface. The well yields approximately 15 gpm. At the conclusion of the extended pumping test period, the water level in the Gulledge Well never dropped below 40 feet below ground surface, leaving in excess of 100 feet of available drawdown. It is our opinion, that pumping Wells E-1, E-6, and E-7 together will have no long-term adverse impact on availability or usefulness of the Gulledge Well to meet their daily water supply needs. This opinion is based upon the substantial drawdown available, the well's high yield (15 gpm), and the recovery water level data collected from this well during the pumping test.

In addition to the Gulledge Well, the Tenant Well responded with one to two feet of water level decline, and the Radio Station Well responded with approximately four feet of drawdown (Plate 1, Appendix E). The minimal influence observed in these wells indicate that their usability will not be adversely impacted by pumping Wells E-1, E-6, and E-7.

The Gulledge Well reportedly had a brief water quality problem following the completion of the step test on Well E-6, several days prior to the beginning of the long-term pumping test. There is no logical explanation for the step test creating turbidity in this well, since the step test withdraws only a small volume of water and the well is a great distance from Well E-6 (approximately 1600 feet). EGGI believes that the water discoloration was caused by a new well being installed just two lots to the north (about 600 feet) on the Woolridge Property (installation by Leazer Drilling Company, Mr. John Leazer). This is further supported by the fact that, upon start-up of the long-term pumping test, when the maximum stress was induced on the fractured bedrock system, no such water quality problems were observed by EGGI geologists at the Gulledge Well.

In addition, two independent reported instances of iron staining in the water were received during the pumping of Wells E-1, E-6 and E-7: the Jamison Well and the McDaniel Well. Results from the monitoring of those wells show that no "interference" water level changes occurred in either of these domestic wells while groundwater was being withdrawn during the pumping tests (Appendix E). Therefore, it is highly unlikely that the iron-stained water was a result of pumping (Plate 1). The only other potential source of iron is from scaling on the interior of the wells, which may have been loosened during the installation of the automatic water level recorders. However, these installations were completed days prior to the instances of iron staining and any iron released during those installations would only create a temporary period of water discoloration (i.e., 5-10 hours).

2. Responses in Other Monitoring Wells

Ambient (pre-pumping) water levels in the area decreased throughout the monitoring period. Those wells which did not respond to pumping Wells E-1, E-6, and E-7 show a decrease of 0.5 to 1.5 feet in groundwater levels due to natural seasonal groundwater level declines (Plate 1, Appendix E).

The greatest water level response observed in a groundwater monitoring well was seen in the Greenhouse Well. This well is unused and is located about 500 feet east of Well E-1 (Plate 1). Approximately 42 feet of drawdown was measured in this well which is just a few feet less than measured in the E-1 pumping well. Based upon the response of this well, EGGI recommends that it be purchased and used as a permanent monitoring well.

The "Irrigation" Well is owned by Mr. B. Semple and was drilled to irrigate a portion of his holly tree farm. Upon drilling, the yield of this well was insufficient to irrigate and, therefore, has remained unused for many years. This well experienced an approximate three-foot water level decline as observed during the pumping test period.

The existing FCWSA Snow Hill production well is located northeast of Well E-6 and along a linear stream segment thought to reflect a bedrock fracture system. The Snow Hill Well was impacted by pumping Well E-6, with a total of 3.1 feet of drawdown. This well has been abandoned for use by the FCWSA and should be used in the future as a permanent monitoring well.

The most interesting water level responses associated with pumping Wells E-1, E-6, and E-7 are those which did not occur. The B. Semple Well is located within 700 feet of Well E-6 and extensive efforts were made before the pumping test to provide potable water to the Semple residence from a tanker truck. These preparations assumed that the relatively shallow well would be dewatered during the test. However, the B. Semple Well never responded to pumping, even though wells such as the Tenant and Gulledge wells, farther to the west, did respond. This lack of response must reflect a geologic boundary between E-6 and the domestic well, which prevents impacts from occurring. Similar to the lack of response observed in Mr. B. Semple's well, the following monitoring wells also showed no measurable interference with pumping Wells E-1, E-6, E-7, and M6-a:

Monitoring Well E-4	Mercado Domestic Well
Booth Domestic Well	Miller Domestic Well
Fling Domestic Well	B. Semple Domestic Well
Jamison Domestic Well	S. Semple Domestic Well
McDaniel Domestic Well	Simone Domestic Well
Medvitz Domestic Well	

All data collected from these wells are presented on Figure 16, Plate 1, and Appendix E.

VII. LONG-TERM CONSTANT RATE PUMPING TEST ON WELL M-6a: DRAWDOWN RESPONSES

A. Pumping Phase -- Well M-6a

Based upon the pumping test data collected and reviewed, it is apparent that pumping Well M-6a is influenced by another pumping well within the same fractured bedrock aquifer system. EGGI believes that this "other" well is likely the existing City of Warrenton's production well which lies approximately 2,000 feet to the southeast (Figure 4). Pre-pumping water levels varied by as much as several feet and the water level measured prior to the extended pumping test was 36.10 feet below ground surface, much deeper than expected for this hydrogeologic setting. The well lies on the floodplain of Cedar Creek and was not more than 8 to 10 feet higher than the surface water elevation observed during the pumping test. Static water levels were expected between 6 and 10 feet below the top of casing.

The chosen pumping rate for Well M-6a was 100 gpm and that rate was maintained throughout the duration of the pumping test (76 hours). The well responded very favorably to pumping with a maximum of 82.61 feet of drawdown, providing a specific capacity of 0.83 gpm/ft for Well M-6a (Figures 17 and 18, Table IV, Appendix F). The first significant water-bearing zone is at 190 feet below ground surface, so only 54% of the available drawdown was used. The pumping curves reveal a steadily expanding cone of depression until 200 minutes into the test when "leaky recharge" or a recharge boundary begins to flatten out the curve very quickly. The water level in the pumping well varied by several feet during the remainder of the test but as the data show, it is clear that water levels are declining no further than 123 feet below the top of casing (Plate 1). The variation in water levels is attributed to the interference effects of another pumping well in the fractured bedrock aquifer. The observed variations in water level are too great in magnitude and at too long an amplitude to reflect barometric changes or other natural phenomena.

Disregarding the irregular changes in water level, EGGI is confident that Well M-6a is capable of pumping 100 gpm (144,000 gpd) for extended periods of time. Near complete stabilization of pumping water levels was established under pumping conditions. The transmissivity calculated from the pumping data is 990 gpd/ft.

B. Recovery Phase -- Well M-6a

Full recovery is difficult to judge because of the variation in static water level, but it appears to occur very rapidly, within about 1000 minutes of the termination of pumping (Figure 18). Water levels in Well M-6a recovered fully within a time period equal to (or less than) the duration of pumping. The recovery curve reflects a very favorable recharge setting for Well M-6a. As expected, the extensive floodplain deposits around Cedar Creek are providing a mechanism for the infiltration and storage of groundwater. The recovery transmissivity as calculated for this well was 1,380 gpd/ft (Table IV).

VIII. WATER QUALITY MONITORING PROGRAM DURING THE EXTENDED PUMPING TESTS

A. Field Chemistry Tests of All Four Pumping Wells (E-1, E-6, E-7 and M-6a)

Analyses of iron, manganese, conductivity, temperature, and pH were conducted at each well site on numerous occasions during the pumping tests (Table V). The results of the continuous water quality testing showed no *significant* variations in water chemistry parameters throughout the pumping period for all four wells. There is no evidence of dramatic changes in chemistry or temperature which would indicate predominant surface water influences to the pumping wells.

B. Results of Laboratory Analyses of Water Quality from all Wells Tested

1. Introduction

Three separate water samples were collected from each well and delivered to Virginia Certified Laboratories. Two of the samples, collected after one day of pumping and on the third day of pumping, were submitted to National Testing Laboratories of Cleveland, Ohio, for analysis of all regulated drinking water parameters. On the third day of pumping, a complete set of samples was also collected from each well and submitted to the Virginia State Laboratory for analyses of bacterial, inorganic, nitrogen, metals, pesticides, volatile organic compounds and radiological parameters, according to the Virginia Waterworks Regulations. The dispersed collection of water samples throughout the pumping period allowed water chemistry to be monitored over time and provided duplicate analyses of the final water chemistry samples.

2. Results of Laboratory Water Quality Analyses of Well E-1

Well E-1 analyses indicated no significant changes in chemistry over pumping time and in general, is of very good quality. Two parameters were found to exceed drinking water standards: manganese and radium (Table VI, Appendix G). Manganese was found to be present at 0.07 mg/l, slightly exceeding the secondary standard of 0.05 mg/l[3]. Such low levels of manganese are not expected to cause a problem if the pumping schedule is managed properly and if a sequestering agent is used for treatment.

Radiological parameters analyzed for this well show that Gross Alpha was measured at 11.2 pCi/l which exceeds the recommended level of 5 pCi/l. Exceeding Gross Alpha required that a test for radium-226 and -228 be completed. Results of this test show radium-226 and -228 to be 3.1 and 2.1 pCi/l, respectively. Combined radium concentrations should be less than 5.0 pCi/l, but for Well E-1, the resultant value is 5.2 pCi/l. At these levels, it is not anticipated that treatment will be required for radium, since the accuracy for radium-226 and -228 analyses, as recorded by the state laboratory, is +/-1.3 pC/l. Also, EPA is currently reconsidering modifying action levels for radium-226 and radium-228, which are likely to be dependent upon EPA decisions on radon.

[3] The actual laboratory results were only half of the field chemistry kit results discussed earlier.

Radon gas is present in Well E-1 at a concentration of 4,100 pCi/l. Although there are no current regulations set forth by EPA for radon gas, it is possible that some form of treatment (i.e., aeration) may be required in the future. EGGI recommends that both radon and radium-226 and -228 be analyzed once every six months for the first two years of use to assess water quality trends and future potential treatment needs.

C. Results of Laboratory Analyses of Water Quality from Well E-6

The quality of water derived from Well E-6 is very good, except for the elevated levels of iron and manganese (Table VI, Appendix G). Iron is four times the secondary standard with a value of 1.28 mg/l and manganese is double the standard at a level of 0.10 mg/l. These results are not surprising since iron mineral deposits were observed in Well E-6 during drilling. However, proper management of the pumping schedule and special attention to preventing excessive drawdown will promote the long-term usefulness of Well E-6 as a water supply well. Iron concentrations at this level cannot easily be controlled using sequestering agents and, therefore, it is likely that the construction of an iron and manganese treatment facility (i.e., oxidation/filtration) will be required prior to fully utilizing this well.

Radon gas was detected in Well E-6 at a level of 1,700 pCi/l. Turbidity was detected at 6 nephelometric turbidity units (ntu), above the recommended limit of 5 ntu (for groundwater supplies), but it is expected that prolonged pumping of this well (at the appropriate sustainable yield) will cause turbidity to diminish to acceptable levels.

D. Results of Laboratory Analyses of Water Quality from Well E-7

Well E-7 yields water of excellent quality, with no parameters exceeding EPA primary and Secondary Drinking Water Standards (Table VI, Appendix G). Iron and manganese were both found at very low levels, .02 and .03 mg/l, respectively. Although the yield of E-7 is lower than E-1 and E-6, EGGI recommends that the water be used concurrently with Wells E-1 and E-6. The first round of bacteriological samples showed that seven out of nine samples were contaminated, however, sampling errors are expected to be the cause. EGGI re-tested the well by collecting an additional 20 bacteriological samples. The results of this analyses showed all samples to have a MPN <2.

E. Results of Laboratory Analyses of Water Quality from Well M-6a

The chemistry of water derived from Well M-6a is similar in nature to that observed in Well E-6. Iron, manganese, and turbidity were all reported at levels exceeding the regulated drinking water standards (Table VI, Appendix G). Iron was detected at 0.73 mg/l and manganese at 0.22 mg/l, both elevated above standards. Treatment requirements for iron and manganese may be limited to sequestering agents at these concentrations; however, EGGI recommends that, if this well is planned for future use, an appropriate filtration system be constructed to treat this water. As with E-6, EGGI does not anticipate the high turbidity to be a continuing problem under normal pumping conditions. No radon sample was collected from M-6a, but the gross alpha and beta tests indicate no radiological concerns.

IX. CONCLUSIONS / RECOMMENDATIONS FOR GROUNDWATER SUPPLY DEVELOPMENT IN NEW BALTIMORE -- PRODUCTION WELL E-1, E-6, E-7, AND M6-a

Based on the results of test well drilling, pumping tests and water quality tests, two new favorable zones for groundwater development have been proven capable of supplying sustainable, potable water resources for the New Baltimore Service District. Zone E contains three production wells which were pumped at a combined yield of 778 gpm (1.1 mgd). The total volume of groundwater withdrawn from Zone E during the pumping test period was 4,136,000 gallons. Zone M has only been partially explored to date, with just a single well (M-6a) being tested at a rate of 100 gpm (0.144 mgd).

The results of this comprehensive groundwater exploration and development program conducted to date in New Baltimore, Virginia, has led EGGI scientists to reach the following conclusions regarding these new water supplies:

A. Water Quality Considerations

The water quality observed from the four production wells (E-1, E-6, E-7, and M6-a) range from good to excellent. Wells E-1 and E-7 produce water of better quality than Wells E-6 and M6-a. All wells were devoid of bacteriological contamination as determined by a repeated series of bacteriological analyses. No regulated or unregulated volatile organic compounds (VOC's) were detected in any well. Likewise, analyses of pesticides and herbicides showed no remnant compounds in any well.

With regard to other water quality parameters, the following summary provides a review of water chemistry for each well.

1. Well E-7

Well E-7 provides the best quality water available from Zone E and meets all EPA Primary and Secondary Drinking Water Standards. Iron and manganese levels were low and measured to be 0.02 and 0.03 mg/l, respectively (Table VI).

2. Well E-1

The water quality observed in Well E-1 is considered to be very good. Two parameters were found to exceed drinking water standards: manganese and radium (Table VI, Appendix G). Manganese was found to be present at 0.07 mg/l, slightly exceeding the secondary standard of 0.05 mg/l. Such low levels of manganese are not expected to cause a problem if the pumping schedule is managed properly and if a sequestering agent is used for treatment.

Radiological parameters analyzed for this well show that Gross Alpha was measured at 11.2 pCi/l which exceeds the recommended level of 5 pCi/l. Exceeding Gross Alpha required that a test for radium-226 and -228 be completed. Results of this test show radium-226 and -228 to be 3.1 and 2.1 pCi/l, respectively. Combined radium concentrations should be less than 5.0 pCi/l, but for Well E-1, the resultant value is 5.2 pCi/l. At these levels, it is not anticipated that treatment will be required for radium, since the accuracy for radium-226 and -228 analyses, as recorded by the state laboratory, is +/-1.3 pC/l. Also, EPA is currently reconsidering modifying action levels for radium-226 and radium-228, which are likely to be dependent upon EPA decisions on acceptable radon levels.

Radon gas is present in Well E-1 at a concentration of 4,100 pCi/l. Although there are no current regulations set forth by EPA for radon gas, it is possible that some form of treatment (i.e., aeration) may be required in the future. EGGI recommends that both radon and radium-226 and -228 be analyzed once every six months for the first two years of use to assess water quality trends and future potential treatment needs.

3. Well E-6 and Well M6-a

Although the water produced from these wells is considered very good, the water is elevated in iron and manganese, as follows:

Well	Iron	Manganese	Maximum Recommended Level
E-6	1.28 mg/l	0.10 mg/l	iron 0.30 mg/l
M-6a	0.73 mg/l	0.22 mg/l	manganese 0.05 mg/l

Proper management of the pumping schedule and special attention to preventing excessive drawdown will promote the long-term usefulness of Well E-6 as a water supply well. Iron concentrations at this level cannot easily be controlled using sequestering agents and, therefore, it is likely that the construction of an iron and manganese treatment facility (i.e., oxidation/filtration) will be required prior to integrating this well into the New Baltimore water system.

Radon gas was detected in Well E-6 at levels of 1,700 pCi/l. Turbidity was detected at 6 nephelometric turbidity units (ntu), slightly above the recommended limit of 5 ntu (for groundwater supplies). Based upon previous experience, EGGI expects that prolonged pumping of this well (at the appropriate sustainable yield) will cause turbidity to diminish to acceptable levels.

B. Selection of Wells for Incorporation into New Baltimore's Water System

Based upon the pumping test data collected and analyzed from the extended testing of Wells E-1, E-6, E-7, and M6-a, EGGI recommends that *Wells E-1 and E-7* be immediately incorporated into the New Baltimore water distribution system. These wells produce water of the best available quality and can be pumped simultaneously to supplement existing FCWSA water supply demands. Water low in manganese from Well E-7 mixed with water from Well E-1 should help to keep manganese at acceptable levels.

Subsequent to integrating Wells E-1 and E-7 into the New Baltimore water system, both Wells E-6 and M-6a could then be brought on-line to meet future water supply demands. More extensive treatment of water to remove elevated iron and manganese levels will be required at these locations.

We do not recommend the use of Well E-3 at this time, but suggest that it be considered for use as an emergency back-up well. This well is eight inches in diameter and was used as an observation well during the testing period. The well yields approximately 100 gpm. Prior to interconnection with the water distribution system, the well would require complete pumping tests and water quality analyses.

C. Pumping Rates / Schedules

As demonstrated in the pumping test program conducted at Zone E and Well M6-a, Wells E-1, E-6, E-7, and M-6a can be pumped for prolonged periods of time on a simultaneous basis. It is likely, however, that all of these wells will not be interconnected with the water system at the same time. Based upon the data analyzed to date, EGGI recommends the following pumping rate schedules for two different combinations of well use:

1. Simultaneous Use of Wells E-1 and E-7 Only

Well E-1 can be pumped at a rate of 350 gpm for extended periods of time (i.e., 30-60+ consecutive days), if desired. However, for normal daily use, pumping this well at this rate for 13 hours "on" and 11 hours "off" each day would be considered more desirable. This will allow sufficient recovery of water levels in the bedrock aquifer system and will help prevent water quality degradation.

Well E-7 can be pumped at 75-80 gpm for extended time periods (30-60+ consecutive days). A water-bearing bedrock fracture exists at approximately 80 feet and EGGI recommends that a low water shut-off switch be installed in the well to prevent water levels dropping below 75 feet. For "best management" practices, EGGI recommends that normal daily pumping schedules be maintained at 13 hours "on" and 11 hours "off".

2. Simultaneous Use of All Wells (E-1, E-6, E-7, and M-6a)

Wells E-1 and E-6 withdraw groundwater from a bedrock system that is interconnected and, therefore, when pumped simultaneously, should be considered together in terms of long-term management of the water resource.[4]

For short-term pumping periods (i.e., 10-15 consecutive days), EGGI recommends that Wells E-1 and E-6 be collectively pumped at 700 gpm (1 MGD). However, normal operation pumping schedules should maintain a 350 gpm pumping rate for each well -- 13 hours "on" and 11 hours "off." Well M6-a and Well E-7 can be pumped at a sustainable rate of 100 gpm and 75-80 gpm, respectively, in accordance with the same pumping schedule as recommended for Wells E-1 and E-6 under this scenario.

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[4] EGGI recommends that, during the interim period between when Well E-1 is put on-line and Well E-6 is interconnected, water levels should be continuously monitored at the Snow Hill Well, Well E-3, the Greenhouse Well, and at Well E-6 (Plate 1). Water level data collected during this time period may serve to increase/decrease the overall water production yields projected for Zone E.

D. Results of Groundwater Monitoring of Local Wells

An extensive groundwater monitoring program was established to observe the potential impact that pumping high yield production wells might have on existing local users of groundwater. A total of 18 different monitoring wells were selected based on observations in the field, type of well, geologic site conditions and landowner permission. These monitoring wells included 13 domestic wells, four existing bedrock wells, and the FCWSA Snow Hill production well (Plate 1, Figures 2 and 3, and Table III).

Water levels in eighteen monitoring wells were recorded before, during, and after the pumping of Wells E-1, E-6, and E-7 for a period of 15-20 days. A detailed discussion of the individual impacts on local domestic wells is presented in Section VI-E of this report. In summary, only three domestic wells responded to the extended pumping test with decreased water levels.

The following monitoring wells showed no measurable interference associated with withdrawing 778 gpm from Wells E-1, E-6, E-7:

Monitoring Well E-4
Booth Domestic Well
Fling Domestic Well
Jamison Domestic Well
McDaniel Domestic Well
Medvitz Domestic Well
Mercado Domestic Well
Miller Domestic Well
B. Semple Domestic Well
S. Semple Domestic Well
Simone Domestic Well

All data collected from these wells are presented on Plate 1 and Appendix E.

Those active domestic wells which showed a minor response to pumping Wells E-1, E-6, and E-7 included the Gulledge Well, Tenants Well, and Radio Station Well. Other monitoring wells that showed minor interference effects include the FCWSA Snow Hill Well, an unused irrigation well owned by Mr. B. Semple, Well E-3, and an *unused* well identified as the Greenhouse Well owned by Mrs. Jamison.

Although the domestic well monitoring program has shown that three active local wells responded to pumping Wells E-1, E-6, and E-7, it is unlikely that these homeowners will be negatively impacted under the proposed pumping schedules outlined in **B)** and **C)** above. It is anticipated that all affected domestic wells exceed 100 feet in depth. The high yield of the bedrock aquifer and substantial saturated portion of the aquifer leaves sufficient water for use for local homeowners. However, as a conservative precaution, EGGI recommends that the FCWSA consider the following:

1) Install a permanent automated groundwater monitoring device in the Gulledge domestic well. This was the domestic well that responded the most to the simultaneous pumping of Wells E-1, E-6, and E-7 at a combined rate of 778 gpm. Collection of water levels in this well over time will allow the FCWSA to closely monitor the anticipated maximum groundwater level fluctuations in the local area that would be associated with pumping the new production wells. This data can then be used to estimate water level fluctuations in other domestic wells. If excessive lowering of the water table appears to be threatening domestic well supplies, pumping management schemes of FCWSA wells can then be modified or domestic wells can be drilled to a deeper level.

or ....

2) Install one or two permanent observation wells at strategic locations between pumping wells and selected domestic wells so that continued groundwater monitoring of the local water table can be accomplished. As part of this plan, EGGI recommends that the FCWSA monitors the unused Greenhouse Well at the Jamison property, Well E-3, and the FCWSA Snow Hill Well. Data collected from this monitoring program could be used to select appropriate mitigation measures, if necessary.

E. Pump Settings

Selected pumps should be installed at the following depths in each well.

Well E-6	Bottom of pump should be set at 200 feet below ground surface.
Well E-7	Bottom of pump should be set at 200 feet below ground surface.
Well E-1	Bottom of pump should be set at 200 feet below ground surface.
Well M-6a	Bottom of pump should be set at 230 feet below ground surface.

These pump settings were chosen on the basis of well performance and presence of water-bearing fracture zones observed during the drilling of each well.

F. Development of Additional Groundwater Supplies in the New Baltimore Area

As described in EGGI's Phase I report (July, 1992), a total of ten primary groundwater development zones and four secondary groundwater development zones were identified based upon hydrogeologic criteria considered favorable for developing groundwater supplies.

To date, we have completed test well drilling in only two Zones -- E and D. We have initiated test well drilling in an additional three Zones which include M, G, and H. Test well drilling completed in Zones G and H indicate that up to 400,000-500,000 gpd can be developed within *each* of these zones. Preliminary water quality results indicate that Zone H will yield water of higher quality than Zone G.

Only one well was drilled within Zone M. A total of five other wells have been selected within the area and EGGI anticipates that a minimum of 400,000-600,000 gpd could be developed within this area.

Test well drilling has not been completed in the remaining primary Zones (A, B, C, and F) or any secondary zones. Based upon hydrogeologic data presented in EGGI's Phase I report (*Groundwater Resource Investigation -- New Baltimore Service District*, July, 1992), we believe that an additional 2 million gallons per day (MGD) can be developed from a series of wells drilled within these remaining areas.

G. Other

EGGI highly recommends that the permanent pumping system installed for Wells E-1, E-6, E-7, and M6-a be equipped with the means to monitor water level fluctuations and production rates on a *daily* basis. This can be accomplished by using automated data loggers. Long-term records of water levels and pumping rates within each pumping well are very valuable for properly maintaining the well over the lifetime of its use.

Monitoring of water quality for all drinking water standards should also be completed at a minimum of once every six months. However, certain parameters such as iron can be monitored easily using field testing kits and tests could be completed as often as once per month as a general indicator of the water quality of the bedrock aquifer.

This groundwater investigation and report was prepared for the use of the FCWSA, County of Fauquier, and pertinent regulatory review agencies. The findings and conclusions provided by EGGI in this report are based solely on the information contained and referenced within this document. The report has been prepared in accordance with professionally accepted hydrogeologic practices; no warranty, expressed or implied, is made herein.

TABLES

TABLE I

Summary Table of Test Well and Production Well Drilling Data
New Baltimore, Virginia

Well ID	Date Drilled	Length of Temp. Casing (feet)	Total Depth (feet)	Air-Lift Yield (gpm)	---- Final Water Chemistry Values ---- Sulfate (mg/l)	Hardness (mg/l)	Iron (mg/l)	Manganese (mg/l)	----Following Reaming to Production Wells---- Date Reamed	Casing Length 8" (feet)	Reamed Depth (feet)	Air-Lift Yield (gpm)
D-1a	8/21-22/93	48	700	18	*0*	*100*	*0.020*	*0.040*				
D-2	8/22-23/93	42	440	15	*0*	*180*	*0.090*	*0.100*				
D-2b	8/26-27/93	38	500	30	*0*	*260*	*0.080*	*ND*				
E-1	8/27-28/93	63	360	> 300	16	110	0.056	**0.054**	8/14-15/94	95'	230'	400+
E-3	8/24-26/93	23	540	85	51	135	0.037	0.045	8/13-14/94	56'	450'	100
E-4	8/23-24/93	35	460	20	*0*	*30*	*0.250*	*ND*				
E-6	6/15-16/94	84	300	>300	6	130	0.210	**0.062**	8/17-19/94	94'	295'	400+
E-7	4/28-29/94	60	500	70	0	80	0.000	0.000	8/12-13/94	65'	200'	75
G-1	6/14-15/94	21	400	75	**293**	235	0.440	**0.100**				
G-3	4/27-28/94	20	340	190	**327**	295	0.170	**0.076**				
H-1	4/26-27/94	20	480	150	11	100	0.000	0.000				
H-3	6/13-14/94	21	600	90	44	130	0.190	0.015				
M-6a	5/9-10/94	21	540	95	19	140	0.200	**0.230**	8/11-12/94	60'	300'	105
			Total Yield = 1438 gpm		(based on 300 gpm from E-1 and E-6)				**Total Production Well Air-Lift Yields = 1080 gpm**			

ND = Not Determined

Groundwater samples were collected at the conclusion of drilling and submitted to National Testing Laboratories for analysis.

Italicized values were determined in the field using portable testing kits, results may be misleading.

Bold values exceed Secondary Drinking Water Standards = 250 mg/l for sulfate; 0.3 mg/l for iron; 0.05 mg/l for manganese.

Hardness is considered high if it exceeds 100 mg/l, but no drinking water standard has been set.

Table II

Variation in Groundwater Chemistry with Depth - Observed During Test Well Drilling Utilizing Field Water Chemistry Testing Kits*

Fauquier County Water and Sanitation Authority, New Baltimore Service District

Test Well Name	Water-Bearing Zone Depth (feet)	Air-Lift Yield (gpm)	Sulfate (mg/l)	Hardness (mg/l)	Dissolved Iron (mg/l)	Dissolved Manganese (mg/l)	Specific Conductivity (uS)
D-1a	500	13	<50	100	0.02	0.04	NT
D-2 (bottom)	440	15	<50	180	0.09	**0.10**	NT
D-2b	360	20	<50	180	0.05	NT	94
bottom	500	30	<50	260	0.08	NT	79
E-1	210	200	<50	140	< 0.05	**0.11**	89
	260	250	<50	120	< 0.05	**0.07**	76
	318	>250	<50	120	< 0.05	**0.29**	67
bottom	360	>250	<50	120	0.09	**0.17**	NT
E-3	93	10	<50	90	NT	NT	NT
	153	32	<50	120	0.10	**0.08**	NT
	360-420	63	20	140	0.20	**0.11**	NT
	475	NT	<50	120	0.15	NT	98
bottom	540	85	50	120	NT	NT	59
E-4	34-36	15	<50	20	**0.30**	0.02	NT
bottom	460	20	<50	30	0.25	0.01	NT
E-6	60	85	<50	120	NT	NT	205
	69	170	<50	130	**0.60**	NT	222
	90-100	190	NT	NT	**1.00**	NT	204
	114	200	<50	130	**0.50**	**0.12**	203
	216-218	230	<50	130	**0.30**	**0.07**	213
	275-280	>400	<50	140	**0.30**	0.01	220
E-7	80	15	<50	90	0.01	0.00	NT
	115-117	45	<50	80	0.00	NT	NT
	120	60	<50	90	0.05	0.03	NT
	150	63	NT	NT	NT	NT	NT
	173	70	<50	75	0.13	0.03	180
G-1	118	20	70	130	NT	NT	360
	138	50	240	110	NT	NT	655
	233	62	**250**	100	NT	NT	712
	285-300	75	**>300**	300	NT	NT	835
G-3	145	22	90	160	NT	NT	NT
	175-185	105	90	160	0.04	NT	NT
	240	130	90	140	NT	NT	NT
	254	150	170	200	NT	NT	NT
	294	175	200	210	NT	NT	NT
	316	190	**300**	320	NT	NT	NT
H-1	148	15	10	120	NT	NT	NT
	220	75	10	120	NT	NT	NT
	272	130	NT	NT	NT	NT	NT
	300	135	10	110	0.04	NT	NT
	327	150	10	100	0.01	NT	NT
H-3	205	62	<50	110	NT	NT	220
	220-260	77	<50	130	NT	NT	235
	452	84	<50	140	NT	NT	268
M-6a	48	16	<50	140	**1.20**	NT	NT
	190	52	<50	170	**0.40**	NT	320
	255	68	<50	120	0.15	NT	317
	498	95	<50	140	NT	NT	318
bottom	540	95	19	140	0.20	**0.23**	NT

NT = Parameter "Not Tested" at that interval.

Bold values exceed secondary drinking water standards; Sulfate =250, Iron = 0.3, Manganese = 0.05 mg/l

* Note: Field testing kits may provide results which are not identical with concentrations determined in a laboratory.

Table III
Domestic Wells Utilized for Groundwater Monitoring During the Long-term Pumping Tests
Favorable Zone E, New Baltimore, Virginia

Tax Map Location	Owner(s)	Well Name	Address			Acreage
PUMPING WELLS						
699576 6630 699502	JAMISON, T. and W. C., Trustees	Well E-1	RT 6 BOX 12	Warrenton, VA	22186	63.41
699579 4111 699502	Semple Family Limited Partnership	Well E-6	RT 6 BOX 271 - Suffield Farm	Warrenton, VA	22186	120.23
699557 6353 699502	SIMONE, Arman R.	Well E-7	ROUTE 3 BOX 193B	Warrenton, VA	22186	111.74
MONITORING WELLS						
699587 1781 699502	CRESCENTE, Joyce	Well E-3	P O BOX 740	Warrenton, VA	22186	14.24
699576 2586 699502	JAMISON, T. and W. C., Trustees	Well E-4	RT 6 BOX 12	Warrenton, VA	22186	63.41
699576 6630 699502	JAMISON, T. and W. C., Trustees	Greenhouse Well	RT 6 BOX 12	Warrenton, VA	22186	63.41
5184 6996.04	Fauquier Water and Sanitation (FCWSA)	Snow Hill Well				
699568 1903 699502	MILLER	Miller Well				2.99
699587 1781 699502	CRESCENTE, Joyce	Radio Station Well	P O BOX 740	Warrenton, VA	22186	14.24
699587 9544 699502	MEDVITZ	Medvitz Well				5.08
699598 3229 699502	FLING, Otis R. AND Mont O.	Fling Well	RT 6 BOX 267	Warrenton, VA	22186	7.09
699576 2586 699502	JAMISON, T. and W. C., Trustees	Jamison Well	RT 6 BOX 12	Warrenton, VA	22186	63.41
699576 6630 699502	JAMISON, T. and W. C., Trustees	Booth Well	RT 6 BOX 12	Warrenton, VA	22186	63.41
699559 8176 699502	MCDANIEL, Lynn H. and Stewart, Jr.	McDaniel Well	RT 6 BOX 273A	Warrenton, VA	22186	3.90
699568 7161 699502	GULLEDGE	Gulledge Well				3.00
699568 5287 699502	MERCADO, Jose L. and Kathleen H.	Mercado Well	RT 6 BOX 272A	Warrenton, VA	22186	3.00
699579 4111 699502	Semple Family Limited Partnership	B. Semple Well	RT 6 BOX 271 - Suffield Farm	Warrenton, VA	22186	120.23
699579 4111 699502	Semple Family Limited Partnership	Tenant Well	RT 6 BOX 271 - Suffield Farm	Warrenton, VA	22186	120.23
699579 4111 699502	Semple Family Limited Partnership	Irrigation Well	RT 6 BOX 271 - Suffield Farm	Warrenton, VA	22186	120.23
699568 2679 699502	SEMPLE, Stephen Hamilton	S. Semple Well	RT 6 BOX 273	Warrenton, VA	22186	2.91
699557 6353 699502	SIMONE, Arman R.	Simone Well	ROUTE 3 BOX 193B	Warrenton, VA	22186	111.74

Information Modified from Fauquier County Tax Records.

Table IV

Long-Term Pumping Test Information
Fauquier County Water and Sanitation Authority, New Baltimore Service District
New Baltimore, Virginia

Pumping Well	Static Water Level (feet below top of casing)	Average Pumping Rate (gpm)	Maximum Drawdown (feet) (% available)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft) Pumping *Recovery*	Start Date and Time	Shutdown Date and Time	Pumping Test Duration (hours)	Total Volume Pumped (gallons)
Well E-1	8.46	340	48.93 (24)	7.0	5,280 *6,060*	8/29/94 13:00	9/2/94 12:00	95	1,938,000
Well E-6	5.84	340	46.85 (43)	7.3	5,450 *5,440*	8/29/94 17:45	9/2/94 12:00	90.25	1,852,000
Well E-7	6.32	78	63.26 (84)	1.2	1,270 *750*	8/29/94 11:00	9/1/94 13:00	74	346,000
Well M-6a	36.10*	100	82.61 (54)	1.21	990 *1,380*	8/29/94 8:00	9/1/94 12:00	76	456,000

*The static water level in Well M-6a fluctuates several feet, presumably as a result of another nearby pumping well(s).

Table V

Summary of Water Quality Results as Analyzed by Field Tests Conducted at the Wellhead
Data Collected During the Long-term Pumping Tests of Wells E-1, E-6, E-7 and M-6a
Fauquier County Water and Sanitation Authority, New Baltimore Service District
New Baltimore, Virginia

	Cumulative Time (minutes)	pH	Temperature (degrees C)	Specific Conductivity (uS)	Iron (mg/l)	Manganese (mg/l)
Well E-1	230	7.57	15	210	0.07	NT
	1260	7.48	15	219	0.03	NT
	1520	7.64	15	221	0.03	**0.130**
	2670	7.07	15	226	0.08	**0.170**
	3060	7.14	15	231	0.06	**0.130**
	4120	7.3	15	238	0.06	**0.100**
	4490	7.14	16	239	0.10	**0.130**
	5450	7.04	15	243	0.10	**0.130**
Well E-6	1035	7.04	15	214	**1.20**	**0.130**
	1265	7.11	15	208	**1.25**	**0.150**
	1425	6.92	15	210	**1.23**	**0.180**
	2440	6.63	15	204	**>1.25**	**0.190**
	3855	6.66	14	202	**>1.25**	**0.140**
	4155	6.46	15	199	**>1.25**	**0.140**
	5175	6.82	14	196	**>1.25**	**0.120**
Well E-7	390	7.09	14	151	0.04	NT
	1470	7.06	15	152	<0.01	0.038
	2820	6.74	15	152	<0.01	0.047
Well M-6a	1500	7.32	15	313	**0.79**	NT
	1890	7.37	15	314	**0.77**	**0.290**
	2940	7.02	15	NT	**0.85**	NT
	3390	7.02	15	310	**0.76**	**0.250**

NT = Parameter "Not Tested" During that Interval.
Bold values exceed the Drinking Water Standard for Iron (0.3 mg/l) or Manganese (0.05 mg/l).

Table VI

Summary of the Virginia State Laboratory's Water Quality Results for Pumping Wells E-1, E-6, E-7 and M-6a
Fauquier County Water and Sanitation Authority, New Baltimore Service District
New Baltimore, Virginia

	Bacteria	*Inorganics*							*Metals*		*Organic Compounds*		*Radiologicals*		
Pumping Well	**Bacteria** (Yes or No)	**pH**	**Color** (APHA)	**Turbidity** (ntu)	**Hardness** (mg/l)	**Total Dissolved Solids** (mg/l)	**Sulfate** (mg/l)	**Nitrate** (mg/l)	**Dissolved Iron** (mg/l)	**Dissolved Manganese** (mg/l)	**Volatile Organic Compounds** (Yes or No)	**Pesticides** (Yes or No)	**Gross Alpha** (pCi/l)	**Gross Beta** (pCi/l)	**Radon** (pCi/l)
MCL	*Yes*	*6.5-8.5*	*15 cu*	*5 ntu*		*500*	*250*	*10*	*0.30*	*0.05*			*5*	*50*	
Well E-1	No	7.67	7	0.5	110	169	24.3	0.34	0.10	**0.07**	No	No	**11.2***	9.7	4100
Well E-6	No	7.20	12	**6.0**	120	145	8.5	<0.05	**1.28**	**0.10**	No	No	1.1	2.6	1700
Well E-7	No**	7.23	4	0.04	79	125	2.3	0.88	0.02	0.03	No	No	0.2	1.2	450
Well M-6a	No	7.57	6	**7.0**	170	236	16.7	<0.05	**0.73**	**0.22**	No	No	4.1	6.1	NT

Those results shown in bold exceed existing Maximum Contaminant Levels (MCL) for drinking water.

All samples were collected on 9/1/94 and submitted to the Virginia State Laboratory, except radon which was analyzed by Niton Corp.

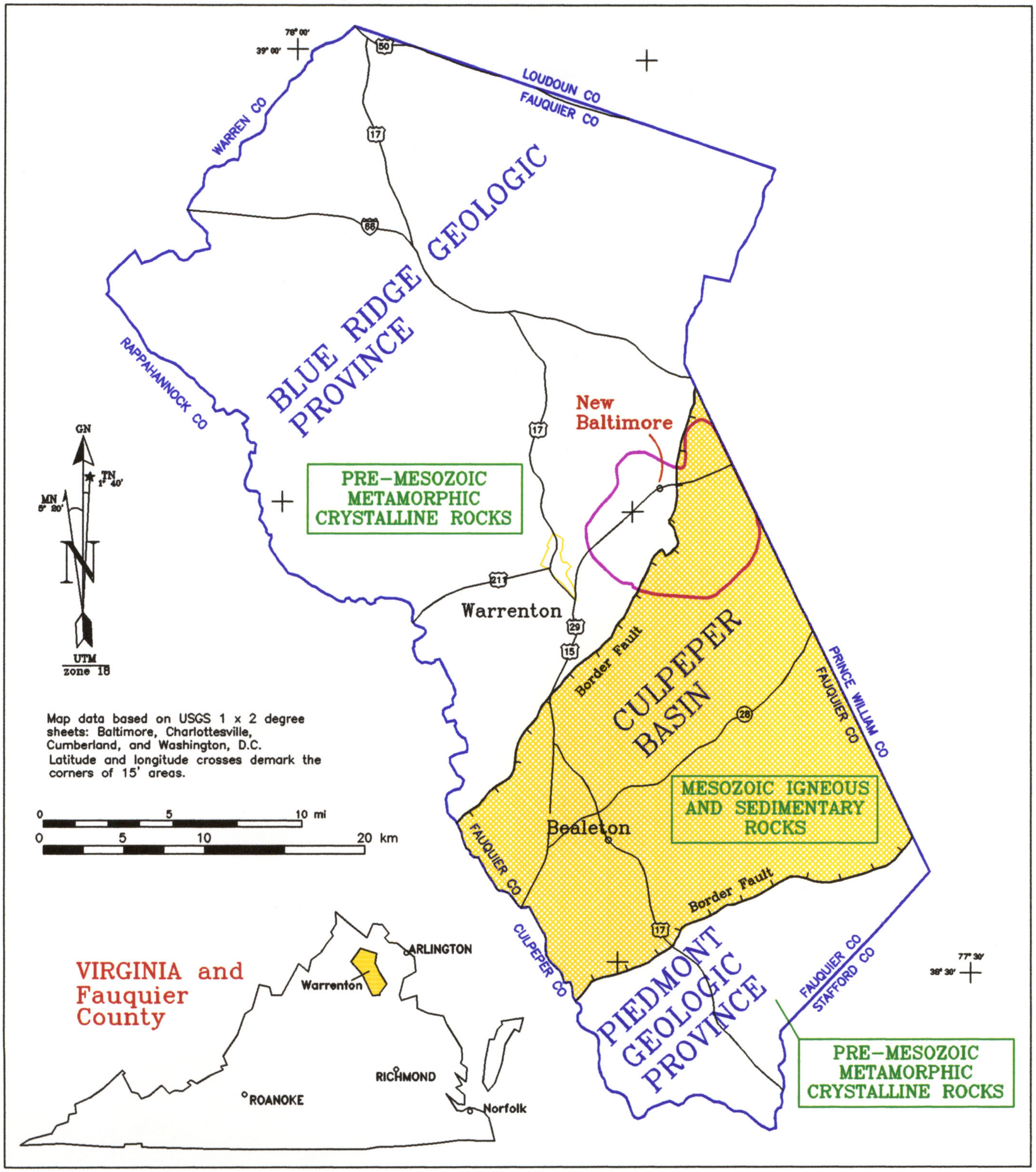
NT = Not Tested

*Because Gross Alpha exceeded 5 pCi/l, Radium-226 and Radium 228 were measured; at 3.1 and 2.1 pCi/l, respectively.

**Originally, 7 of 9 samples collected at the conclusion of pumping did show bacteria, therefore, twenty additional samples were collected, all of which showed MPN<2 colonies per 100 milliliters.

FIGURES

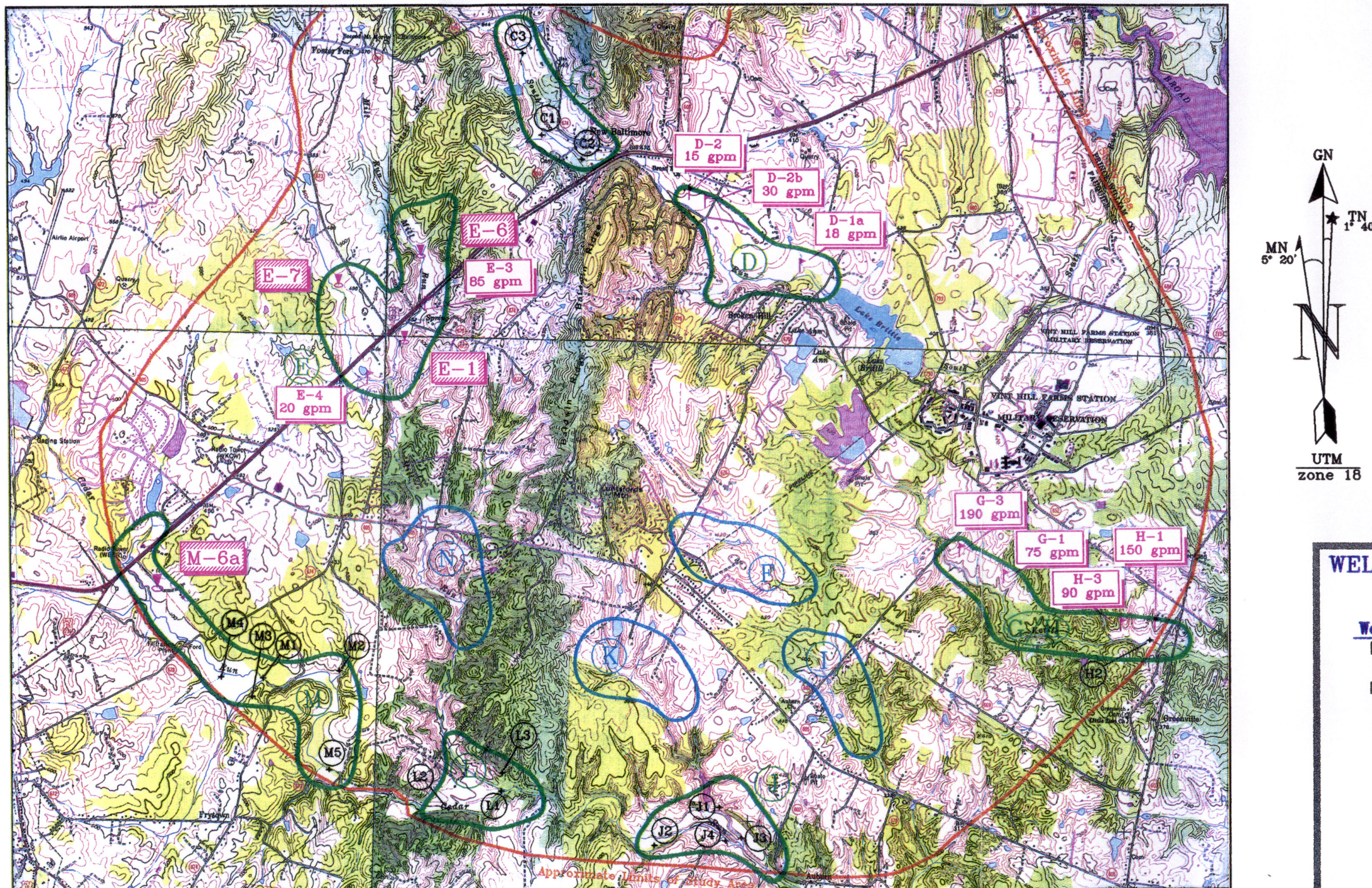
FIGURE 1a. REGIONAL GEOLOGIC SETTING OF FAUQUIER COUNTY, VIRGINIA



New Baltimore

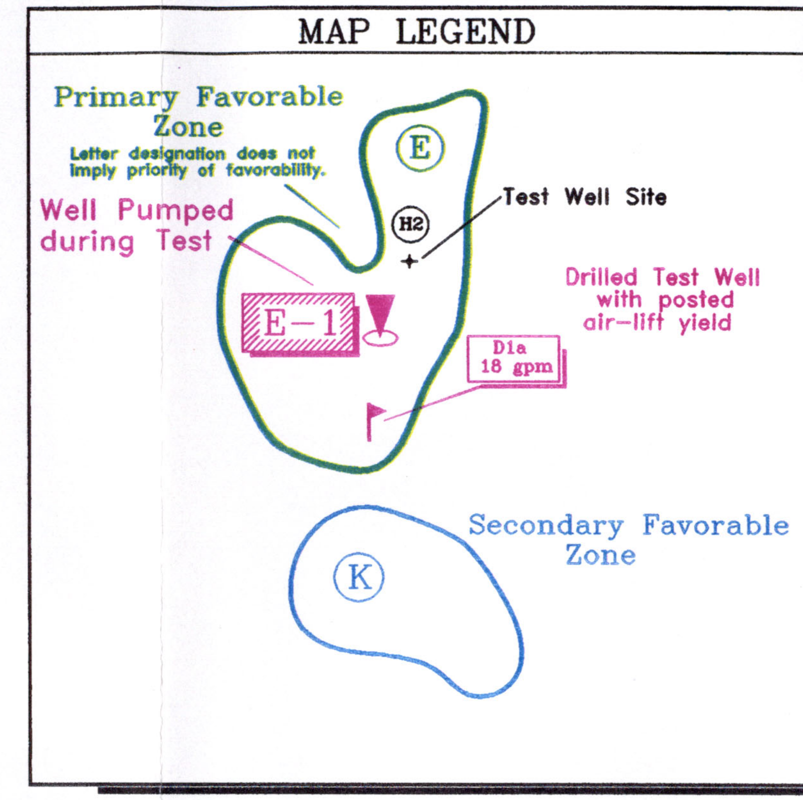
Approximate Limits of the New Baltimore Service District Study Area.

FIGURE 1b Topographic Setting of the New Baltimore Study Area Showing Favorable Zones for Groundwater Development and Test Wells Drilled to Date



Scale is 1" = 4000' (1:48000)

Contour Intervals = 10' and 20'
Polyconic projection. 1927 North American Datum.
Base map information from USGS topographic quadrangle maps of Catlett, Marshall, Thoroughfare Gap, and Warrenton, Virginia.



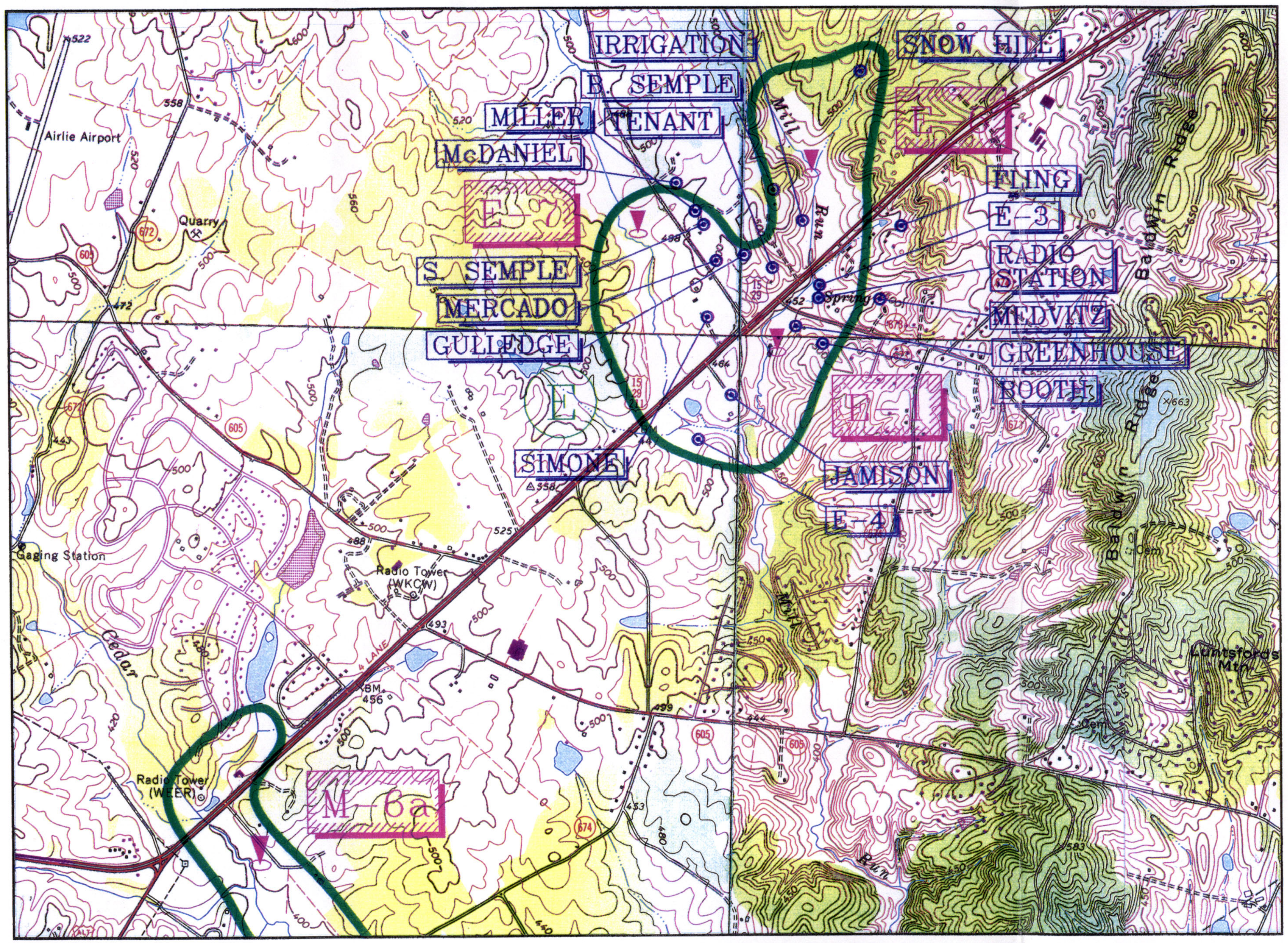
WELL INFORMATION for WELLS DRILLED TO DATE

Well ID	Date Drilled	Length of Temp. Casing (feet)	Total Depth (feet)	Air-Lift Yield (gpm)
D-1a	8/21-22/93	48	700	18
D-2	8/22-23/93	42	440	15
D-2b	8/26-27/93	38	500	30
E-1	8/27-28/93	63	360	>300
E-3	8/24-26/93	23	540	85
E-4	8/23-24/93	35	460	20
E-6	6/15-16/94	84	300	>300
E-7	4/28-29/94	60	500	70
G-1	6/14-15/94	21	400	75
G-3	4/27-28/94	20	340	190
H-1	4/26-27/94	20	480	150
H-3	6/13-14/94	21	600	90
M-6a	5/9-10/94	21	540	95

FIGURE 1b

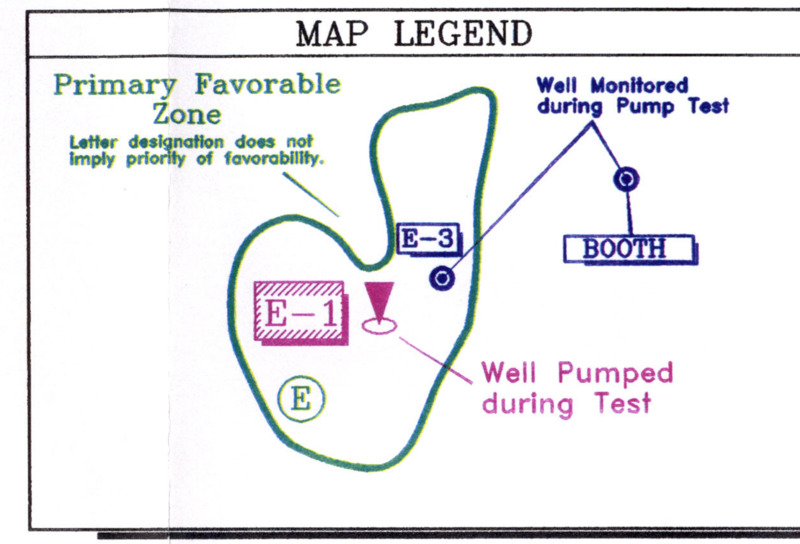
Emery & Garrett Groundwater, Inc.

FIGURE 2. Topographic Setting of the Wells Tested and Monitored in the New Baltimore Study Area



Scale is 1" = 2000' (1:24000)

Contour Intervals = 10' and 20'
Polyconic projection. 1927 North American Datum.
Base map information from USGS topographic quadrangle maps of Catlett, Marshall, Thoroughfare Gap, and Warrenton, Virginia.



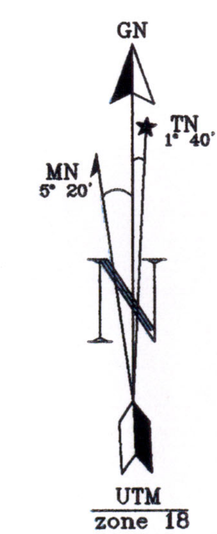
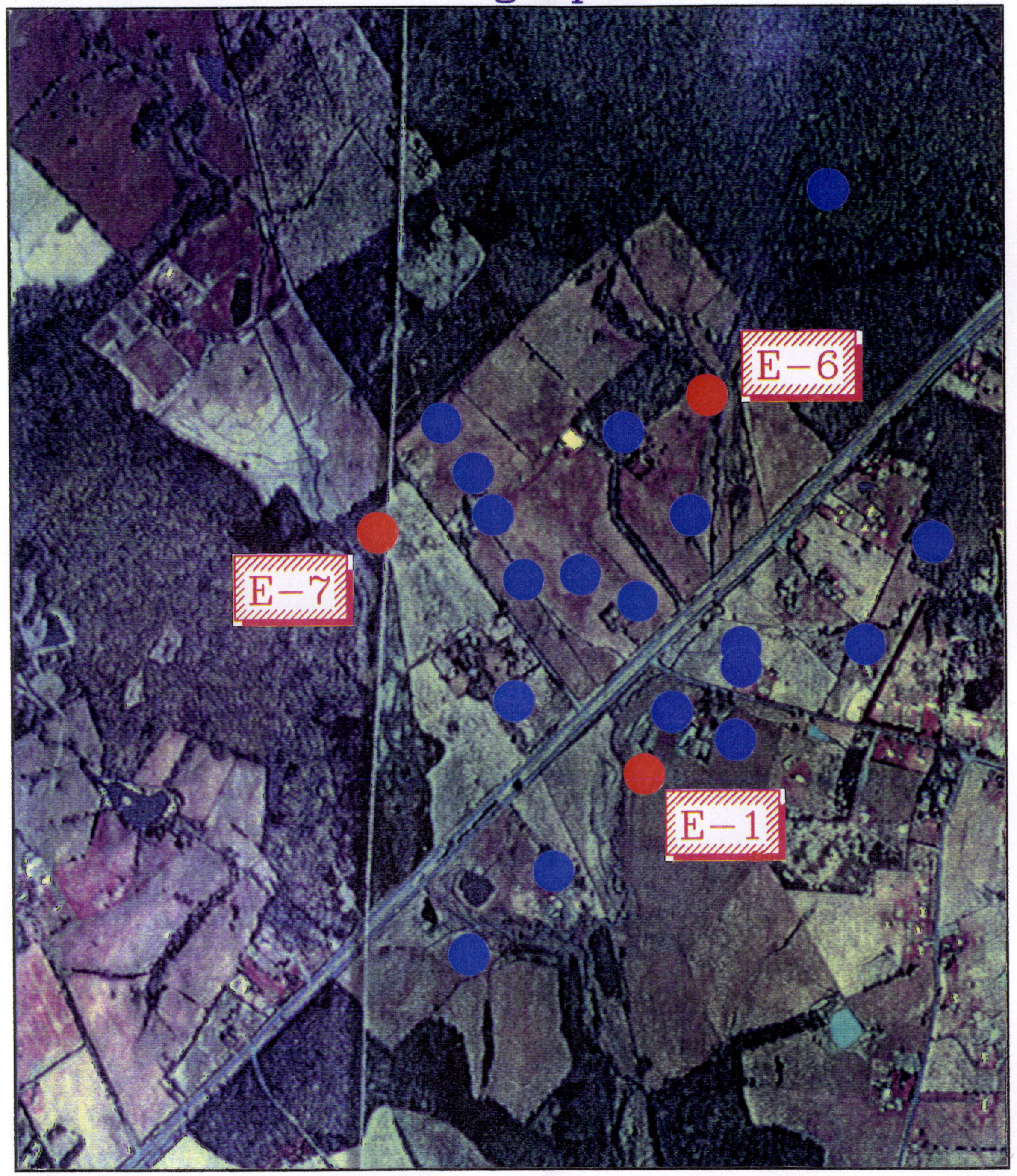


FIGURE 2

Emery & Garrett Groundwater, Inc.

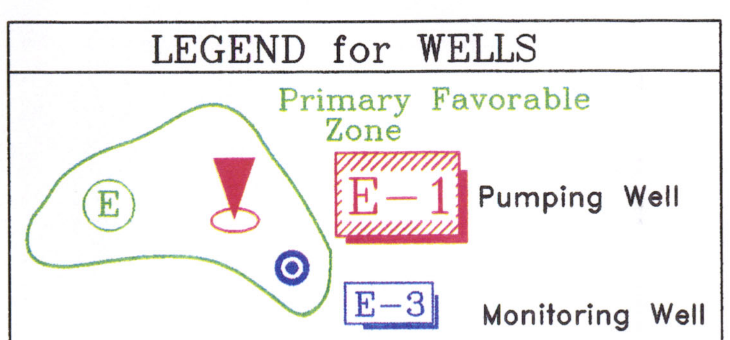
FIGURE 3. Wells Tested and Monitored in Zone E – New Baltimore

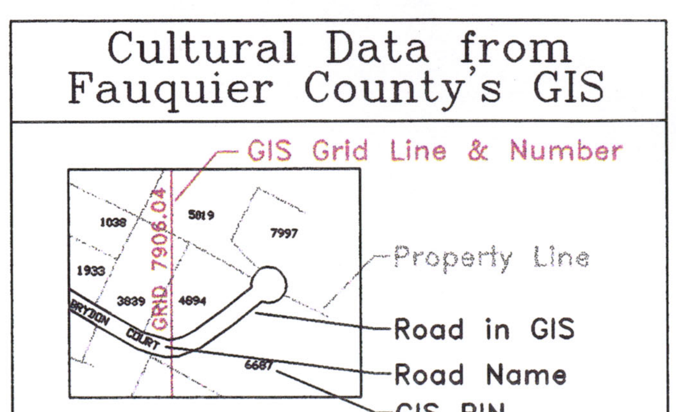
On an Aerial Photograph



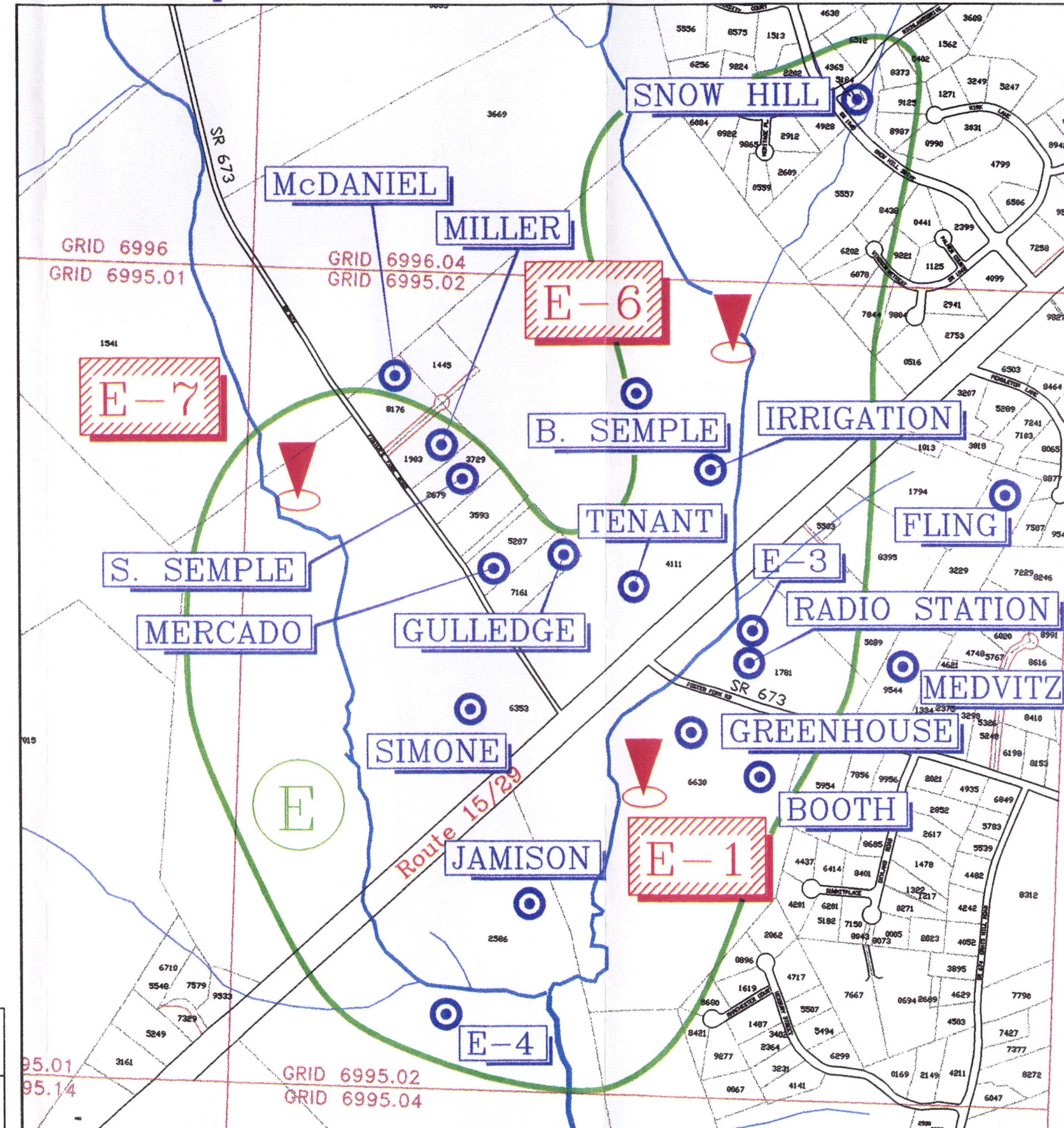
Scale is 1" = 1208' (1:14500)

Aerial coverage is on NHAP 80, color infrared photographs:
Roll 17, Frames 82 and 118, taken on March 27, 1980.





On a Map of Lot Boundaries and Lot Numbers



Scale is 1" = 800' (1:9600)

FIGURE 3

Emery & Garrett Groundwater, Inc.

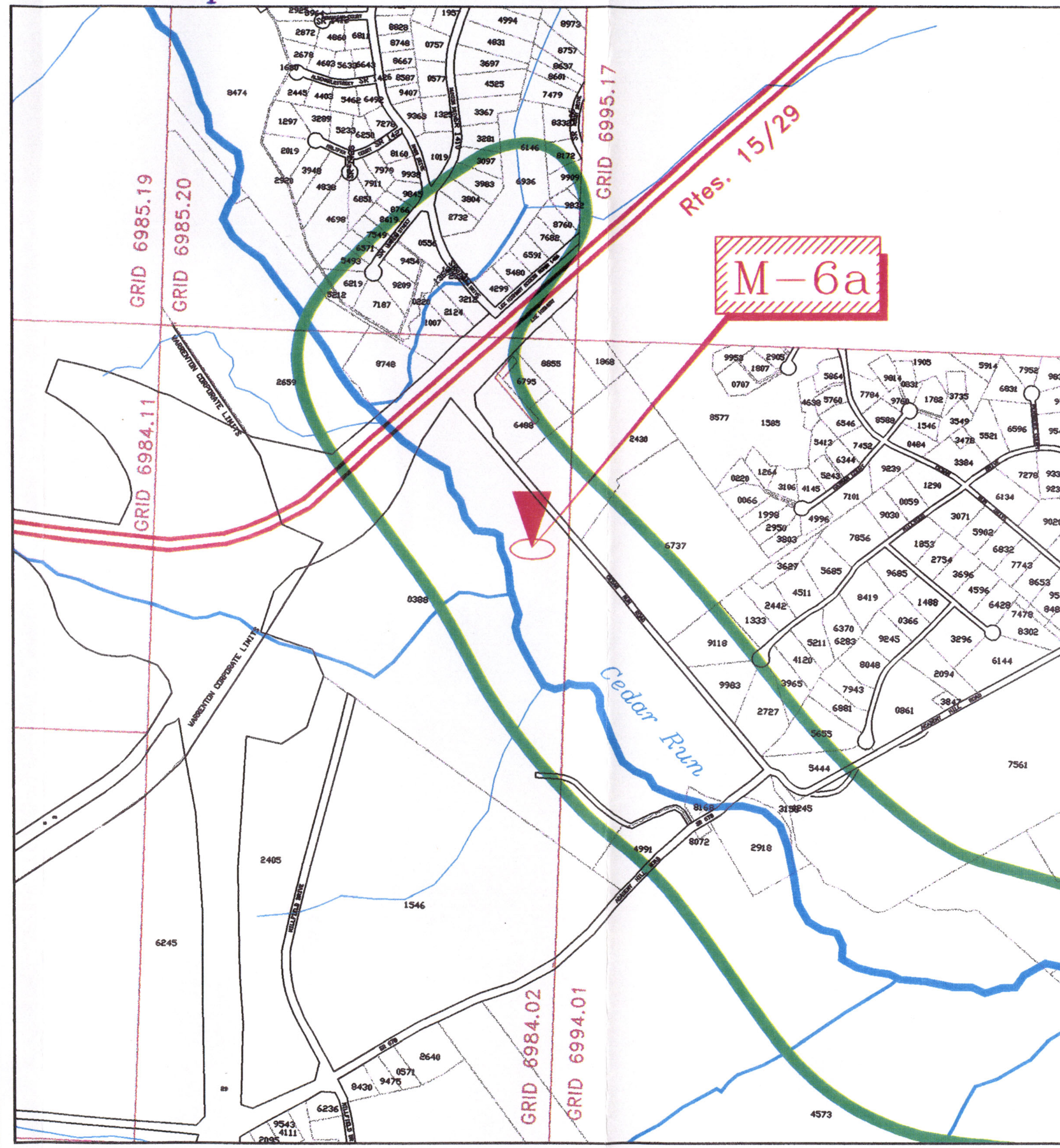
FIGURE 4. Location of Well M-6a – New Baltimore

On an Aerial Photograph

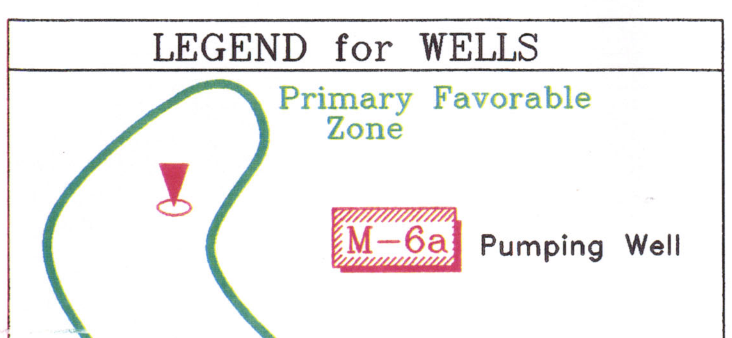
Scale is 1" = 1208' (1:14500)

Aerial coverage is on NHAP 80, color infrared photograph:
Roll 17, Frame 82, taken on March 27, 1980.

On a Map of Lot Boundaries and Lot Numbers



Scale is 1" = 800' (1:9600)



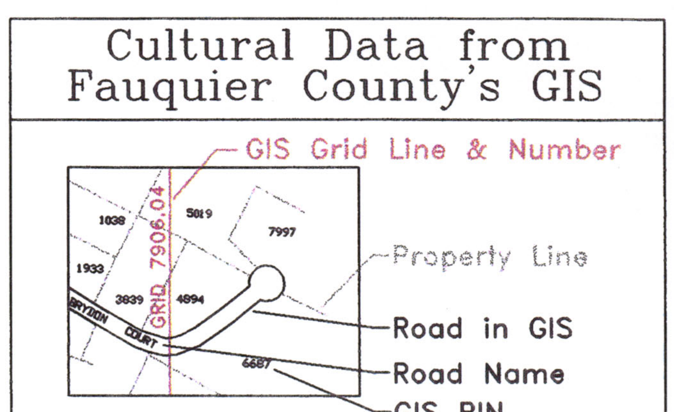


FIGURE 4

Emery & Garrett Groundwater, Inc.

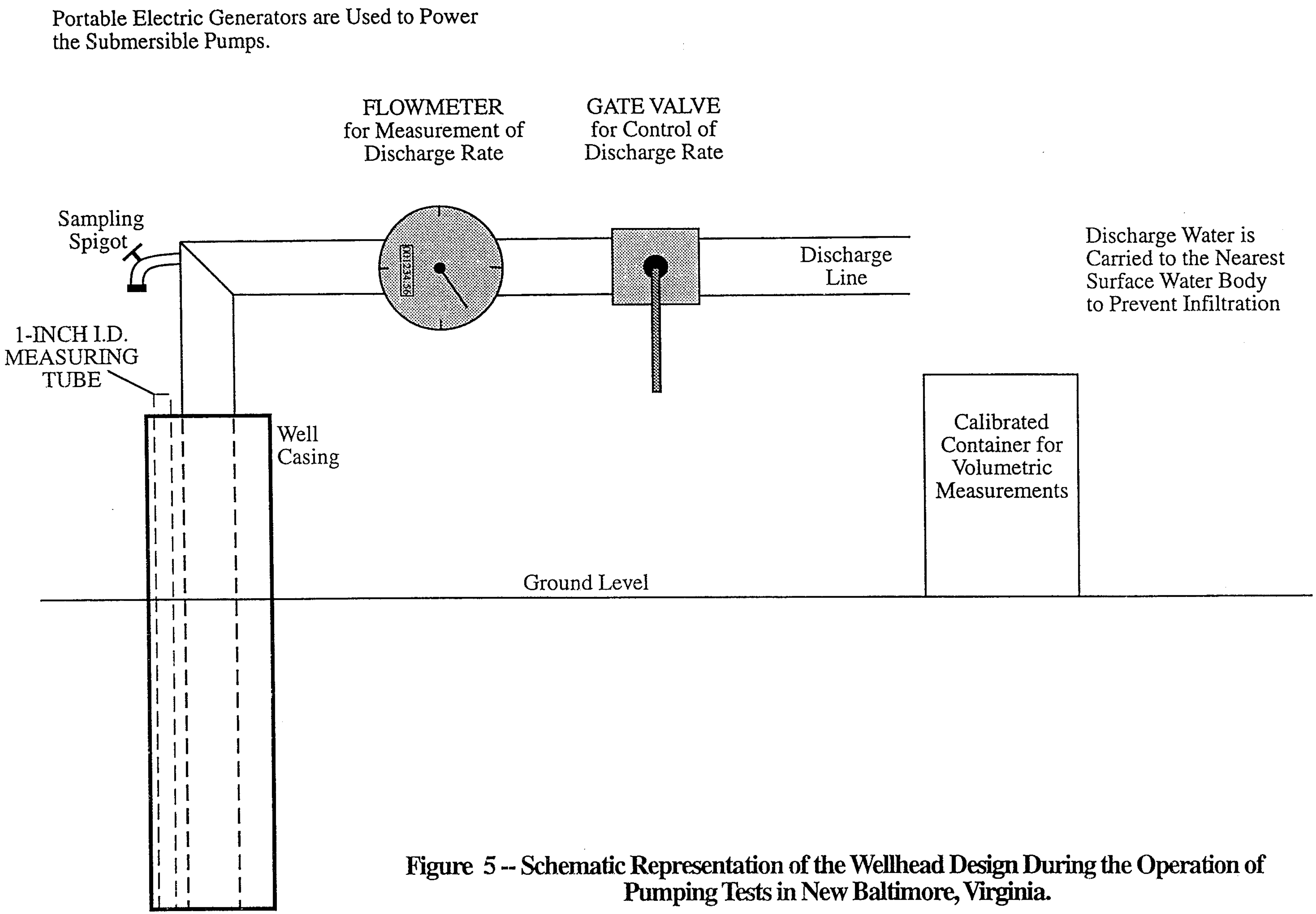


Figure 5 -- Schematic Representation of the Wellhead Design During the Operation of Pumping Tests in New Baltimore, Virginia.

BAROMETRIC PRESSURE FLUCTUATIONS
DURING THE E-1, E-6, E-7 AND M-6a PUMPING TESTS

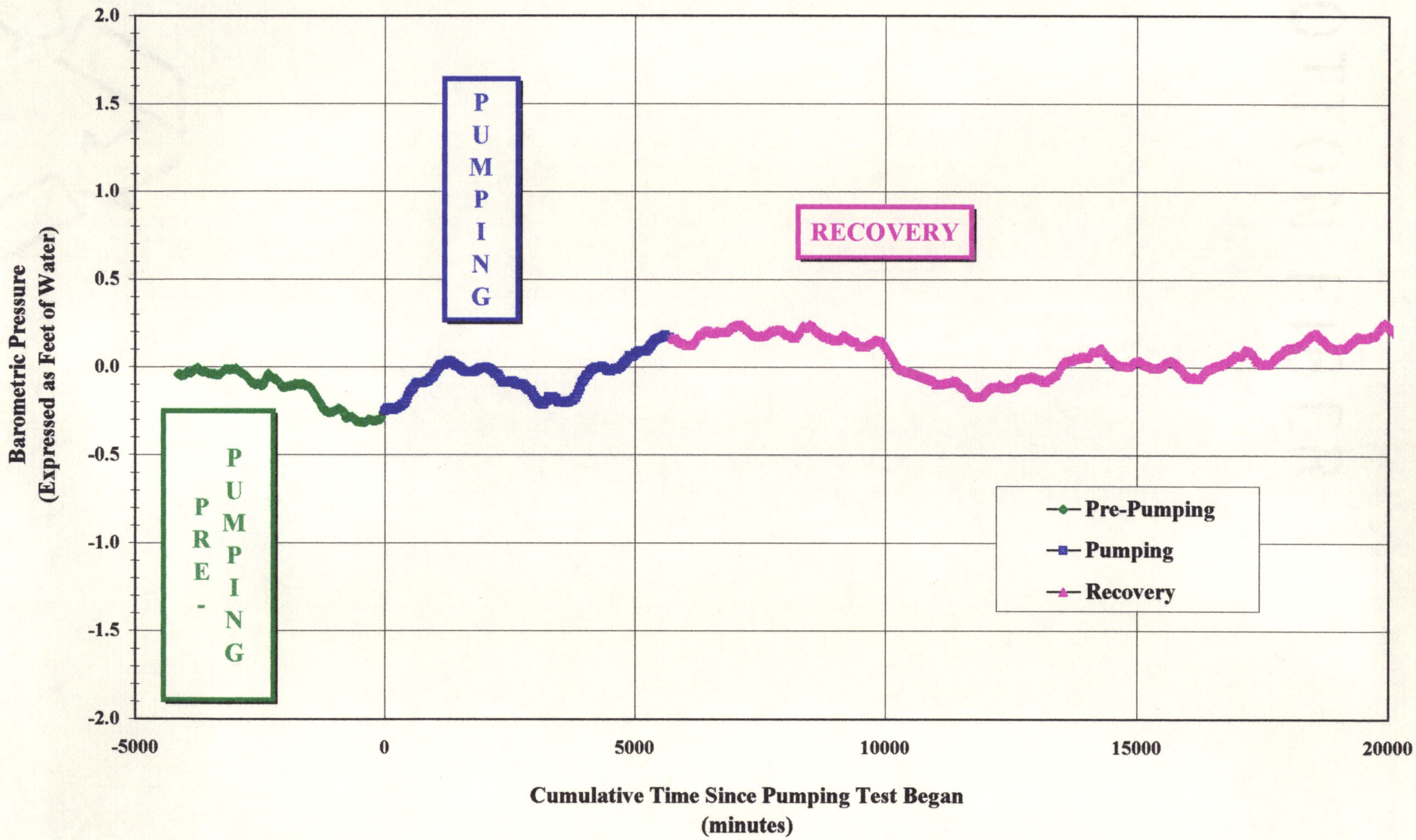
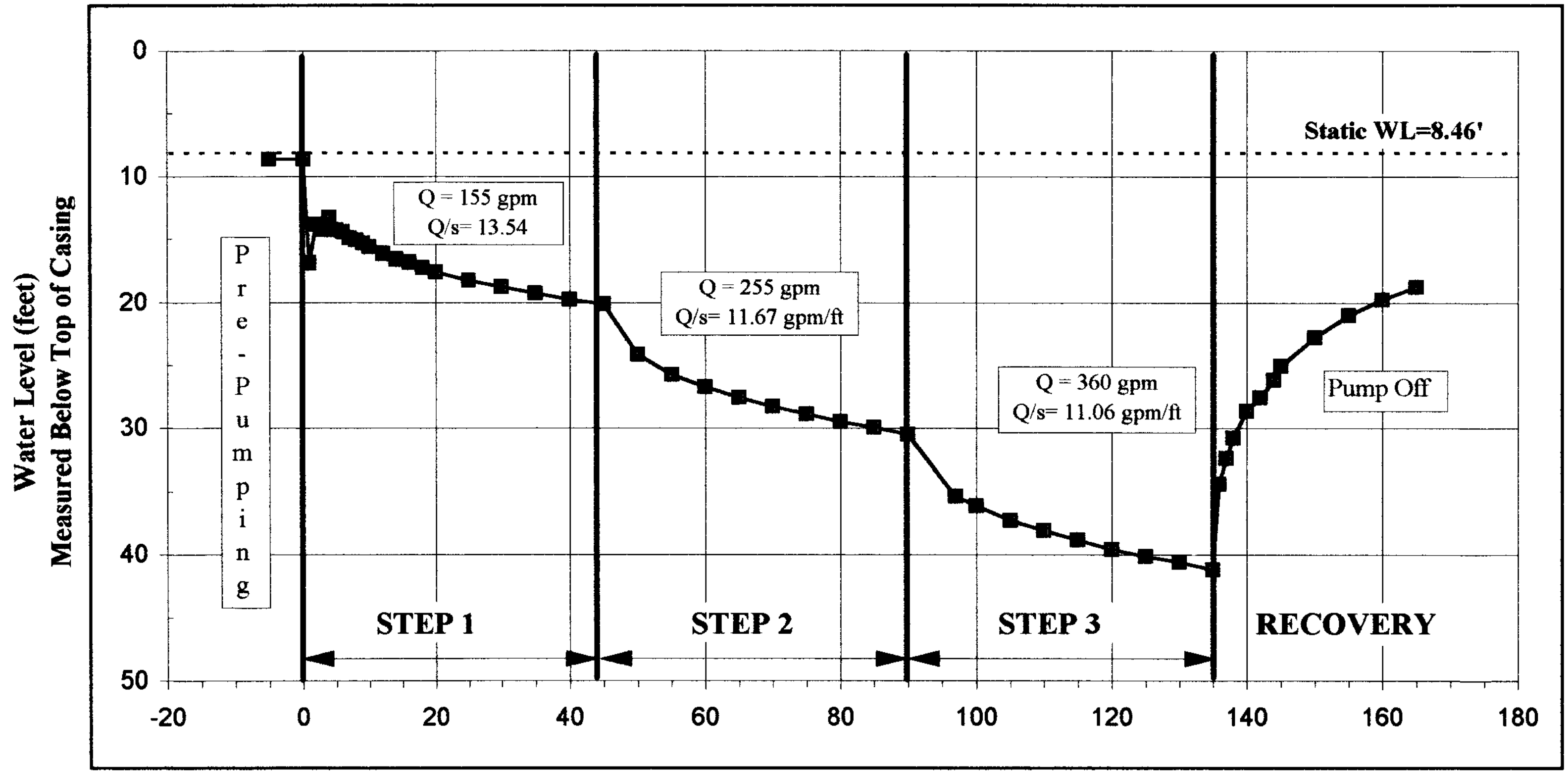


Figure 6 -- Time versus Barometric Pressure - Data Collected Throughout the Groundwater Monitoring Period August 26 to September 12, 1994, New Baltimore, Virginia

Pumping Well E-1 Step Drawdown Test



Cumulative Time Since Pumping Began
(minutes)

Figure 7 -- Step Drawdown Test Results for Pumping Well E-1, August 26, 1994, New Baltimore, Virginia

Pumping Well E-6 Step Drawdown Test

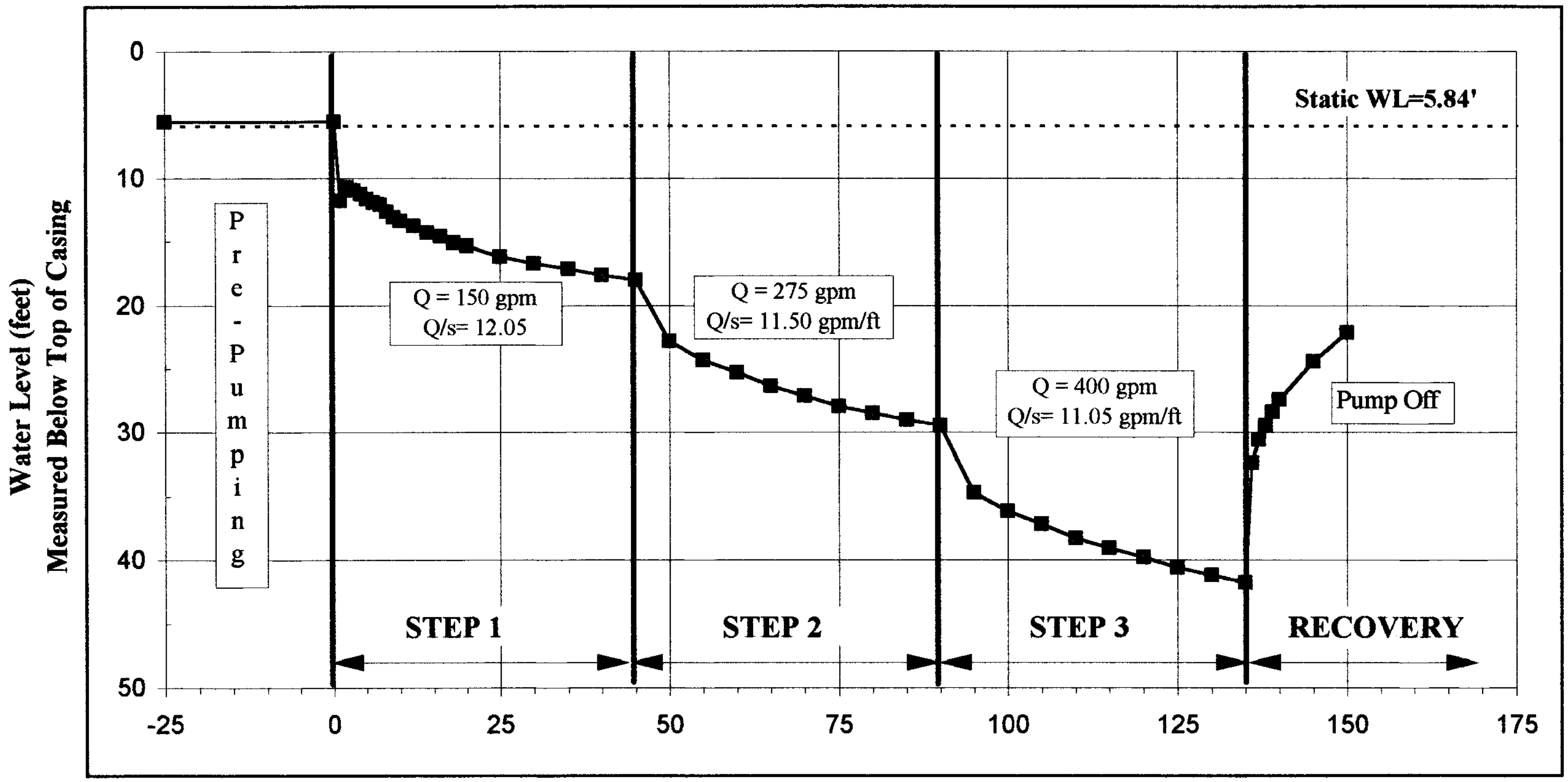


Figure 8 -- Step Drawdown Test Results for Pumping Well E-6, August 26, 1994, New Baltimore, Virginia

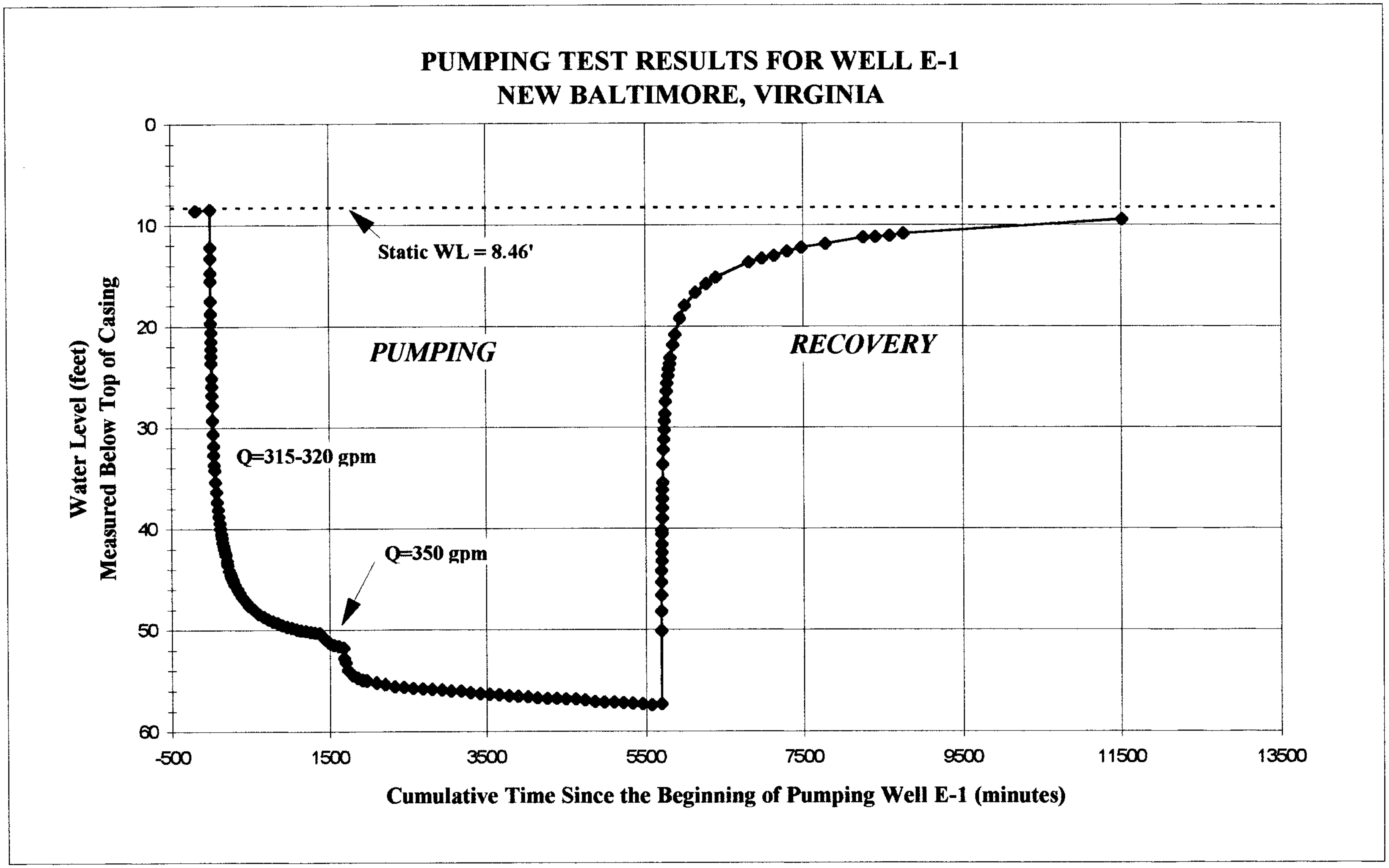
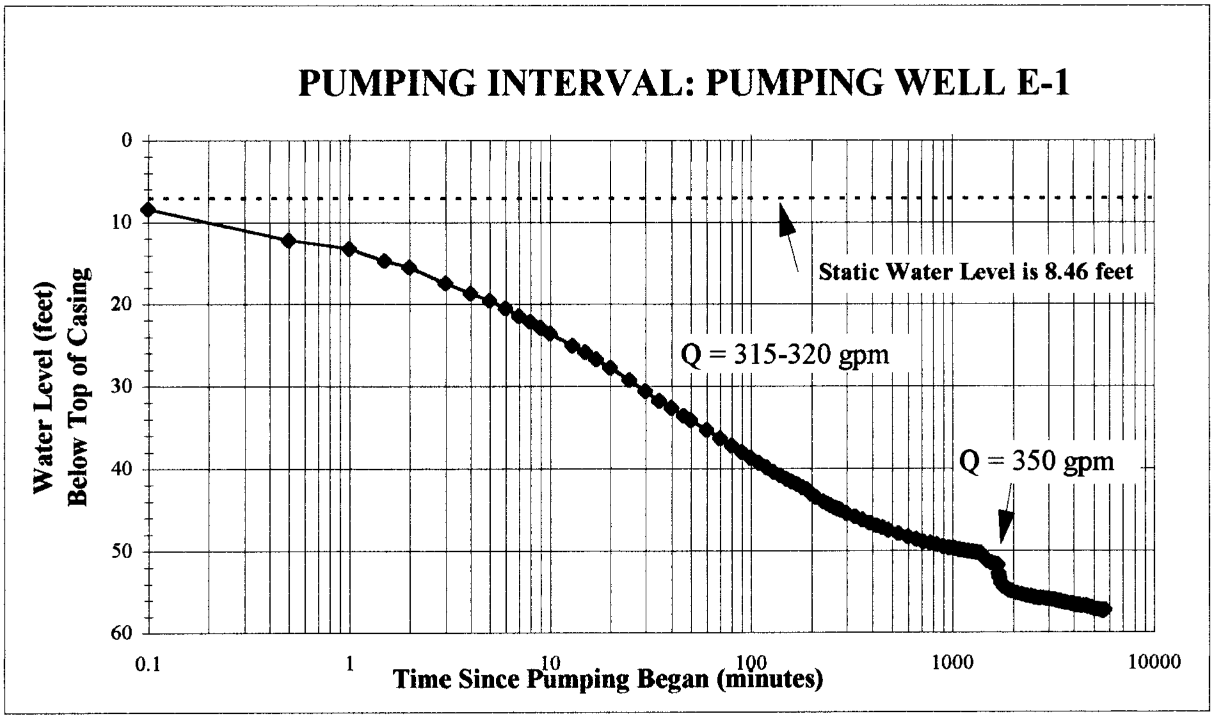


Figure 9 -- Arithmetic Time versus Water Level Plot of Pumping Well E-1, Data Collected Throughout the Monitoring Period, August 29 to September 6, 1994



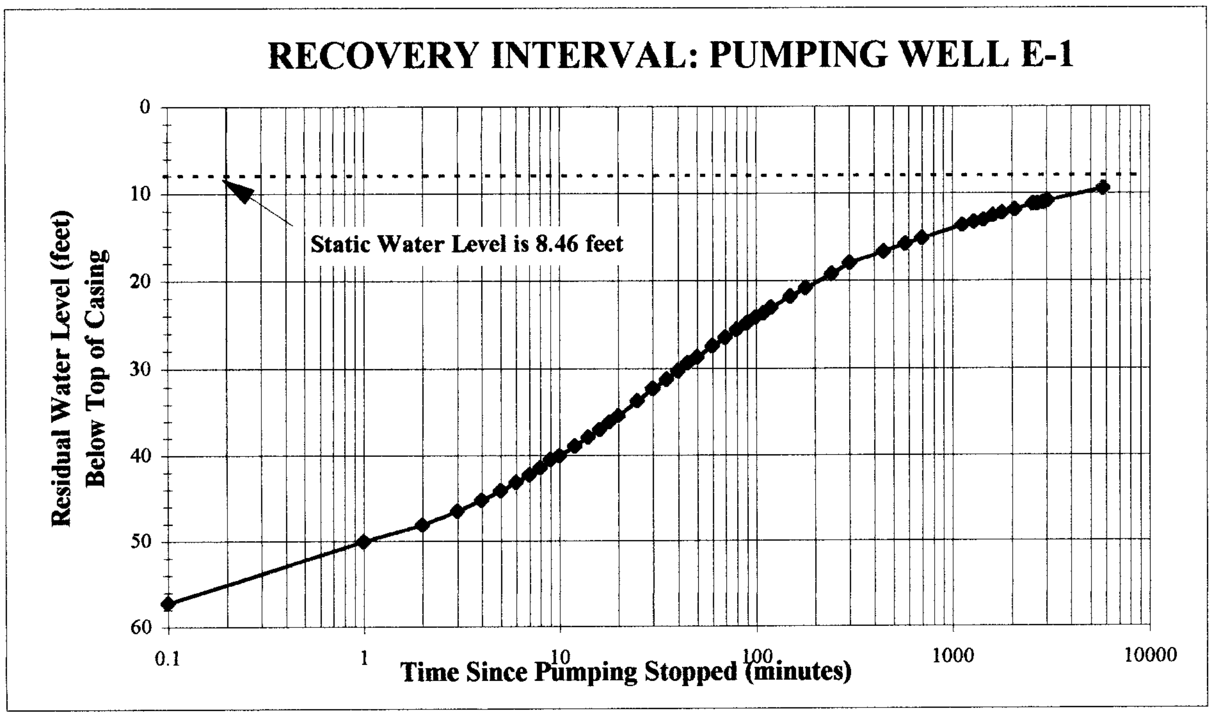


Figure 10 -- Semi-logarithmic Time versus Water Level Plot of Pumping Well E-1 During Pumping and Recovery, August 29 to September 6, 1994, New Baltimore, Virginia

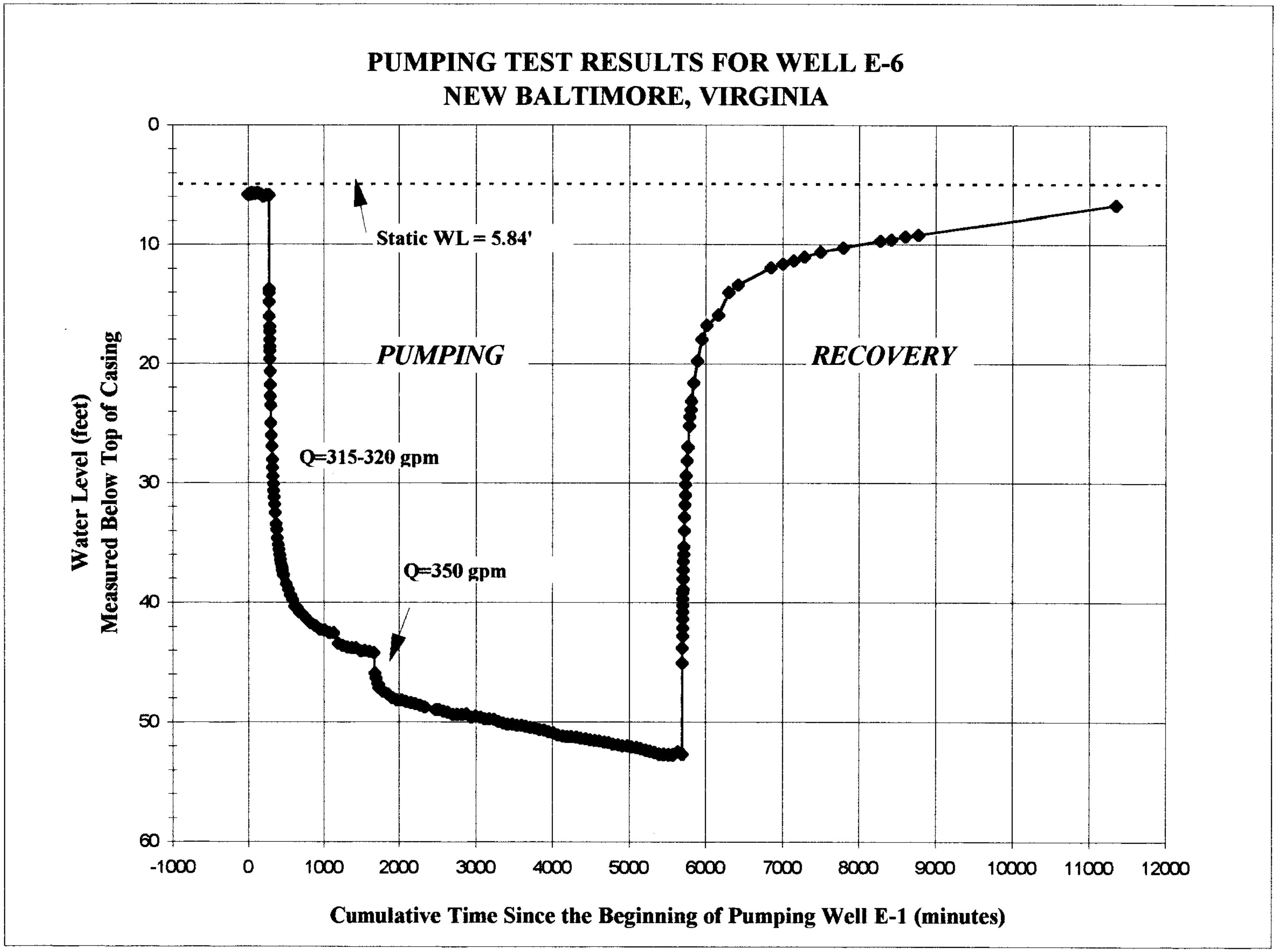
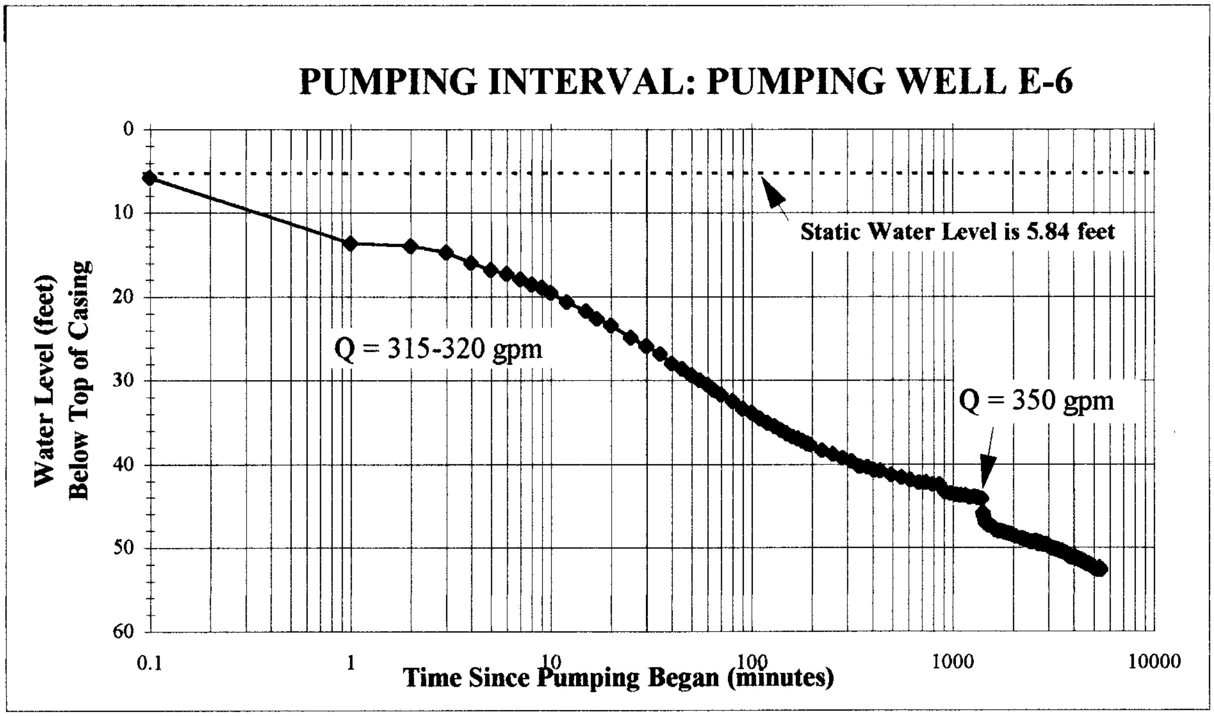


Figure 11 -- Arithmetic Time versus Water Level Plot of Pumping Well E-6
Data Collected Throughout the Monitoring Period, August 29 to September 6, 1994



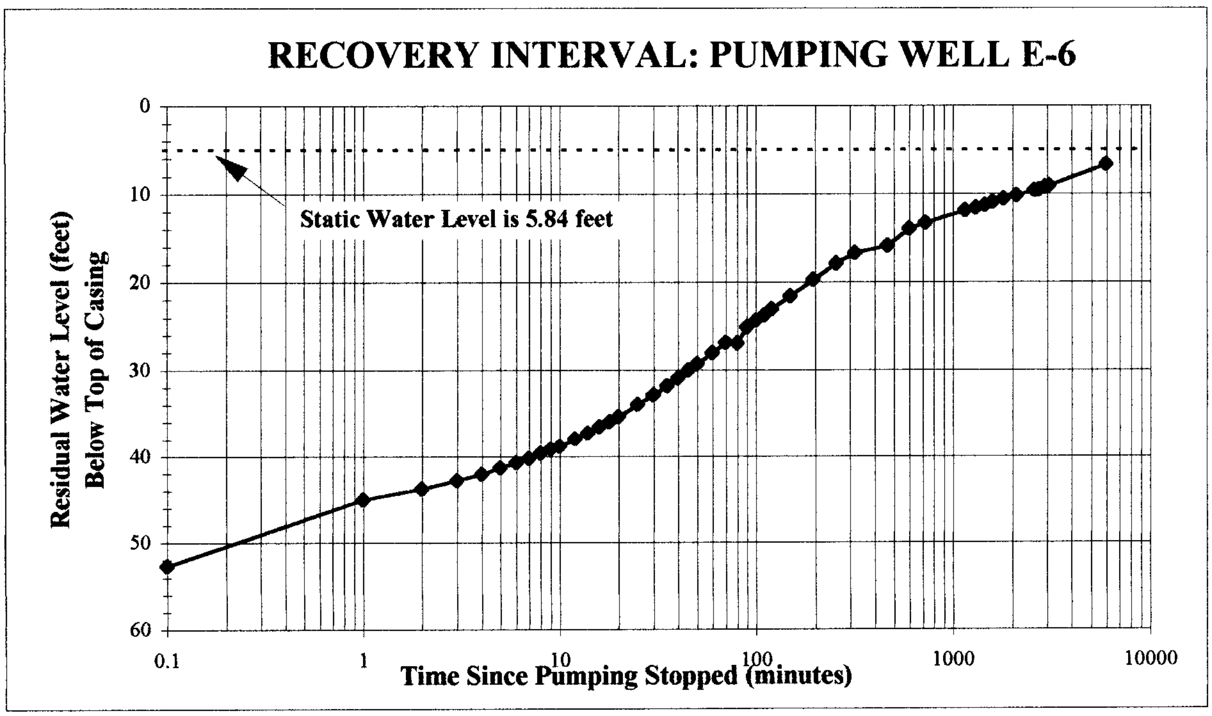


Figure 12 -- Semi-logarithmic Time versus Water Level Plot of Pumping Well E-6 During Pumping and Recovery, August 29 to September 6, 1994, New Baltimore, Virginia

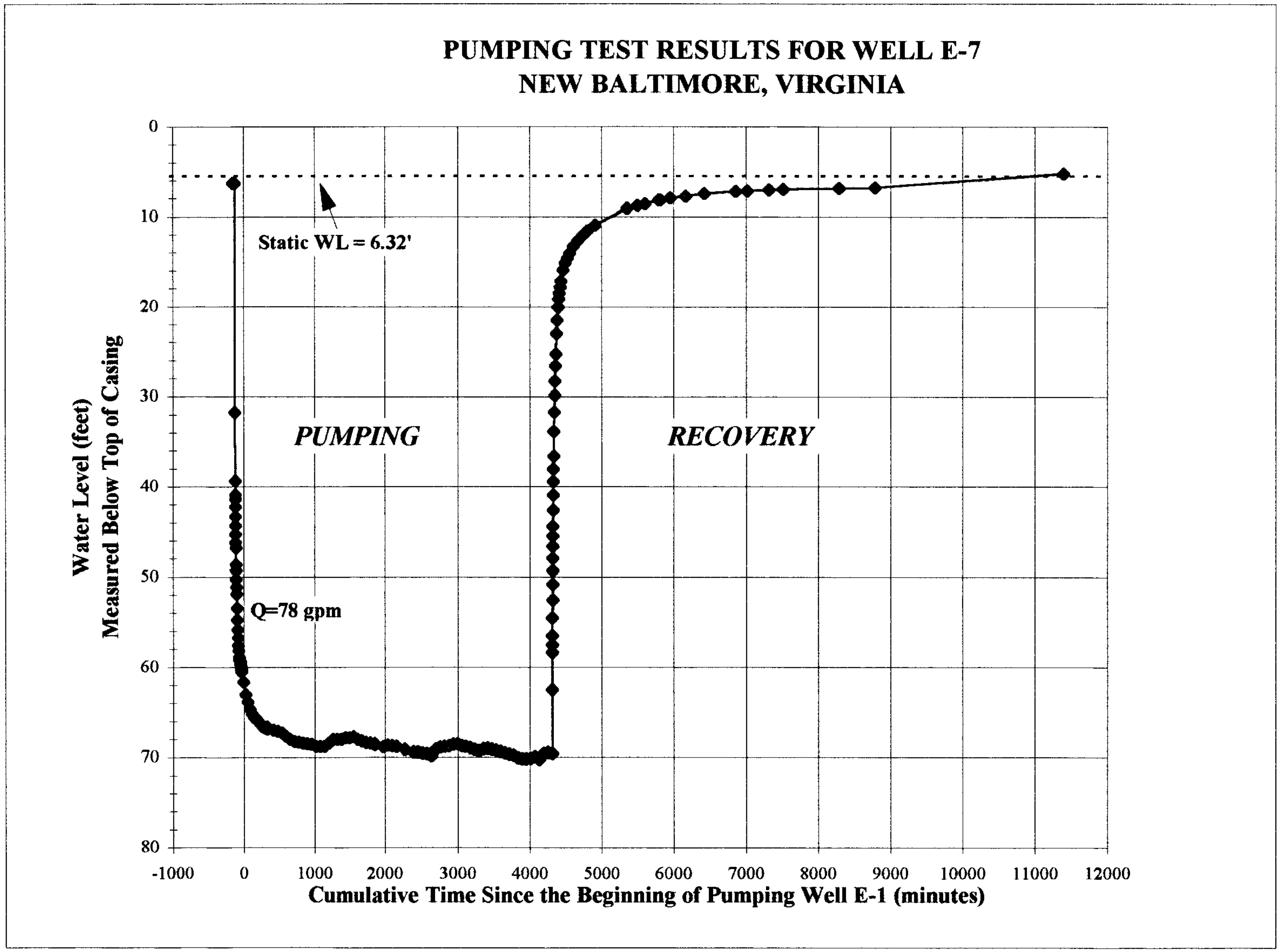
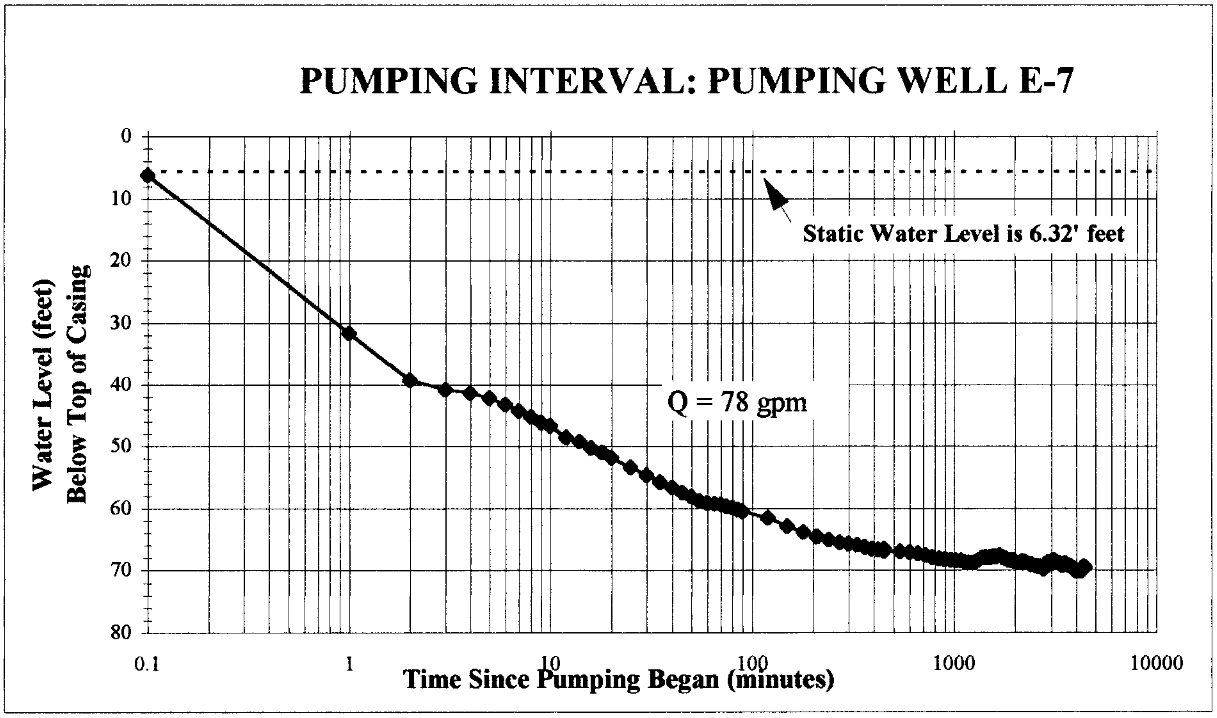


Figure 13 -- Arithmetic Time versus Water Level Plot of Pumping Well E-7
Data Collected Throughout the Monitoring Period, August 29 to September 4, 1994



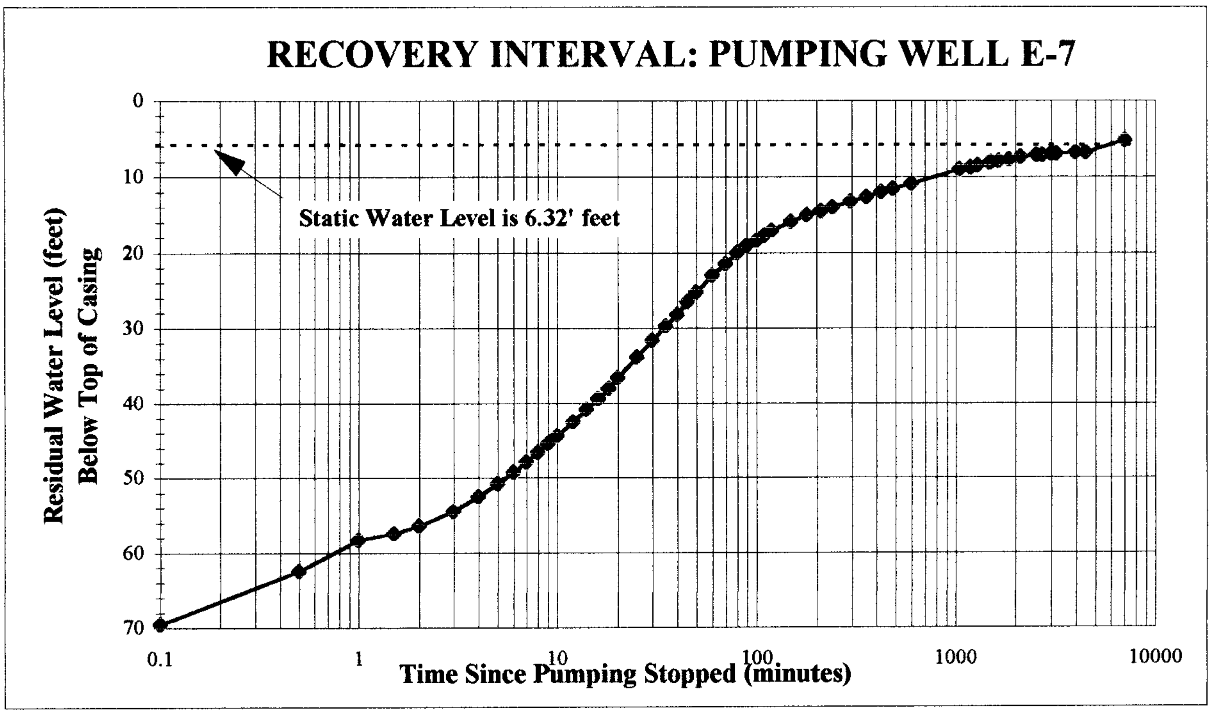


Figure 14 -- Semi-logarithmic Time versus Water Level Plots of Pumping Well E-7 During Pumping and Recovery, August 29 to September 4, 1994, New Baltimore, Virginia

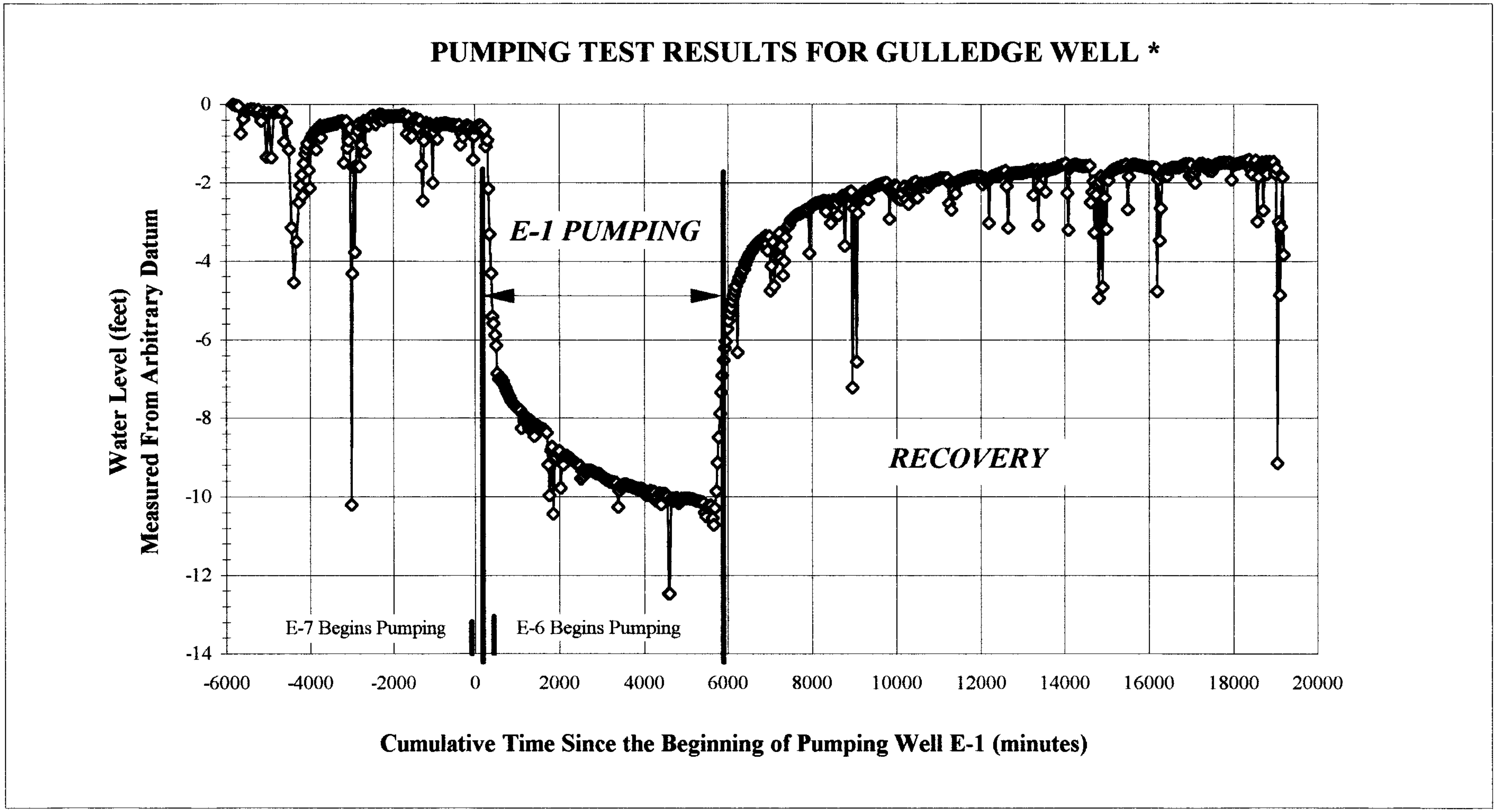


Figure 15 -- Plot of Time versus Water Level for the Gulledge Well
Data Collected Throughout the Monitoring Period August 29 to September 12, 1994, New Baltimore, Virginia

* Groundwater monitoring data collected for all other domestic wells are presented on Plate I and in Appendix E of this report.

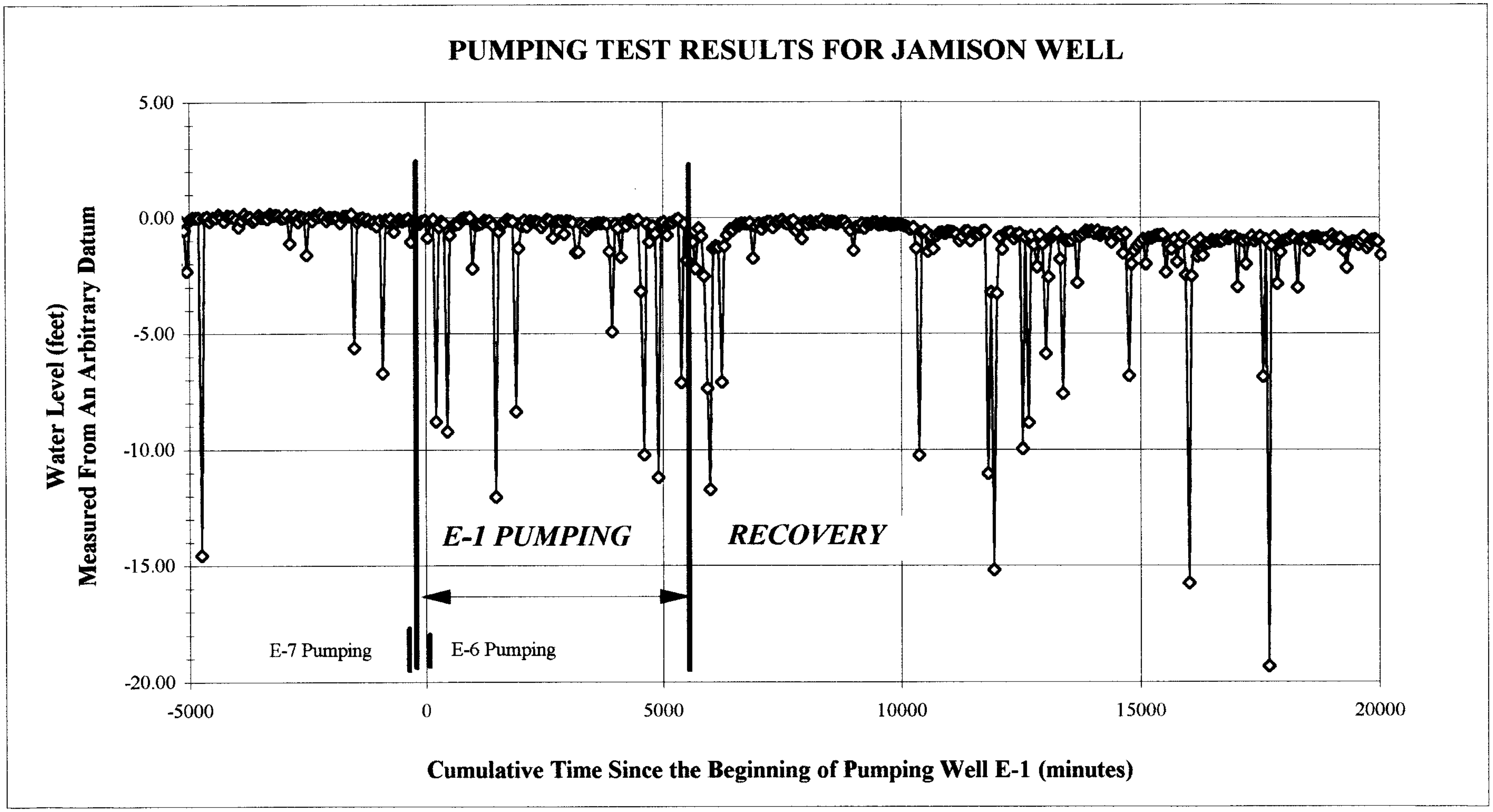


Figure 16 -- Plot of Time versus Water Level for the Jamison Well
Date Collected Throughout the Monitoring Period August 29 to September 12, 1994, New Baltimore, Virginia

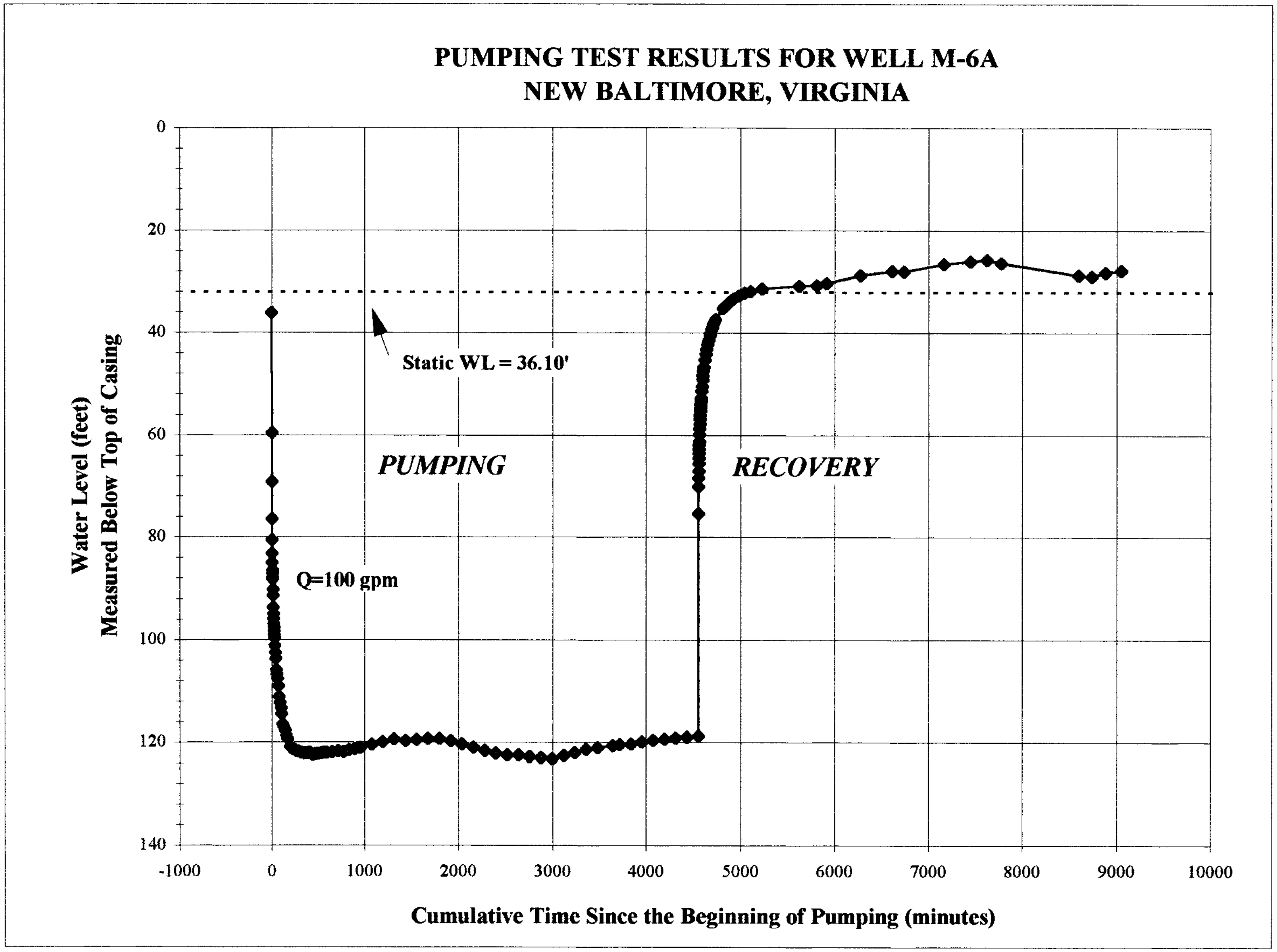
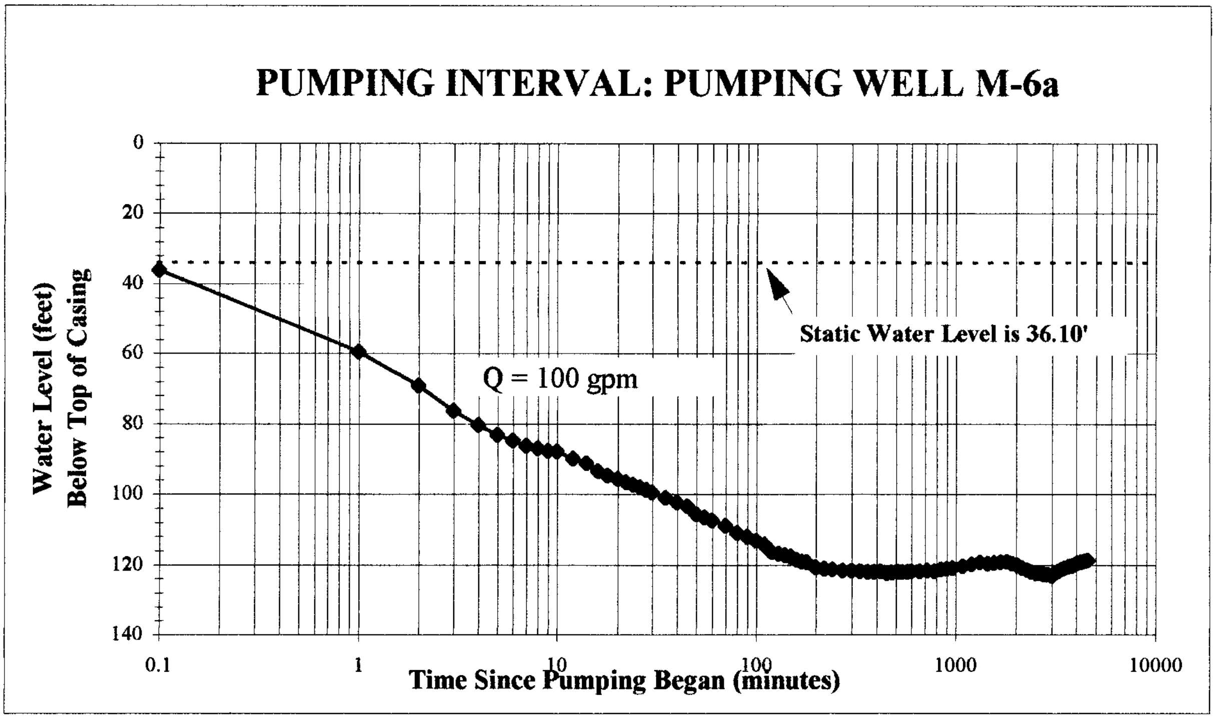


Figure 17 -- Time versus Water Level Plot of Pumping Well M-6A
Data Collected Throughout the Monitoring Period, August 29 to September 4, 1994



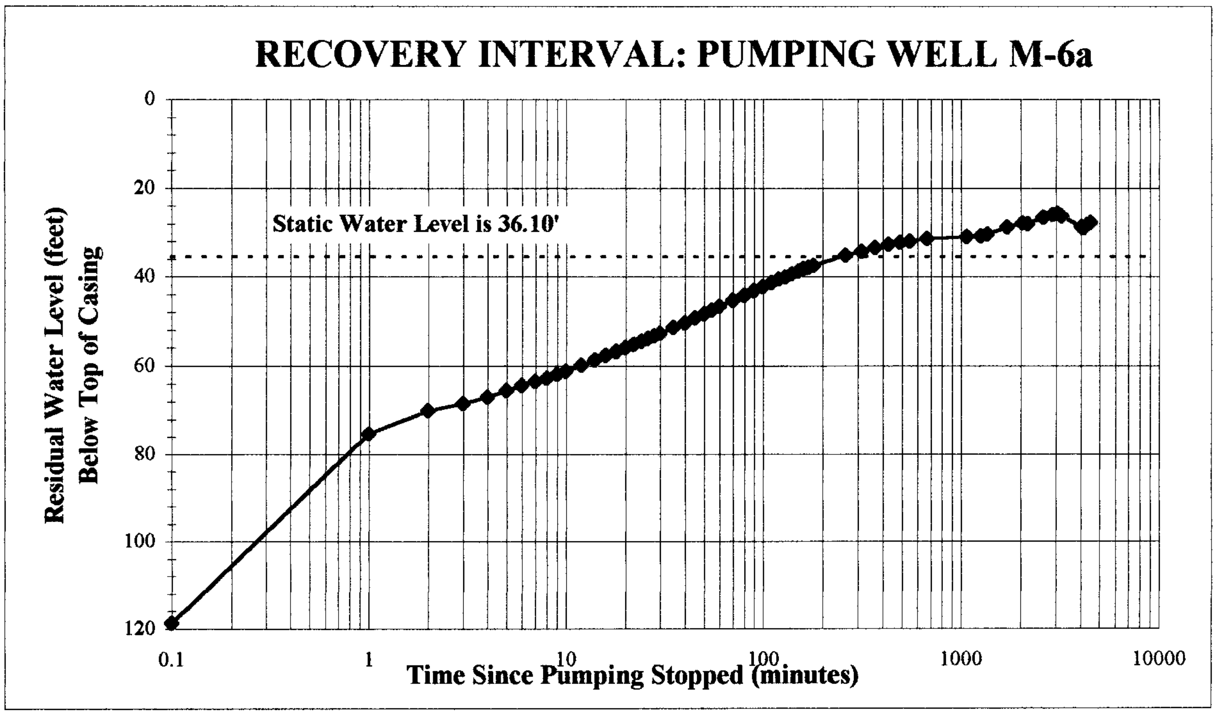


Figure 18 -- Semi-logarithmic Time versus Water Level Plots of Pumping Well M-6A During Pumping and Recovery, August 29 to September 4, 1994, New Baltimore, Virginia.

PLATE