PAUL B. ALDINGER & ASSOCIATES, INC.
Consulting in Geotechnical Engineering & Groundwater Hydrology
860A Waterman Avenue Suite 9 East Providence, Rhode Island 02914 (401) 435-5570

December 15, 2020

Mr. Bruce Hagerman
Crossman Engineering, Inc.
151 Centerville Road
Warwick, RI 02886

Re: Geotechnical Letter
Victory Woods Housing Project
West Greenwich, Rhode Island
PBA No. 11051

Dear Mr. Hagerman:

At your request we have prepared this geotechnical engineering letter for the above referenced project. This report specifically addresses the question of a presumptive bearing capacity for the proposed buildings at the project site. This report is subject to the limitations that are outlined in Appendix A.

The overall project is proposed to include the development of 12 new apartment buildings with 4 units in each building on a 59.6-acre parcel (Assessor's Plat 14, Lots 15 & 16) located adjacent to the BHMHP in West Greenwich, Rhode Island. The site is located at Racoon Hill on the northeast side of Route 102 about 1 mile northwest of the intersection of Route 102 and Route I-95. The new housing project is to be called the Victory Woods Housing Development (VWHD).

PBA previously completed a Geohydrological Investigation Report for the project site dated September 19, 2011. For our report we reviewed existing geologic publications the 1962 U.S. Geological Survey *Surficial Geology of the Hope Valley Quadrangle, Rhode Island* by T. Gustaf Feininger and the U.S. Geological Survey *Bedrock Geology Map of the Hope Valley Quadrangle, Rhode Island* by George E. Moore, Jr. We also were provided with the logs of two groundwater wells drilled at the Blueberry Hills Mobile Home Park. Following are the results of our findings of our review of these publications:

- The subsurface soils at the project site consist of a deposit of glacial till soils. Glacial till is typically a compact, non-sorted mixture of sand, silt, clay, stones and boulders. For this site, the till mostly 10 to 20 feet in thickness with high percentages of "rottenstone" fragments (disintegrated and weathered granite gneiss and alaskite gneiss bedrock) in some places. The glacial till deposit generally reflects the topography of the underlying bedrock.

- The bedrock at the project site consists of Scituate Granite Gneiss which is comprised of gray to pink, medium to coarse grained granite gneiss.

- Wells drilled at the project site were completed to depths of approximately 300 feet below the ground surface. The subsurface strata is described as 35 to 36 feet of clay with boulders at the ground surface underlain by soft brown rock. The clay with boulders is likely glacial till soils.

Geotechnical subsurface explorations with SPT blow counts is the most common method to obtain data for bearing capacity analysis. It is our understanding that no test borings have been performed for the project as of this date. In lieu of boring information, we were asked to provide a preliminary presumptive bearing capacity for the site. In order to develop this presumptive bearing capacity we reviewed International Building Code (IBC), other references and our experience from previous projects with glacial till soils.

- The IBC separates subsurface soils into two classes of bedrock and three classes of soils. Glacial till soils would most likely fall in class 4, sandy, silty sand, clayey sand, silty gravel and clayey gravel. The presumptive vertical foundation pressure is indicated as 2,000 pounds per square foot. The IBC text indicates that values included in this table are intended to be the lower-bound allowable pressures to be used when test borings are not completed.

- NAVFAC and AASHTO references indicate that the consistency and bearing capacity of glacial till soil can vary quite a lot from a low of 2,000 pounds per square foot to a high in excess of 10,000 pounds per square foot.

- From our experience performing test borings, SPT blow counts within glacial till soils can vary from medium dense to very dense with SPT blow counts in some cases exceeding 100 blows per foot. Glacial till soils we have encountered are most commonly dense to very dense. Based on our analysis this can result in a range of 3 to more than 10 kips per square foot.

Based up our review of the above references, and our personal experience we recommend that a presumptive bearing capacity of 3 kips per square feet be used for the project site. This presumptive bearing capacity assumes the following:

- that footings will be founded a minimum of 4 feet below the ground surface, which is the frost depth for the Town of West Greenwich,
- that no foundations will be founded on topsoil, subsoil, or any existing site fills, and,
- that groundwater may rise to footing invert during spring months, which can be common in glacial till soils, and,

- that test borings be performed at the site to confirm the presence of glacial till soils, soil density and our presumptive bearing capacity.

We appreciate the opportunity to have been of service to Crossman Engineering. and we trust that the information contained in this report is adequate for your needs at this time. Please contact the undersigned if there are questions on these recommendations or if you need additional information.

Very truly yours,

PAUL B. ALDINGER & ASSOCIATES, INC.

Paul B. Aldinger, Ph.D., P.E.
Chief Engineer

PAUL B. ALDINGER
NO. 3449
REGISTERED
PROFESSIONAL ENGINEER

APPENDIX A

LIMITATIONS

A. Explorations

1. The analyses and recommendations submitted in this report are based in part upon the data obtained from area geologic publications and groundwater wells. The nature and extent of variations from these conditions may not become evident until the recommended explorations are completed. If variations then appear evident, it will be necessary to reevaluate the recommendations of this report.

2. In the event that any changes in the nature, design, or location of the proposed structures are planned, the conclusions and recommendations contained in this report shall not be considered valid unless the changes are reviewed and conclusions of this report are modified or verified in writing by Paul B. Aldinger & Associates, Inc.

B. Final Design and Construction

It is recommended that this firm be retained to provide soil engineering services during final design and construction phases of the project. This is to complete the recommended subsurface explorations, analysis and report and during construction to observe compliance with the design concepts, specifications, or recommendations and to allow design changes in the event that subsurface conditions differ from those anticipated prior to the start of construction.

C. Use of Report

1. This preliminary report has been prepared for the exclusive use of Crossman Engineering for specific application to the proposed Victory Woods Housing Project in West Greenwich, Rhode Island in accordance with generally accepted soil and foundation engineering practices. No warranty, express or implied, is made.

2. This preliminary geotechnical engineering report has been prepared for this project by Paul B. Aldinger & Associates, Inc. This report is for preliminary design purposes and it is not intended to be included as part of the construction contract documents.

GEOHYDROLOGICAL INVESTIGATION REPORT

VICTORY WOODS HOUSING PROJECT

WEST GREENWICH, RHODE ISLAND

Prepared for:
STAND Corporation
105 Pennsylvania Avenue
Warwick, Rhode Island 02888

Prepared by:
Paul B. Aldinger & Associates, Inc.
860A Waterman Avenue, Suite 9
East Providence, Rhode Island 02914

September 2011
PBA Project No. 04027

PAUL B. ALDINGER & ASSOCIATES, INC.
Consulting in Geotechnical Engineering & Groundwater Hydrology
860A Waterman Avenue, Suite 9 East Providence, Rhode Island 02914 (401) 435-5570

September 19, 2011

Mr. Craig Sutton
STAND Corporation
105 Pennsylvania Avenue
Warwick, Rhode Island 02888

Re: Geohydrological Investigation Report
Victory Woods Housing Project
West Greenwich, Rhode Island
PBA No. 11051

Dear Mr. Sutton:

In accordance with our proposal dated July 1, 2011, Paul B. Aldinger & Associates, Inc. (PBA) is pleased to submit a geohydrological report to STAND Corporation regarding the existing water supply well for the above-referenced project. This well has a permit from the Rhode Island Department of Health (RIDOH) to operate as a drinking water well for the Blueberry Hills Mobile Home Park (BHMHP) . This report will present our conclusions from two pump tests conducted at the subject site for use in your design effort. This report is subject to the Limitations set forth in Appendix A.

1.00 INTRODUCTION AND PROJECT LIMITS

The overall project is proposed to include the development of 50 homes on a 59.6-acre parcel (Assessor's Plat 14, Lots 15 & 16) located adjacent to the BHMHP in West Greenwich, Rhode Island. The site is located at Racoon Hill on the northeast side of Route 102 about 1 mile northwest of the intersection of Route 102 and Route I-95 (See Figure 1, Site Vicinity Plan). The new housing project is to be called the Victory Woods Housing Development (VWHD).

Water for the proposed housing development and the existing mobile home park is proposed to be supplied from a bedrock well that currently supplies about 11,700 gallons per day (gpd) of water to approximately 27 mobile homes in BHMHP. The location of the supply well, BH-3, is presented on Figure 2. It is located approximately 2,000 feet southeast of the existing mobile home park and approximately 450 feet east-southeast of the nearest proposed house lot. Well BH-3 has supplied the mobile home residents of BHMHP since its installation in 1993.

2.00 SCOPE OF WORK

The objectives of this investigation were to determine if the supply well BH-3 is capable of sustaining a continuous yield of 34,200 gallons per day and how an increase in withdrawal from 11,700 gallons per day to 34,200 gallons per day will affect water levels and yields in nearby private supply wells. Completion of this assessment involved the following scope of work:

- Conduct site visits to review relevant site features and facilities,
- Collect and review relevant data concerning the site geology and site facilities,
- Seek access to wells of nearby private well owners,
- Conduct preliminary pump testing of the proposed drinking water well, BH-3,
- Locate and take preliminary measurements in any available observation wells in the overburden,
- Perform slug tests in unused wells to see if they are in communication with aquifer,
- Install supplemental observation wells, where appropriate,
- Mobilize and install pressure transducers in selected observation wells,
- Set-up a water meter to monitor well discharge,
- Conduct a 7-day pump test on well #3 to determine the sustained yield of the well,
- Conduct a 48-hour pump test at twice the anticipated maximum demand in accordance with RIDOH permit requirements,
- Collect and organize the data collected during each pump test,
- Analyze aquifer test data,
- Measurement of flows of two small streams that drain the study area before, during, and after pumping well BH-3,
- Develop an estimate of recharge to the estimated contributing area to well #3,
- Develop an estimate of aquifer storage,
- Collect and test water samples from well #3,
- Estimating impact of well-water withdrawals on water levels in wells of abutting landowners,
- Prepare a data and interpretive report.

3.00 BACKGROUND INFORMATION

3.10 Estimation of Water Demand

Pare Engineering Corporation (Pare) has estimated that potential maximum daily water demand by the BHMHP is as much as 11,700 gallons per day, or an average of about 8.1 gallons per minute. Potential average annual water demand by the 50 homes (three bedroom homes in the VWHD) is estimated by Pare to be about 22,500 gallons per day (an average of approximately 15.6 gallons per minute). Total maximum daily demand is therefore estimated to be about 34,200 gallons per day, or an average of about 23.75 gallons per minute.

3.20 Existing Wells In and Near Project Site

All water supplies for homes and businesses near the project area are obtained from wells, either public or privately owned. Most of these are believed to be 50 feet or more in depth. Driller's records for a few of these wells have been filed with the Rhode Island Water Resources Board and/or the Rhode Island Department of Environmental Management, copies of which are available in the local USGS office in Lincoln, Rhode Island. Information was obtained for these well installations.

3.21 Bedrock wells drilled for Blueberry Heights Mobile Home Park

According to the driller's log and RIDOH records, well BH-3 is 300 feet deep, with 6-inch diameter steel casing to a depth of 61 feet. This well when not pumping flows above the ground surface indicating true artesian conditions. This flow rate has been reported to be 4.5 gpm. A 48-hour pump test was completed in 1993, when the well was installed. The well yield was reported to be 60 gallons per minute (gpm) with 60 feet of drawdown, indicating a specific capacity (yield per foot of drawdown) of approximately 1 gpm/ft. Appendix B provides the well log for this well.

A second drilled well (BH-2) is located approximately 80 feet north of BH-3. According to the RIDOH records, this well is 300 feet deep with 6-inch diameter casing to a depth of 52 feet. The reported well yield is 25 gpm at a pumping level of 200 feet, but apparently is reduced to 3 gpm at a pumping level of 100 feet when well BH-3 is pumped at 60 gpm (recorded information for this well is not entirely clear). This well also is reported to flow, indicating true artesian conditions. Well BH-2, which was also drilled in 1993, has reportedly been approved by RIDOH for use as a public supply well, but has never been placed in service. Appendix B provides the well log for this well.

A third 6-inch diameter bedrock well (BH-1) was also drilled in 1993 but has not been approved for use by RIDOH. This well is located near the crest of Blueberry Hill within the BHMHP approximately 30 feet southwest of a small, partially below-ground structure that houses three pressure tanks and a water meter. The measured depth of BH-1 is 339 feet. This well had a static water level of 15 to 20 feet below ground surface. No well log was available for this well.

3.22 Private bedrock supply wells

There are numerous private domestic wells drilled into bedrock in the site vicinity. There are also some commercial and industrial wells drilled into bedrock in the site vicinity. An effort was made by SWAP, Inc. (Stop Wasting Abandoned Property) to contact all the abutting property owners to obtain access to their wells before, during and after the pump testing work planned for the project and to obtain permission to measure water levels in their wells. The purpose was to gain a better understanding of this bedrock aquifer and to observe the effect, if any, caused by the stress applied to the aquifer by the pumping of the proposed supply well. We were successful in getting this information and access for the following wells, identified by number of their address:

- 724 Victory Highway - No well log available but said to be a 6-inch diameter residential well drilled 70 to 100 feet into bedrock and will yield "plenty of water".

- 765 Victory Highway - No well log available but said to be a drilled 6-inch diameter commercial well in bedrock with "adequate" yield.

- 773 Victory Highway - No well log available but said to be a 6-inch diameter commercial well drilled 200 feet into bedrock with a yield of 7 gpm. Bedrock was reported at the ground surface.

- 793 Victory Highway - No well log available but said to be a drilled 6-inch diameter residential well in bedrock with "a large yield".

- 310 Robin Hollow Drive - A drilled 6-inch residential well, no well log available but Owner indicated it was 250 to 300 feet deep with a yield of 2 gpm.

We also located some information on the closest offsite drilled well to the pumped well, although this well was not available for monitoring during the pump test.

- 780 Victory Highway - A drilled 6-inch commercial well. No well log available but Owner indicated it was 900 feet deep with 35 feet of overburden and a yield of 0.5 gpm after hydro-fracturing the well.

We have not tried to locate unused bedrock wells on surrounding properties. Any such well is likely to have been abandoned because of its low yield and, if so, would not make a very good observation well. Such wells typically penetrate bedrock with few water bearing fractures and these may be poorly connected, hydraulically, to those that feed well BH-3.

3.23 Shallow Dug Wells

In addition to the three drilled wells on the site, there are two shallow dug wells located 240 and 280 feet, respectively, southwest of the proposed supply well, BH-3 (see Fig 2). The closest well was reportedly filled-in, however during our site visit we did locate this well. It is contained within a 2.5' diameter concrete cover and this well extends approximately 20.5 feet below grade. This well was slug tested and confirmed to be in hydraulic communication with the surficial aquifer.

The other well located near the small well house reportedly supplies water to the nearby Morton residence. We attempted to include this well in our study, but we were told not to utilize this well for any purpose, so we did not attempt to monitor it during our tests. This well will reportedly be abandoned.

3.24 Shallow soil test holes used as observation wells

During one of our site visits we noticed a few perforated PVC pipes installed in old test pits in the vicinity of the pumping well. We suspect that these PVC pipes were installed in the test pits to act as observation wells to allow subsequent groundwater readings. They are 4 to 7.5 feet deep and were most likely related to previously planned development. We have no records of these test pits or observation wells, however, we decided to use them as monitoring wells. They were slug tested and found to be in hydraulic connection with the surficial aquifer. They were located and assigned designations of PVC-A through PVC-F. The locations of these wells are indicated on Figure 2.

In conjunction with the proposed development, several test pits were excavated around the site and perforated PVC pipes were installed in them prior to backfilling them. The logs of these test pits are presented in Appendix C. They were located and assigned designations of TH-1 through TH-12. These observation wells are re-labeled as TP-1 through TP-12 and the locations are indicated on Figure 2.

3.30 Topography and drainage

The Blueberry Heights Mobile Home Park and the Victory Woods project area are located on the northeast side of State Route 102, where it straddles the Crest of Racoon Hill, the top of which is at an altitude of 600 feet above mean sea level (NGVD of 1929). The northwestern part of the mobile home park is within the Wood River basin; the remainder of the park and the Victory Woods project area drains to Racoon Brook, a tributary of Nooseneck River in the southwestern part of the Big River basin.

Surface water and groundwater from nine of 27 lots in the mobile home park, and from all nearby home and commercial lots located on Route 102, flow to the southwest, away from the drainage area that contains supply well BH-3. The small drainage area that contains well BH-3 is indicated on Figure 3 and it includes parts or all of 33 of the 50 lots to be developed. This area is drained by an intermittent stream that passes within 260 feet of well BH-3 and flows onto stratified glacial deposits in the Racoon Brook valley. An adjacent drainage area drained by a roughly parallel intermittent stream contains parts or all of 14 lots to be developed as well as seven lots containing mobile home units in BHMHP. Lots containing the nine remaining mobile homes and parts or all of seven remaining lots to be developed as part of the Victory Woods project drain to the northeast toward Robin Hollow Road. The significance of this drainage pattern is discussed later.

Surface and groundwater from the remainder of the mobile home park and from all of the flow southeast into Racoon Hill Brook, which flows NNE into the Nooseneck River, a tributary of the Big River. Much of the groundwater flow from the remaining mobile homes and from most of the proposed home building sites may be captured by the supply well, BH-3. We believe that none of the drainage from the BHMHP goes directly into the drainage area which includes BH-3. About 500 feet down gradient from supply well BH-3 at an altitude of about 450 feet, ground water flows from till into more permeable stratified glacial materials that were deposited in the valley bottom of Racoon Brook Valley. Figure 4 presents a geologic cross section down slope from Racoon Hill to the Valley below. Figure 5 presents a copy of the groundwater map for the site vicinity.

4.00 GEOLOGIC INFORMATION

4.10 Soils

A soils map of the project area prepared for SWAP, Inc., by Crossman Engineering, Inc., (see Plan 6 dated November 2003) shows the soils to be mostly stony to very stony, fine sandy loams. Records of ten test holes dug to depths of 10 to 14 feet at locations 700 to 1,800 feet WNW to NNW of well BH-3 (See TP1 to TP11 in Figure 2) indicate that none penetrated an impervious or limiting layer. PVC pipes left in several of these holes were used to monitor ground-water levels during the 7-day pumping test (See Appendix C and D). The soil data indicate that precipitation will infiltrate into these soils to recharge the underlying till and bedrock.

4.20 Surficial Geology

Surficial geology of the project area has been mapped by the USGS (Feininger, 1962) and more recently by Stone and Dickerman (2002). The mapping shows that the Victory Woods site is covered by a mantle of glacial till. Till is typically a compact, non-sorted mixture of sand, silt, clay, stones and boulders. Approximately 300 feet east of the project area the surface is covered by unconsolidated sand and gravel deposits that were laid down and stratified by glacial meltwaters. The outwash is described by the Groundwater map as "Gravel and Sand ... water-laid ice contact deposits." The Groundwater map indicates that this material is "medium to coarse sand and gravel interbedded with fine sand, silt and clay; unconsolidated; generally well sorted and stratified". These sediments fill the valley bottom of the northward flowing Racoon Brook. It is possible that water stored in these stratified sediments is within the zone of ground water capture by well BH-3.

The Surficial map indicates that the ground moraine is a layer of till mostly 10 to 20 feet in thickness with high percentages of "rottenstone" fragments (disintegrated and weathered granite gneiss and alaskite gneiss bedrock) in some places. The ground moraine deposit generally reflects the topography of the underlying bedrock. The till is believed to have deposited by a single ice sheet. The till is described as a massive, compact, light gray, unsorted material containing more than 90 percent sand and finer grained materials. The Groundwater map indicates that this till deposit consists of "Boulders, Gravel, Sand, Silt, and clay; unconsolidated; poorly sorted and unstratified." This material, generally dense and compact, overlies the bedrock in the area with an "average thickness of 25 feet, and reaches a maximum known thickness of 80 feet."

The thickness of the till in the vicinity of the project area is indicated by 10 large-diameter wells dug into this material on the flanks of Racoon Hill. The wells range from 11 to 27 feet deep and average 19 feet deep (Craft, 2001). The thickness of till within the project site is known from driller's logs of wells, BH-2 and BH-3 (see Fig. 2 for location). The unconsolidated overburden (till) in these wells is reported to be 35 and 36 feet thick, respectively. The driller described the overburden as "clay" from 0 to 20 feet in BH-3 and from 0 to 31 feet in well BH-2 (see geologic section in Figure 6). Based on descriptions of soils in the study area it is likely that much of the material described as clay is actually silt or fine sandy silt.

4.30 Bedrock Geology

Bedrock is not exposed within the project area or within a radius of 0.75 miles of the site. However, geologic maps by Quinn (1971) and by Hermes and others (1994) indicate that bedrock beneath the site is part of an extensive complex of granitic rocks. Quinn notes that these rocks commonly exhibit strong lineation marked by splotches of biotite. Map symbols indicate that the lineation generally strikes northwest-southeast and plunges to the northwest. Stone and Dickerman (2002) report that in the Big River basin, which includes the Victory Woods study area, these rocks are locally massive, but in most places are foliated and compositionally layered. They note that in the western part of the Big River basin the strike of foliation and layering generally is north-northeast with low (25^0-35^0) northwest dips. With regard to joints and fractures, which constitute storage space for water and avenues for its movement, they note that "Ubiquitous fractures and joints cut the bedrock" and that "fractures include near-horizontal unroofing joints and high-angle to vertical fractures generated by tectonic stresses."

5.00 YIELD OF BEDROCK WELLS

Yields of wells in crystalline bedrock are typically very low compared to wells that tap sand and gravel aquifers. Yields of wells in crystalline bedrock in the Big River basin are reported to range from less than 1 to as much as 50 gallons per minute with a median yield of 5 gallons per minute (Stone and Dickerman, 2002). The wells range in depth from 25 to 500 feet, with a median depth of 200 feet (Gonthier, 1966). In a study of bedrock wells in Massachusetts (Hansen and Simcox, 1994), it has been shown that median yield of 3,351 wells having a median depth of 173 feet in crystalline bedrock is 6 gallons per minute. The median specific capacity (or yield per foot of water level drawdown) of these wells is 0.1 gpm/ft (gallons per minute per foot of drawdown). With this information for perspective, supply well BH-3,the subject of this study, appears to be an unusually productive well. When constructed in 1993, the driller reported its yield to be 60 gallons per minute with a water level drawdown of 60 feet during a 48 hour pumping test. This indicates that, for this rate and duration of pumping, it has a specific capacity of 1.0 gpm/ft. Thus, the well is 10 times more productive than the average well in crystalline bedrock in Massachusetts.

6.00 HYDRAULIC CHARACTERISTICS OF GLACIAL TILL & BEDROCK

Specific yield, hydraulic conductivity and transmissivity are hydraulic characteristics that determine the capacity of an aquifer to store and transmit water. Specific yield is a measure of the volume of water a saturated rock or unconsolidated material will yield by gravity drainage. It may be expressed as either a fraction or a percentage. Hydraulic conductivity is a measure of the rate at which water will flow through a unit volume of material under a unit hydraulic gradient. Values are commonly reported in units of feet per day. Transmissivity is the product of the average hydraulic conductivity of an aquifer and its saturated thickness. It is commonly expressed in cubic feet per foot per day, or Ft^2/d. Transmissivity is used to estimate the capacity of an aquifer to transmit water through its entire thickness.

6.10 Specific yield

Relatively loose surface tills like that in the study area have the capacity to store large volumes of precipitation recharge, which may be subsequently released to nearby streams and to fractures and joints in the underlying bedrock. The average specific yield of surface tills in southern New England is reported by Melvin and others (1992) to be 0.28. A cubic foot of saturated till having a specific yield of this magnitude will yield 0.28 cubic feet of water (2.1 gallons) by gravity drainage. Expressed another way, a pumping well that causes the water level to be lowered an average of one foot over one acre of till having a specific yield of 0.28 will cause drainage of over 91,000 gallons. The significance of the water storage capacity of till to the sustainable yield of well BH-3 is discussed in further detail below.

The specific yield (or storage coefficient) of fresh crystalline bedrock in which water is stored in fractures and joints under confined conditions is extremely low. Reported storage coefficients for fractured rock aquifers range from 2×10^{-4} to 6×10^{-6} (Tiedman and Hsieh, 2001). Near the bedrock surface and in some linear zones where crystalline rocks are more intensely fractured storage space is slightly greater. In some moderately to highly fractured rocks specific yields are reported to be 0.001 to 0.005 (Gburek and others, 1999). The driller's log of well BH-3 indicates soft brown rock from 36 to 70 feet below the unconsolidated till. This is interpreted to be granite that has been intensely fractured and highly weathered to form a material locally known as rottenstone. This material may have a specific yield in the order of 0.05 or more.

6.20 Hydraulic conductivity

The hydraulic conductivity of till is typically very low. As a result, it transmits water very slowly under low to moderate hydraulic gradients. Melvin and others (1992) report an average hydraulic conductivity of 2.7 ft/day (1 x 10^{-3} cm/sec) for loose surface till, which is one to two orders of magnitude lower than hydraulic conductivities of stratified sands and gravels. The average hydraulic conductivity and transmissivity of crystalline bedrock are also very low, which accounts for low yields obtainable from most bedrock wells. Randall and others (1966) report average hydraulic conductivity of 0.5 ft/d (1.8 x 10^{-4} cm/sec) and average transmissivity of about 33 ft^2/d for crystalline bedrock in the Quinebaug River basin of eastern Connecticut. The transmissivity of the bedrock aquifer in the vicinity of well BH-3 is estimated to be 267 ft^2/d based on a graphical method developed by Walton (1962) that relates specific capacity to transmissivity. Average hydraulic conductivity at this site for a saturated thickness of 300 feet would therefore be 0.89 ft/d (3.1 x 10^{-4} cm/sec).

The above average transmissivity of the bedrock near well BH-3 may be due to the presence of a linear zone in which rock fracturing is more intense. A pumping well in such a zone generally results in an elliptical cone of drawdown around the well with the long axis of the ellipse parallel to the linear zone of fracture. Drawdown perpendicular to this axis is generally smaller owing to the lower transmissivity in those directions. The existence of such a zone is purely speculative but, if present, could explain the lack of significant drawdown in bedrock wells on Victory Highway in response to pumping well BH-3. If present, then a likely orientation of the zone is parallel to the small northwest-southeast trending brook near well BH-3, which parallels the strong northwest-southeast lineation in the underlying bedrock. No elliptical pattern of drawdown could be discerned from decline in the shallow observation wells surrounding well BH-3.

7.00 PRECIPITATION AND RUNOFF IN THE STUDY AREA

Precipitation on the study area is the source of all water that sustains the yields of wells in addition to supporting the surface water and groundwater runoff to the intermittent streams that drain it. Average annual precipitation measured at the climatological station at Kingston, R.I., was 50.3 inches for the period 1964-98 and ranged from 30.8 inches to 70.4 inches (Granato and others, 2003, p. 5). For perspective, one inch of rain on 1 acre is equivalent to 27,152 gallons. Thus, the combined areas of BHMHP and the Victory Woods project of 84.1 acres receives an average of 114 million gallons per year and a minimum of about 70 million gallons:

Average of 50.3 inches -> 84.1 ac x 27,152 gal/ac/in x 50.3 in = 114,859,205 gallons

Minimum of 30.8 inches -> 84.1 ac x 27,152 gal/ac/in x 30.8 in = 70,331,283 gallons

About 24 inches (48 percent) of this water evaporates or is consumed by vegetation. The remaining 26 inches runs off to streams and may be referred to as total runoff. Some of this water flows over land surfaces directly to nearby stream channels. This water is referred to as surface water runoff, and is commonly discharged to the ocean within a matter of days. Some of this water infiltrates through the soils to the water table and flows to streams through sediments and rock fractures over a period of weeks, months or years. This part of the runoff is termed ground-water runoff, which is equivalent to ground-water recharge.

7.10 Recharge to till and bedrock

All water available to the supply well for BHMHP (Well BH-3) and for wells on abutting properties is derived from precipitation. USGS streamflow records show that an average of 26 inches of the 50 inches that falls on the area during an average year, runs off to streams. The remaining 24 inches evaporates or is consumed by vegetation. Some of this total runoff quantity flows directly overland to streams and some infiltrates into soils and percolates to the water table. The infiltrated water is recharge, which then flows through the ground to streams. When it discharges to streams, it is termed ground-water runoff. The percentage of precipitation that infiltrates into soils in till-bedrock areas is less than that in areas underlain by highly permeable deposits of sand and gravel in valley areas. This is because of the lower hydraulic conductivity (permeability) of the till and its overlying soils and the generally steeper slopes in the till-bedrock areas. Consequently, recharge rates are somewhat lower in areas underlain by till than in valley areas covered by sand and gravel.

To obtain estimates of recharge to till and bedrock for the study area, a program developed by Rutledge (1993) that separates ground-water runoff from total runoff. The program was applied to runoff data from Furnace Hill Brook , a 4.19-square mile watershed in central Rhode Island that is underlain entirely by till. The stream was gaged by the USGS during water years 1966-75 (A water year begins Oct 1 and ends Sep 30). Results of the analysis indicate that ground-water recharge ranged from 5.84 inches in Water-Year (WY)1966, one of the driest years on record, to 21.32 inches in WY1973. Average annual recharge for the 9 year period was 15.1 inches.

To place this rate of recharge in perspective, one inch of recharge on one acre is equivalent to 27,152 gallons; an average of 15 inches of recharge per acre is equivalent to 407,280 gallons per year, or about 1,116 gallons per day.

The total area from which well BH-3 can divert water at an average pumping rate of 23 gpm could not be determined exactly from the data obtained. However, the diversion area includes all of the drainage area upgradient from the well plus an undetermined area downgradient from the well. It is estimated that the minimum area from which recharge can be diverted to the well is 40 acres.

It is likely that the diversion area is considerably larger. Average annual recharge of 15 inches on a 40 acre diversion area is equivalent to 16.3 million gallons per year, or 44,600 gallons per day.

Since 407,280 gpy/ac x 40 ac = 16,291,200 gallons per year,
Then 16,291,200 gal/yr /365d/yr = 44,600 gpd

This compares with the average 34,200 gpd required to supply BHMHP and the 50 proposed homes.

In addition, all but about 11 percent of the water pumped to homes from well BH-3 will be returned to the ground-water flow system by way of septic systems and will become available for re-use. Water delivered to several mobile homes in the northwestern part of the study area will increase the natural recharge to this area (See Figure 3 map showing GW flow directions). Thirty three of the 50 lots proposed for development lie within the drainage area of the stream that flows near well BH-3. Return flow of wastewater estimated to be 89 percent of pumpage, because consumptive losses are estimated to be about 11 percent of deliveries (USGS, 2002). Thus of the 22,500 gpd needed to supply the new homes approximately 14,850 gpd will be delivered to these 33 homes within this drainage basin and about 13,200 gpd will be returned to the capture zone of well BH-3. Net withdrawal from the watershed will thus be about 9,300 gpd or about 6.5 gpm.

7.20 Seasonal water-table fluctuation

Ground water levels fluctuate seasonally in response to recharge and discharge. Ground water discharges continuously to streams, wetlands, ponds, and pumping wells. The rate of discharge depends on natural or pumping-induced hydraulic gradients, and to the rate of infiltrated precipitation recharge. During the growing season, most of the precipitation is intercepted in the soil zone and is either evaporated or consumed by vegetation. During these periods the average rate of natural discharge exceeds the rate of recharge and water levels decline. During the non-growing months when evaporation and plant transpiration are minimal the average rate of recharge exceeds the average rate of discharge causing water levels in wells to rise. Calculations of recharge to till in the Furnace Hill Brook drainage basin indicate that 68 percent of recharge occurs during October-April and 32 percent during May-September.

Figure 7 illustrates the seasonal rise and decline of water levels in two till wells in the town of Exeter, Rhode Island, that are part of the USGS long-term ground-water monitoring network (Socolow and others, 1999). Water levels in the well designated as Exeter 158 naturally fluctuated by as much as approximately 14 feet whereas water levels in the well designated as Exeter 238 naturally fluctuated by only approximately 3 feet. Wide variations are possible and will generally be larger in fine grained soil (till included), water levels can be expected to naturally fluctuate by as much as 14 feet.

8.00 WATER STORING CAPACITY OF TILL AND BEDROCK

In the vicinity of well BH-3 the saturated thickness of till is estimated to range from 32 feet in the spring to perhaps as little as 18 feet in late summer under non-pumping conditions. Under pumping conditions, some of the water that would otherwise discharge naturally from the area as water levels decline between early spring and late summer will be captured by well BH-3 and some will discharge to the nearby intermittent stream or flow downgradient to the nearby sand and gravel aquifer in the Racoon Brook valley. The amount captured will depend on the timing and rate of withdrawal from the well.

The amount of natural drainage from the assumed 40 acre capture area for well BH-3 can be estimated as the product of the specific yield of the till aquifer and the volume of aquifer drained. As indicated the average specific yield of loose surface till in southern New England has been shown to be 0.28. The average saturated thickness in the spring over the entire study area is not known but is considered to be at least 8 feet. At BH-3, the saturated thickness is approximately 32 feet. Assuming a natural decline in water level of 8 feet over an area of 40 acres in material having a specific yield of 0.28 would result in the potential release of about 29.2 million gallons of water. If one assumes a water level decline over a 6 month period, this is equivalent to 162,200 gallons per day. This is potentially equal to the amount of water available for capture by well BH-3.

40 ac x 43,560 ft^2/ac x 8 ft	= 13,939,200 ft^3
13,939,200 ft^3 x 0.28	= 3,902,976 ft^3
3,902,976 ft^3 x 7.48 gal/ft^3	= 29,194,260 gallons
29,194,260 gallons/180 days	= 162,190 gal/day

Because the saturated thickness of till in the vicinity of well BH-2 and BH-3 is about 32 feet in the early spring, additional drainable storage is available for capture by well BH-3 in the period of declining water levels during the growing season. The area over which the maximum saturated thickness of till is as much as 32 feet is not known. If it is assumed to exist over a radius of about 500 feet from these wells, which is an area of about 18 acres, then the amount of drainable storage available from an additional 24 feet of saturated till (32-8 feet already assumed = 24 feet) would be about 39.5 million gallons or the equivalent of 219,325 gallons per day over a six month period.

Area $= \pi r^2 = \pi$ x 500 ft x 500 ft	= 785,398 ft^2/43560 ft^2/ac	= 18.03 acres
Volume = 18 ac x 43,560 x 24 ft	= 18,849,556 ft^3 x 0.28 Sy	= 5,277,875 ft^3
5,277,875 ft^3 x 7.48 gal/ft^3	= 39,478,510 gallons,	
or 39,478,510 gal/180 days	= 219,325 gal/d	

Total volume of drainable water in till available for capture by pumping well BH-3 is estimated to be about 68.7 million gallons [29.2 million gallons from the upper 8 feet of till over an area of about 40 acres, plus 39.5 million gallons from an additional 24 feet of saturated thickness within a radius of 500 feet from well BH-3. This is equivalent to an average daily yield of 381,700 gallons per day for a 6 month period, which compares with the proposed water supply demand of 34,200 gallons per day required for the Blueberry Heights Mobile Home Park and the 50 proposed new homes. Not considered in these calculations is additional drainable storage available from the saturated pore space in the zone of presumably highly fractured and weathered bedrock between the depths of 35 and 70 feet in the vicinity of wells BH-2 and BH-3 as indicated by their well logs.

9.00 FIELD TESTING PROGRAM

To determine whether a well can provide a certain quantity of water and can sustain it, it is necessary to subject the well to a field pump test. This pump test should be maintained at the desired flowrate for an extended period of time. The RIDOH has no set minimum period of time for the test duration, however they require that a well demonstrate that it can provide the required design flow for an extended period of time. RIDEM typically requires a 5 hour test of all wells. We decided to run a seven day test to determine the magnitude of water level drawdown at approximately 23 gpm, the proposed average withdrawal rate. When plotting drawdown data for a seven day test on a semi-log graph, the plot will extend six time cycles. We are then able to extend the drawdown trend to 180 days, thereby providing an estimate of maximum drawdown under extreme conditions of no recharge. A second requirement of an application to RIDOH is that you must prove that the well is capable of pumping at a rate twice the design flow rate for 24 hours.

9.10 Preliminary 2-hour Pumping Test

A preliminary pumping test was conducted on March 8, 2004 at well BH-3 with the assistance of Russell Water Well, Inc. (RWW). The purpose of this test was:

1) to check the value of specific capacity and,
2) to determine whether the existing pump could pump enough water to provide adequate yield for the needs of the BHMHP while maintaining an adequate line pressure (we considered this to be 20 psi) at the residences in the park. Mr. Russell concluded from data obtained from RIDOH that the pump in Well BH-3 had a maximum discharge capability of 45 gpm.

9.11 Set up for 2-hour Pumping Test

During the test, the supply well, BH-3, was pumped at a rate of approximately 20 gpm. Water levels within this well and in the nearby well BH-2 were monitored during this test. The water was pumped to the BHMHP well house where it was split with some water going into their water supply system for domestic use and the remainder piped away from the site and discharged into a drainage ditch along Route 102 where the water would flow out of the drainage area in which the pumped well is located. Both of these outflows were metered continuously. It was difficult to maintain a consistent flow rate during this test due to the changing demands of the BHMHP and the piping required to discharge the excess.

The test was stopped just short of 2 hours because an adequate pressure could not be maintained to supply water to the residents of BHMHP.

9.12 Results and Conclusions of 2-hour Pumping Test

The results of this test were conclusive in several respects:

1) When pumping the well at a rate of 20 gpm we measured the drawdown at about 12.7 feet, for a specific capacity of 1.57 gpm/ft. This value is consistent with the value of 1.0 gpm/ft from the earlier testing reported by the driller in 1993. Specific capacity varies somewhat with the rate and duration of pumping and it would be expected to be somewhat lower at a rate of 60 gpm after 48 hours.
2) The well is capable of providing a significant quantity of water, at least for the limited time period tested.
3) The drawdown response in well BH-2 to the pumping of well BH-3 is almost instantaneous.
4) The existing pump is not capable of pumping water at the minimum desired rate of 23 gpm to the elevated area of the BHMHP while maintaining an adequate line pressure for the residences in the park. Thus if we were to use this pump we would have to reduce the head loss by relocating the discharge point to a lower elevation.

9.20 Seven Day Pumping Test

A seven-day pump test was planned and completed between April 5 and April 12, 2004 with the assistance of RWW. RWW provided part-time observation of the test, taking periodic manual readings at selected well locations. PBA staff visited the site daily to take manual readings and to monitor electronic readings of the wells during the tests. Nearby groundwater observation wells were monitored during the pumping test.

9.21 Set-up for Seven Day Pumping Test

Given the limitations of the existing pump, we developed a program which would separate the pump test completely from the needs of the BHMHP. The BHMHP was supplied with a separate supply of purchased water which was delivered in tanker trucks from April 4 to April 15. Water was pumped from the bedrock supply well BH-3 at a rate of 23 to 25 gpm for a period of 7 days. The water pumped from BH-3 during the 7-day test was metered and in addition measured manually, using a bucket and stopwatch. This water was then discharged to the drainage ditch along Victory Highway in front of the commercial building at 780 Victory Highway. Figure 8 presents the flow rate versus time measured by the two different methods.

9.21.1 Observation wells on site

Water levels were monitored in several wells onsite, both in dug wells (in overburden) and in bedrock wells. These wells included the following:

- the pumped well, BH-3
- the nearby drilled well, BH-2, approximately 80 feet to the northeast,
- the unused drilled well at the BHMHP, BH-1, approximately 2,360 feet to the northwest,
- the dug well near the pump house approximately 240 feet to the southwest,
- the four shallow observation wells installed in the glacial till overburden identified as PVC-A through PVC-D,
- the eight shallow observation wells installed in the glacial till overburden identified as TP-1 through TP-5, TP-7, TP-8 and TP-11.

9.21.2 Off site private bedrock supply wells used as observation wells

Water levels were monitored in several private bedrock water supply wells. These wells included the following:

- a drilled well at 793 Victory Highway, approximately 1,330 feet to the northwest,
- a drilled well at 773 Victory Highway, approximately 1,305 feet to the south-southwest,
- a drilled well at 765 Victory Highway, approximately 1,230 feet to the west-southwest,
- a drilled well at 724 Victory Highway, approximately 1,265 feet to the west-northwest,
- a drilled well at 310 Robin Hollow Rd, approximately 2,430 feet to the northeast.

East and northeast of well BH-3 there are no homes or businesses, other than a gravel extraction operation within a radius of 2,000 feet. The operator reported no wells onsite.

9.21.3 Methods of data collection and recording

Water levels in several bedrock wells were monitored manually using electric tapes and with pressure transducers before the start and throughout the duration of the 7-day pump test. The wells which were monitored electronically included BH-1, BH-2, BH-3, three private wells located at residences along Victory Highway and a private well located on Robin Hollow Road.

The pressure transducers were In-situ minitroll dataloggers. These can be lowered into the wells and they read the water pressure above that point. Water levels can then be calculated directly from the change in water pressure. They can be set to read the water pressure at any time interval desired. For this test we generally read the pressure at 30 minute intervals. For the pumping well, BH-3 and for BH-2, however, we read the pressure every 15 seconds at the start and end of the test but at other times during the test the pressure was read at 30 minute intervals. These data readings can be downloaded while continuing to operate.

Several other observation wells in the glacial till overburden, were monitored manually. The readings were taken by lowering an electrical probe at the end of a tape and the depth to the water was read directly. Generally these were read at 30 minute intervals at start-up and shut down and periodically, at approximately 8 hour intervals during the remainder of the pump test.

9.21.4 Location of pump discharge point

Pumped water was discharged during the pump test to a pipe inlet in the drainage ditch along Victory Highway in front of the commercial building at 780 Victory Highway. The location is indicated on Figure 2. Also indicated is the approximate location near the Route 95 off-ramp where the stormwater pipe discharges this water to the ground.

9.21.5 Pump and stream discharge measurements

Flow of an intermittent unnamed stream located approximately 270 feet from the pumping well was measured manually by direct measurement of the flow passing through a pipe installed in a temporary dam constructed across the stream, using a bucket and stopwatch. The location of this temporary dam is indicated on Figure 2.

A continuous measurement of flow from the pump at well BH-3 was made by a standard water meter located in the discharge line from the well to the discharge at Victory Highway. In addition the flow was periodically measured by the use of a bucket and stopwatch.

9.22 Precipitation prior to and during 7-day test

The occurrence of rainfall during a pump test can make interpretation of the test results difficult, particularly if pumping rates are low. Rainfall may raise groundwater levels and thus water levels within the wells, while pumping tends to lower groundwater levels. Thus these events can tend to cancel each other out. We delayed the start of the pump test from Friday, April 2 because of a very significant storm event. The test ran from noon April 5 to noon April 12. Unfortunately it was not possible to totally eliminate the effects of this rainfall from the results of the pump test.

Figure 9 presents the recorded precipitation before, during and after the pumping test measured at the weather station in Providence. We note the following:

- Prior to March 31, 2004, only 6.63 inches of precipitation had been recorded for the year (which is below normal for that time period).
- Immediately before the start of the test, between March 31 and April 4, 2004, 3.67 inches of precipitation was recorded.
- During the 7-day test period, between April 5 and April 12, 2004, no precipitation was recorded.
- Immediately following the pumping test, between April 12 and April 14, 2004, another 2.90 inches of precipitation was recorded.

9.23 Water level trends prior to test

Generally, a rise of the groundwater levels across the site was observed prior to the start of the pump test, which corresponded with a significant rainfall. As indicated we delayed the start of the pump test from Friday, April 2 because of this very significant storm event. A rise of 4.55 feet was recorded at bedrock well BH-1 between March 26 and April 9, 2004. At PVC well TP-1, a 4.41-foot rise was recorded between March 31 and April 7, 2004. In the shallow dug well a 2.51-foot rise was recorded between March 30 and April 5, 2004.

9.24 Pumping Equipment used for test

We utilized the existing pump which is presently used to pump water to the BHMHP for their use. We considered installing a larger pump into the well to allow higher flow rates and to keep the BHMHP on the well water. We did not do this because to do this would have caused a significant disruption to the BHMHP water users, to the inside of the well itself and would have delayed the test. We did not raise the pump to inspect it and at the time of this test did not know the exact type or the depth of this pump. It was reported to be set at 60 feet and to have a capacity of 45 gpm.

9.25 Results of seven day pumping test of well BH-3

The flow rate was maintained fairly consistently during the pump test from noon on April 5, 2004 till noon on April 12, 2004 at approximately 23 to 25 gpm. We did note that one major adjustment to the flow was made at approximately one day into the test. Figure 8 presents a record of the measured flow measured by the two different methods. There was some difference in these readings with the flowmeter developing an average flow of 23.3 gpm and the bucket and stopwatch developing an average flow of 25.1 gpm. When comparing these methods we tend to trust the bucket and stopwatch method because of its simplicity.

Pumping of well BH-3 at a rate of approximately 25 gpm appeared to have caused a decline of the groundwater levels greater than 500 feet from BH-3 as was observed across the site. The rate of groundwater drawdown in the pumping well appeared to slow after approximately 100 minutes of continuous pumping, indicating that the groundwater withdrawal rate was nearly balanced by the groundwater recharge from leakage of water from the overlying glacial till. Appendix D presents the manual water level readings in the wells.

9.25.1 Water level trends in well BH-3 and nearby unused bedrock well BH-2

Figure 10 presents the water level readings versus time in wells BH-2 and the pumping well BH-3. We had a slight problem with the transducer pressure readings in the pumping well at the start of the pump test. We had inserted the transducer in a PVC pipe within the well to try to eliminate the effects of turbulence in the well as it was pumped. It appears that this caused a retardation of the water dropping in the casing and resulted in erroneous readings. We corrected this as the test was underway by removing the inner casing. We had manual readings with the electric tape which we utilized in the interpretation of the pump test.

Figure 11 presents the water level readings versus time in wells BH-2 and the pumping well BH-3. Figure 12 presents a plot of water level after pumping has ceased, indicating the rebound with time in BH-3. We note the following:

- The rate of drawdown slowed after about 100 minutes of pumping indicating that the withdrawal rate was nearly balance by the rate of recharge by downward leakage of water from the overlying till aquifer.
- The observed drawdown in BH-2 (80 feet away) was almost instantaneous after pumping began in BH-3. This indicates that the expansion of the cone of drawdown in the bedrock aquifer is rapid.
- The observed drawdown in BH-2 (80 feet away) near the end of the test was approximately 18 feet when it was approximately 23 feet in the pumped well.
- The recorded drawdown in BH-3 after 48 hours of pumping at a rate of 25.1 gpm was 22 feet. Therefore, the specific capacity (water yield per foot of drawdown) of well BH-3 is 1.14 gpm per foot, which confirms the rate reported by the driller in 1993, of approximately 1 gpm per foot, after 48 hours of pumping.

9.25.2 Water level trends in shallow (4 to 7.5 feet) observation wells 200 to 525 feet from well BH-3

Figures 13 and 14 present the observed decline in the overburden observation wells PVC-A thru PVC-D which are the closest to the pumping well. On Figure 13 we have included the drawdown in the pumping well for comparison. Figure 14 has an expanded scale and in that figure it is easier to see the response of these overburden wells to the bedrock well (BH-3) being pumped. We note that the water level is rising just prior to the test as a result of the precipitation. We interpret this figure to indicate a fairly rapid response of decline in these wells upon initiation of the pumping. These wells underwent approximately 1.25 to 1.9 feet of decline during the time of the pump test. The table below indicates the decline for each well along with the distance that well is from the pumping well. We believe that although some of this may reflect natural water level decline due to the lack of rainfall during that time, it also illustrates a relatively direct connection of surficial glacial deposits with the underlying bedrock.

Observation Well No.	Distance from Pumping Well (feet)	Decline During Period of Test (feet)
PVC-A	200	1.9
PVC-B	275	1.45
PVC-C	450	1.8

Observation Well No.	Distance from Pumping Well (feet)	Decline During Period of Test (feet)
PVC-D	525	1.25

9.25.3 Water level trends in nearby 20-foot dug well 285 feet from well BH-3

Figures 13 and 14 also present the observed decline in the dug well located approximately 285 feet to the southwest, near the pump house structure. Figure 14 has an expanded scale and in that figure it is easier to see the response of this well to the bedrock well (BH-3) being pumped. We note that the water level is rising just prior to the test as a result of the precipitation. We interpret this figure to indicate a fairly rapid response of drawdown in the dug well. This well appeared to undergo approximately 0.85 feet of decline during the time of the pump test. We believe that although some of this may reflect the lack of rainfall during that time and it also illustrates a relatively direct connection of surficial glacial deposits with the underlying bedrock.

9.25.4 Water level trends in shallow test pit wells 710 to 2,050 feet from well BH-3

Figures 15 and 16 present the observed decline in the shallow test pit observation wells TP-1 through TP-11 which are some distance from the pumping well. On Figure 15 we have included the decline in the pumping well for comparison. Figure 16 has an expanded scale and in that figure it is easier to see the response of these wells to the well being pumped. We note that the water level is rising just prior to the test as a result of the precipitation. We interpret this figure to indicate a fairly slow, if any, response or decline in these wells when compared to the other wells closer to the pumping well. The table below indicates the change in water level during the test for each well along with the distance that well is from the pumping well. A positive value indicates a water level rise, and a negative value indicates water level decline. We note that the first five wells are outside the surface water watershed that the pumping well is in and three of the five have water level rise during the test. We believe that this illustrates that the effect on the groundwater from pumping from the test well is dependent upon the distance from the test well and it is less clear that for the area where these PVC wells are located that the surficial glacial deposits tend to have a direct connection with the underlying bedrock which is open to the pumping well.

Observation Well No.	Distance from Pumping Well (feet)	Water Level During Period of Test (feet)
TP-1	2,050	- 0.1
TP-2	1,800	+0.4
TP-3	1,760	+1.15
TP-4	1,540	+0.4
TP-5	1,820	- 0.9
TP-7	1,480	- 0.6
TP-8	1,130	- 1.2
TP-11	710	- 1.0

9.25.5 Streamflow trend 270 feet from well BH-3

Flow of an intermittent unnamed stream located approximately 270 feet from the pumping well was measured just prior to and during the pump test. We noted a steady increase in flow prior to the start of the test (presumably due to a prior rain event), then an abrupt decline at the start of the test, a steady decline during the test and then an abrupt increase after the test was complete. We measured flow of approximately 40 gpm just prior to the test start and by the time the test ceased the flow had reduced to 22 gpm. Flow measurements shortly thereafter show an increase to 24 gpm. The day after the test there was a significant rain event and flow increased beyond our capacity to measure. We estimated that flow exceeded 100 gpm. This data indicates a fairly rapid response of streamflow and illustrates a relatively direct connection of the surficial glacial deposits with the underlying bedrock fractures accessed by BH-3. Figure 17 presents the stream discharge versus time for this test period. Appendix E presents the pump discharge and streamflow readings.

9.25.6 Water level trend in unused 339-foot deep bedrock well BH-1 2,360 feet from well BH-3

The 6-inch diameter bedrock well (BH-1) which is located within the BHMHP approximately 30 feet southwest of a small, partially below-ground structure that houses the water storage tanks and a water meter for their water system was also monitored before, during and after the pump test. Figures 18 and 19 present the observed change in water level with time for this well. This well is approximately 2,350 feet north of the pumping well. This record indicates that the groundwater level was steadily rising before and during the pumping test, with a net rise of approximately 0.6 feet during the test. After the test the water level continued to rise with a sharp upward movement the day after the test ended, probably due to the significant rainfall event.

9.25.7 Water level trends in private bedrock supply wells on Victory Highway and Robin Hollow Road

The water levels in several private bedrock supply wells on Victory Highway and one on Robin Hollow Road were monitored before, during and after the pump test. Figures 18 through 21 present the observed change in water level with time for these wells. The table below presents the well name, distance from the pumping well and decline during the test. A positive value indicates a water level rise, and a negative value indicates water level decline. This figure indicates that the groundwater level was steadily rising before the pumping test for all of the wells. This figure indicates that during the test, the water level in half of the wells fell and half rose. After the test the water level generally rose in these wells and all exhibited a sharp upward movement the day after the test ended, probably due to the significant rainfall event.

Private Bedrock Well Designation	Distance from Pumping Well (feet)	Water Level During Period of Test (feet)
BH-1	2,360	+0.6
724-VH	1,265	+3.3
765-VH	1,230	+0.15
773-VH	1,305	- 1.7
793-VH	1,330	- 0.3
310-RH	2,430	- 1.7

9.30 48-Hour Pump Test

RIDOH regulations require that a community supply well be pumped for 48 hours at two times the maximum daily demand rate. This means well BH-3 should be shown to be capable of sustaining a withdrawal rate of at least 61,200 gal/d (42.4 gal/min) for 48 hours. Believing that the original driller's acceptance test of 86,400 gal/d (60 gal/min) for 48 hours would satisfy this requirement, this phase of testing was not done during our earlier field testing. Another consideration for not doing this phase of testing was to minimize disruption of water supply to BHMHP. It was determined that pumping at a rate of 42.4 gal/min would have required temporary replacement of the existing pump in well BH-3 with a higher capacity pump. Doing so would have extended the total time that BHMHP would have had to be supplied by tank truck and bottled drinking water by several days. However subsequent to the initial test and discussion with the Town Planning Board it was decided to conduct a 48-hour test on this well.

9.31 Test Set-up

After the mobile home park was disconnected from well BH-3, the pump in BH-3 was removed and a 5 horsepower submersible pump capable of pumping 60 gpm was installed in the well to a depth of 160 feet. Because well BH-3 flowed when drilled and when tested in April 2004, a 4-inch PVC extension was added to each well (BH-2 and BH-3) to prevent overflow when the wells were not being pumped. On May 11, 2005, the static levels in wells BH-2 and BH-3 were 5.2 and 5.7 feet above ground surface, respectively.

9.32 Step-drawdown test of well BH-3

To determine the optimum pumping rate for the well, a brief step-drawdown test was conducted. A step draw-down test consists of pumping a well at successively higher rates for the same intervals of time while measuring water level drawdown in the well.

On May 11, 2005, a step-drawdown test was conducted on well BH-3. Discharge from the well was measured by a meter in the discharge line near the well and by bucket and stop watch at the end of a 2-inch diameter hose on the bank of a small stream 290 feet ENE of the well. It was determined that the meter was under-recording the discharge rate. Measurements by bucket and stopwatch are considered to be most accurate. Nevertheless, the meter reading was helpful in establishing the desired pumping rate for each step. The step test consisted of three 40-minute pumping steps at rates of 34 , 49, and 60 gpm, which resulted in drawdowns at the end of each period of 26.19 feet, 42.50 feet, and 57.13 feet, respectively. The specific capacities (yield per foot of drawdown) at rates of 34, 49, and 60 gpm were 1.3, 1.17, and 1.05 gpm/ft, respectively. The data for the step test are presented in Appendix B. The results are shown graphically in Figure 22. Because the specific capacity obtained using data from the 1993 driller's report was 1.0 gpm/ft after 48 hours of pumping at 60 gpm, it was decided to pump well BH-3 at 60 gpm (about 12.8 gpm more than the 47.2 gpm required) for 48 hours.

9.33 48-hour pumping test of well BH-3

During May 12-14, 2005, well BH-3 was pumped for 48 hours at an average rate of 60.4 gpm. Maximum drawdown at the end of the test was 68.3 feet, which was 60.7 feet below ground surface and was at the reported depth of the bottom of the casing. The specific capacity of the well at the end of the 48-hour test was 0.90 gpm/ft, which compares with the specific capacity of 1.05 gpm/ft computed during the step drawdown test and 1.0 gpm/ft computed from data reported when the well was drilled in 1993.

Water was discharged onto the ground during the test approximately 600 feet ENE of the well in an adjacent surface water drainage area where land surface slopes away to the ESE. During the test, most of the discharge percolated into the ground over a distance of about 130 feet.

The discharge was measured by a water meter installed in the discharge line near well BH-3 and at the end of the discharge line by a circular orifice weir with a manometer. Discharge was also checked periodically by bucket and stopwatch. On the late evening of May 13th, a voltage spike caused the generator to shut down. According to the graph of drawdown produced from the data logger in the well, the pump was off for about 30 minutes before being restarted by the driller (See Figure 23). The driller believes the voltage spike resulted when a piece of gravel briefly bound the pump impeller.

Water levels were measured in all observation wells and streamflow was measured by means of a bucket and stop watch at 4-inch diameter PVC pipes inserted through small earth dams constructed at two nearby stream sites during the test. Manually measured water level data, and discharge data, collected during the test are given in Appendix B and Appendix C respectively. Graphical displays of water level fluctuations in well BH-3 and in on-site and off-site observation wells during the pumping test of BH-3 are presented in Figures 23, 24, and 25. Graphical representation of streamflow during the pumping test of BH-3 is shown in Figure 26.

The pumped water appeared clear throughout most of the test. However, on most occasions when a bucket and stopwatch measurement was made there was about a thimble full of sediment present at the bottom of the bucket. The sediment was mostly fine to medium grained sand, but included some coarse grained sand and traces of gravel.

10.00 POTENTIAL SUSTAINED YIELD OF WELL BH-3

10.10 Projected Drawdown in Well to 180 Days at 25 gpm

A semi-logarithmic plot of the drawdown that occurred in supply well BH-3 during the seven days it was pumped at an average rate of 25 gpm is shown in Figure 10. As noted previously, the rate of the drawdown decreased after about 100 minutes of pumping. Our interpolation is that this change resulted when the cone of pumping influence in the bedrock aquifer had expanded over an area large enough to cause vertical leakage from the overlying till aquifer to nearly balance the rate of pumping from the well.

As was demonstrated previously, the volume of drainable water stored in the overlying till aquifer is more than adequate to sustain a yield of 34,200 gallons per day (23.6 gpm) from well BH-3. Moreover, as discussed previously, about 13,200 gallons per day of waste water will be returned to the small watershed in which well BH-3 is located so that net withdrawal from the aquifer will average only about 21,000 gallons per day (or 14.6 gpm).

Extension of the drawdown curve to 259,000 minutes (180 days) in Figure 10 suggests that drawdown after 6 months of pumping continuously at a rate of 25 gpm may be as little as 24 feet.

10.20 Capacity to Meet Peak Demand Flows of 60 gpm or More

The primary objective in pumping well BH-3 was to determine if it is capable of sustaining for 48 hours a withdrawal rate of 68,400 gal/d (47.5 gpm), which is twice the estimated maximum-day demand of 34,200 gal/d (23.6 gpm) as required by RIDOH. It was pumped for 49 hours at 60.4 gpm (or 86,976 gal/d), which demonstrates that it more than meets this RIDOH requirement. Moreover, inasmuch as maximum drawdown was only at the bottom of the 60-foot casing in this 300-foot deep well at the end of the test, its relatively high specific capacity of 0.90 gpm/ft indicates that it would likely sustain a much higher 48-hour yield. To determine actual maximum 48-hour yield of the well would require knowledge of the depths of yielding zones and their rates of contribution to the well, which were not recorded by the driller. Moreover, if the depth of major yielding zones are near the bottom of this well (yield zone depths were not reported) it is probable that this well could produce in excess of 100 gpm for at least several hours. Only if a single yielding zone is located at the bottom of the casing would the maximum short-term pumping capacity of this well be expected to be limited to 60 gpm. Once the pumping level drops below the major yielding zones in a bedrock well, the yield cannot be increased.

It is concluded therefore that well BH-3 can readily sustain a continuous withdrawal of at least 34,200 gpd (23.6 gpm) and that it is readily capable of producing at least 60 gpm for a minimum of two days and we believe that most likely significantly in excess of 60 gpm for many days beyond that. We only have data to confirm the 60 gpm rate, however.

A specific capacity of 1.0 gpm/ft was reported by the driller who installed and tested the well in 1993. At the time of installation, the well was pumped for 48 hours at 60 gpm with 60 feet of drawdown. The results of the more recent test suggest that there has been relatively little change in the yielding capacity of this well over a period of 12 years. Moreover, the decreased rate of drawdown near the end of the test suggests that this well may be capable of sustaining a yield of 60 gpm or more for several weeks or months during periods of little or no recharge.

11.00 EFFECT OF WITHDRAWALS FROM WELL BH-3 ON NEARBY ONSITE WELLS

An unused large-diameter dug well and several shallow 4-in diameter PVC wells located within a radius of 650 feet of well BH-3 was monitored during the pumping tests to determine the effect of pumping on the water table in the overlying glacial till. Except for the test well and the dug well, in which an electronic water-level data recorder was installed, water level measurements were made manually by electric tape. Hydrographs of these wells are shown in Figure 7.

As the well reports done at the time of original development indicated, the pumping of well BH-3 causes significant immediate drawdown in well BH-2, and vice versa. We noted that after pumping BH-3 for 48 hours at 60.4 gpm, the drawdown in BH-3 was 68.3 feet whereas the drawdown in BH-2 was approximately 56 feet (or 82% of the drawdown in the pumping well). This observation provides further data on the interaction of these two wells upon one another.

It is obvious to us that the water level in the dug well, which is about 20 feet deep, and located 240 feet from well BH-3, responds rapidly to pumping of the well, indicating that water stored in the till flows rapidly into fractures tapped by this well in the underlying bedrock. A similar, but much smaller response to pumping occurs in wells PVC-A and PVC-B that are within 200 to 270 feet of well BH-3. Water levels in PVC wells C and D, which are 375 to 520 feet from the pumped well, show a steady decline throughout the test, but little or no rebound after the test on BH-3. The rate of water level decline appears to be somewhat greater than that shown in well BH-1 and USGS observation well RIW-600 that show natural water level trends during the test period (See Figure 6 for hydrographs of BH-1 and RIW-600).

PVC wells E and F are near the end of the discharge line, 450 to 690 feet from the pumped well. Well PVC-E, located about 50 feet up gradient from the discharge point shows a rise in water level during the test and a decline afterward. This was caused by infiltration and percolation of the discharge to the water table. The water level in PVC well F, located about 120 feet upgradient from the discharge point was not similarly affected.

12.00 EFFECT OF WITHDRAWALS FROM WELL BH-3 ON NEARBY STREAMS

Because there was no rainfall on the study area during the period May 11-20, 2005, all flow in streams 1 and 2, which drain the study area, was base flow or ground water inflow from the glacial till. The measurement site for stream 1 is located 260 feet from well BH-3. The measurement site for stream 2 is located about 720 feet from well BH-3. The graph of stream discharge rates shown in Figure 26 shows clearly that streamflow declined at both measurement sites when well BH-3 was pumped for two days at 60.4 gal/min and increased following cessation of pumping. Pumping from this well appears to divert water from the shallow groundwater table from distances as much as 700 feet.

13.00 EFFECT OF PUMPING FROM WELL BH-3 ON OFF-SITE WELLS

Water level fluctuations in three off-site, private supply wells were measured by electronic data loggers that were installed in them prior to the start of the pumping tests on well BH-3. The wells are on the east side of Victory Highway on lots that abut the study area. The location of these wells is shown in Figure 2 and the distances and approximate direction from well BH-3 are given in Table 1. No other wells were available for monitoring during the test period. The wells, numbered 680-VH, 696-VH, and 740-VH, are 6 inches in diameter and are drilled into bedrock, but their depths and yields were not determined.

Water level fluctuations in these three wells during the period May 11-20, 2005, are shown graphically in Figure 25. The abrupt declines in water levels are caused when the pump in the well goes on to replenish water used for various domestic needs such as lawn watering, washing laundry, showering, etc. Because amounts withdrawn are typically small, and because most of the water is returned to septic systems, the non-pumping water levels provide an indication of the general water level trend. Comparison of the trend of non-pumping levels in these wells with that of the water level trend in bedrock well BH-1 (also shown in Figure 25) located in the BHMHP, indicates that they are nearly identical. The water level in well BH-1 shows a small, gradual decline from May 10-20, corresponding to a natural growing season decline. This trend is nearly identical to the water level trend in USGS observation well RIW-600, also shown in Figure 25. The USGS observation well is an 8-inch diameter well screened from 49-54 feet in sand and gravel in Richmond, Rhode Island.

We conclude from Figure 25 that pumping from the three domestic wells to provide daily needs is the principal cause of water level fluctuations in them. If pumping from well BH-3 affects the water levels in these wells, the effects are small to negligible. Similar conclusions were presented for a similar group of off-site wells in our April, 2004 report.

14.00 WATER QUALITY ANALYSES

Water samples were collected on July 7, 2005, from wells BH-2 and BH-3 and at streamflow measurement sites from the two streams that drain the study area. These were submitted to Rhode Island Analytical Laboratories, Inc., for water quality analyses. Copies of the laboratory analyses of the samples are provided in Appendix D.

The sample from well BH-2 was analyzed for bacteria, nitrates/nitrites, common inorganic constituents (IOCs), volatile organic constituents (VOCs), synthetic organic constituents (SOCs), lead, copper, arsenic, iron, and manganese. None of the constituents in the sample from well BH-2 exceeded, or even approached, maximum concentrations allowed or recommended in public drinking water supplies by USEPA or RIDOH.

Because well BH-3 is periodically tested for these same constituents, samples for this well were submitted for analysis of only nitrates/nitrites and bacteria. Owing to the close hydraulic connection of wells BH-2 and BH-3, it is likely that the water quality from both wells is nearly the same. The dissolved solids content in water from well BH-2 was exceptionally low (50 mg/L). The concentrations of nitrate-nitrogen in water samples from wells BH-2 (0.02 mg/L) and BH-3 (0.08 mg/L) were also exceptionally low.

Samples of stream base flow (i.e., groundwater inflow to streams) were analyzed only for nitrate nitrogen. The results of nitrate nitrogen analyses for both well water and stream baseflow will be used in the calibration of a nitrate loading model to be run at a later date. This model may be used to assist in estimating potential increase in nitrate-nitrogen concentrations that will result from disposal of septic system waste to the groundwater flow system within the study area.

The concentrations of nitrate nitrogen in the base flow at sampling sites of stream #1 and stream #2 were 0.07 and 0.09 mg/L, respectively. The very low concentrations of nitrate-nitrogen in the water samples from both wells and both stream sites, in addition to the very low dissolved solids content in water from well BH-2 indicate there has been little or no anthropogenic impact on the quality of groundwater in the study area.

15.00 CONCLUSIONS OF STUDY

The following conclusions can be reached after evaluation of the data from the pumping tests of well BH-3:

1) Estimated maximum-day demand for the proposed water supply system is 34,200 gal/d (23.75 gal/min); twice the maximum day demand is 68,400 gal/d (47.2 gal/min). Pumping well BH-3 for 49 hours at an average rate of 86,976 gal/d (60.4 gal/min) has demonstrated that this well fully meets the RIDOH requirement of having the capacity to be pumped for 48 hours at twice the maximum-day demand for the proposed water supply system.

2) The pump tests confirmed the results of the original pump test performed in 1993 at the time the well was installed that the well can provide an average rate pumping rate of more than 60 gal/min for 48 hours.

3) Graphs of water level drawdown in shallow on-site observation wells and a graph of discharge of the stream nearest the pumped wells demonstrate that water stored in the

overlying glacial deposits flows downward into fractures in the underlying bedrock soon after pumping begins in well BH-3.

4) Comparison of water-level trends in three off-site domestic wells on properties that abut the study area with those of the unused bedrock well (BH-1) in BHMHP and a USGS observation well during the period of the pumping tests, shows that small overall declines in water levels in the domestic supply wells (when they are not being pumped) closely resemble the natural growing-season decline of the water levels. It is concluded, therefore, that pumping from well BH-3 has no significant impact on the water levels of supply wells on properties that abut the study area.

5) The absence of significant drawdown effects in those private supply wells in which water levels were observed during the test indicates that the proposed increase in the average withdrawal rate from well BH-3 from 11,700 gallons per day to 34,200 gallons per day will have no significant impact on the yields of wells on properties adjoining or near the Victory Woods project site.

6) Supply well BH-3 can sustain a continuous yield of at least 34,200 gallons per day. The estimated average annual recharge rate of 15 inches to the area from which the well can divert water is more than adequate to sustain this withdrawal rate, and during years of below average ground-water recharge, the abundant supply of water stored in the overlying till aquifer is more than adequate to sustain this withdrawal rate.

7) It appears that downward leakage from the overlying surficial deposits will prevent extensive expansion of the cone of pumping influence in the bedrock aquifer and is believed to be the reason that no significant drawdown effects were observed in wells along Victory Highway and Robin Hollow Road.

8) Based upon our calculations of available recharge from precipitation on the project site, it is anticipated that the water demand of the development can be fully satisfied by precipitation, even in dry years.

9) Pumping of well BH-3 produced sediment. The sediment appears to be from overlying glacial sediments and may be entering near the bottom of the casings in the well. This situation will need to be corrected to prevent damage to pumping equipment and to prevent discharge of sediment into transmission lines during periods when the well is pumped at the maximum rate. A down-hole camera survey is recommended as a first step in determining where the sediment is entering the well. Rigorous well development at pumping rates in excess of the maximum design pumping rates is also recommended.

10) Water quality tests were completed on samples collected from nearby well BH-2, which

draws its water supply from the same aquifer as BH-3. The results of the water quality testing indicate that the water supply is free from constituents at concentrations exceeding the recommended values established by USEPA or RIDOH for public drinking water supplies.

We trust that the information contained in this report is adequate for your needs at this time. If any of the assumptions cited herein are not correct, if there are questions on these recommendations or if you need additional information, please do not hesitate to contact the writer.

Yours truly,

PAUL B. ALDINGER & ASSOCIATES, INC.

Paul B. Aldinger, Ph.D., P.E.
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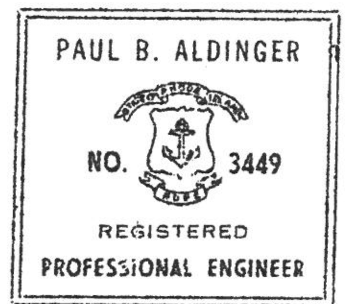

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