Appendix C – Hydrogeologic Investigation Report

Hydrogeologic Investigation Report

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TABLE OF CONTENTS

FIGURES

TABLES

ATTACHMENTS

LIST OF ACRONYMS AND ABBREVIATIONS

bgs	Below Ground Surface
CHA	CHA Consulting, Inc.
DER	Division of Environmental Remediation
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Resources Management
HAS	Hollow Stem Auger
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NYCRR	New York Code, Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
PCB	Polychlorinated Biphenyls
PFAS	Per- and Polyfluoroalkyl Substances
PFCs	Perfluorinated Compounds
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PID	Photoionization Detector
POC	Principal Organic Contaminant
PPE	Personal Protection Equipment
QA	Quality Assurance
QC	Quality Control
SCGs	Standards, Criteria and Guidelines

1.0 INTRODUCTION

The Remedial Investigation and Feasibility Study (RI/FS) Work Plan prepared pursuant to Order on Consent and Administrative Settlement; Index No. CO 4-20160212-18, between the New York State Department of Environmental Conservation (NYSDEC) and Saint-Gobain Performance Plastics (Saint-Gobain) and Honeywell (the Companies) required a study and assessment for the potential creation of an alternate public water supply source for the Village of Hoosick Falls (Village). This study includes five separate water supply alternatives and is documented in the "Municipal Water Supply Study for the Village of Hoosick Falls" (CHA & ERM, June 2019), hereafter referred as the Water Supply Study.

Alternative 1 in the Water Supply Study is a new groundwater source. A scope of work to advance this alternative entitled "Supplemental Hoosic Valley Aquifer Groundwater Source Investigation Work Plan" (CHA & ERM, July 2018) was approved by NYSDEC[1].

This Hydrogeologic Investigation Report presents the results of the field studies described in the approved Work Plan. This report also includes a summary of geophysical survey work conducted concurrently with the groundwater supply investigation that was performed to help define the geology and stratigraphy in the study area south of the Village of Hoosick Falls.

1.1 PREVIOUS FIELD INVESTIGATIONS

The consulting firm Arcadis, working on behalf of the NYSDEC, conducted an initial screening study and preliminary field investigations of some potential areas where a new groundwater source might be located, including the Wysocki Farm property (Arcadis, July 12, 2016). After identification of favorable geological deposits, a test well and observation wells were installed on the Wysocki Farm property for a more detailed study of water supply potential and water quality in that area. The water quality was found to have low level perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) impacts, low level pesticide detections, and an anomalous volatile organic compounds (VOC) impact which was unconfirmed; however, results were promising for an acceptable groundwater source with treatment. The long-term maximum yield of the Wysocki test well was reported as 300 gallons per minute based on a 72-hour pumping test (Arcadis, July 6, 2017). Arcadis did not assess whether multiple pumping wells could be installed in this hydrogeologic unit to sustain a higher pumping rate to meet current and conceptual future Village water demand. The results of the Arcadis work suggested that the aquifer may have a recharge boundary and is not entirely confined. Further analysis of the Wysocki pumping test performed by the USGS (Williams and Heisig, 2018) provided additional interpretation regarding potential aquifer boundaries and sources of recharge.

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[1] NYSDEC provided contingent approval of the Work Plan on June 20, 2018 and following discussion with the Department, the requested changes were incorporated into the final Work Plan dated July 2018.

1.2 EVALUATION AREA

Based on the results of the Desktop Study (described in Section 4.1 of the Water Supply Study) and the work conducted by Arcadis, an Evaluation Area south of the Village was selected for further evaluations (see Figures 1 and 2). This area is mapped as glacial outwash sand and gravel deposits and includes the Wysocki Farm property (parcel 8), as well as an area north and east of the Wysocki Farm property. The mapping represents surficial geology and does not reflect any potential deeper semi-confined or confined aquifers.

1.3 TECHNICAL APPROACH OVERVIEW

The field investigation activities were conducted on select sites in the Evaluation Area where access agreements with property owners were obtained. These investigation activities were conducted to better understand the areal and vertical extent of the deep confined aquifer and its recharge characteristics. The progression of activities involved in this field investigation was as follows:

1. Surface geophysical surveys were performed where the stratigraphy suggests there is sufficient saturated thickness to meet the water yield target. The surface geophysical surveys were used to determine the lateral and vertical extent of the water-bearing unit(s).
2. Test borings were installed through the unconsolidated deposits at locations selected based on the geophysical survey results. Stratigraphic information was collected in the field, from surface grade to bedrock. Monitoring wells were installed at these test boring locations.
3. Preliminary groundwater samples were collected from these monitoring wells and analyzed for a variety of analytes.
4. At the location with the highest potential for capacity and acceptable water quality, one 10” diameter test well, constructed to production well standards, was installed.
5. The test well was evaluated in a step-drawdown pumping test and a constant rate pumping test to estimate the yield of the well and the properties of the aquifer
6. A groundwater quality sampling event was performed near the end of the pumping tests to establish groundwater quality for both the test well and the surrounding monitoring wells.
7. An evaluation was performed to determine whether groundwater extracted from the test well can be considered under the direct influence of surface water.
8. An evaluation of the potential long-term yield of the contributing zones to the test was performed.

The details of each activity are discussed in the following sections.

2.0 PRELIMINARY SITE INVESTIGATIONS

The intent of the preliminary site investigations was to identify one or more target areas that had the potential to provide groundwater of suitable quality and in sufficient quantity to meet the project objectives. The work included performing geophysical surveys, advancing test borings to confirm the geology of the area, and installing and sampling monitoring wells to provide an indication of groundwater quality.

Within the Evaluation Area identified in the approved Work Plan, ERM was able to obtain access to parcels 2, 7, 8, 9, and 10 (Figure 2).

2.1 GEOPHYSICAL SURVEYS

Hager-Richter Geoscience, Inc. (HRGS) was contracted perform geophysical surveys in areas where published mapping indicates the presence of geologic deposits with sufficient porosity, permeability and saturated thickness to act as a water-bearing unit capable of meeting the project objective. HRGS used a combination of seismic refraction and electrical resistivity methods to:

- Determine the combined thickness of unconsolidated materials (sediments) and weathered bedrock;
- Distinguish, to the degree possible, major unconsolidated strata;
- Determine depth of competent bedrock;
- Map competent bedrock topography.

2.1.1 July 2018 Survey

In July 2018, HRGS surveyed 3 lines within the Evaluation Area (Lines 1-3). These lines were placed over parcels 9 and 10, north of the Wysocki Farm based on the mapped geology (Figure 3). Both the details and the results of the surveys are discussed in HRGS's report which is included in its entirety in Attachment 1.

In each case, the seismic survey shows three distinct velocity layers; the uppermost layer is interpreted to represent unsaturated sediments; the intermediate layer represents saturated sediments (undifferentiated silt and clay or sand and gravel deposits), and the lowermost layer is interpreted to represent bedrock. The results of the seismic survey indicate the depth to bedrock is 100 feet or greater, consistent with borings previously drilled.

The resistivity profiles generally show a 15-20-foot-thick high resistivity layer, overlying a 20- to 100-foot thick low resistivity layer interpreted to represent the unsaturated soils overlying a silt and clay layer. Beneath the low resistivity area, there is another zone of moderate to high resistivity. The resistivity method is not sensitive enough to distinguish between sand and gravel layers and bedrock. By superimposing the depth to bedrock data obtained from the seismic surveys on top of the resistivity data, HRGS inferred the presence of sand and gravel layers.

Using a combination of the seismic and resistivity surveys, it appeared that a relatively thick confining layer overlying a sand and gravel layer is present in the area. This interpretation is consistent with information developed by Arcadis for the Wysocki Farm parcels located to the south.

2.1.2 April 2019 Survey

An additional geophysical survey effort was conducted in April 2019, again using both seismic refraction and electrical resistivity, to provide additional information regarding the lateral and vertical extent of the aquifer. Lines 4A and 4B were surveyed on a Wysocki family property located to the south of the Evaluation Area. Line 4A runs from the western limb of the valley to Route 22, and Line 4B runs from Route 22 to the Hoosic River. Line 5 was surveyed on property owned by the Hoosac School parallel to Route 7 (Figure 3).

The results of these surveys indicate that the depth to bedrock is very shallow over the western portion of Line 4A, as expected given this line extends up from the valley floor. Line 4B reflects a similar profile to Lines 1-3 located further north. Line 5 reflects bedrock located close to land surface which is consistent with mapped rock outcrops in the vicinity.

2.2 TEST BORING INSTALLATION

Cascade Environmental, LP was contracted as the NYS-licensed driller for installation of all test borings and monitoring wells described herein. Prior to drilling, Dig Safely New York (DSNY) was contacted to locate and mark utilities in public rights-of-way. In addition, a private utility location subcontractor (New York Leak Detection, Inc.) was retained to scan a 10-foot radius around each proposed drilling locations using ground penetrating radar (GPR), magnetometry/metal detection and inductive cable/pipe location. No sub-surface utilities were identified at the proposed drilling sites.

Seven test borings were installed using the sonic drilling method with collection of a continuous soil core. All borings were advanced to bedrock with collection of a five-foot rock core (except borings GWI-04 and GWI-07, which did not include a rock core). Each rock core was drilled into the Walloomsac Formation which consists of phyllite in this area. The borings were installed in two mobilizations, consistent with the approved Work Plan (see Figure 4 for locations; Attachment 2 for lithologic logs).

2.2.1 Round 1 Borings

Following the geophysical surveys, three borings, designated GWI-01 through GWI-03, were drilled at the intersections of geophysical survey Lines 1-3 in September 2018.

In GWI-01, silt, sand and gravel unsaturated sediments were present to a depth of approximately 13 feet below ground surface (bgs). A gray, soft clay was then present to a depth of 35 feet bgs. This clay layer overlies various mixtures of sands and gravels to a depth of 102 feet bgs. A gray silt layer is present from 102 to 125 bgs, at which point bedrock was encountered.

The stratigraphy in GWI-02 is somewhat similar to GWI-01 although the clay layer is much thicker and extends from 12 to 86 feet bgs. The sand and gravel layer in this boring extends from 86 to 98 feet bgs. In this boring, bedrock was encountered at 100 feet bgs.

In GWI-03, the clay layer extends from 14 to 68.5 feet bgs. The clay layer overlies a sand layer from 75 feet to 102 feet bgs. The sand layer is much finer grained than that observed in GWI-01 or GWI-02. Bedrock was encountered at 104 feet bgs.

2.2.2 Round 2 Borings

In late October, early November 2018, four additional test borings were drilled. In GWI-04, unsaturated clayey silt was present to a depth of approximately 5.5 feet bgs. A brown fine to medium sand with varying amounts of gravel was present to a depth of 12 feet bgs and became saturated at 10 feet bgs. A brown to gray soft clay was then present to a depth of 35 feet bgs. This clay layer overlies a layer with varying percentages of clay and silt extending to 86 feet bgs. Between 86 feet bgs and 110 feet bgs a layer of various mixtures of sands and gravels was observed. A gray silt layer is present from 110 to 120 bgs, at which point the boring was finished.

The stratigraphy in GWI-05 is somewhat similar although the clay layer is thicker and extends from 8 to at least 40 feet bgs. No samples were recovered from 40 feet to 60 feet bgs. The silt and clay layer extend to at least 90 feet bgs followed by a 10-foot interval of no recovery. The observed sand and gravel layer in this boring extended from 90 to 111 feet bgs. In this boring, bedrock was observed at 111 feet bgs.

In GWI-06, the interval from 0 to 40 feet bgs is generally comparable to those observed in GWI-04 and GWI-05. The clay layer extends to 44 feet bgs in this boring. Underlying the clay layer is a silt and clay layer extending to nearly 60 feet bgs. Differing from GWI-04 and GWI-05, the sand and gravel layer is much thicker in GWI-06, extending from 60 feet bgs to 130 feet bgs with varying amounts of fine to coarse sands and gravels. Underlying the sand and gravel layer is a unit of fine sandy silt with gravel extending to 156 feet bgs. Bedrock was encountered immediately below this unit.

Pilot boring GWI-07 was installed in the approximate location of the test well. This boring was advanced using a sonic-type drill rig driving 4-inch casing to a final depth of 110 feet bgs. Topsoil was encountered to a depth of approximately 1.5 feet followed by silty sand. At a depth of 10 feet bgs a layer of clay and silty clay was encountered extending to a depth of 31 feet bgs. This clay layer was identified in previous borings in the vicinity and is believed to act as an aquitard over the confined aquifer below. Below the aquitard are generally fine to medium sands with varying amounts of fine to coarse gravels. At a depth of 85 feet bgs a 4-foot thick layer of fine to coarse gravel interval was encountered followed by fine to coarse sands and gravels to approximately 105 feet bgs. At 105 feet bgs, a silty fine sand layer was encountered. Previous borings have shown that this layer generally overlies bedrock and is very dense.

The pilot boring identified an interval of approximately 85 feet to 105 feet as the most likely to be acceptable for a groundwater test well. Therefore, this interval was targeted for the test well installation. The boring logs for GWI-04 through GWI-07 are presented in Attachment 2.

2.2.3 Summary of Geologic Conditions

The unconsolidated materials are heterogeneous in the investigation area. A shallow deposit consisting of silt, sand and gravel overlies silt and clay of varying thickness. A deeper sand and gravel unit underlies the silt and clay. In places, the deeper deposit is very coarse, consisting predominantly of gravel and has the potential to be a productive aquifer. A glacial till underlies the deeper sand and gravel unit in some locations, which in turn is underlain by bedrock (phyllite). In other locations, bedrock directly underlies the deeper sand and gravel unit. A geologic cross section running north-south through the valley is included as Figure 5. Figure 6 presents an isopach map for the confining clay unit.

2.3 MONITORING WELL INSTALLATION

All test borings, except GWI-07 were converted to two-inch diameter monitoring wells (see Figure 4). All monitoring wells were constructed with PVC riser pipe and machine-slotted well screen with a slot size of 0.020-inches. A sand pack, consisting of a minimum radial thickness of one inch, was placed within the annulus between the borehole and the well screen. A two-foot bentonite seal was placed above the sand pack. The remaining borehole between the bentonite seal and the ground surface was tremie-grouted with bentonite-cement grout. A steel stick-up protective pipe and gripper caps were installed at each well location to protect the riser pipe as the area is actively farmed. See Attachment 2 for well construction diagrams.

2.4 INITIAL GROUNDWATER QUALITY SAMPLING & RESULTS

2.4.1 Monitoring Well Sampling

All monitoring well samples were collected by low flow/minimal drawdown purging and sampling procedures (USEPA, 1996) using peristaltic pumps and HDPE tubing. Field parameter analyses were conducted using a calibrated YSI 566 meter with a flow-through cell which allows measurement of temperature, specific conductance, dissolved oxygen, pH, turbidity, oxidation/reduction potential, and a water level indicator to measure depth to water. The monitoring wells were sampled in three separate events as described below:

- September 2018 – The initial three monitoring wells (GWI-01 through GWI-03) were sampled and analyzed for all parameters in the NYSDOH Part 5 regulations for a public drinking water source. In addition, these samples were analyzed for: (a) 21 PFAS constituents using EPA Method 537-1.1; and (b) 1,4-dioxane via EPA Method 8270C with selected ion monitoring (SIM).
- November 2018 – All six monitoring wells (GWI-01 through GWI-06) were sampled and analyzed for 21 PFAS constituents using EPA Method 537-1.1. Results of the first two sampling rounds are presented in Table 1. These data indicate the presence of low PFAS levels in the deep confined aquifer targeted for production. Based on these results and consultation with NYSDEC and NYSDOH, the decision was made to proceed with installation of a test production well and aquifer testing.
- May 2019 – All six monitoring wells were sampled after completion of the constant rate aquifer test and analyzed for:

  - Principal organic contaminants via EPA Method 502.2
  - Selected metals via EPA Methods 6010 and 7470
  - Wet chemistry parameters
  - 21 PFAS constituents using EPA Method 537-1.1

All analyses were conducted by a laboratory NYSDOH-certified for the specified analytical methods.

2.4.2 Results of Monitoring Well Sampling

Table 1 presents a summary of all monitoring well groundwater sampling analytical results with comparison to New York State Ambient Water Quality Standards or Guidance Values for Class GA groundwater. Most of the broad spectrum NYSDOH Part 5 parameters were reported as “non-detect” in all samples. The only analytes detected at concentrations exceeding their respective comparison values were inorganic constituents. Most were only detected in one well, except for iron, manganese and sodium, which were more common. Well GWI-03 had elevated pH, believed to be due to grout contamination.

In addition, low levels of PFAS were detected as follows:

- Perfluorooctanoic acid (PFOA): (ND to 38 ng/L);
- Perfluorobutanoic Acid (PFBA): (ND to 3.0 ng/L);
- Perfluorooctanesulfonic acid (PFOS): (ND to 0.9 ng/L);
- Sodium 1H,1H,2H,2H-Perfluorooctane Sulfonate (6:2): (ND to 41 ng/L);
- Perfluorohexanoic acid (PFHxA): (ND to 2.1 ng/L); and
- Perfluorononanoic acid (PFNA): (ND to 0.46 ng/L).

The highest detected concentrations of PFAS (PFOA and Sodium 1H,1H,2H,2H-Perfluorooctane Sulfonate 6:2) were found in well GWI-3 in May 2019. However, earlier sampling of this well in September and November 2018 found much lower concentrations of these compounds.

2.4.3 Data Validation

Data Usability Summary Reports (DUSRs) were prepared for all samples. The DUSRs include an assessment of the deliverables with a description of the analytical results and any qualifications that should be considered when using the data. The DUSRs highlight data that did not meet QC limits and therefore required data qualification. These tables include information such as, blank contamination, surrogate recoveries, and internal standard area counts that did not meet QC criteria.

Qualification of data, where appropriate, was made by the use of qualifier codes based upon the data validation process. These qualifiers serve as an indication of the qualitative and quantitative reliability of the data. The qualifier codes utilized are as follows:

- No qualifier – Positive Detect. The compound was analyzed for and was positively identified above the sample reporting limit. The reported value is valid and useable.

- U – Non-Detect. The compound was analyzed for, but not detected. The associated numerical value is the reporting limit (RL). The value is valid and useable as a non-detect at the reporting limit.
- J - Positive Detect at an estimated value. The compound was analyzed for and was positively identified; the associated numerical value is the approximate concentration of the compound in the sample. The value was designated as estimated as a result of the data validation criteria or when an organic compound is present (mass spectral identification criteria are met), but the concentration is less than the RL. The value is valid and useable as an estimated result.
- UJ – Non-Detect at an estimated value. The compound was analyzed for, but not detected above the RL. The associated numerical value is the RL; however, the RL is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the compound in the sample. The value is valid and useable as a non-detect at the estimated RL.
- R – Rejected. The sample results are rejected due to deficiencies in the ability to analyze the sample and meet quality control criteria. The data are unusable. The presence or absence of the analyte cannot be verified.

The final review of the DUSRs was performed by the ERM Quality Assurance Officer. Results from the NYSDOH Part 5 analysis of the LaCroix test well meet all requisite quality criteria[2]. A small amount of data from the monitoring wells was rejected. These results are identified with an "R" qualifier on Table 1. Overall, the groundwater analytical data are valid and usable for the purposes of evaluating water quality for a potential potable source. DUSRs for all samples collected as part of this groundwater supply development project are provided in Attachment 4.

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[2] See Section 4.3 for presentation of these results.

3.0 TEST WELL INSTALLATION

Based on the results of the test boring program, the deep sand and gravel unit in the area of GWI-01 was determined to be most favorable for groundwater development and was chosen as the location for a test well. This property is owned by the LaCroix family; thus, the test well is also referred to as the LaCroix well. As noted previously, boring GWI-07 was installed within 20 feet of GWI-01 to provide a more detailed analysis of subsurface conditions prior to installing the test well.

The test well installation began on February 11, 2019. The well driller, Smith Well Drilling, recommended drilling the test well using a cable-tool rig to advance the test well based on the targeted depth of the well, the confined aquifer conditions, and their experience with drilling the Wysocki Farm well.

Additionally, this method has the advantages of a relatively light-weight drill rig and a minimal amount of drilling water required. The location of this well within an active farm field necessitated a light-weight drill for access. Additionally, due to the PFAS concerns associated with this project, certified clean water was required during the drilling process. The cable-tool method uses less water than other methods and was therefore ideal. This method utilizes a heavy drill bit on the end of drill rods suspended by a cable. The drill bit is repeatedly raised and allowed to drop to the boring bottom, loosening the material being penetrated. At certain intervals a bailer is lowered to remove drill cuttings that are suspended in water, which is added to the boring as needed. To prevent cave in, casing is driven below the interval being drilled.

The final location of the test well was approximately 4 feet west of the pilot boring GWI-07. This was done to allow the boring to progress through undisturbed soils. The drilling process began with the installation of a 16" diameter boring into the silt and clay deposit to a depth of 25 feet bgs. This provides a seal to prevent any shallow groundwater from migrating into the confined aquifer during the drilling process.

Following the 16" casing installation, drilling was advanced using 10" diameter steel casing and a 10" drill bit. The boring was advanced to a depth of approximately 60 feet bgs without sampling. From 60 feet bgs to the bottom of the boring at 104 feet bgs, samples were collected continuously using a bailer and allowing the water and sediment to settle in a bucket. The test well boring log is included in Attachment 2.

3.1.1 Well Screen Size Selection

Samples collected during the drilling phase were sent to Johnson Screens for sieve analysis. These samples were collected continuously from 60.3 feet to 104.8 feet bgs. The results of the sieve analysis indicated that the ideal screen interval was from 75 feet to 105 feet bgs. The recommended slot size was 100-slot from 75 feet to 89 feet bgs and 50-slot from 89 feet to 105 feet bgs. Typically, the entire productive zone would be screened in a confined aquifer, but Johnson recommended only 30 feet of screen to allow for greater drawdown above the pump level. Results of the sieve analysis are included in Attachment 3.

3.1.2 Final Well Construction Details

The final well is constructed of 10" steel casing consisting of 10- and 20-foot lengths welded together. The well screen is a nominal 10" telescoping continuous wrap stainless steel screen fabricated by Johnson

Screens. It is variable slot size with 100-slot from 75 feet to 89 feet bgs and 50-slot from 89 feet to 105 feet bgs. The screen was dropped inside the casing and pushed to the bottom of the borehole. The casing was then pulled back to expose the well screen with excess casing cut off as needed. The well screen was naturally packed (no filter pack was installed). The final casing extends from ground surface to 75 feet bgs. The well has a stickup above ground of approximately 4 feet. Construction was completed on April 9, 2019. A well construction log is included in Attachment 2.

3.1.3 Well Development Details

Following installation of the well screen and pull back of the casing the well was developed starting on April 10, 2019. Initial development was preformed using a 20-gallon bailer. Removal rates of up to 80 gallons per minute (gpm) were attained with this method with very minimal drawdown. Following bailing, a pump was installed and used to extract water at approximately 100 gpm. Drawdown of approximately 0.5 feet was observed during development pumping, with the water being very clear.

A surge block and pump were then installed to mechanically remove any fine material from the well screen interval. Pumping rates during this portion of development were approximately 190 gpm. After three working days of development turbidity was below 5 NTU, and the discharge water was clear. Well development was completed on April 12, 2019 based on field observations and the driller's recommendations.

3.1.4 Well Disinfection

After well development was completed, Smith used tablets of calcium hypochlorite to disinfect the well. Smith later checked the residual chlorine level during the pumping test to ensure it had been used up and removed from the well.

4.0 TEST WELL EVALUATION

After completion of the installation of the test well and monitoring wells, the pumping test phase of the field investigation was initiated. Prior to starting any pumping tests, a discharge hose was installed to convey the discharged water away from the test well to eliminate the possibility that the discharged water could recharge the well or result in erosion of soil. The discharge hose was directed several hundred feet south of the test well into a drainage swale that ultimately discharged to the Hoosic River. The pumping tests consisted of two parts; a step drawdown pumping test and a constant rate pumping test.

4.1 STEP DRAWDOWN TEST

The step drawdown test was conducted on April 17, 2019 to determine the optimum pumping rate for a constant rate test and evaluate the specific capacity and anticipated well yield. Step intervals of 250, 350 and 450 gpm were chosen based on pump capacity and observations during development. As specified in the Work Plan, prior to the step test pressure transducers with data logging capability were deployed to monitor groundwater elevations on a continuous basis throughout the step test. These transducers were deployed in the test well, GWI-01, GWI-04, GWI-06 and a staff gauge in the Hoosic River to monitor groundwater and surface water elevations.

The step test was started at 10:00 on April 17, 2019 with a static water level approximately 13 feet below the top of casing. The test well was pumped at 250 gpm for 90 minutes with approximately 3 feet of drawdown. The second step was 350 gpm for 90 minutes with approximately 5 feet of drawdown. The final step was 450 gpm which was the highest flow rate the pump could reliability produce. At this step, there was approximately 6 feet of drawdown after 2 hours of pumping.

At the completion of the step drawdown test, water levels were monitored until over 90-percent recovery was achieved in the test well. Recovery took place within minutes of the test ending. See Attachment 5 for hydrographs of the test well and monitoring well GWI-01 vs. barometric pressure and Attachment 6 for hydrographs of the test well and monitoring well GWI-01 vs. river stage.

4.2 CONSTANT RATE PUMPING TEST

As described in the Work Plan, a constant rate pumping test was performed on the test well after the step drawdown test activities were completed. The constant rate pumping test consisted of three segments; an ambient monitoring period during which no pumping occurred, a 72-hour pumping period at a constant rate of 450 gpm, and a recovery period. The pumping test was conducted in accordance with “Pumping Test Procedures for Water Withdrawal Permitting” (NYSDEC, August 2018).

Note that the pump for this pumping test was a 15 HP Grundfos submersible turbine pump placed at 34 feet below grade leaving more than 20 feet of drawdown from the static water level. If this well was placed in permanent service, the pump would be placed at a greater depth providing for more available drawdown (see discussion in Section 5.8).

Prior to the pumping test a number of pressure transducers with data logging capability were deployed in monitoring wells both at the test well site and at other sites in the Hoosic Valley. These transducers were deployed on April 18, 2019. The monitoring wells selected for transducers are shown on Figure 7 and Table 2. The selected monitoring wells were chosen to provide a diverse set of data with which to evaluate aquifer characteristics in the vicinity of the test well. In addition, to evaluate the potential hydraulic connection between the aquifer and the river, the Hoosic River staff gauge was also monitored during the pumping test. The pressure transducers recorded data continuously during each testing phase (48-hour ambient monitoring period, 72-hour pumping period and 48-hour recovery period). All of the data from the pumping test collected by the pressure transducers are included in Attachment 11 and will be transmitted electronically.

For further evaluation of a potential hydraulic connection between the test well and the Hoosic River, field parameters including pH, oxidation-reduction potential, specific conductivity, turbidity, dissolved oxygen, temperature and total dissolved solids were measured. Prior to the start of the pumping test a set of readings was collected from the river to establish baseline conditions of the surface water. During the pumping test a field meter with data logging capabilities was set up to record field parameters of the discharge water on 4-hour intervals. At the conclusion of the pumping test an additional set of surface water parameters was collected.

It is noted that during the pumping test anomalous turbidity measurements were observed. It is believed that this was due to air bubbles in the meter’s flow-thru cell interfering with the sensor. A separate turbidity meter was used to collect several turbidity readings are these results are believed to be correct. A summary of field parameters is included in Table 3.

The weather was monitored in advance of initiating the pumping test and a period with minimal rain in the forecast was selected. During the 72-hour pumping test there were several instances of very light rain; however, these rainfall events totaled 0.17 inches over the entirety of the pumping period.

The 72-hour pumping test was started at 9:30 am on April 29, 2019. Discharge rates quickly stabilized at 450 gpm and remained steady for the entirety of the pumping test. The pumping test was completed at 9:30 am on May 2, 2019.

Analysis of the constant rate pumping test is presented in Section 5.0.

4.3 WATER QUALITY TESTING

One water quality sample was collected from the test well immediately prior to shut down of the constant rate pumping test. The sample was collected from a sampling port directly on the discharge piping of the test well. The test well sample was analyzed for the complete list of parameters as listed in the NYSDOH Part 5 regulations for a public drinking water source, in addition to PFAS (list of 21 compounds) by USEPA Method 537-1.1 Modified. All analyses were conducted by a laboratory NYSDOH-certified for the specified analytical methods. The full results are presented in Table 4.

A summary of the water quality testing (detected parameters only) from the LaCroix test well is provided below. Only sodium and manganese exceeded their groundwater standard and then only slightly. No PFAS compounds were detected.

Detected Parameters
LaCroix Test Well

Parameter	Unit	NYDEC TOGS 111 CLASS GA STANDARD	LACROIX TEST WELL (sampled 5/2/19)
E200.7			
Iron	mg/l	0.3	0.027 J
Manganese	mg/l	0.3	0.36
Sodium	mg/l	20	29.9
E200.8			
Barium	ug/l	1000	236
Copper	ug/l	200	0.58 J
Nickel	ug/l	100	1.4 J
Uranium-238	ug/l	none	4.6
E300.0			
Chloride (As Cl)	mg/l	250	56
Fluoride	mg/l	1.5	0.065 J
Sulfate (As SO4)	mg/l	250	26
SM2130B			
Turbidity	NTU	none	0.14
shaded values exceed standard			

4.4 INTERCONNECTION BETWEEN GROUNDWATER & SURFACE WATER

A Microscopic Particulate Analysis (MPA) test was performed to evaluate the potential for groundwater under direct influence of surface water (GWUDI) in the source aquifer. Environmental Associates Ltd of Ithaca, New York was retained to perform the MPA test using EPA method 910/9-92-029. The test involved diverting a minimum of 1,000 gallons of discharge water, at a rate of 1 gpm, through a water filtration unit near the end of the test. The filter and water within in the filter housing were submitted to the qualified laboratory for analysis. Prior to, and after the sample for MPA was collected, the discharge was monitored for pH, temperature and specific conductance. The MPA test is utilized to generate a risk rating score that indicates the likelihood that the groundwater is under the direct influence of surface water.

The results of the MPA analysis indicate that there is a low risk of surface water influence. The laboratory report indicated that iron bacteria were the only biological organisms observed. The report notes that iron bacteria are not considered a risk factor for surface water influence.

Prior to and immediately following the pumping test a set of field parameters (pH, oxidation-reduction potential, specific conductivity, turbidity, dissolved oxygen, temperature and total dissolved solids) were measured in the Hoosic River to establish baseline surface water parameters. Throughout the pumping test field parameters were measured in the discharge from the test well. The measurements were collected from a flow through cell connected to a sampling port on the discharge line. These parameters are included in Table 3. As shown, several of these parameters exhibit stark differences between the surface water and the test well discharge. These include specific conductivity, dissolved oxygen, temperature and total dissolved solids. Additionally, oxidation-reduction potential and pH show differences between the surface water and discharge water to a lesser degree. These results indicate a lack of direct hydraulic link between the test well aquifer and the Hoosic River and therefore, this potential drinking water source would not likely be considered GWUDI, but the NYSDOH makes the final determination.

5.0 AQUIFER TEST INTERPRETATION

In this section of the report, we describe the interpretation of the aquifer test data. This interpretation includes evaluation of river efficiencies and associated lag times, barometric efficiencies, and any pre-aquifer test water level trends. These parameters, if applicable, were calculated from the antecedent water level data and then used to correct the observed aquifer test drawdown data during the pumping period to eliminate any interferences attributable to variations in barometric pressure, to river fluctuations, and for any pre-aquifer test trends in observation well water levels. The corrected aquifer test drawdown data were then analyzed to determine aquifer transmissivity, storativity, hydraulic conductivity, and specific storage.

5.1 AQUIFER TESTING THEORY

An aquifer test must optimally be designed, implemented, and interpreted based upon an understanding of the nature of the hydrogeologic system being studied. It is evident from older and more recent aquifer testing of the deep glacial outwash aquifer that this aquifer behaves as a “semi-confined” (or “leaky artesian”) aquifer. Semi-confined aquifers require special efforts to ensure that appropriate data is collected and that the data is interpreted correctly. This aquifer is also a buried valley aquifer generally bounded on two sides by valley walls composed of lower-permeability soil and rock. In this sense, it might be considered as a classic “strip aquifer” (Walton, 1970). These factors, and others, need to be considered in interpretation of aquifer test data from this hydrogeologic regime.

Neuman and Witherspoon (1972), who earlier had developed a complete analytical solution for semi-confined, multi-aquifer systems (Neuman and Witherspoon, 1969a, 1969b), recommend that if the primary objective of the aquifer test of a semi-confined aquifer is determination of the transmissivity and storativity of the pumped aquifer (as is principally the case here), three things should be done:

1. Drawdown should be measured close to the pumping well;
2. Only early-time data, before significant leakage occurs, should be analyzed; and
3. This early-time data should be analyzed by means of the Theis Method.

Neuman and Witherspoon (1972) also demonstrated that the Hantush “r/B” method (1955) of analyzing semiconfined aquifers, typically overestimates aquifer transmissivity and underestimates the vertical hydraulic conductivity of subjacent aquitards. It does this because it makes several simplifying assumptions that limit its usefulness to most field situations. The most limiting of these recommendations are the following:

1. The storativity of overlying and underlying aquitards can be neglected; and
2. Drawdown in overlying and underlying aquifers is negligible.

Rarely are these conditions encountered in practice. Recognizing the limitations of his “r/B” solution to most field situations, Hantush developed another solution that incorporated the storativity of the aquitards (Hantush, 1960). In that solution, he maintained the assumption of zero drawdown in overlying or underlying aquifers. This solution is referred to as the "B" solution. Unfortunately, type curves for different values of "B" are very similar in shape, limiting the method's usefulness as a diagnostic tool for determining aquifer properties. As mentioned earlier, Neuman and Witherspoon developed a complete analytical solution for multiple aquifer/aquitard systems in 1969. Based upon that solution, they definitively addressed the issues associated with field determination of the hydraulic properties of leaky aquifer/aquitard systems of the type we are dealing with at Hoosick Falls (Neuman and Witherspoon, 1972). They state the following:

> *"Thus, we arrive at the important conclusion that one can evaluate the transmissibility and storage coefficient of a leaky aquifer by using conventional methods of analysis based on the Theis solution. The errors introduced by these methods will be small if the data are collected close to the pumping well, but they may become significant when the observation well is placed too far away."*

The reliance on wells close to the pumping well and the use of early-time data, before significant leakage occurs, as recommended by Neuman and Witherspoon (1972), is doubly important in the case of this "strip aquifer" because boundary effects also are manifested in the drawdown data. As the cone of influence expands it in effect "reflects" off the aquifer's boundaries causing additional drawdown within the bounded aquifer. This additional drawdown produces a positive departure from the Theis method-predicted drawdown (i.e. more drawdown than would occur in an unbounded aquifer of comparable properties). These boundary effects typically occur in the mid-range to later-time drawdown data, not in the early-time data. In contrast to bounded aquifers, semi-confined aquifers exhibit negative departures from Theis method-predicted drawdown (i.e. less drawdown than would occur in a confined aquifer of comparable properties) due to leakage. The combination of semi-confined aquifer behavior causing negative departures and boundaries causing positive departures makes analysis of mid- and later-time data problematic.

Therefore, in the analysis of aquifer test data from this semiconfined aquifer, the above-described recommendations of Neuman and Witherspoon was observed. Hence, time-drawdown analyses is limited to early-time data from wells relatively close to the pumping well.

5.2 ANTECEDENT MONITORING OF GROUNDWATER LEVELS, BAROMETRIC PRESSURE AND HOOSIC RIVER STAGE

Pre-aquifer test, antecedent water levels and aquifer test water levels were monitored in a total of thirty-four monitoring wells. The groundwater monitoring wells monitored are listed in Table 2. As indicated in the table, datalogging pressure transducers were programmed to record groundwater levels at either 1-minute or 5-minute intervals. These monitoring frequencies were maintained throughout the antecedent water level monitoring, the aquifer test, and the post-aquifer test recovery monitoring. Maintaining these uniform monitoring frequencies precluded the need for reprogramming of the data loggers for either the aquifer test or recovery period

Barometric pressure was simultaneously monitored using a Van Essen Baro-Diver deployed near GWI-01. River stage in the adjacent Hoosic River was also contemporaneously monitored using a Solinst Levelogger deployed as a river stage gauge deployed near the Water Supply Area. This river stage gauge was removed during the time between the step yield test conducted on 4/17/2019 and the start of the constant rate aquifer test on 4/29/2019 due to concerns over equipment safety during anticipated high river flow events from rain storms. The river gauge was re-deployed approximately one hour prior to the start of the constant rate aquifer test. During the time between the step yield test and aquifer test, the USGS monitoring station 01334500 near Eagle Bridge, NY, which is approximately 5.5 miles downstream, was used as a surrogate. During the deployment of the Van Essen Baro-Diver deployed near GWI-01, the river stage data collected trended quite similarly to the USGS monitoring station 01334500 near Eagle Bridge, NY. The river stage data were utilized, where applicable, to calculate river efficiencies and associated lag times in wells proximal to the LaCroix well.

5.3 EVALUATION OF BAROMETRIC EFFICIENCIES, RIVER EFFICIENCES AND ASSOCIATED LAG TIMES, AND PRE-AQUIFER TEST WATER LEVEL TRENDS

Hydrographs of all the wells monitored during the aquifer test are presented in Attachment 5. In addition to groundwater levels, selected wells in proximity to the LaCroix Test Well also have barometric pressure included on the graph. The barometric pressure was measured with the onsite Solinst barologger. Barometric pressure, expressed in feet of water, is on the secondary Y axis and is plotted in reverse order; that is, with barometric pressure increasing downward. Plotted this way, barometric pressure should trend with water levels if the wells have a significant barometric efficiency. A review of these hydrographs and barometric pressure graphs indicate that no wells exhibit any perceptible barometric efficiency. This is likely due to the aquitard overlying the aquifer pinching out along both the east and the west sides of this valley fill aquifer, thus allowing barometric pressure changes to reach the aquifer itself and be transmitted throughout the aquifer given the high hydraulic conductivity and diffusivity of this aquifer.

In contrast to barometric efficiency, the hydrographs and co-plotted river stage graphs in Attachment 6 indicate that the wells in the Water Supply Development Area and Wysocki Farm Area may be influenced by river stage. As illustrated in the co-plotting of groundwater elevations and Hoosic River stage, water levels in all of the monitoring wells show a strong correlation with river stage during the antecedent period. In Attachment 7, the river efficiency and associated time lag of each observation well has been calculated. The results of those analyses are presented below.

Calculated River Efficiencies and Lag Times

Well	River	Lag Time (min)
Test Well	72.4%	82
GWI-01	78%	108
GWI-02	63%	187
GWI-03	69%	153
GWI-04	70%	108
GWI-05	63%	244
GWI-06	72%	93

Calculated River Efficiencies and Lag Times

Well	River	Lag Time (min)
WF-OBS-01	64%	171
WF-OBS-02	63%	167
WF-OBS-03	64%	178
WF-OBS-04	71%	189
WF-OBS-05	44%	248
WF-OBS-BR	63%	182

The river efficiencies range from 44 to 78 percent and the time lags from 93 to 248 minutes.

In Attachment 8, daily precipitation, recorded at the McCaffrey site weather station, is co-plotted with the groundwater level hydrographs. The correlation between rainfall events and groundwater level rises is evident in these figures. However, given the substantial thickness of glaciolacustrine clay overlying the aquifer and separating the Hoosic River from the aquifer in the vicinity of the test well, the observed river efficiencies are not believed indicative of actual hydraulic communication between the Hoosic River and this semi-confined aquifer through the glaciolacustrine clay, but rather may be attributable to two factors[3]:

1. Increases in total stress on the aquifer due to the sheer weight of the water in the river. Increases in river stage increase the total stress on the aquifer beneath and adjacent to the river, which in turn, as dictated by Terzaghi's Law, is apportioned between increases in effective stress within the aquifer and increases in aquifer pore pressure (i.e. increases in potentiometric levels). This is a common phenomenon in confined and semi-confined aquifers that are subject to loads imposed by rivers, estuaries, and other heavy loads, such as railroad cars (Freeze and Cherry, 1979).
2. The rises in river stage correlate with rainfall events. These same rainfall events, particularly the larger events, in addition to causing rises in river stage, likely also produce recharge to the aquifer, particularly from the surrounding hillsides and along the margins of the valley where the clay pinches out, causing rises in potentiometric levels throughout the aquifer.

A plan view plot of river lag times of each monitoring well and interpolated contours are illustrated in Figure 8. They indicate that river lag times generally increase with distance from the Hoosic River suggesting that changes in total stress on the aquifer due to rises and declines in river stage are the principal mechanism accounting for the river efficiencies and river lag times measured in the monitoring wells.

Trends in the antecedent data just prior to the aquifer test were not explicitly calculated, as they were subsumed within the river efficiency calculations.

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[3] The drawdown adjustments described in Section 5.4 are independent of the mechanism by which the semi-confined aquifer responded to river stage variations.

5.4 ADJUSTMENT OF OBSERVED DRAWDOWN DATA

The observed aquifer test drawdown data were adjusted for water level fluctuations induced by changes in the stage of the Hoosic River before undergoing early-time Theis and Cooper-Jacob analysis. The adjustments made to the data were quite small given that only modest changes in river stage occurred during the 72-hours of the aquifer test.

5.5 THEIS EARLY-TIME ANALYSES

As discussed in the technical approach section, time-drawdown analyses have been limited to wells relatively close to the pumping well and only to the early-time data observed in those wells. Four wells were selected that meet the criteria set forth by Neuman and Witherspoon (1972). These wells are GWI-02, GWI-03, GWI-04, and GWI-06. The radial distances from the pumping well to these wells varies from 251 to 717[4] feet. The results of the Theis early-time analyses are shown in Figures 9 through 12 and are summarized in the table below.

Summary of Early-Time Theis Analyses

Well	Transmissivity (ft^2/day)	Effective Hydraulic Conductivity* (ft/day)	Storativity (dimensionless)	Specific Storage* (ft^{-1})
GWI-02	12,800	711	2.9×10^{-4}	1.6×10^{-5}
GWI-03	7,700	428	1.6×10^{-4}	8.8×10^{-6}
GWI-04	9,200	511	9.9×10^{-5}	5.6×10^{-6}
GWI-06	9,800	544	1.8×10^{-4}	1.0×10^{-5}
Arithmetic Mean	9,880	548	1.8×10^{-4}	1.0×10^{-5}

** Based upon an average thickness of 18 feet*

As indicated in this table, the calculated transmissivities from these time-drawdown analyses vary from 7,700 to 12,800 feet^2/day, with an arithmetic mean of 9,880 feet^2/day. The calculated storativities vary from 1.0×10^{-4} to 2.9×10^{-4}, with an arithmetic mean of 1.8×10^{-4}.

It should be noted that these calculated transmissivities and storativities are representative in large measure of the higher hydraulic conductivity, gravel and sand unit within the aquifer since it is primarily through that subunit of the aquifer that the early-time lateral propagation of drawdown occurs. Consequently, calculation of unit properties, such as hydraulic conductivity and specific storage, must consider the effective thickness of the aquifer during the early-time data. It is reasonable to conclude that the effective

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[4] GWI-01, which is only 9.3 feet from the pumping well, was not selected for time-drawdown analyses because of its proximity to the pumping well. A slug test of this well indicated that it has a well response time (time to recover 63% of the initial instantaneous head difference created by the slug test) of approximately 10 seconds, which is too large to reflect the rapid potentiometric declines occurring this close to the pumping well at the beginning of the aquifer test. A simple Theis method calculation of drawdown 9.3 feet from the pumping well using the parameters calculated from the four observations wells indicates that after 6 seconds there would be over 3 feet of drawdown in the aquifer at GWI-01. At 6 seconds, GWI-01 is only recording 1.4 feet of drawdown due to piezometer time lag. This well will be useful, however, for analysis of later-time data.

thickness of the aquifer during the early-time lateral propagation of drawdown is consistent with the thickness of the high hydraulic conductivity (high K) gravel and sand subunit of the aquifer as observed in the well logs. Based upon the logs of wells GWI-01 through GWI-07, the thickness of the high K subunit varies from 9 to 25 feet and averages 18 feet in thickness. We used this thickness in converting transmissivity and storage to the unit properties of hydraulic conductivity and specific storage, respectively. The hydraulic conductivity and specific storage of the high K zone are given in the table above. Hydraulic conductivity varies from 428 to 711 ft/day, which is consistent with the coarse-grained lithology described in the well logs. Specific storage varies from $5.6\text{x}10^{-6}$ to $1.6\text{x}10^{-5}$ ft^{-1} and averaged $1.0\text{x}10^{-5}$ ft^{-1}. These values of specific storage are consistent with very dense gravels and sand (Batu, 1998).

5.6 COOPER-JACOB ANALYSIS OF DRAWDOWN IN THE PUMPING WELL

The time-drawdown, Cooper-Jacob method can be used to estimate the transmissivity of an aquifer based upon the measured drawdown in the pumping well, itself. The method is less precise than time-drawdown analyses of observation wells and can be subject to error if flow rates are not well-maintained during the test or if the pumped well is inefficient. Additionally, the method cannot estimate the storativity of the aquifer. In this case, flow rates were well maintained, and the well is efficient, so the Cooper-Jacob method was performed focusing, like the Theis analyses and for the same reasons, on the early-time data. The results of this analysis are shown in Figure 13. The transmissivity calculated by the Cooper-Jacob method is 9,000 ft^2/day, which comports well with the more precise early-time Theis analyses described above.

5.7 AREAL EXTENT OF THE AQUIFER TEST CONE OF INFLUENCE

The drawdowns measured in the monitoring wells after 1,000 minutes of pumping are depicted on Figure 14. An elapsed time of 1,000 minutes was selected because after 1,000 minutes drawdown begins to slightly fluctuate. As illustrated in Figure 14, drawdowns range from 5.94 feet in GWI-01, which is 9.3 feet from the pumping well, to 2.14 feet in WF-OBS-05, which is over 3,000 feet southeast of the pumping well. The full extent of the cone of influence is not well delineated by this data. However, the 2.14 feet of drawdown observed at WF-OBS-05 indicates that the cone of influence extends at least 3,000 feet to the southeast. In addition, the absence of any observed aquifer test drawdown in GW-2, which is approximately 3,740 feet north of the pumping well in the Village MWS well field, indicates that the cone of influence does not extend that far to the north.

As illustrated in Figure 14, the drawdown in the Lacroix Well produced at 1000 minutes of pumping was 3.64 feet and reached a maximum of 5.94 feet after 72 hours. The 2017 aquifer test conducted by Arcadis on the Wysocki Farm (Arcadis, 2017) generally produced 5.5 to 9 feet of drawdown on the Wysocki property.[5] The total drawdown created by both wells running at the same rates used in both aquifer tests (i.e. 450 gpm and 300 gpm, respectively, for the LaCroix and Wysocki well) can be estimated by

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[5] The one exception was WF-OBS-02, which had approximately 60 feet of drawdown. However, this well is 8.1 feet from the extraction well, which exhibited approximately 65 feet of drawdown. These drawdowns in the pumping well and the observation well, WF-OBS-02, indicate that the pumping well was operating near its maximum flow rate, since Arcadis recommended a maximum drawdown in the test well of about 87 feet.

superimposing the drawdowns from each test upon each other. If one superimposes the two sets of drawdowns, the resultant drawdowns would be on the order of 13 to 15 feet. Given that there is more than 60 feet of available drawdown in the Lacroix well, it is evident that this well could be pumped at least at 500 gpm and probably at substantially higher rates without exceeding available drawdown limits in this well.

5.8 PROJECTED 180-DAY DRAWDOWNS

Although this aquifer test and the analysis of the data have been completed as part of a feasibility study, it could eventually be submitted to NYSDEC as part of a Water Withdrawal Application. NYSDEC has published guidance on "DEC Pumping Test Procedures" for Water Withdrawal Applications that, among other things, requires estimation of a 180-day projection of drawdown in any pumping wells that fail to reach a condition of stabilized drawdown during an aquifer test. Moreover, if more than one well is planned for a well field, well interference; that is, the superimposed drawdown from each well on the other wells, must also be taken into account. This section addresses projected 180-day drawdowns and well interference between the LaCroix and Wysocki pumping wells if both wells were pumping simultaneously.

In the 2017 aquifer testing of the Wysocki well (Arcadis, 2017) and in this aquifer testing of the LaCroix wells, drawdowns in both pumping wells and their respective observation wells indicate that the aquifer behaves as a semi-confined aquifer[6]. This is evidenced by leakage entering the aquifer and causing negative departures from drawdowns that would be expected if the aquifer were confined. In semi-confined aquifers, leakage increases as the cone of influence expands until eventually the amount of leakage balances the pumping rate of the well and further drawdown ceases. This condition is often referred to as "stabilized drawdown" or as a state of "equilibrium". Both the Wysocki well and the LaCroix well showed substantial evidence of leakage during their respective aquifer tests and were likely approaching a point of stabilized drawdown as shown in Figures 15 and 16. The drawdown in the LaCroix well is shown in Figure 15. It is evident from that figure that the rate of drawdown is diminishing over time as the drawdowns do not plot in a straight line on the semilogarithmic graph, as would be expected in a confined aquifer. Similarly, the drawdown in the Wysocki well illustrated in Figure 16 also does not plot on a straight line in a semi-logarithmic plot, but instead shows a significantly declining rate of drawdown and may well have reached a state of stabilized drawdown after 1000 minutes. For the purposes of calculating a projected drawdown after 180 days of pumping, we have plotted a trend line on each drawdown curve beginning at a time of 200 minutes and have extended that trendline out to a time of 180 days in order to project drawdown at that time. Given that both curves show diminishing rates of drawdown, this is a conservative approach because either well could reach a state of stabilized drawdown or equilibrium before 180 days.

In the analysis of the LaCroix well, the trendline projects 8.1 feet of drawdown after a pumping period of 180 days, as illustrated in Figure 15. The Wysocki well drawdown, illustrated in Figure 16, has a trendline that projects 70 feet of drawdown after a pumping period of 180 days. The disparity in the productivity of

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[6] All drawdowns from the 2017 Arcadis aquifer testing were degraphed from the figures presented in the 2017 Arcadis Report as we do not have electronic copies of the drawdown data.

these two wells is abundantly clear in these figures. The Wysocki well produces 64 feet of drawdown after 72 hours, with a pumping rate of 300 gallons per minute, which translates to a specific capacity 4.7 gallons per minute per foot of drawdown (gpm/ft). In contrast, the LaCroix well produces less than 7 feet of drawdown after 72 hours while pumping 450 gallons per minute. The specific capacity of the LaCroix well is approximately 64 gpm/ft, which is more than 13 times the specific capacity of the Wysocki well. The above calculations indicate that, operated independently, the Wysocki well would have a 180-day drawdown of approximately 70 feet and the LaCroix well would have a projected 180-day drawdown of approximately 8.1 feet.

Estimation of Well Interference with the LaCroix and Wysocki Wells Operating at the Aquifer Testing Pumping Rates

If both wells are operating simultaneously at the aquifer test pumping rates, the cones of influence will overlap, producing additional drawdown in each pumping well. The amount of superimposed drawdown can be calculated based upon the results of the aquifer testing. The calculation of 180-day projected drawdown from the LaCroix well on the Wysocki well is relatively easy because drawdowns in the Wysocki observation wells were also measured during the 2019 LaCroix aquifer test. In fact, one of the observation wells, WF-OBS-02, is within 8 feet of the Wysocki well. The distance between the LaCroix well and WF-OBS-02 is approximately 705 feet as shown on Figure 4 of this report. Therefore, drawdown in WF-OBS-02 serves as a good surrogate for drawdown in the Wysocki production well. However, the analysis of 180-day projected drawdown at the LaCroix well due to the simultaneous pumping of the Wysocki well is a bit more difficult because at the time of the Wysocki well pumping test in 2017, the LaCroix test well and the observation wells associated with the 2019 LaCroix well test were not yet constructed. Nonetheless, the estimated 180-day superimposed drawdown from the Wysocki well at the Lacroix well can be reasonably well estimated from drawdown measured in the Wysocki observation wells during the Wysocki aquifer test.

We will begin with an analysis of the superimposed drawdown on the Wysocki well from the LaCroix well at a pumping period of 180 days.

Superimposed Drawdown on the Wysocki Well from Pumping of the LaCroix Well for 180-Days

During the 2019 aquifer test of the LaCroix well, drawdown was measured in WF-OBS-2, which as discussed above, is situated very close the Wysocki production well. They are both approximately 705 feet from the LaCroix well. The drawdown observed during the 2019 aquifer test of the LaCroix well in WF-OBS-2 is shown on Figure 17. This figure shows a semi-logarithmic plot of drawdown observed in WF-OBS-2 with a trendline fitting the data from 200 minutes to the conclusion of the 72-hour test and extrapolating that trendline out to 180 days. It shows that the projected drawdown in WF-OBS-02 from pumping of the LaCroix well at 450 gpm after a pumping period of 180-days is approximately 6.8 feet.

Superimposed Drawdown on the LaCroix Well from Pumping of the Wysocki Well for 180-Days

As mentioned above, the LaCroix well is approximately 705 feet from the Wysocki aquifer test pumping well, PW-01. However, the LaCroix well had not yet been constructed at the time of the Wysocki aquifer test in 2017. There were, however, two Wysocki observation wells at distances bracketing the distance of the LaCroix well from the Wysocki well. These are WF-OBS 3 and WF-OBS-04 that are at distances of 415.2 and 840.24 feet, respectively, from the Wysocki pumping well, PW-1. The projected 180-day drawdowns in these wells should allow for a reasonable estimate to be made of the 180-day drawdown to be expected in the LaCroix pumping well. As shown in Figures 18 and 19, the 180-day projected drawdowns in these two observation wells, using the same trendline method described earlier, are 12.74 feet and 12.71 feet, respectively. We can, therefore, estimate that the 180-day superimposed drawdown at the LaCroix well from the Wysocki well pumping at 300 gpm would be approximately 13 feet.

Total Estimated 180-Day Drawdowns in the LaCroix and Wysocki Pumping Wells During Simultaneous Operation

Figure 20 shows side by side schematics of Wysocki Well, PW-1, and the Lacroix Well showing their screen depths and lengths. Also depicted on this figure are the following:

- Approximate static water levels;
- 180-day projected drawdowns in each well when they are pumping independently at the aquifer test pumping rates of 300 gpm and 450 gpm;
- 180-day projected superimposed drawdowns from the LaCroix Well on the Wysocki well and from the Wysocki Well on the LaCroix Well;
- The total projected 180-day drawdown in each well with both wells pumping at the aquifer test pumping rates of 300 gpm and 450 gpm;
- The approximate maximum allowable drawdown in each well, which is assumed to be 12 feet above the top of the well screens (five feet from the top of the well screen to the base of the pump intake, a two-foot long pump intake, and five feet from the top of the pump intake to the water surface in the well); and
- The amount of addition available drawdown in each well, which equals the difference between the total projected 180-day drawdowns with both wells operating at the aquifer test flow rates and the maximum allowable drawdowns.

As illustrated in Figure 20, with both wells operating simultaneously at their respective aquifer testing pumping rates, the total drawdown in the Wysocki Well is 87.8 feet, while the maximum allowable drawdown is assumed to be 106 feet. This leaves 18.2 feet of additional available drawdown in the Wysocki Well. Under the same pumping conditions, the total drawdown in the LaCroix Well is 29.1 feet, while the maximum allowable drawdown is assumed to be 63 feet. This leaves 33.9 feet of additional available drawdown in the LaCroix Well.

6.0 ANALYSIS OF AQUIFER RECHARGE

The analysis of the pumping test data indicate that the LaCroix test well can be pumped at a rate of at least 450 gpm with a drawdown of less than 6 feet. A greater well yield is likely possible. To estimate the yield of the aquifer relative to its ability to support long term withdrawals, an analysis of potential groundwater recharge was performed.

Based on other studies (Morrissey, et. al.; 1987 and Miller, et. al.; 1998) recharge to stratified drift and gravel aquifers likely comes from several sources:

1. Infiltration directly into the aquifer where the confining unit is absent
2. Infiltration from upland drainage areas that occurs along the margins of the valley or seepage from underlying areas of bedrock
3. Seepage loss from upland tributary streams

Other potential sources of recharge include induced recharge from the Hoosic River associated with pumping and leakage through the confining units.

A first order estimate of available recharge was made by developing a water budget for the drainage area that likely contributes groundwater recharge to the semi-confined aquifer that is tapped by the LaCroix Well. A water budget can be constructed at varying levels of detail, considering seasonal changes in precipitation and evapotranspiration, variation in land cover, and a host of other variables. This water budget is based on long term annual mean values. The water budget equation is:

$$R = P - (ET + RO)$$

where:

R = groundwater recharge
P = mean annual precipitation
ET = mean annual evapotranspiration
RO = runoff

According to the National Weather Service, for the period 1981 to 2010, in Bennington VT, the average annual precipitation was 40.70 inches. Using the Glens Falls, NY records, the average annual precipitation was 39.06 inches. For purposes of our analysis, we have assumed 40 inches for the Hoosick Falls area.

Based on work by Sanford and Selnick (2012), the annual average evapotranspiration for Rensselaer County has been estimated to range between 40 to 49% of the annual precipitation (equivalent to 16 to 19.6 inches per year). In the same paper, they estimate the annual amount of evapotranspiration is 51-60 cm/year (equivalent to 20.1 to 23.6 inches/year). These estimates were made using streamflow data and assuming there is no significant change in groundwater storage. For the purposes of our analysis, we assumed a conservative value of 22 inches of water is lost to evapotranspiration.

The balance of the water budget consists of runoff directed to channeled streams and rivers, and/or water that is available to recharge the aquifer. For a simple unconfined aquifer, all runoff may eventually recharge the aquifer. However, given the presence of a thick confining unit over portions of the Hoosic Valley (see Figures 5 and 6), some water may be intercepted and flow to the river and therefore will not recharge the deeper semi-confined aquifer. This area has been subtracted from the total contributing area.

To be conservative, we have assumed that 50% of the remaining water (after evapotranspiration) is runoff that never reaches the semi-confined deeper aquifer. Additionally, we subtracted any area where the confining clay is present at depth from the total contributing area.

To determine the contributing area for the LaCroix well, the topographic divides on the western and eastern sides of the Hoosick Valley were identified to delineate a sub-basin of the Hoosic River watershed. Randall and others (1988) noted that "the water-table configuration in uplands nearly replicates topography throughout the region". Note that the groundwater flow system in the bedrock may not be entirely limited to this area if the tributaries in the sub-basin do not act as fully penetrating hydraulic boundaries. The northern boundary generally followed topographic divides but cuts across the valley south of the Village of Hoosick Falls. The southern boundary also generally follows topographic divides but cuts across the valley north of Route 7 (see Figure 15). This results in a total effective contributing area of 2,354 acres.

As can be observed, using a number of conservative factors, there is almost 700 million gallons of groundwater recharge occurring annually or 1.7 times the proposed maximum daily demand

Average Annual Recharge Available to Semi-Confined Aquifer

Watershed Area (ac)	Area of Confining Unit (ac)	Total Contributing Area (ac)	Mean Annual Rainfall (in)	Annual Average ET (in)	Annual Runoff (in)	Annual Available Recharge (in)	Annual Recharge (gal)
3,710	874	2,836	40	22.0	9.0	9.0	693,037,858

7.0 CONCLUSIONS AND RECOMMENDATIONS

The findings of this hydrogeologic investigation can be summarized as follows:

1. The LaCroix well was successfully tested at 450 gpm with a little less than 6 feet of drawdown
2. It is evident from the time-drawdown plots of drawdown in the aquifer that the aquifer behaves as a “semi-confined” (or “leaky artesian”) aquifer. This aquifer is also a buried valley aquifer bounded on two sides by valley walls composed of lower-permeability rock.
3. The transmissivity and storativity of the aquifer were determined from early-time, Theis, time-drawdown analyses to be 9,880 ft^2/day and 1.8×10^{-4}, respectively. The transmissivity of the aquifer was corroborated by a Cooper-Jacob analysis of early-time drawdown in the pumping well.
4. Given the average effective thickness of the high K, gravel and sand subunit of the aquifer of approximately 18 feet, the above-estimated transmissivity and storativity translate to a horizontal hydraulic conductivity of 548 ft/day and a specific storage of 1.0×10^{-5} ft^{-1}. Both values are consistent with the expected hydraulic conductivity and specific storage of the dense, gravels and sands comprising the high K subunit of this aquifer.
5. The cyclical pumping of Well #7 located at the Village MWS creates cyclical drawdown and recovery in water levels in many wells near and to the north of the Village MWS, as shown in Attachment 5. These water level fluctuations in monitoring wells have been used in the past to calculate directional hydraulic conductivities in the deep glacial aquifer. However, no monitoring wells in the vicinity of the LaCroix well exhibited any perceptible fluctuations associated with Village Well #7.
6. Similarly, none of the wells up near the Village well field and wells further to the north show any influence from the 72-hour aquifer test conducted on the LaCroix well.
7. The fact that no perceptible influence is observed in the vicinity of the LaCroix well from the intermittent pumping of Village Well #7 and, similarly, no influence is observed in the Village well field area and further to the north from the 72-hour aquifer test on the LaCroix well is likely attributable to two factors:
    a. The glaciolacustrine clay is known to thin or be absent in the area just south of Village Well #7 and may well also be absent further to the south of the well field. In these areas, the absence of glaciolacustrine clay would mean that the aquifer in these areas becomes unconfined, rather than semi-confined. Propagation of drawdown would tend to stall in unconfined portions of the aquifer as the hydraulic diffusivity[7] of unconfined portions of the aquifer would be substantially lower in magnitude than the semi-confined portions of the aquifer.
    b. The village well field and the LaCroix well are nearly a mile apart.
8. Although monitoring wells in the vicinity of the LaCroix well do not show any influence from the cyclical pumping of Village Well #7, some wells do show intermittent, short-lived, drawdown and recovery cycles two or three times a day, which is likely attributable to the high school well. The magnitude of the intermittent drawdown observed in these wells is quite small, usually varying between 0.7 and 0.05 feet. The wells that exhibit this intermittent drawdown are GWI-02, WF-

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[7] Hydraulic diffusivity is defined as the ratio of Transmissivity/Storativity (T/S) and controls the rate of drawdown or recovery propagation through geologic media. Given that the storativity of the semi-confined aquifer has been defined as approximately 1×10^{-4} and the storativity (or specific yield) of an unconfined portion of this aquifer would likely be on the order of 0.1, the hydraulic diffusivity of the unconfined portions of this aquifer could be approximately 1,000 times lower than the hydraulic diffusivity of the semi-confined portions of the same aquifer.

OBS-01, WF-OBS-02, WF-OBS-03, and WF-OBS-04. The likelihood that these intermittent drawdowns are attributable to the high school well is supported by the fact that the magnitude of the drawdown generally decreases from west to east, away from the high school well.

9. The approximate maximum allowable drawdown in each well is assumed to be 12 feet above the top of the well screens. The projected 180-day drawdowns for both the Wysocki well and the LaCroix well are 87.8 feet and 29.1 feet, respectively with both wells pumping together. Under this scenario, the Wysocki well still has >18 feet of available drawdown and the LaCroix well has almost 34 feet of drawdown.

10. Most of the broad spectrum NYSDOH Part 5 parameters were reported as "non-detect" in the monitoring well samples. The only analytes detected at concentrations exceeding their respective comparison values were inorganic constituents detected in a single well, except for iron, manganese and sodium, which were more commonly detected in multiple wells. In addition, low levels of PFAS were detected as follows:

    - Perfluorooctanoic acid (PFOA): (ND to 38 ng/L);
    - Perfluorobutanoic Acid (PFBA): (ND to 3.0 ng/L);
    - Perfluorooctanesulfonic acid (PFOS): (ND to 0.9 ng/L);
    - Sodium 1H,1H,2H,2H-Perfluorooctane Sulfonate (6:2): (ND to 41 ng/L);
    - Perfluorohexanoic acid (PFHxA): (ND to 2.1 ng/L); and
    - Perfluorononanoic acid (PFNA): (ND to 0.46 ng/L).

    The highest detected concentrations of PFAS (PFOA and Sodium 1H,1H,2H,2H-Perfluorooctane Sulfonate 6:2) were found in well GWI-3 in May 2019. However, earlier sampling of this well in September and November 2018 found much lower concentrations of these compounds.

11. Water quality testing for NYSDOH Part 5 parameters in the LaCroix test well indicates that only sodium and manganese exceed groundwater standards, but only marginally. No PFAS were detected.

12. An evaluation of the potential hydrologic connection between the Hoosic River and the semi-confined aquifer does not indicate that groundwater is under the direct influence of surface water, but the NYSDOH makes the final determination.

13. A first order estimate of potential groundwater recharge to the semi-confined aquifer indicates that, even under conservative assumptions, there is more than adequate recharge to support the long-term extraction of groundwater.

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