Hydrogeologic Investigation Report

Highlander Solar Project
Spotsylvania County, Virginia

September 26, 2018

Terracon Project No. EY18P057

Prepared for:

S·POWER
An AES and AIMCo Company
Salt Lake City, Utah

Prepared by:

Terracon Consultants, Inc.
Germantown, Maryland

September 26, 2018

S•POWER
Sustainable Power Group
2180 South 1300 East, Suite 600
Salt Lake City, Utah 84106

Attn: Mr. Daniel Menahem
Sr. Manager, Project Management

Re: Hydrogeologic Investigation Report
Highlander Solar Project
Spotsylvania County, Virginia
Terracon Project No. EY18P057

Dear Mr. Menahem:

Terracon Consultants, Inc. (Terracon) appreciates the opportunity to submit this summary report of the results of our Hydrogeologic Investigation for the above referenced site. This report describes the exploration and installation of four test wells, as well as 72-hour pump testing of three of the wells. A Fracture Trace Analysis and Geophysical Survey Report conducted earlier this year to assist in identifying potential test well sites is attached as an Appendix.

We appreciate the opportunity to provide this report and our continued services for you on this project. Please call the undersigned if you have any questions or comments regarding this report.

Sincerely,
Terracon Consultants, Inc.

Stewart Dixon, P.G.
Senior Hydrogeologist

Eric B. Rehwoldt, P.E., P.G.
Senior Principal | Regional Manager

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1.0 INTRODUCTION

Terracon has completed a hydrogeologic investigation of four potential production water well sites selected for additional investigation as the result of the findings of our report titled, Fracture Trace Analysis and Geophysical Survey Report, dated May 29, 2018 (Appendix D). This work was undertaken to determine if the fractured rock aquifer at the selected well sites is capable of meeting the water supply needs of the 500 MW ac photovoltaic solar facility during construction, operation, and maintenance; and to estimate the area of influence of the completed wells.

The proposed 500 MW ac photovoltaic solar facility will need up to 400,000 gallons of water per day for construction, operation, and maintenance. At least four production wells (70 gallons per minute/well) are estimated to be needed for water supply during construction. Two wells will be abandoned in place after construction is complete and two wells will remain in use for long-term operations. Terracon assumes the wells are not intended for use as drinking water sources; however, all of the wells were permitted and constructed to meet the Class IIIB drinking water source requirements (Virginia Administrative Code 12VAC5-630). Copies of the well construction permits are included in Appendix B.

1.1 Site Description

The site is located in Spotsylvania County, Virginia approximately three miles east of Mine Run. The latitude and longitude for the approximate center of the site is 38.24959°, -77.78346°, respectively. The site covers approximately 3,500 acres as shown in Figure 1.

1.2 Scope of Services

1.2.1 Water Well Site Selection

In order to identify test well locations with the greatest potential to achieve the desired target well capacity, a fracture trace analysis and geophysical survey was performed to identify possible water-bearing bedrock fractures in advance of test well drilling. Results of this study are provided in the referenced report dated May 29, 2018 (Appendix D). The scope of work for the fracture trace analysis and geophysical survey phase of the project included the following tasks:

- Perform a fracture trace analysis,
- Perform a geophysical survey of select locations based on the fracture trace analysis, and
- Recommend potential test well locations based on the results of the study

Based on the results of the fracture trace analysis and geophysical survey, a total of eight locations were chosen as candidates for potential water well drill sites based on the presence of anomalies consistent with water saturated fractured bedrock. Although more ERI survey lines with potential fractures were identified, the potential drill sites were chosen based on the length of potentially exploitable fractured rock. The potential drill sites are as follows:

- ERS-2 – approximately 300 feet north northwest of ERS-2 center point;
- ERS-3 – approximately 330 feet northwest of ERS-3 center point;
- ERS-7 – at ERS-7 center point;
- ERS-9 – at ERS-9 center point;
- ERS-8 – approximately 300 feet north of ERS-8 center point,
- ERS-10 – approximately 165 feet southeast of ERS-10 center point,
- ERS-12 – possible two targets, approximately 60 southwest of center point and approximately 135 northeast of center point; and
- ERS-14 – approximately 120 feet northwest of ERS-14 center point.

Based on the discussions with the client concerning locations of preferred well sites with respect to the proposed site construction, the eight initial potential drill sites were reduced to four preferred locations. The locations of these preferred drill sites are listed in the following table and shown on Figure 1. The potential drill sites were ranked based on the greatest potential of encountering water bearing fractures with 1 being the highest potential.

Table 1: Potential water well drill sites with recommended and maximum drill depths based on the Fracture Trace Analysis and Geophysical Survey.

Site Ranking	ERS Station Number	Latitude	Longitude	Target Total Depth (Feet, BGS)	Maximum Total Depth (Feet, BGS)
1	ERS-12	38.203765° N	77.798901° W	270 to 300	600
2	ERS-9	38.234053° N	77.754651° W	270 to 300	600
3	ER-7	38.229065° N	77.790210° W	270 to 300	600
4	ER-3	38.251447° N	77.765146° W	270 to 300	600

Based on conversations with local drillers and local landowners, we understand that the highest yielding wells in the area are approximately 270 feet deep. Other wells in the area are as deep as 600 feet; however, the yield of these deeper wells is an order of magnitude less than wells in the 270-foot range. Therefore, the recommended target well depth of between 270 feet to 300 feet depending was chosen with the final well depth dependent upon aquifer yield observed during drilling.

During well installation, casing depth at each location was determined in the field based on drilling observations and the depth at which competent bedrock was encountered at each drill site. A Terracon geologist was on-site during all drilling operations to install test wells and related monitoring wells at the four selected sites, as well as during pump testing of three of the test wells (ERS-3, ERS-7, and ERS-9). The drilling observations and testing were conducted in general accordance with the procedures outlined in Terracon's Proposal No. PEY185011, dated March 2, 2018.

1.3 Geologic Overview

1.3.1 Regional Geologic Conditions

Based our review of local geologic and hydrogeologic maps and reports, the project site is underlain by rocks of the Mine Run Complex (Ordovician and/or Cambrian) (Mixon et al., 2000) labeled as OCml-IV in Figure 2. The Mine Run Complex consists of melange deposits which has a metasedimentary matrix in which sparse to abundant metamorphosed rock fragments and exotic blocks of varied composition are embedded. The Mine Run Complex is a block-in-phyllite (small to large rock fragments enclosed in a matrix of phyllite or schist). The melange is interpreted as having formed in a back-arc basin between the continental margin to the west and an island arc to the east. In fresh outcrop, the matrix of the rocks of the four thrust slices are various shades of gray or green and many of the matrix rocks are metagrawackes.

The block-in-phyllite melange of the Mine Run Complex is considered to be an olistostromal-tectonic melange that occurs in four imbricated thrust slices (numbered I through IV from east to west) (Mixon et al., 2000). Each thrust slice has its own characteristic exotic-block assemblage. The two easternmost thrust slices (melange zones I [OCml] and II [OCmll]) contain blocks of metavolcanic and granitoid rocks that are petrographically similar to rocks within the Chopawamsic Formation (Cc) to the east. The exotic blocks of these melanges are interpreted as fragments shed from the metamorphosed and deformed Chopawamsic Formation as it was thrust onto the accumulating sediments of the Mine Run Complex. Melange zone III (OCmlll) contains metamorphosed mafic and ultramafic blocks, interpreted as fragments of the back-arc basin ocean floor, that were derived from various sources such as ultramafic protrusions or talus rubble along steep submarine scarps (Pavlides, 1989). Melange zone IV (OCmiV) lacks exotic material in the map area but contains mafic and ultramafic blocks along strike to the southwest.

Large-scale folds in the melange deposits (OCmi-IV) are difficult to detect due to lack of marker beds and inadequate exposure (Mixon et al., 2000). The matrix rocks of the melange deposits, however, have a well-developed phyllitic foliation that locally is axial planar to small folds. The phyllitic foliation in the project area has a general northeast trend and steeply dipping (>60° to vertical).

The Chopawamsic thrust fault bounds the project site to the east, west, and south is interpreted to be a thrust that moved the island-arc terrane westward and northward onto the melanges of the Mine Run Complex. The fault is marked at a number of places by steeply dipping mylonite. The fault attitude may be related to an original listric nature, or deformation after thrusting, or both. Because of poor exposure, direct evidence for the continuity of the fault is sparse.

As previously discussed, the Mine Run Complex, which forms the bedrock of the site, lies between the Mountain Run fault zone and the Chopawamsic thrust fault, is interpreted as a collage of four thrust slices containing melange deposits. The thrusts within the Mine Run Complex are based on sparse, widely separated physical evidence, such as isolated outcrops of mylonite. Some of the postulated thrust slices of melange, however, are characterized locally by aeromagnetic map patterns and each has a unique assemblage of exotic blocks that distinguishes one thrust slice from another (Pavlides, 1989). Scattered outcrops of mylonite within some of the thrust slices suggest internal faults but poor exposure and lack of marker beds preclude tracing them.

1.3.2 Local Geologic Conditions

Based the recent drilling activities conducted at each the potential water well site, the fractured rock aquifer consists primarily of a matrix of dark gray, black and dark olive green schist, with some zones of phyllite. The water bearing zones appear to be associated fractures filled with white quartz, as indicated by an increase in the amount of white quartz minerals returned to the surfaced during drilling within zones of observed increased water flow. Typically, the lithology of the overburden soils consisted of silts (elastic and non-elastic), lean clays, and varying amounts of sand sized weathered rock fragments. The depth to bedrock varied from as shallow as 27.5 feet below ground surface (bgs) at ERS-7 to approximately 160 feet bgs at ERS-12. A more detail description of the soil and rock units encountered and depth to bedrock shown on the well logs included in Appendix C.

1.4 Well Construction Permits

In accordance with 12VAC5-630-230 (Procedures for Obtaining a Construction Permit for a Private Well), well construction permits were submitted by the selected water well contractor (Northern Virginia Drilling Company) on behalf of the client to the Spotsylvania County Health Department.

Permit documentation for all four proposed well locations were submitted to the Spotsylvania County Health Department as well as supporting documentation indicating that each well will be constructed to Class IIIB standards. As each well was permitted as a Class IIIB well, a minimum 50-foot radius buffer will need to be maintained around each of the wells so that no pesticides/herbicides will be applied, nor any potential source of contamination will be constructed within 50 feet of each Class IIIB well. Also, each Class IIIB well was permitted such that the well will supply either less than 25 persons or a structure with a building occupancy of less than 25 persons. Copies of the well construction permits are included in Appendix B.

2.0 HYDROGEOLOGIC INVESTIGATION

2.1 Test Well Drilling

Terracon contracted with Northern Virginia Drilling, Inc. (NOVA) to drill and construct the test wells as well as provide support during the aquifer performance test portion of the project. In addition to the construction of the test production wells, two observation wells (MW-1 and MW-2) were constructed at ERS-7 to be used to monitor water level response during the aquifer performance testing.

The following paragraphs and sections generally describe the well construction details of each test well. The sections below describe the equipment used in the drilling of the borehole, drilling method, casing installation, grouting method, well development, aquifer performance testing, and calculation of aquifer and well hydraulic properties with a discussion of radius of influence of each well.

2.1.1 Drilling Rig and Method

During the drilling program at the site, multiple drill rigs were used to complete the drilling and installation of the test water wells and observation wells. Drilltech 25K top head drive straight circulation rigs with 4 $^{1}/_{2}$ inch IF drill stem were used at the project site. The boreholes were drilled using the direct (straight) rotary air-hammer method using air as the primary drilling “fluid”. Water and/or NSF approved drill foam were used necessary to help flush the cuttings from the borehole. In direct rotary air-hammer drilling, air is injected down through the drill pipe into and out of the hammer and bit to activate the hammer; the air and water (added water and/or formation) then flows upward in the annular space between the hole and drill pipe, carrying the cuttings to the surface. Once at the surface, water and cuttings are deposited around the borehole for collection. All materials used during drilling of the test water well met the applicable NSF standards.

The specific drilling and well completion activities will be discussed in the following paragraphs in the appropriate section for the task completed.

2.1.2 Nominal 12-Inch Borehole and 8-inch Casing Installation

At each well location, a nominal 12-inch borehole was drilled using a 12-inch air hammer bit until competent bedrock was encountered in order to set the 8-inch production casing. The borehole was cleaned out using straight circulation using air prior to removing all drill tooling from the borehole in preparation for installation of the nominal 8-inch carbon steel production casing.

New Schedule 40 carbon steel pipe with a nominal 8.625 inch outside diameter (O.D.) and a wall thickness of 0.322 inches meeting ASTM A53 specifications was installed as production casing at each well site. Generally, the top of the surface casing is approximately 1 to 2 feet above the ground surface. The casing depth at each well site is presented in Table 2 below.

Table 2: Summary test water well and observation well construction details.

Parameter	ERS-3	ERS-7	MW-1	MW-2	ERS-9	ERS-12	ERS-12A
Cased Borehole Size (Inches)	12	12	8	8	12	12	12
Nominal Casing Size (Inches)	8	8	6	6	8	8	8
Casing Depth (Feet, bgs)	71	51	40	59	91	158	105
Casing Pipe Schedule	40	40	40	40	40	40	40
Casing Wall Thickness (Inches)	0.322	0.322	0.280	0.280	0.322	0.322	0.322
Grout Interval (Feet, bgs)	0 – 70	0 – 51	0 – 40	0 – 59	0 – 91	--	0 – 105
Grout Type	Cement	Cement	Bentonite	Bentonite	Cement	Cement	Cement
Open Borehole Size (Inches)	8	8	6	6	8	--	8
Total Well Depth (Feet, bgs)	306	600	300	300	350	158	600

*Casing and borehole size are presented in nominal sizes. Borehole and cased depths are reported from top of ground surface at the time of construction. ERS-12 was abandoned, offset/redrilled as ERS-12A because of borehole caving problems.

The nominal 8-inch production casing was joined together by field welding at each well site.

2.1.3 Grout

After the well casing was welded and installed, 1-inch PVC tremie pipe was installed in the annulus between borehole and casing in preparation of pumping grout. Portland cement (neat cement) conforming to ASTM C 150 Type I or II was used during grouting operations for each of the test production wells. The neat cement grout was pumped down the tremie pipe, which was installed in the annulus between the casing and borehole wall. Approximately 5.5 gallons of water was added to each 94-lbs bag of neat cement. Visible grout returns were observed flowing out of the annulus of the casing and borehole. The two observation/monitoring wells were grouted using a high solids bentonite grout and granular bentonite (e.g., benseal).

2.1.4 Nominal 8-inch Borehole Drilling

An air hammer with a nominal 8-inch bit was used to drill each test production well, while the monitoring wells were completed using a 6-inch bit.

The final completion depth of each test well borehole was determined based on the anticipated volume of water each well was expected to produce. During drilling of the test production wells, a Terracon geologist and/or engineer was present to document the lithology encountered, location of potential fractures, location of encountered water-bearing zones, and to conduct field tests of these water-bearing zones to determine anticipated well yield. These field tests included using a graduated 5-gallon bucket to periodically check well yield based on the amount of water being discharged drill the drilling activities. These yield tests were the basis for determining how deep each individual well/borehole would be drilled.

The yield tests completed during drilling ERS-7 and ERS-12 were each drilled a depth of 600 feet because the anticipated yield was less than or at the target rate of 70 gpm. The yield tests completed at ERS-3 and ERS-9 indicated the possibility of each well producing in excess of 70 gpm prior to reaching the total maximum depth of 600 feet. Therefore, these wells, ERS-3 and ERS-9 were only drilled to 305 feet and 350 feet, respectively.

All water wells (production and/or observation) drilled on-site were be constructed in accordance with applicable local and Commonwealth of Virginia regulations by Northern Virginia Drilling, Inc., a certified/licensed water well professional.

3.0 WELL DEVELOPMENT AND AQUIFER PERFORMANCE TESTING

Upon completion of the drilling activities at each well site and monitoring well site, the wells were developed using air-lift methods until each well produces relatively clear water free from visible sediment.

3.1 Constant Rate Test

Terracon conducted a 72-hour constant rate aquifer performance test at each of the test production wells. A step drawdown test was originally planned to be performed at each well. However, in an effort to accelerate the field schedule, a stand-alone step test was not conducted. The pumping rates used at each well site were determined by monitoring discharge rate and depth to water during the first 8 hours of the constant rate test.

Water levels in the pumping well and any monitoring wells in the vicinity were monitored using an In-situ LevelTroll 700 data logging pressure transducer. Also, a pressure transducer dedicated to monitor barometric pressure changes during the entire aquifer performance testing period was be deployed at the project site. In addition to the time and drawdown (depth to water level) measurements, pumping rate data was collected throughout the pumping phase of the test.

Any additional factors affecting the quality of the well testing data were recorded, including but not limited to; precipitation events, changes in barometric pressure, mechanical breakdown, and other factors as appropriate. When the pumping portion of the test was stopped, the water level in the pumping well and available water level monitoring wells were allowed to recover for at least one day prior to removing the transducers.

Observation well data was collected during the constant rate tests conducted at ERS-7 using the monitoring wells installed as part of this project labeled as MW-1 and MW-2 (See Figure 15). Also, an existing domestic supply well identified as MWW was used as a monitoring well during the test conducted at ERS-3 (See Figure 11). No observation well data was available for the constant rate test conducted at ERS-9. After consultation with the client, a constant rate test was not conducted at ERS-12A, as the pumping rate was expected to be in the range of about 25 gpm, which is less than half of the target rate of 70 gpm.

The depth to water data graphs from the aquifer performance tests conducted at ERS-3, ERS-7, and ERS-9 are presented in Figures 7 through 18.

3.2 Aquifer Performance Test Data Analysis

The depth to water and discharge rate data collected during both the step-drawdown and constant rate aquifer performance tests were analyzed to calculate aquifer properties and well performance properties. The calculated aquifer properties and aquifer test water level data was used to determine the potential radius of influence of each test well. The following sections discuss the results of the constant rate test completed at each test well location.

3.2.1 ERS-3

ERS-3 was drilled to a depth of 306 feet below ground surface and constructed with 8-inch casing set to a depth of 71 feet. Testing during drilling indicated that ERS-3 was capable of producing in excess of 100 gpm. The aquifer performance test at ERS-3 was started on September 4, 2018. The water level data collected during the testing is presented in Figures 7, 8, and 9. The initial pumping rate was set at approximately 165 gpm. However, on September 5, 2018, the discharge rate was reduced to 135 gpm after the water level had declined to new the depth of the pump intake. The pumping rate remained set at 135 gpm until the pumping phase ended on September 7, 2018.

In addition to the collecting water level data from ERS-3, water level data was collected from an existing domestic water supply well located 1,565 feet north of ERS-3 and identified as MWW. Water level data collection from MWW began on September 5, 2018 after receiving permission from the well/land owner. MWW was also being used to supply a residence on-site during the test; therefore, the pump at MWW would periodically turn on to supply water to the residence. The times the pump in MWW would turn on and off can be seen in Figures 7, 8, and 9 as short duration water level changes.

Once the pumping phase of the test at the ERS-3 site ended on September 7, 2018, water level recovery data was collected until September 10, 2018 in both ERS-3 and MWW.

The following is a summary of the water level and field water quality data collected from ERS-3 during the constant rate test:

ERS-3 Water Level Data

- Discharge Rate: 135 gpm
- Static Water Level: 26.74 feet
- Pumping Water Level: 180.48 feet
- Drawdown: 153.74 feet

- **MWW Water Level Data**
- Starting Water Level: 57.81 feet
- Pumping Water Level: 64.34 feet
- Drawdown: 6.53 feet

The specific capacity of a well is defined as the yield per unit of drawdown, generally expressed in gallons per minute per foot (gpm/ft). Specific capacity is chiefly related to the transmissivity of the aquifer with the aquifer storage coefficient, well efficiency of the well, pumping time, and discharge rate having important influences (Driscoll, 1986; Newcome, 1993; Fetter, 1994). Specific capacity from the 72-hour pump test data for ERS-3 is 0.87 gpm/ft.

The final drawdown readings from ERS-3 and MWW was used to calculate the hydraulic conductivity of the fractured rock aquifer system in area of ERS-3 using the distance-drawdown method as shown in Figure 10. Using the distance-drawdown data results in a hydraulic conductivity of one foot/day and a transmissivity of 240 ft^2/day.

To verify the hydraulic conductivity value calculated from the distance-drawdown method and as a way to model the radius of influence, the aquifer test data analysis software program AquiferWin32 was used to simulate the aquifer test conducted at ERS-3. The simulation was run using the Moench (1984) fracture aquifer solution for both the tested pumping rate of 135 gpm as well as the project target rate of 70 gpm. The simulated drawdown in both ERS-3 and MWW is presented in Figure 9 for 135 gpm and 70 gpm. The hydraulic conductivity value used in the simulation was 1.1 ft/day with a storativity of 4.0×10^{-7} (dimensionless). The simulated drawdown curve for ERS-3 and MWW at 135 gpm matches the observed data fairly well as is a reasonable fit to the data. The projected radius of influence at 135 gpm and 70 gpm are presented in Figure 11 and indicated an impact less than 10 feet at approximately 3,900 ft at 135 gpm, and less than 3,000 ft at 70 gpm.

3.2.2 ERS-7

ERS-7 was drilled to a depth of 600 feet below ground surface and constructed with 8-inch casing set to a depth of 51 feet. Testing during drilling indicated that ERS-7 was capable of producing at least 70 gpm. The aquifer performance test at ERS-7 was started on August 30, 2018. The water level data collected during the testing is presented in Figures 12 and 13. The pumping rate was stabilized at approximately 73 gpm. During the later portion of the test, the flowmeter began to malfunction and the discharge rate was verified using a graduated 5-gallon bucket and a stop watch and appeared to maintain at approximately 73 gpm.

In addition to the collecting water level data from ERS-7, water level data was collected from two observation wells denoted as MW-1 and MW-2 and installed within 100 feet of ERS-7 as shown in Figure 15. These observation wells each were drilled to a total depth of 300 feet.

Once the pumping phase of the test at the ERS-3 site ended on September 7, 2018, water level recovery data was collected until September 10, 2018 in both ERS-3 and MWW.

The following is a summary of the water level and field water quality data collected from ERS-7 during the constant rate test:

ERS-7 Water Level Data

- Average Discharge Rate: 73 gpm
- Static Water Level: 0.5 feet
- Pumping Water Level: 398.74 feet
- Drawdown: 398.24 feet

- **MW-1 Water Level Data**
- Starting Water Level: -3.72 feet (i.e., 3.72 feet above ground surface)
- Pumping Water Level: 153.02 feet
- Drawdown: 156.74 feet

- **MW-2 Water Level Data**
- Starting Water Level: 8.84 feet
- Pumping Water Level: 166.18 feet
- Drawdown: 157.34 feet

The specific capacity of a well is defined as the yield per unit of drawdown, generally expressed in gallons per minute per foot (gpm/ft). Specific capacity from the 72-hour pump test data for ERS-7 is 0.18 gpm/ft.

The final drawdown data from ERS-7, MW-1, and MW-2 were used to calculate the hydraulic conductivity of the fractured rock aquifer system in area of ERS-7 using the distance-drawdown method as shown in Figure 14. Using the distance-drawdown data results in a hydraulic conductivity of 0.079 ft/day and a transmissivity of 43 ft^2/day.

As discussed previously, the aquifer test data analysis software program AquiferWin32 was used to simulate the aquifer test conducted at ERS-7 to verify the hydraulic conductivity value calculated and to model the radius of influence. The simulation was run using the Moench (1984) fracture aquifer solution for the tested pumping rate of 73 gpm. The simulated drawdown in ERS-7, MW-1, and MW-2 is presented in Figure 13. The hydraulic conductivity value used in the simulation was 0.099 ft/day with a storativity of 1.45×10^{-8} (dimensionless). The simulated drawdown curve for ERS-7 matches the observed data fairly well as is a reasonable fit to the data. The simulated drawdown curve for MW-1 and MW-2 slightly under predicts the drawdown compared to the observed data. The projected radius of influence is presented in Figure 15 and indicates an impact of less than 10 feet at approximately 4,500 ft, and greater than 10 feet at less than 2,200 feet.

3.2.3 ERS-9

ERS-9 was drilled to a depth of 350 feet below ground surface and constructed with 8-inch casing set to a depth of 91 feet. Testing during drilling indicated that ERS-9 was capable of producing in excess of 70 gpm. The aquifer performance test at ERS-9 was started on August 25, 2018. The water level data collected during the testing is presented in Figures 16 and 17. The pumping rate was stabilized at approximately 63 gpm. A pumping rate of 70 gpm was attempted; however, the water level declined to a depth of 340 feet, which was the setting depth of the pump. There were no observation wells available to collect water level data from at in the vicinity of ERS-7.

Once the pumping phase of the test at the ERS-9 site ended on August 28, 2018, water level recovery data was collected until August 29, 2018.

The following is a summary of the water level and field water quality data collected from ERS-9 during the constant rate test:

ERS-9 Water Level Data

- Average Discharge Rate: 63 gpm
- Static Water Level: 25.44 feet
- Pumping Water Level: 281.39 feet
- Drawdown: 255.95 feet

The specific capacity of a well is defined as the yield per unit of drawdown, generally expressed in gallons per minute per foot (gpm/ft). Specific capacity from the 72-hour pump test data for ERS-9 is 0.25 gpm/ft.

Drawdown and recovery data were used to calculate the hydraulic conductivity of the fractured rock aquifer system in area of ERS-9 using the Barker (1988) fractured aquifer with slab blocks solution method as shown in Figure 18, which results in a hydraulic conductivity of 0.373 ft/day and storativity of 7.68 x 10^{-8}.

As discussed previously, the aquifer test data analysis software program AquiferWin32 was used to simulate the aquifer test conducted at ERS-9 to verify the hydraulic conductivity value calculated and to model the radius of influence. The simulation was run using the Moench (1984) fracture aquifer solution for the tested pumping rate of 63 gpm as well as the project target rate of 70 gpm. The simulated drawdown in ERS-9, MW-1, and MW-2 is presented in Figure 17. The hydraulic conductivity value used in the simulation was 0.2955 ft/day with a storativity of 1.189 x 10^{-8} (dimensionless). The simulated drawdown curve for ERS-9 matches the observed data fairly well and is a reasonable fit to the data. As the ERS-9 does not contain monitoring/observation wells, two wells were simulated at 1,000 ft, and another well at 2,000 ft. The projected radius of influence is presented in Figure 19 and indicates an impact less than 10 feet at approximately 6,800 ft and greater than 10 feet at less than 3,300 feet.

3.2.4 ERS-12/12A

During the construction of ERS-12, the installed casing broke and ERS-12 subsequently was abandoned. ERS-12A was completed about 20 feet from the original ERS-12. ERS-12A was drilled to a depth of 600 feet below ground surface and constructed with 8-inch casing set to a depth of 105 feet. Testing during drilling indicated that ERS-12A was capable of producing no more than 25 gpm.

After consulting with our client, no aquifer performance test was conducted at the ERS-12A project site because the anticipated yield of 25 gpm was less than half of the target pumping rate of 70 gpm. Therefore, no aquifer performance and/or water quality testing was conducted at ERS-12A.

3.3 Water Quality Testing

At the end of each of the 72-hour aquifer performance tests, Terracon collected water quality samples from the each well for the following inorganic and physical parameters in the field and laboratory:

- Temperature,
- Dissolved oxygen,
- Iron,
- Manganese,
- Sulfate,
- Total dissolved solids,
- Alkalinity,
- Specific conductance (electrical conductivity),

- Total and fecal coliforms, and
- Silica (as SiO_2).

All groundwater samples were analyzed in the field for temperature, dissolved oxygen, specific conductance, and pH using an YSI 556 Multiparameter Meter, and turbidity using a LaMotte® Model 2020 Turbidimeter.

The results of both the field and laboratory analyses are summarized in Table 3 and the laboratory analytical data is included in Appendix E. All samples were logged on a chain of custody form, and placed on ice in an insulated cooler at the time of sampling. After completion of the sample collection activities, the sample coolers were shipped via overnight courier service directly to the Pace Analytical in Asheville, North Carolina (Virginia/VELAP Certification No. 460222) for analysis.

Table 3: Summary of Field and Laboratory Water Quality Data

Parameter	ERS-3	ERS-7	ERS-9	US EPA MCL and Secondary MCL
Date of Measurement	7 September 2018	4 September 2018	28 August 2018	--
Casing Depth	71 Ft bgs	51 Ft bgs	91 Ft bgs	--
Total Well Depth	306 Ft bgs	600 Ft bgs	350 Ft bgs	--
Discharge Rate	135 gpm	73 gpm	63 gpm	--
pH	7.72 s.u.	10.67 s.u.	7.27 s.u.	6.5 – 8.5*
Turbidity	1.02 NTU	4.58 NTU	1.53 NTU	5.0 NTU
Temperature	15.23° C	15.01° C	15.00° C	--
Dissolved Oxygen	3.95 mg/L	8.51 mg/L	4.94 mg/L	--
ORP	122.0 mV	109.2 mV	175.8 mV	--
Specific Conductance (field)	0.132 mS/cm	0.213 mS/cm	0.085 mS/cm	--
Specific Conductance (lab)	0.18 mS/cm	0.215 mS/com	0.085 mS/cm	--
Total Dissolved Solids	112 mg/L	122 mg/L	50.0 mg/L	500 mg/L*
Iron	0.18 mg/L	0.0852 mg/L J	3.74 mg/L	0.3 mg/L*
Manganese	0.114 mg/L	0.192 mg/L J	0.721 mg/L	0.05 mg/L*
Silica (as SiO_2)	14.1 mg/L	13.7 mg/L	15.8 mg/L	--
Sulfate	8.6 mg/L J	4.0 mg/L J	8.4 mg/L J	250 mg/L*
Total Coliform	NA	Present	Absent	Absent
Fecal Coliform	NA	Absent	Absent	Absent

*US EPA Secondary Water Quality Standard
mg/L = milligrams per liter
s.u. = Standard Units
mV = millivolts
mS/cm = millisiemens per centimeter
J = J-flagged laboratory result. Estimated value between the laboratory detection limit and the laboratory reporting limit.
NA = Not analyzed by the laboratory.

The results of the limited water quality testing indicate the water quality characteristics of the fractured aquifer system across the subject site are relatively similar in composition from site to site with the exception of iron and pH. Also, all tested parameters are below their respective U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) and/or USEPA Secondary Water Quality Standard (SMCLs), except for exceedance of the SMCLs for iron in ERS-9, pH at ERS-7, and manganese in ERS-3, ERS-7, and ERS-9. The SMCLs are non-mandatory water quality standards established as guidelines for managing water supply sources for aesthetic (taste, color, and odor) and technical (corrosion, scaling, and sedimentation) effects.

As presented in Table 3, iron concentrations varied by an order of magnitude from well to well and ranged from 0.18 mg/L (ERS-3) to 3.74 mg/L (ERS-9). The SMCL iron of 0.3 mg/L was exceeded in the sample collected from ERS-9 (3.74 mg/L). Potential noticeable effects of the concentration of iron exceeding the SMCL at ERS-9 could be rusty colored water, sedimentation/precipitation of iron scale/deposits, metallic taste, and reddish or orange staining.

As presented in Table 3, manganese concentrations measured across the site were within the same order of magnitude from well to well and ranged from 0.114 mg/L (ERS-3) to 0.721 mg/L (ERS-9). The SMCL manganese of 0.05 mg/L was exceeded in all three sample collected from subject site. Potential noticeable effects of the concentration of manganese exceeding the SMCL could be black to brown colored water and black staining.

The pH value of ERS-3 and ERS-9 compare well with each other at values of 7.72 and 7.27, respectively. However, the pH of ERS-7 is high at a value of 10.67 and exceeds the SMCL of less than 8.5. The elevated pH may be caused by cement leaching from the neat cement grout seal at ERS-7.

Groundwater samples for total and fecal coliform analysis were collected and submitted to Pace Analytical from all three wells. However, the sample from ERS-3 arrived at the laboratory on Saturday morning and the sample was not analyzed. Neither Total Coliform nor fecal coliforms were detected in the sample submitted from ERS-9. Fecal coliforms were not detected in ERS-3; however, total coliforms were detected. Coliforms are naturally present in the environment and they are not a health threat in and of itself. Total coliforms are used to indicate whether other potentially harmful bacteria are available. As each well and downhole pumping equipment were not disinfected prior to installation, Terracon recommends that each well be resampled upon installation of a disinfected permanent pump.

4.0 FINDINGS AND RECOMMENDATIONS

4.1 Test Well Sites

Based on the results of the aquifer performance testing, two (ERS-3 and ERS-7) of the four test production wells are capable to producing in excess of the project goal of 70 gpm. ERS-9 was tested for 72 hours at a rate of 63 gpm. Well ERS-12A was not tested at the direction of the client, because the production rate for ERS-12A is expected to be at most 25 gpm. A summary of the water level data collected during the 2018 production well testing event is presented in Table 4.

Table 4: Summary of 2018 Production Well Testing Results

Parameter	ERS-3	ERS-7	ERS-9	ERS-12A
Static Water Level	26.74 Feet	0.5 Feet	25.44 Feet	10 Feet
Discharge Rate	135 GPM	73 GPM	63 GPM	~ 25 GPM*
Pumping Water Level	108.48 Feet	398.74 Feet	281.39 FT	--
Drawdown	153.74 Feet	398.24 Feet	255.95 FT	--
Specific Capacity	0.87 GPM/Foot	0.18 GPM/Foot	0.25 GPM/FT	--
Hydraulic Conductivity	1.1 Foot/Day	0.079 Foot/Day	0.2955 Foot/Day	--
Casing Depth	71 Feet	51 Feet	91 Feet	105 Feet
Total Well Depth	306 Feet	600 Feet	350 Feet	

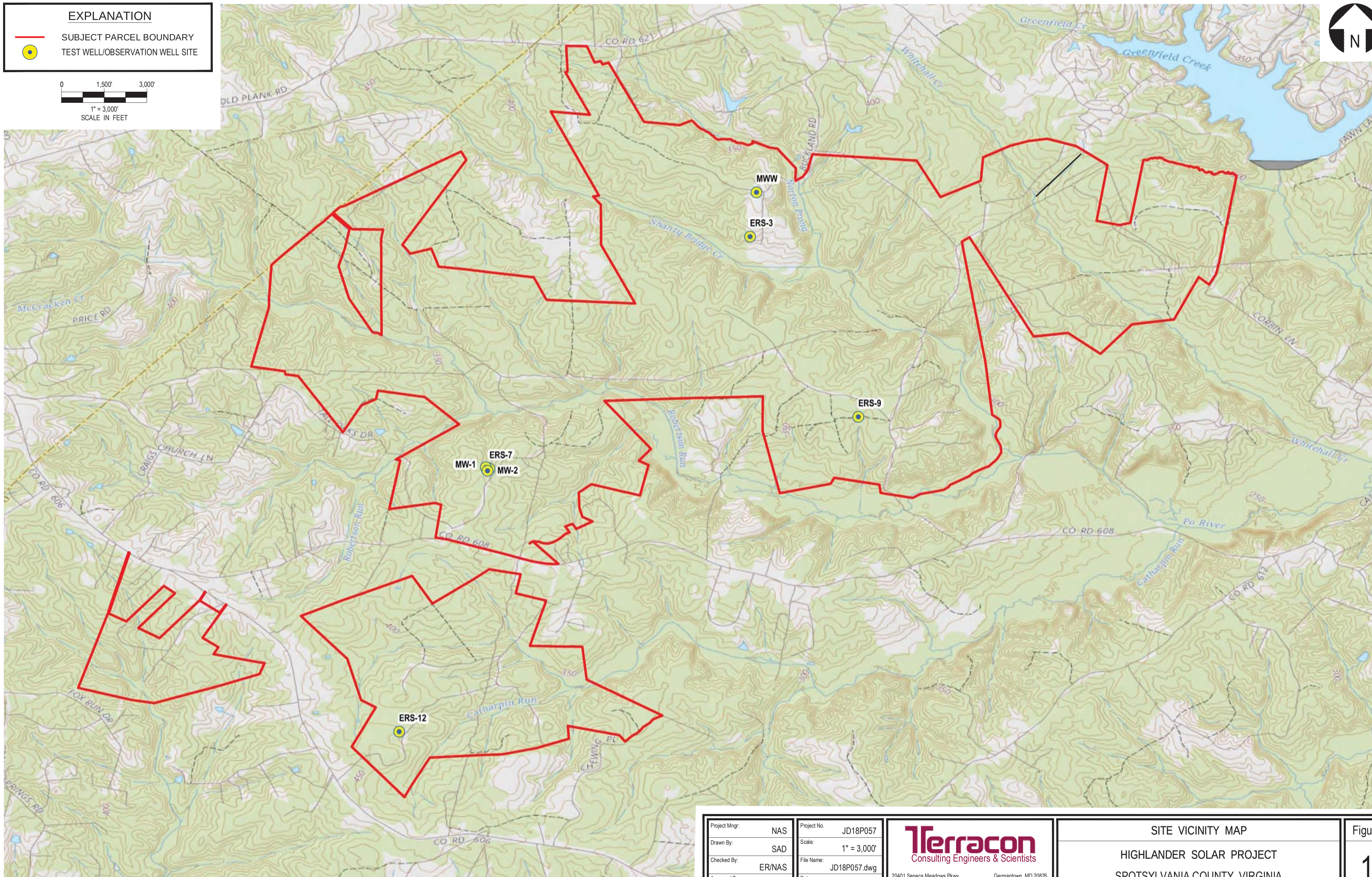
*Discharge rate estimated based on drilling observations.

Assuming the above wells will be placed into production for the solar facility construction, Terracon recommends static water levels, pumping water levels, and pumping rates continue to be collected regularly from each on-site production well as part of the operational and maintenance plan for the facility. Also based on the result of the limited water quality sampling, Terracon recommends each well and pump be properly disinfected during the installation of the permanent pumps. Also, Terracon recommends periodic monitoring of pH at ERS-9 along additional well development.

4.2 Potential Impact to Area Wells

As discussed previously, Terracon modeled the water level responses from each of the tested wells as a check of the calculated hydraulic conductivity and as a very conservative method to evaluate the radius of influence of each pumping well. As shown in Figures 11, 15, and 19, the calculated radius of influence extends in some cases 4,500 feet from the pumping well. These estimates of the radius of influence are generalized, and should be considered very conservative and likely an over representation of the true radius of influence one would expect in a fractured aquifer system. The calculated radius of influence assumes an aquifer system that is homogeneous, isotropic, and infinite, whereas, fractured rock aquifers do not fit this governing assumption. Flow in fractured rock aquifers is controlled by orientation of fractures and most sensitive to horizontal hydraulic conductivity, which is control by the frequency and orientation of the fractures. The area of influence in a horizontally anisotropic aquifer (fractured aquifer) is typically elongated in the direction of higher horizontal hydraulic conductivity (i.e., the water-bearing fractures) and shortened in the direction of lower horizontal hydraulic conductivity compared to area of influence in a homogeneous, isotropic aquifer.

APPENDIX A
FIGURES



EXPLANATION

SUBJECT PARCEL BOUNDARY

TEST WELL/OBSERVATION WELL SITE

0 1,500' 3,000'

1" = 3,000'
SCALE IN FEET

Project Mngr:	NAS	Project No.	JD18P057
Drawn By:	SAD	Scale:	1" = 3,000'
Checked By:	ER/NAS	File Name:	JD18P057.dwg
Approved By:	ER	Date:	September 2018

Terracon
Consulting Engineers & Scientists
20401 Seneca Meadows Pkwy Germantown, MD 20876
PH. (301) 354-6100 FAX (301) 354-6101

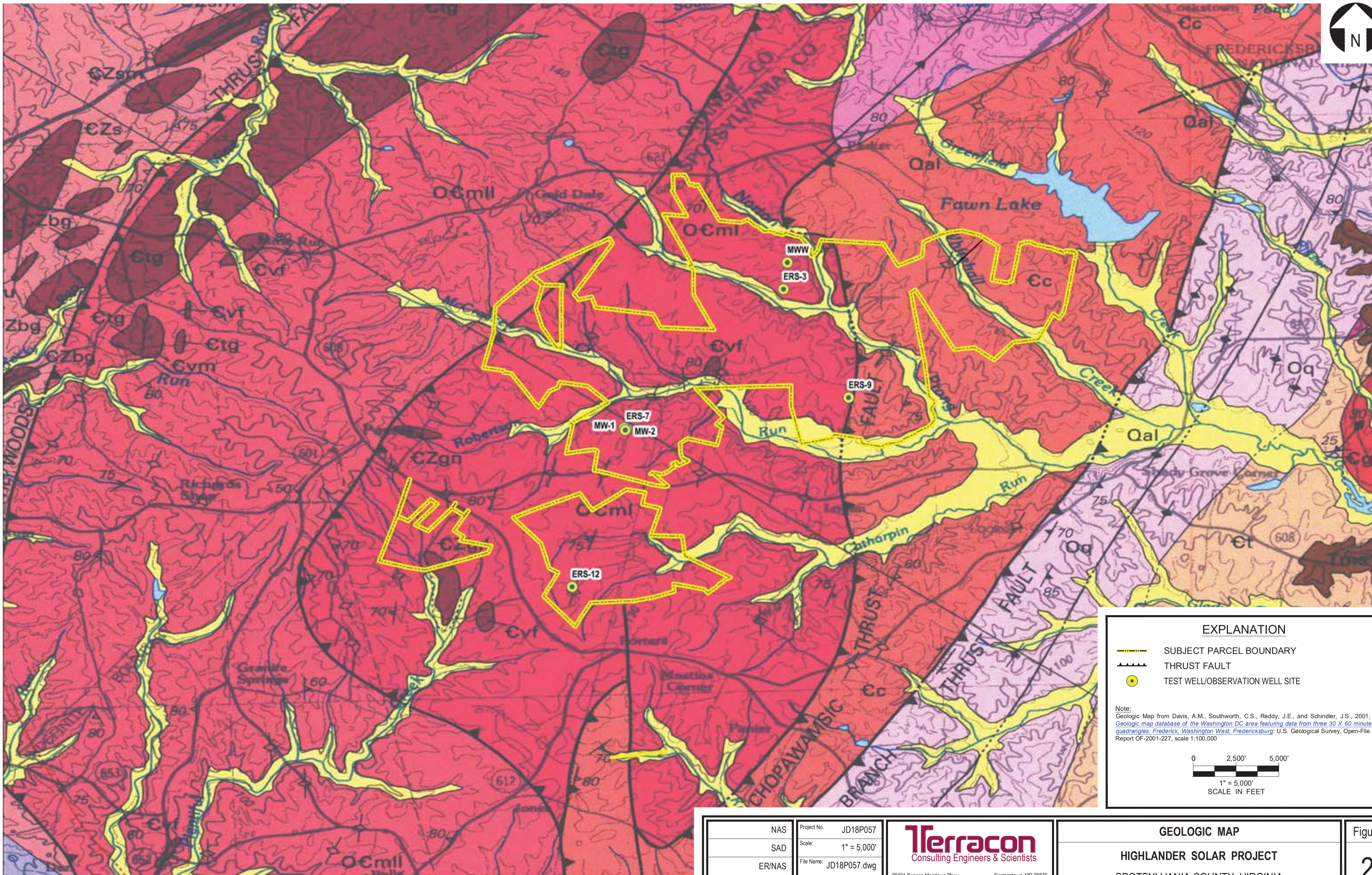
SITE VICINITY MAP

HIGHLANDER SOLAR PROJECT

SPOTSYLVANIA COUNTY, VIRGINIA

Figure

1



EXPLANATION

SUBJECT PARCEL BOUNDARY

THRUST FAULT

TEST WELL/OBSERVATION WELL SITE

Note:
Geologic Map from Davis, A.M., Southworth, C.S., Reddy, J.E., and Schindler, J.S., 2001, *Geologic map database of the Washington DC area featuring data from three 30 X 60 minute quadrangles: Frederick, Washington West, Fredericksburg*: U.S. Geological Survey, Open-File Report OF-2001-227, scale 1:100,000

0 2,500' 5,000'

1" = 5,000'
SCALE IN FEET

NAS	Project No.	JD18P057	
SAD	Scale:	1" = 5,000'	
ER/NAS	File Name:	JD18P057.dwg	
ER	Date:	September 2018	

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GEOLOGIC MAP

HIGHLANDER SOLAR PROJECT

SPOTSYLVANIA COUNTY, VIRGINIA

Figure

2