# Geotechnical Engineering Report

**HIGHLANDER SOLAR PROJECT**

**Spotsylvania and Orange Counties, Virginia**

December 14, 2017

Terracon Project No. EY175038

**Prepared for:**
Sustainable Power Group
San Francisco, CA

**Prepared by:**
Terracon Consultants, Inc.
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Terracon

December 14, 2017

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Re: **Geotechnical Engineering Report**
**Highlander Solar Project**
**Spotsylvania and Orange County, Virginia**
**Terracon Project No. EY175038**

Dear Mr. McBride:

Terracon Consultants, Inc. (Terracon) has completed the geotechnical engineering services for the above referenced project. These services were performed in general accordance with the following documents:

- Terracon Proposal for Geotechnical Engineering Services PEY175038, dated September 18, 2017
- Master Service Agreement between S-Power and Terracon

This geotechnical engineering report presents the results of the subsurface exploration, laboratory testing, engineering analyses and geotechnical engineering recommendations with regard to the design and construction of the proposed solar facility.

We appreciate the opportunity to be of service to you on this project. If you have any questions concerning this report, or if we may be of further service, please contact us.

Sincerely,
**Terracon Consultants, Inc.**

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Environmental Facilities Geotechnical Materials

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## EXECUTIVE SUMMARY

A geotechnical engineering exploration has been performed for the proposed Highlander Solar Facility located in Spotsylvania and Orange Counties, Virginia, approximately 3 miles east of Mine Run, Virginia. Terracon's scope of work included the advancement of 75 borings, 22 test pits, field resistivity testing, thermal resistivity testing, laboratory testing on representative samples of the subsurface materials, engineering analyses, and development of engineering recommendations for design and construction of pile foundations and conventional shallow foundations at the proposed project site.

Based on the results of our field exploration, laboratory testing and engineering analyses, the site is considered suitable for the planned solar energy center provided the recommendations contained in this report are properly implemented in the design and construction of the project. The following geotechnical considerations were identified:

- The typical subsurface profile at the site consisted of residual soils weathered from bedrock below. Encountered soils were primarily classified as silt, elastic silt, and lean clay with occasional layers of fat clay and silty quartz gravel to the maximum depth of exploration of 20 feet.
- Groundwater was not encountered in any of the borings at the time of exploration. Based on the closest well, approximately 22 miles away in Orange County, the depth to regional groundwater is approximately 30 to 36 feet below ground surface.
- Based on the silt, clay and gravel soils encountered on site, pile embedment depths may be deeper than normal due to the potential for significant adfreeze forces.
- Piles should be designed with an ultimate skin friction of 250 psf when founded at a minimum of 5 feet below existing grade in natural undisturbed soils. Additional recommendations for the piles including LPILE input parameters can be found in Section 5.2.1.2 of this report. A load test program should be performed to provide more accurate parameters for use in design of the pile embedment depths.
- A net allowable bearing capacity of 2,500 pounds per square foot (psf) is recommended for shallow spread footing or slab foundations for ancillary structures associated with the facility.

This executive summary should be used in conjunction with the entire report for design and/or construction purposes. It should be recognized that specific details were not included or fully discussed in the Executive Summary, and that the report must be read in its entirety for a comprehensive understanding of the discussion and recommendations presented herein. The section titled General Comments should be read for an understanding of the report limitations.

# GEOTECHNICAL ENGINEERING REPORT
# HIGHLANDER SOLAR PROJECT
# SPOTSYLVANIA AND ORANGE COUNTIES, VA

**Terracon Project No. EY175038**
**December 14, 2017**

## 1.0 INTRODUCTION

This report presents the results of our geotechnical engineering services performed for Sustainable Power Group's (S-Power) proposed Highlander Solar Facility located in Spotsylvania and Orange Counties, Virginia. The purpose of these services is to provide information and geotechnical engineering recommendations relative to:

- subsurface soil conditions
- earthwork
- seismic considerations
- groundwater conditions
- soil permeability
- foundation design and construction

## 2.0 PROJECT INFORMATION

### 2.1 Project Description

| ITEM | DESCRIPTION |
|---|---|
| **Structures** | The site will include a photovoltaic (PV) solar power plant and a substation. We anticipate the PV structures will consist of steel piles, a racking system and PV modules. The steel pile foundations for the solar arrays are anticipated to consist of wide flange steel piles (W6x7, W6x15 or similar). We understand the inverters will also be supported on wide flange steel piles, while transformers, and other appurtenant equipment in the substation area are anticipated to be supported on shallow spread or mat foundations.<br><br>Substation – The site will include a substation, and we anticipate the substation structure foundations will include drilled shafts (with diameters of 2 to 5 feet) for the support of pole-mounted equipment, and shallow mat foundations for the support of the transformer, circuit breaker and control house. |
| **Foundation Loads** | The following foundation loads were provided:<br>▪ Solar Panel Piles:<br>o Axial Compression: 3.7 kips<br>o Axial Uplift: 1 kip<br>o Shear Load: 3.1 kips<br>▪ Other lightly loaded structures: 2 kips per foot wall load (assumed) and 25 kip column load (assumed) |

| ITEM | DESCRIPTION |
|---|---|
| **Grading** | We anticipate the solar field will be cut and filled to achieve final grades but earthwork plans were unavailable at the time of this report. As we understand, grades may change by as much as 10 to 15 feet depending on location across the site. |

If the project understanding, proposed construction, foundation loads, or grading are modified to be different than presented above, Terracon should be consulted to review the changes and revise our recommendations.

### 2.2 Site Location and Description

| ITEM | DESCRIPTION |
|---|---|
| **Location** | Exhibit A-1 in Appendix A presents a site vicinity map. The project site covers approximately 3,500 acres in Spotsylvania and Orange Counties, Virginia. It is located between Orange Plank Road on the north and W. Catharpin Road on the south. The approximate center of the site is located approximately 3.35 miles east of Mine Run, Virginia in Spotsylvania County, Virginia, with latitude and longitude 38.24344° N and 77.77514° W, respectively. |
| **Existing Improvements** | Based on our review of real estate plats and aerial imagery, existing features at the site include tree farms, agricultural fields, dirt and gravel roads, and a distribution transmission line. An existing electrical substation is located near the center of the site. |
| **Current Ground Cover** | The project is located on private land that is primarily used for timber, logging, and agriculture. The site is mostly wooded with dirt logging roads. |
| **Topography** | According to the Belmont, VA USGS Topographic Map, the ground surface elevation of the site ranges from approximately EL 490 to EL 260 feet above mean sea level. The site topography is hilly with steep slopes along stream valleys. The site is traversed by several streams including McCracken Creek, Robertson Run, Norton Prong, and Shanty Bridge Creek and their tributaries. The topographic map for the site is included as Exhibit A-2 in Appendix A. |

## 3.0 SUBSURFACE CONDITIONS

### 3.1 Site Geology

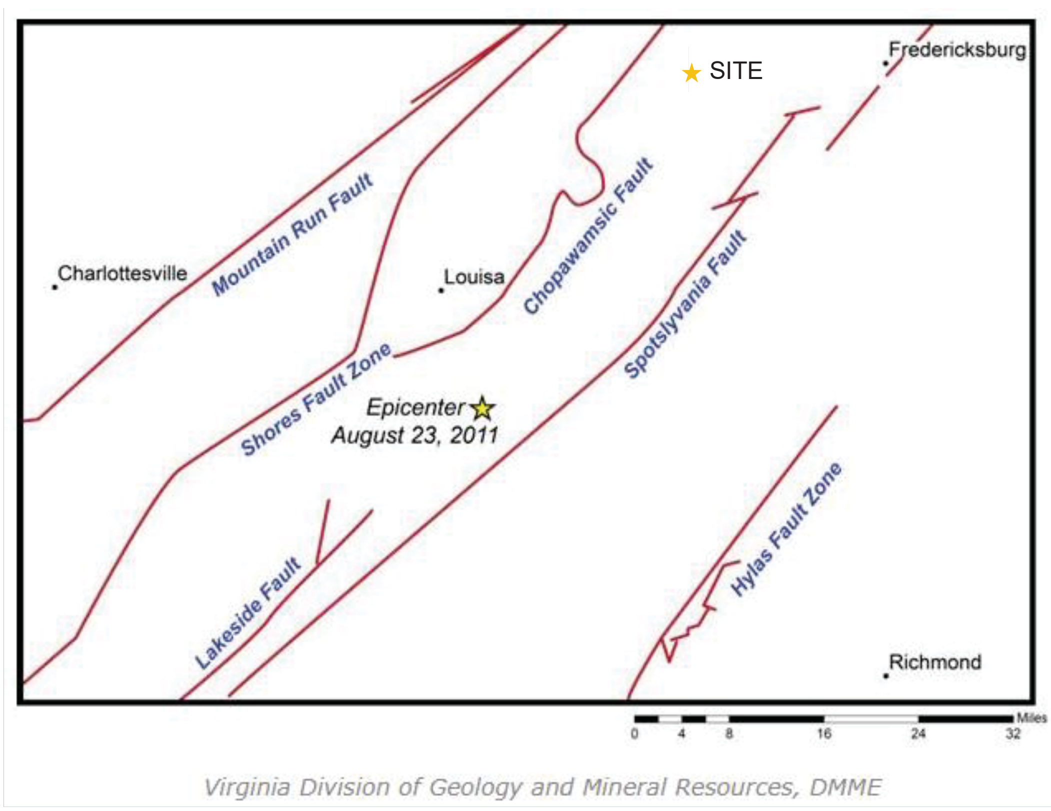
According to the Geologic Map of the Fredericksburg, Virginia Quadrangle[1], the project area is located in the rolling hills and steeply cut valleys of Piedmont physiographic province. The bedrock at the site consists of metamorphic rocks of the Melange zone I formation with some localized blocks of meta-volcanic rocks. The Melange Zone I formation is described as fine-grained schist and phyllites.

[1] Mixon, Pavlides, Powars et al. *Geologic Map of the Fredericksburg 30'x60' Quadrangle, Virginia and Maryland*, USGS. 2002

In the stream valleys, the near surface soils are mapped as alluvium of Holocene to middle Pleistocene age (10,000 to 1 m.y. ago), and described as sand, gravel, silt and clay. The geologic map for the site is included as Exhibit A-3 in Appendix A.

## 3.2 Geologic Hazards

On August 23, 2011, a 5.8 magnitude earthquake occurred in Louisa County, Virginia, located southwest of the project site. The epicenter of the earthquake was located near Cuckoo, Virginia, approximately 22 miles from the site, within the Central Virginia Seismic Zone. The Central Virginia Seismic Zone is an area about halfway between Richmond and Charlottesville with several old faults, as shown on the map below. While these are old, relatively inactive faults, dozens of earthquakes have occurred within the past 120 years.




## 3.3 Typical Subsurface Profile

The subsurface conditions at the site were explored by drilling 71 borings to planned depths of 20 feet, and excavating 21 test pits to depths of 4 to 12 feet. Approximate boring and test pit locations are shown on Exhibit A-4 in Appendix A. The following four borings and one test pit encountered auger refusal at the indicated depths before reaching their respective target depths:

| Boring/Test Pit | Auger Refusal Depth (ft) |
|---|---|
| A12-1 | 14.2 |
| A15-7 | 16.6 |
| A15-11 | 8.5 |
| A20-14 | 12.0 |
| TP-10 | 4.0 |

The soils encountered at the site were consistent with a residual soil profile in the Piedmont Physiographic Province. Soils encountered in the test borings and test pits consisted primarily of medium stiff to hard silt (ML), elastic silt (MH), lean clay (CL), fat clay (CH) and silty gravel (GM) layers to the maximum explored depth of 20 feet. Occasional dense lenses of quartz gravel were encountered in some of the borings.

Subsurface conditions at the site are quite variable and the above description presents a very generalized subsurface profile across the site. Specific conditions found at each boring and test pit location are indicated on the individual logs included as Exhibits A-7 through A-98 in Appendix A of this report. Stratification boundaries on the logs represent the approximate location of changes in soil types; in-situ, the transition between materials may be more gradual.

A description of field sampling procedures is included in Appendix A and laboratory testing procedures and test results are presented in Appendix B. Laboratory testing included moisture contents, Atterberg limits, gradational analyses, moisture-density relationships, corrosion potential, and thermal resistivity.

## 3.4 Groundwater

Groundwater was not observed in any test boring during drilling, nor when checked upon completion of drilling. One sample in boring A16-3 at a depth of 18.5 feet was reported as wet to moist. These observations represent groundwater conditions at the time of the field exploration and may not be indicative of other times, or at other locations. Groundwater conditions can change with varying seasonal and weather conditions, and other factors. Based on the closest groundwater well (USGS 381002078094201 45P 1 SOW 030) approximately 22 miles away in Orange County Virginia as reported in the NWIS Site[2], the depth to groundwater has varied from approximately 30 to 36 feet below the ground surface over the past 120 days.

## 3.5 Electrical Resistivity

Field measurements of soil resistivity were performed between October 7 and 14, 2017, and conducted in general accordance with ASTM Test Method G 57, and IEEE Std. 81, using the Wenner Four-Electrode Method. The approximate soil resistivity test locations are shown on

[2] National Water Information Site Information for USA, U.S. Department of the Interior | U.S. Geological Survey. URL: https://waterdata.usgs.gov/nwis/inventory?

Exhibit A-5 in Appendix A. The soil resistivity measurements were performed using a MiniSting, Memory Earth Resistivity and IP Meter, manufactured by Advanced Geosciences, Inc. The Wenner arrangement (equal electrode spacing) was used with the “a” spacings of 1, 2, 3, 6 10, 20, 30 and 60 feet within the solar array area. Due to access constraints, electrical resistivity tests planned at ER-1 and ER-23 locations were eliminated from field testing. The “a” spacing is generally considered to be the depth of influence of the test. Results of the soil resistivity measurements are presented in tabular and graphical format in Appendix A.

# 4.0 LABORATORY TEST RESULTS

The complete results of the laboratory testing performed for the project are presented in Appendix B and are summarized in the following sections.

## 4.1 Geotechnical Index Testing

Laboratory testing was performed on selected samples to aid in soil classification and to further define the engineering properties of the soils. Geotechnical index testing completed during this phase of work included natural moisture content, grain size distribution, Atterberg Limits, and moisture-density relationship (Proctor). The results of the Atterberg Limit, gradation testing and the moisture content results are presented on Exhibits B-2 through B-67 and on the boring logs in Appendix A. Moisture-Density Relationship (Proctor) curves for representative samples are provided on Exhibits B-68 through B-75.

## 4.2 Corrosion Series Testing

Samples for corrosion testing were obtained from 22 locations in the solar array areas. The samples were obtained from depths of approximately 0 to 4 feet below existing ground surface. The samples were tested for pH, water soluble sulfate, sulfides, chlorides, Red-Ox potential, total salts, and electrical resistivity. The results of the Corrosion Series Testing are presented in Exhibits B-76 and B-82.

## 4.3 Thermal Resistivity Testing

Thermal resistivity testing was performed on eight soil samples obtained during our field exploration from depths of 0 to 4 feet below the ground surface. Four samples were tested in Terracon’s laboratory in Phoenix, Arizona and the other four were sent to Geotherm USA for testing. Thermal resistivity testing was performed in general accordance with the Institute of Electrical and Electronics Engineers (IEEE) standard 442. The dry-out curves were developed from soil specimens compacted to 90% of the maximum dry density determined in accordance with Standard Proctor criteria (ASTM D698). The soils are then dried to 0% moisture while obtaining intermediate moisture contents to develop the dry-out curves. The results of the thermal resistivity testing are presented on Exhibits B-83 through B-90. The thermal resistivity ranged from 74 to 258°C-cm/W for moist soils and 229 to 363 C-cm/W for dry soils.

### 4.4 Site Class and Seismic Parameters

Seismic design of the structures subject to earthquake ground motions requires classification of the upper 100 feet of the site profile in accordance with Chapter 20 of ASCE 7. Our scope of services did not include site profile determination to a depth of 100 feet. Explorations for this project extended to a maximum depth of 20 feet. Additional testing would be necessary to confirm that the soil conditions below the maximum explored depth are consistent with the Site Class noted for this site. However, based on the assumption that the soils below 20 feet will have SPT blow counts equal to or greater than those encountered at the bottom of the borings and continue to a depth of 100 feet, we recommend that Site Class C be used in the design of structures at the site.

We used the United States Geological Survey (USGS) website which includes on-line analysis tools for calculation of site seismic coefficients based, on site location, Site Class, and the 2012/2015 International Building Code (IBC). Boring A15-8 (Latitude 38.24344° N; Longitude 77.77514° W) was used to obtain the seismic design parameters. The following seismic design parameters were obtained:

| Description | Value |
|---|---|
| $S_S$ – Spectral Acceleration for a Short Period | 0.167g |
| $S_1$ – Spectral Acceleration for a 1-Second | 0.060 g |
| $F_a$ – Site Coefficient for a Short Period | 1.2 |
| $F_v$ – Site Coefficient for a 1-Second Period | 1.7 |

These parameters are generally representative of the residual soil profile for the entire site. Printouts of the USGS analysis detailed reports for Site Class determination are included as Exhibits D-1 through D-5 in Appendix D.

## 5.0 DESIGN RECOMMENDATIONS

### 5.1 Geotechnical Considerations

The proposed site presents several geotechnical challenges that will need to be considered during design and construction.

- The site topography is hilly with steeply cut stream valleys. Proposed site grades were not available at the time of this report but the existing topography has over 230 feet of elevation change across the site. We anticipate that significant earthwork will be required to create relatively level areas for the solar arrays.
- The soils at the site consist primarily of non-plastic silts and elastic silts, but also include lean and fat clays. Silts can be very problematic for several reasons as outlined below:

- they have low shear strengths which will result in low pile capacities and the need for longer and/or larger piles than are typically used for such projects;
- they are highly susceptible to frost heave, especially when a source of moisture is present. Buried objects such as piles supporting solar arrays, or shallow foundations supporting unheated structures, can be uplifted or heaved from the ground if they are not designed to resist these adfreeze forces. At sites where the adfreeze forces are significant, this can result in the need for longer piles;
- they are highly erodible. Unprotected/unvegetated surfaces in dirt roads, slopes along road cuts, ponds, or pads for solar arrays may quickly erode if exposed to flowing water or strong winds; and,
- they can soften quickly when exposed to water, becoming difficult to work with during construction and unstable as a roadway surface.

- The test borings and test pits encountered thin layers of quartz gravel at depths as shallow as 4 feet and in four locations refused on rock. Dense gravel and shallow rock may limit the drivability of piles. This means that pre-drilling or oversize drill holes may be required to install some of the piles across the site.

## 5.2 Foundation Recommendations

As discussed in Section 5.1, the subsurface conditions at the site present several geotechnical challenges that must be addressed by the selected foundation system. The optimum foundation system needs to balance the required load capacity, the owner's tolerance for foundation installation and performance risks, and system cost.

### 5.2.1 Pile Foundations

The recommendations below are preliminary and will be revised after the pile load testing is complete.

#### 5.2.1.1 Axial Capacity

The axial uplift capacity of driven piles should be estimated based on the skin friction developed along the perimeter of the pile. Axial compressive capacity may be estimated using the skin friction and end bearing. When determining embedment depths, skin friction from the upper 12 inches of the pile should be neglected. In calculating the skin friction, the area of the pile should be taken as the box perimeter and calculated as twice the sum of the flange width and web depth.

Based on the Spotsylvania, Virginia Residential Building Code, the local depth of frost penetration is 18 inches. Objects buried or embedded in silt soils have a high potential to heave over time as the soil freezes and thaws. The pile should be designed to resist these adfreeze forces. The ultimate unit adfreeze pressure was estimated on typical values for silt in published literature. When determining adfreeze forces, the perimeter of a wide flange beam should be taken as the actual perimeter of pile that is in contact with the soil. In like manner, for determining the uplift capacity of the pile below the depth that adfreeze forces apply, the full perimeter of the pile in contact with the soil should be used instead of the box perimeter described in the above paragraph. Adfreeze forces can be very high, especially in silt, which is highly susceptible to frost heaving.

The ultimate axial capacity of driven steel piles may be calculated using skin friction and adfreeze values as presented in the following table:

| Depth (ft.) | Ultimate Unit Skin Friction (psf) | Ultimate Unit Adfreeze (psf) |
|---|---|---|
| 0 - 15 | 250 | 2,000 |

The ultimate unit skin friction and adfreeze values were estimated based on the results of our test boring program and correlations with typical published values. Actual values for use in design will be derived from a pile load test program that will include axial tension, axial compression and lateral load tests.

For ASD design, we recommend the allowable skin friction provided in the table above be determined by applying a minimum factor of safety of at least 2 to the ultimate value. For LRFD, we recommend a preliminary value for the resistance factor as 0.8. As part of a pile load test program, these values will be revised.

### 5.2.1.2 Lateral Capacity

The stiffness of the pile and the stress-strain properties of the surrounding soils determine the lateral resistance of the foundation. The table below provides recommended preliminary L-Pile input parameters for the design of driven pile foundations embedded in the upper 15 feet of the subsurface soils:

| Depth (feet) | Soil Type | Effective Unit Weight (PCF) | Effective Friction Angle (deg) | Soil Modulus k (PCI) |
|---|---|---|---|---|
| 0 - 15 | Sand (Reese) | 110 | 30 | 60 |

The effective unit weight, friction angle and k-value are typical values based on correlations with the results of test borings. Once pile load tests have been completed, these values will need to be revised based on field lateral load test results.

The structural engineer should evaluate the moment capacity of the pile as part of their structural evaluation. Piles should have a minimum center-to-center spacing of at least 5 times their largest cross-sectional dimension in the direction of the lateral loads, or the lateral capacities should be reduced due to group effects. If piles will be spaced closer than 5 times their largest cross-sectional dimension, Terracon should be notified to provide supplemental recommendations.

## 5.3 Shallow Foundations

Reinforced mat foundations are recommended for support of transformers and other slab mounted equipment on the project. In addition, spread footing foundations may be used to support buildings or other lightly loaded ancillary structures.

The following sections present design recommendations and construction considerations for the shallow foundations for proposed lightly loaded structures and related structural elements, based on the assumptions for structure loading presented in Section 2.1.

### 5.3.1 Shallow Foundation Design Recommendations

| Description | Columns | Walls |
|---|---|---|
| **Net allowable bearing pressure for spread footings [1]** | 2,500 psf | 2,000 psf |
| **Bearing material** | Natural soils or compacted engineered fill placed in accordance with Section 5.4.4 of this report. | |
| **Minimum width** | 30 inches | 18 inches |
| **Minimum embedment below finished grade[2]** | 18 inches<br>30 inches[3] | 18 inches |
| **Maximum estimated total settlement [4]** | <1 inch | <1 inch |
| **Maximum estimated total settlement [4]** | < ½ inch between columns | < ½ inch over 40 ft |
| **Ultimate coefficient of sliding friction [5]** | 0.33 | |
| **Modulus of subgrade reaction for mat slab design** | 100 pci for point loading conditions | |

1. The recommended net allowable bearing pressure is the pressure in excess of the minimum surrounding overburden pressure at the footing base elevation. It assumes any unsuitable soils, if encountered, will be replaced with compacted engineered fill.
2. Required for the allowable bearing pressure, erosion protection and to reduce the effects of seasonal moisture variations and frost depth in the subgrade soils. The allowable foundation bearing pressures apply to dead loads plus design live load conditions. The weight of the foundation concrete below grade may be neglected in dead load computations.
3. If the subgrade consists of natural high plasticity soils (CH or MH).
4. The foundation settlement will depend upon the variations within the subsurface soil profile, the structural loading conditions, the embedment depth of the footings, the thickness of compacted fill, and the quality of the earthwork

operations. Footings should be proportioned to relatively constant dead-load pressure in order to reduce differential movement between adjacent footings.

5. Sliding friction along the base of the footing will not develop where net uplift conditions exist.

Foundation excavations should be observed by the Geotechnical Engineer. If the soil conditions encountered differ significantly from those presented in this report, Terracon should be contacted to provide additional evaluation and supplemental recommendations.

### 5.3.2 Slabs-on-Grade

Floor slabs may be supported on-grade if the subgrade soils consist of silts (ML) and lean clays (CL). Fat clays (CH) and elastic silts (MH) are not recommended for direct support of slabs-on-grade. Where fat clays and elastic silts are encountered at the subgrade elevation, the unsuitable soils should be over-excavated at least 12 inches and replaced with compacted engineered fill.

A 6-inch thick, drainage stone layer, such as VDOT No. 57 stone, should be placed below the slab-on-grade to provide a capillary break. The Contractor should compact the stone in place with at least two passes of suitable vibratory compaction equipment. We recommend that the edges of the slab be turned down to at least 24 inches below the adjacent finished grade to protect against frost heave.

## 5.4 Earthwork

Grading plans are not available at the time of this report. Terracon should be given the opportunity to review grading plans when available so that we may revise any recommendations presented herein. Earthwork for the project is expected to include benching and terracing for solar arrays, trenching for cables and conduits, cutting and filling to achieve roadway grade, and excavations for stormwater management. The earthwork described in the following sections is generally intended for the access roadways, drainage and equipment structure areas.

Earthwork operations should be observed and evaluated by Terracon. The evaluation of earthwork should include observation and testing of engineered fill, subgrade preparation, foundation bearing soils, and other geotechnical conditions exposed during the construction of the project.

### 5.4.1 Site Preparation

Although evidence of old structures, foundations, and utilities were not observed during the site reconnaissance, such features could be encountered during construction. If unexpected underground facilities are encountered, such features should be removed to a depth of at least 2 feet below the bearing level or tip elevation of proposed foundations. Existing facilities that cannot be extracted or removed in pile array areas will create an obstruction to pile driving.

### 5.4.2 Excavation

It is anticipated that excavations for the proposed construction can be accomplished with conventional earthmoving equipment. Based upon the subsurface conditions determined from the geotechnical exploration, some sloughing of the subgrade soils in foundation excavations is anticipated due to their granular characteristics. The subgrade soils exposed during construction are expected to be relatively stable provided adequate slopes or shoring is implemented. The stability of the subgrade may also be affected by precipitation, repetitive construction traffic or other factors. Instability in the form of caving, sloughing, and raveling should be expected in deeper excavations which extend into the low-plasticity silt layers.

The earthwork contractor is responsible for designing and constructing stable, temporary excavations as required to maintain stability of both the excavation sides and bottoms. Excavations should be sloped or shored in the interest of safety following local and federal regulations, including current OSHA excavation and trench safety standards.

### 5.4.3 Subgrade Preparation

The exposed bottom of over-excavated areas which will receive engineered fill, once properly cleared and benched where necessary, should be scarified to a minimum depth of six inches, moisture conditioned, and compacted. Exposed surfaces should be free of mounds and depressions which could prevent uniform compaction. Exposed surfaces which will receive fill should be observed and approved by Terracon prior to placement of engineered fill. Engineered fill should extend below proposed shallow spread footings and mat foundations within the geometric configurations and depths indicated in the following table.

| Structure | Depth of Fill Below Footings and Mat Foundations | Lateral Extent of Fill Beyond the Edge of Footings or Mats |
|---|---|---|
| **Buildings and Equipment Pad Foundations** | A minimum of 18 inches below the footing/foundation bottom, or 18 inches below existing site grade, whichever depth is greater | A minimum of 24 inches horizontally beyond the edges of footings or mats |

The floor slab for any proposed buildings should be supported on a minimum 12 inches of scarified, moisture conditioned, and compacted subgrade. The moisture content and compaction of subgrade soils should be maintained until slab construction. The moisture content and compaction of subgrade soils should be maintained until roadway construction.

### 5.4.4 Fill Materials and Placement

As discussed in Section 5.1, proposed grading plans were not available for this report. However, we anticipate that there may be significant cuts and fills required to develop the site based on the topography of the site. We anticipate that most of the soils excavated as part of site work will consist of silts and clays. These materials can soften and erode when exposed to water and can become difficult to place and compact in wet weather.

Based on our understanding of the proposed construction, fill may be placed during construction to support structures, fill trenches and excavations, improve roads, provide drainage, and to adjust site grades. For best performance, structural fill should be used in fill areas that will support structural loads. However, we understand that this may be cost-prohibitive due to the volume of fill that would need to be imported to the site.

Existing site soils can be reused as structural fill if they are amended using cement, lime or flyash to reduce the soils' sensitivity to moisture and increase their strength. A laboratory study will need to be performed in advance to determine the type, ratio, and method used to add and blend the amendment to produce the improvements in all soil types planned for reuse. Scarifying and drying of excavated soils may still be necessary to achieve the recommended compaction. Drying of these soils will likely result in some delays, and may not be possible during cooler, wetter weather. We recommend that all earthwork be performed during the warmer, drier times of the year, if possible.

All fill materials used on site should be soils free of vegetation or organic matter, debris, and particles larger than 4 inches in size. Recommendations for fill are provided below:

- Structural fill – fill soils used for the support of structural elements such as foundations (including areas where solar panel arrays will be installed) should meet the following requirements:

| Characteristic | Value |
|---|---|
| Gradation | |
| 4 inches | 100 |
| 3 inches | 100 |
| No. 4 Sieve | 50-100 |
| No. 200 Sieve | 5 (min) to 20 (max) |
| | |
| Liquid Limit | 35 (max) |
| Plasticity Index | 15 (max) |

| | |
|---|---|
| Maximum expansive potential (%)* | 1.5 |

*Measured on a sample compacted to approximately 95 percent of the ASTM D698 maximum dry density at about 3 percent below optimum water content. The sample is confined under a 100 psf surcharge and submerged/inundated.

Structural fill should also be used to backfill trenches in areas that will support structural loads. We do not anticipate that most of the existing silt and clay soils present on site will be suitable for reuse as structural fill unless amended with cement, lime or flyash.

- Trench backfill – fill soils used to backfill utility trenches in non-structural areas should meet the following requirements:

| Characteristic | Value |
|---|---|
| Gradation | |
| 4 inches | 100 |
| 3 inches | 70 |
| No. 4 Sieve | 50-100 |
| No. 200 Sieve | 5 (min) to 35 (max) |
| | |
| Liquid Limit | 35 (max) |
| Plasticity Index | 15 (max) |
| Maximum expansive potential (%)* | 1.5 |

*Measured on a sample compacted to approximately 95 percent of the ASTM D698 maximum dry density at about 3 percent below optimum water content. The sample is confined under a 100 psf surcharge and submerged/inundated.

- Aggregate base course – VDOT No. 21A crushed aggregate.
- Drainage stone – washed VDOT No. 57 stone
- Common fill - Clean, debris-free excavated soils may be used in the solar array field, as landscaping and graded areas that will not support structural loads or roads other than the solar array field. On-site soils may be suitable for reuse as common fill. Scarifying and drying of excavated soils may be necessary to achieve the recommended compaction. Drying of these soils will likely result in some delays, and may not be possible during cooler, wetter weather. We recommend that the earthwork be performed during the warmer, drier times of the year, if possible.

If fill soils need to be imported to the site, all borrow soils should be submitted for testing and approval by Terracon prior to being hauled to the site.

Fill should be placed and compacted in loose, horizontal lifts not exceeding 8 inches in thickness, using equipment and procedures that will produce recommended moisture contents and densities (as discussed in Section 5.4.5) throughout the lift.

### 5.4.5 Compaction Requirements

Recommended compaction criteria for engineered structural fill, trench backfill in non-structural areas, and common fill materials are as follows:

| Material Type and Location | Minimum Compaction Requirement (%)[1] |
|---|---|
| Structural Fill (including trench backfill in areas supporting structural elements) | 95 |
| Trench backfill in non-structural areas | 85 |
| Common fill in landscape areas | 85 |
| Aggregate base course | 95 |
| Drainage Stone[2] | Not Applicable |

[1] Per the Standard Proctor Test (ASTM D698)

[2] Drainage stone should be tamped after placement to achieve a stable surface. Compaction requirements are not provided.

Fills should be placed at a moisture content within a range of 3 percentage points less to 2 percentage points more than the optimum moisture content determined in accordance with ASTM D698.

## 5.5 Roadways

On most project sites, the site grading is accomplished relatively early in the construction phase. Fills are typically placed and compacted in a uniform manner. However, during construction the subgrade may be disturbed due to utility excavations, construction traffic, desiccation, or rainfall, particularly with the silt and clay soils on site. The subgrade should be carefully evaluated at the time of construction for signs of disturbance or instability. We recommend that the subgrades be thoroughly proofrolled with a loaded tandem-axle dump truck weighing at least 10 tons, prior to placement of fill. Native soil surfaced roadway areas should be moisture-conditioned and properly compacted to the recommendations in this report.

Evaluation of on-site unpaved roadway section for the project was based on standard engineering practice, the anticipated low traffic volumes, and our understanding of the project. Silt and clay soils in exposed roads are expected to quickly soften and erode when exposed to water and become unstable.

We recommend that a subgrade-stabilizing and separating geotextile or geogrid should be installed with a minimum 6 inches of VDOT 21A aggregate base course be placed on top (as discussed in Section 5.4.4) to create a stable unpaved road. Additionally, where roads will provide access for fire trucks, we recommend that an additional 8 inches of VDOT 21A aggregate base course be placed on top. If the subgrade-stabilizing geotextile or geogrid is not used, additional roadway maintenance will be necessary.

In isolated areas or low areas that are susceptible to holding water, we recommend removing the soft or yielding soils and replacing the material with approved imported structural fill. As an alternative, a subgrade-stabilizing geotextile or geogrid with 12 to 24 inches of aggregate base course placed on top may be required to stabilize the roadway.

Positive drainage should be provided during construction and maintained throughout the life of the roadways. Proposed roadway design should maintain the integrity of the road and eliminate ponding. The surface of the roadway should not impede natural drainage patterns. We anticipate that culverts may also be needed in areas where roads cross existing creeks. Ponding will cause the roadway to erode quicker and become soft or rut quicker. These items should be considered in the maintenance plans for the project.

These roadways, regardless of the section thickness, will require on-going maintenance during and after construction and repairs to keep them in a serviceable condition. It is not practical to design a native soil section of sufficient thickness that on-going maintenance will not be required. This is due to the nature of the silt and clay soils that will allow precipitation and surface water to gradually infiltrate and soften the subgrade soils making it susceptible to rills and rutting. When potholes, ruts, depressions or yielding subgrades develop they must be addressed as soon as possible in order to avoid major repairs. The roadways should be carefully re-evaluated as follows at the time of the use by heavy equipment or critical component delivery for signs of disturbance or excessive rutting. Roadway re-evaluation should include proof rolling immediately prior to use by heavy or critical equipment, particularly after a recent rainfall event. If disturbance and/or excessive wetting have occurred, roadway areas should be reworked, moisture conditioned (if necessary), and properly compacted as indicated in this report.

### 5.5.1 Corrosion Considerations

Ferrous metal and concrete elements in contact with soil, whether part of a foundation or part of the supported structure, are subject to degradation due to corrosion or chemical attack. Therefore, buried ferrous metal and concrete elements should be designed to resist corrosion and degradation.

Based on the “10-point” method developed by the American Water Works Association (AWWA) in standard AWWA C105/A21.5, the soil samples tested at the site for pH, resistivity, sulfides, oxidation-reduction potential and total salts indicated a low corrosion potential for buried ferrous metal.

The degradation of concrete or cement grout can be caused by chemical agents in the soil or groundwater that react with concrete to either dissolve the cement paste or precipitate larger compounds within the concrete, causing cracking and flaking. The concentration of water-soluble sulfates in the soils is a good indicator of the potential for chemical attack of concrete or cement grout. The American Concrete Institute (ACI) in their publication *Guide to Durable Concrete* (ACI 201.2R-08) provides guidelines for this assessment. The test results did not indicate a potential for these soils attack concrete or cement grout.

The reinforcing steel within concrete is at risk of corrosion when exposed to water-soluble chloride in the soil or groundwater through cracks in concrete. American Association of State Highway and Transportation (AASHTO) recommends a chloride threshold of 500 ppm in assessing potential pipe corrosion. No samples tested for chloride exceeded 500 ppm.

# 6.0 CONSTRUCTION CONSIDERATIONS

## 6.1 Pile Foundations

Possible obstructions (dense gravels, hard clay soils or cemented lenses) that could impede the installation of the piles were not observed within a depth of 10 feet from the existing ground surface in the borings or test pits performed at the site. However, the presence of dense quartz gravel lenses should be anticipated as shallow as 4 feet due to the variable weathering in the residual soil profile. Due to the variable weathering of rocks in the residual soil profile, dense seams of gravel-sized quartz fragments or less-weathered rock may be encountered at shallow depths. The contractor should be prepared to encounter shallow pile refusal and therefore may require pre-drilling to penetrate these obstructions or oversize pre-drilled holes if the refusal materials are very hard.

The pile load test program will be a limited indicator of the difficulty to drive piles on the site. Pile drive times will be recorded and presented in the pile load test report, which can be used by S-Power to estimate the potential difficulty to drive piles to the design embedment depths.

## 6.2 Shallow Foundations

Foundation subgrades should be observed by a qualified representative of Terracon. Extremely wet or dry material or any loose or disturbed material at the bottom of the footing excavations should be removed before foundation concrete is placed. Care should be taken to prevent wetting or drying of the bearing materials during construction. Should the soils at bearing level become dry, disturbed, or saturated, the affected soil should be removed prior to placing concrete. Concrete should be placed the same day as subgrade observation and approval to reduce bearing soil disturbance. Alternatively, a mud mat may be placed immediately following subgrade approval to protect the foundation subgrades from exposure to the elements and potential disturbance.

## 6.3 Earthwork Construction Considerations

### 6.3.1 Clearing and Stripping

Prior to any earthwork operations, any subsurface utilities and abandoned subsurface structures should be relocated and/or removed within, as well as five feet laterally beyond, the proposed construction area . All topsoil encountered within the limits of the access roads to 5 feet beyond on each side should be stripped after the removal and relocation of utilities. The topsoil is not suitable for reuse as structural fill/backfill and should be reused in landscaped areas or disposed in a suitable manner.

### 6.3.2 Subgrade Preparation

The on-site soils are susceptible to moisture changes, will be easily disturbed, and will be difficult to compact under wet weather conditions. Drying and reworking of the soils are likely to be difficult during periods of wet months. Earthwork phases of this project performed during the warmer, drier times of the year may be less likely to disturb on-site soils.

### 6.3.3 Grading and Drainage

The site should be graded to provide positive drainage away from the structures during construction and maintained throughout the life of the project. Infiltration of water into utility or foundation excavations must be prevented during construction by constructing berms or diversion ditches as appropriate. Water permitted to pond near or adjacent to the perimeter of the structures (either during or post-construction) can result in significantly higher foundation settlements than those discussed in this report. As a result, any estimations of potential movement described in this report cannot be relied upon if positive drainage is not provided and maintained, or if water is allowed to infiltrate the fill and/or subgrade. Backfill against utility line trenches should be well compacted and free of construction debris to reduce the possibility of water infiltration. After construction and prior to project completion, we recommend that verification of final grading be performed to document that positive drainage, as described above, has been achieved.

# 7.0 GENERAL COMMENTS

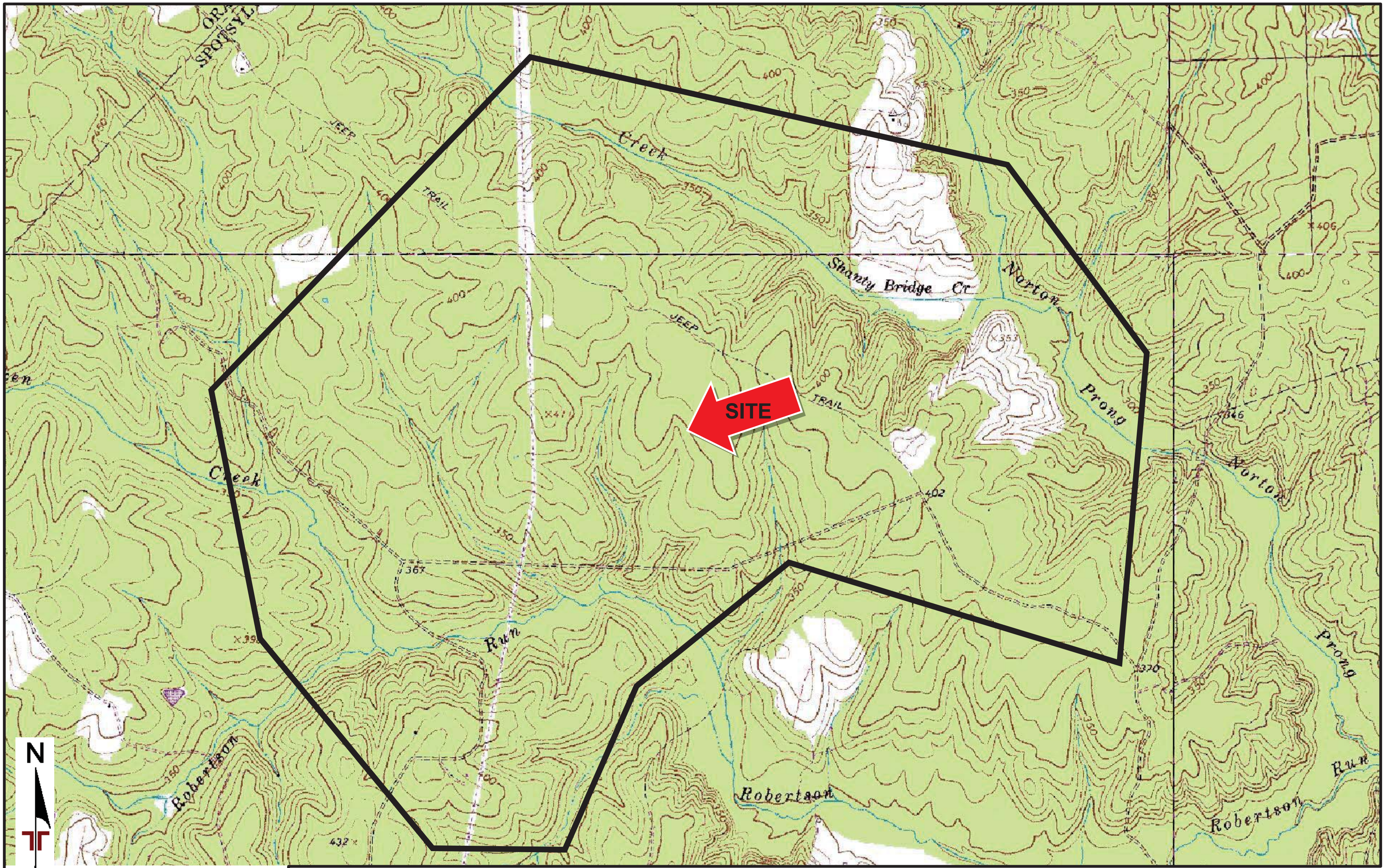
Terracon should be retained to review the final design plans and specifications so comments can be made regarding interpretation and implementation of our geotechnical recommendations in the design and specifications. Terracon also should be retained to provide observation and testing services during grading, excavation, foundation construction and other earth-related construction phases of the project.

The analysis and recommendations presented in this report are based upon the data obtained from the borings performed at the indicated locations and from other information discussed in this report. This report does not reflect variations that may occur between borings, across the site, or due to the modifying effects of construction or weather. The nature and extent of such variations may not become evident until during or after construction. If variations appear, we should be immediately notified so that further evaluation and supplemental recommendations can be provided.

The scope of services for this project does not include either specifically or by implication any environmental or biological (e.g., mold, fungi, bacteria) assessment of the site or identification or prevention of pollutants, hazardous materials or conditions. If the owner is concerned about the potential for such contamination or pollution, other studies should be undertaken.

This report has been prepared for the exclusive use of our client for specific application to the project discussed and has been prepared in accordance with generally accepted geotechnical engineering practices. No warranties, either express or implied, are intended or made. Site safety, excavation support, and dewatering requirements are the responsibility of others. In the event that changes in the nature, design, or location of the project as outlined in this report are planned, the conclusions and recommendations contained in this report shall not be considered valid unless Terracon reviews the changes and either verifies or modifies the conclusions of this report in writing.

# APPENDIX A
# FIELD EXPLORATION




TOPOGRAPHIC MAP IMAGE COURTESY OF THE U.S. GEOLOGICAL SURVEY QUADRANGLES INCLUDE: MINE RUN, VA (1/1/1981), CHANCELLORSVILLE, VA (1/1/1994), BELMONT, VA (1/1/1983) and BROKENBURG, VA (1/1/1981).
DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

| | | | |
|---|---|---|---|
| Project Manager: NS | Project No. EY175038 | Terracon<br>20401 Seneca Meadows Pkwy<br>Germantown, MD 20876-7005 | VICINITY MAP<br>Highlander Solar Proposal -Spotsylvania, VA - Sustainable Power Group<br>**Spotsylvania and Orange Counties**<br>**Mile Run, VA** |
| Drawn by: SP | Scale: 1"=2,000' | | |
| Checked by: NS | File Name: A-1 | | |
| Approved by: QK | Date: NOV, 2017 | | |

Exhibit
A-1

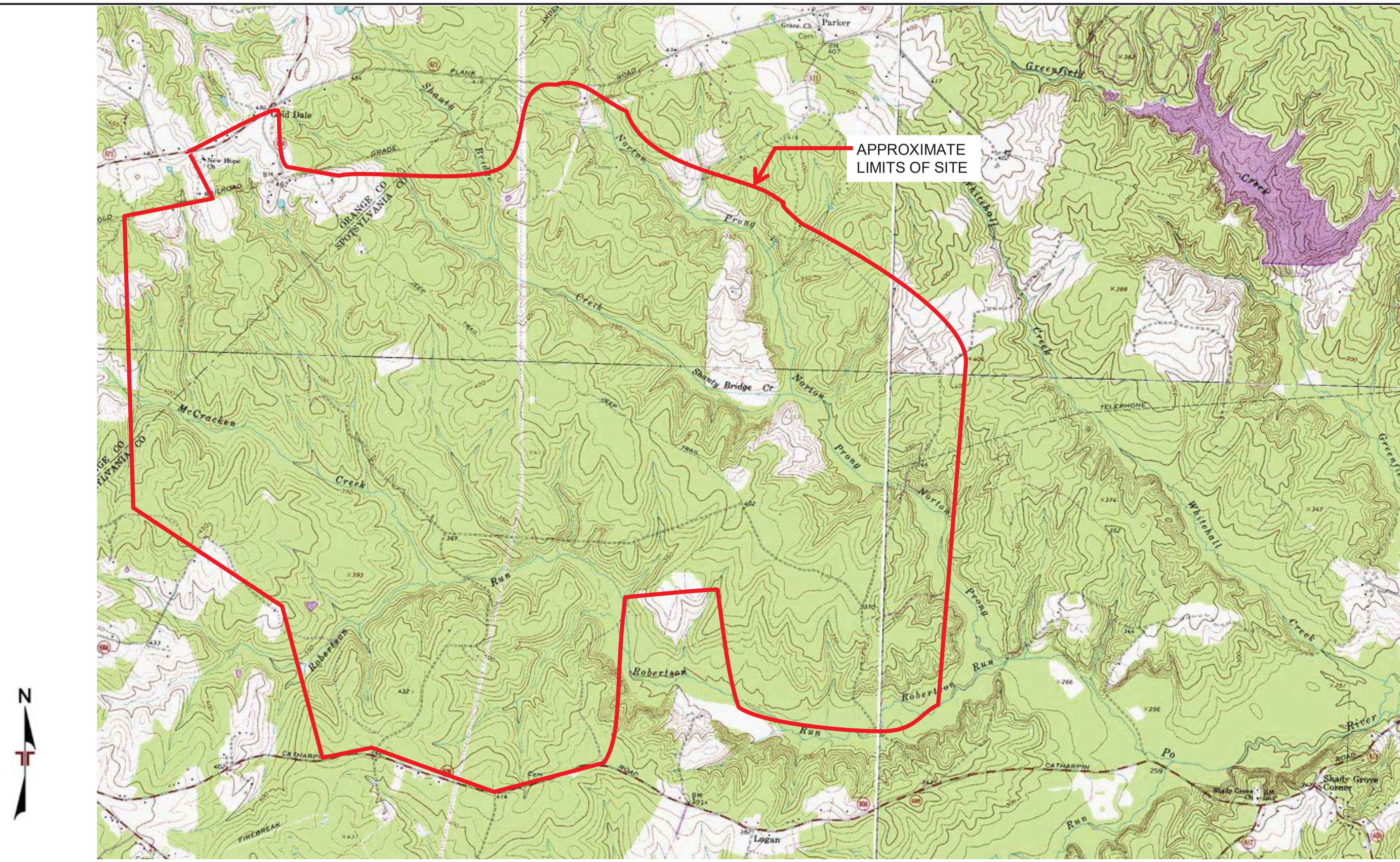



DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

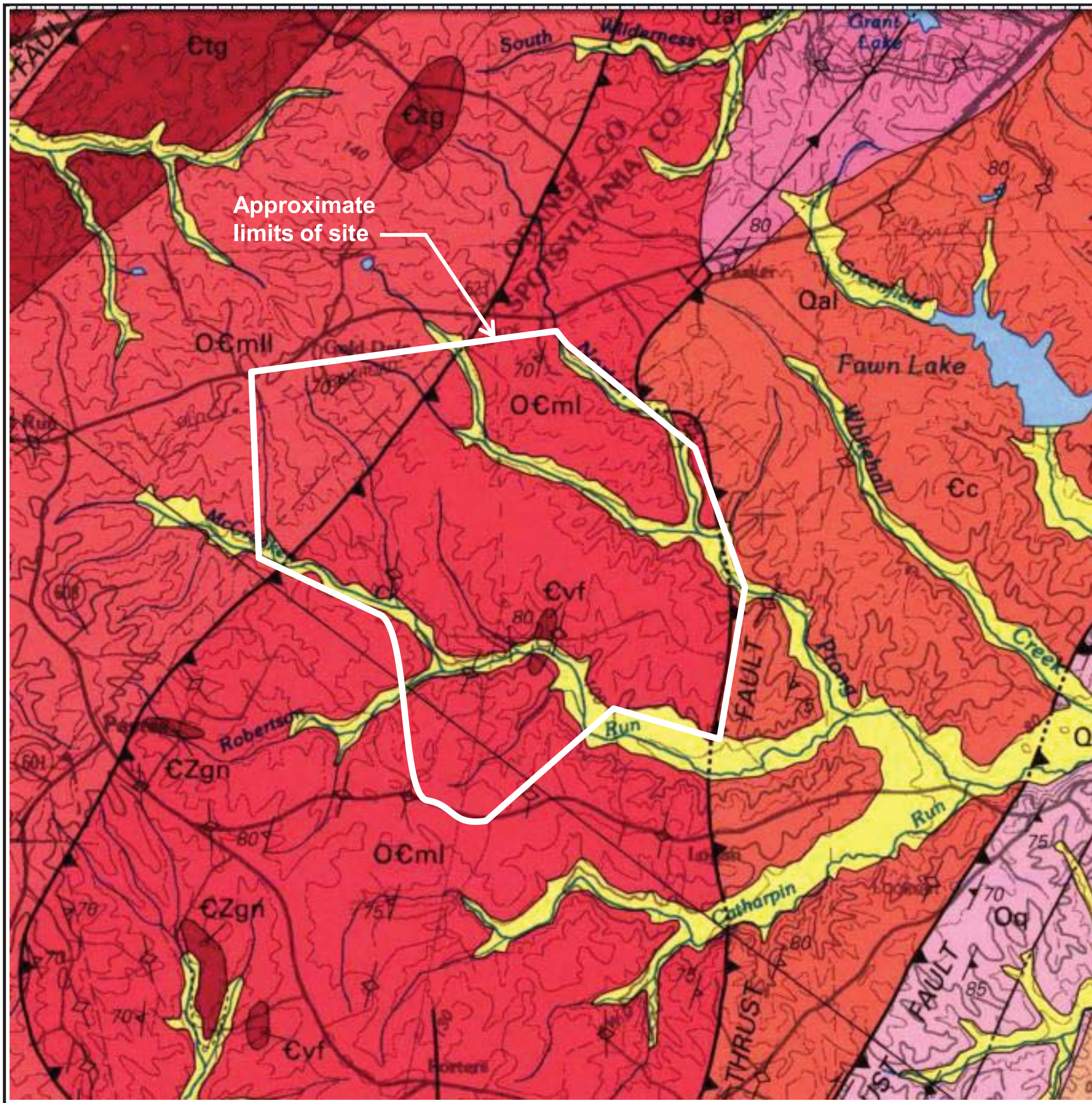
| | | | |
|---|---|---|---|
| Project Manager: NAS | Project No. EY175038 | | |
| Performed by: NAS | Scale: N.T.S. | | |
| Checked by: QK | File Name: TOPO MAP | | |
| Approved by: EHL | Date: 10/27/2017 | | |

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

TOPOGRAPHIC MAP

HIGHLANDER SOLAR
SPOTSYLVANIA AND ORANGE COUNTIES, VIRGINIA

FIG No.
A-2






OꞒmll — Mélange zone II—A thrust slice containing Cambrian(?) felsic (Ꞓvf) and mafic (Ꞓvm) metavolcanic blocks similar to those found in the Chopawamsic Formation; unit also contains Cambrian(?) granitoid blocks of altered tonalite and granodiorite (Ꞓtg). The mélange matrix, which consists of schist and phyllite, generally has crenulation cleavage, indicating that matrix rocks of mélange zone II are more highly deformed than those of mélange zone I

OꞒml — Mélange zone I—Matrix rocks of fine-grained schist and phyllite locally enclose coarse-grained metasandstone beds. Unit includes exotic blocks of felsic (Ꞓvf) and mafic (Ꞓvm) metavolcanic rocks similar to metavolcanic rocks of the Chopawamsic Formation (Ꞓc). Blocks of blastomylonitic tonalite and granodiorite gneiss (ꞒZgn) are present in two separate blocks to the south-southeast of Mine Run

Qal — **Alluvium (Holocene and Pleistocene)**—Gravel, sand, silt, and clay in lenticular layers underlying modern flood plains along streams; yellowish-brown to greenish-gray, fairly well bedded, poorly to moderately well sorted, graded deposits with gravel and sand commonly filling channels at base of upward-fining sequences. Most gravel clasts in streams draining the Piedmont highlands are subrounded greenstone, vein quartz, schist, phyllite, and other crystalline rocks; streams draining the Culpeper basin contain pebbles and cobbles of hornfels, sandstone, siltstone, greenstone, quartz, and diabase. Unit is as much as 6 m (20 ft) thick

Excerpted from the Geologic Map of the Fredericksburg 30'x60' Quadrangle, Virginia and Maryland, 2002 prepared by Mixon, Pavlides, Powars et al.

| | | | | |
|---|---|---|---|---|
| Project Manager: NAS | Project No. EY175038 | Terracon Consulting Engineers & Scientists | GEOLOGIC MAP | FIG No. |
| Performed by: NAS | Scale: JMK | 20401 Seneca Meadows Pkwy, Germantown, MD 20876 | HIGHLANDER SOLAR | A-3 |
| Checked by: QAOK | File Name: | PH. (301) 354-6100 FAX. (301) 354-6101 | Spotsylvania and Orange Counties, Virginia | |
| Approved by: MN | Date: 10/27/17 | | | |

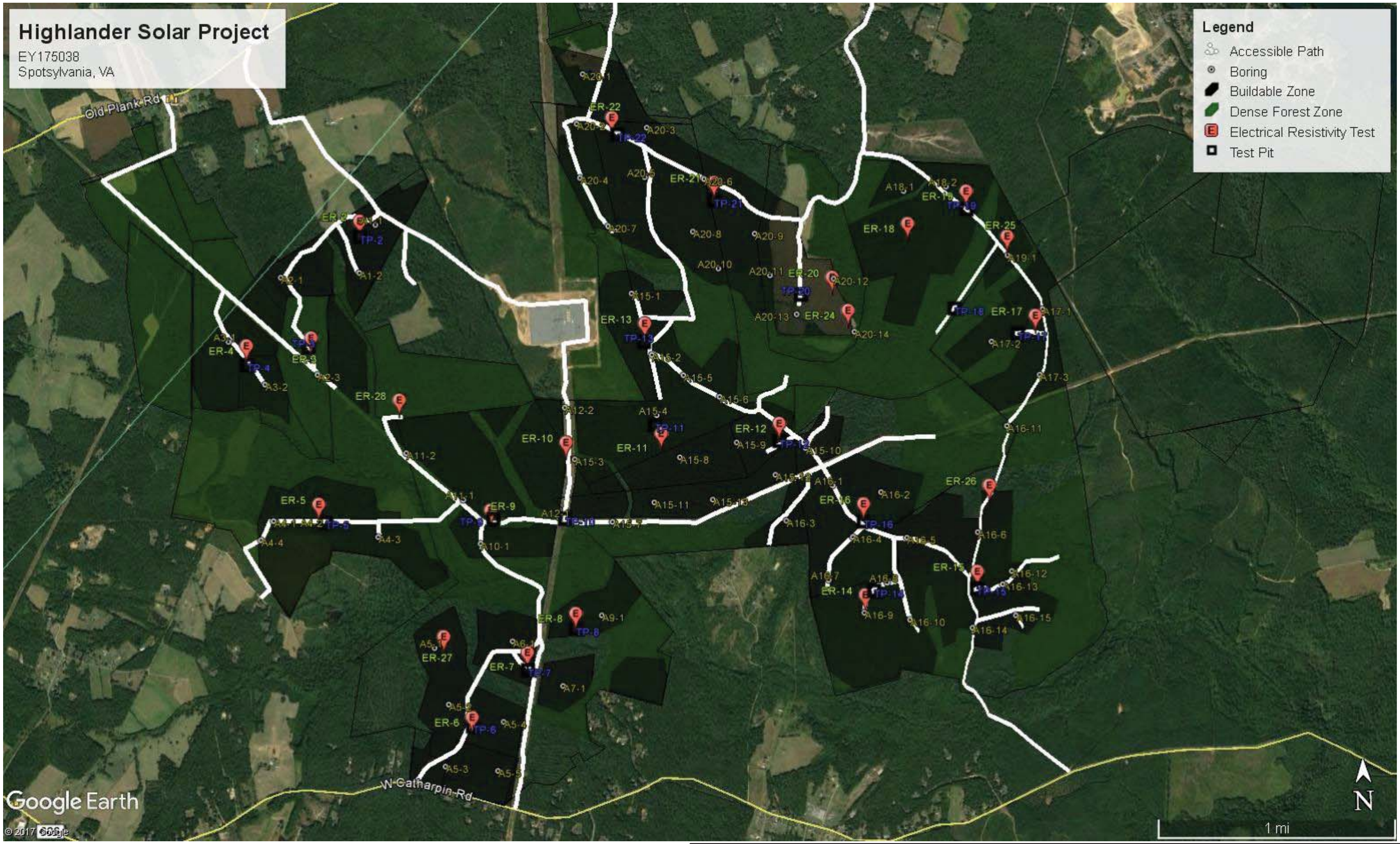



DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

| | | | | |
|---|---|---|---|---|
| Project Manager: NAS | Project No. EY175038 | Terracon Consulting Engineers & Scientists | EXPLORATION LOCATION PLAN | EXHIBIT |
| Prepared by: CV | Scale: N.T.S. | 20401 Seneca Meadows Pkwy Germantown, MD 20876 | HIGHLANDER SOLAR PROJECT | A-4 |
| Checked by: NAS | File Name: BLPEY175038 | PH. (301) 354-6100 FAX. (301) 354-6101 | SPOTSYLVANIA, VIRGINIA | |
| Approved by: NAS | Date: 10/27/17 | | | |