REPORT

Groundwater Exploration Report

Keswick Estates, Albemarle County, Virginia

Submitted to:

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Submitted by:

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1792070

May 14, 2018

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LIST OF FIGURES

(Figures provided after report text)

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1.0 INTRODUCTION

Golder Associates Inc. (Golder) is pleased to present Timmons Group and Keswick Estates with this technical groundwater exploration and well siting report. The purpose of this study is to provide assistance by recommending and ranking the probable best available sites on the property to drill a new public water supply well based on the results of a preliminary hydrogeologic investigation and an electrical resistivity imaging (ERI) geophysical survey. Our company has been successful in locating and developing high yield water supply wells throughout Virginia, including in eastern Albemarle and western Louisa County.

1.1 Background

Keswick Estates is located along Interstate 64 in eastern Albemarle County, Virginia (Figure 1). A community water system is sourced by four existing public water supply wells, two of which (Wells 1 and 4) are currently active and produce about 40 gallons per minute (gpm). The public water supply wells are located on a 12+-acre property along Club Drive at the entrance to Keswick Estates. Keswick Estates would like to locate another well on this property with a sustainable yield of at least 40 gpm.

1.2 Geology

The main geologic formations that underlie the well site from west to east include the Candler Formation, the Everona Limestone, and the Mine Run Complex (Figure 2).

- **Candler Formation (Cca)** consists of medium to dark-gray and greenish-gray, mica phyllite, metagraywacke, and laminated schist. These rocks are fine-grained, weather to a medium brown and have penetrative foliation and some relict compositional layering dipping mostly to the southeast. Water-producing characteristics are considered poor. Water may be hard with local elevated iron and manganese concentrations.

- **Everona Limestone (Cev)** lies along a narrow linear topographic depression that can be traced southwest to northeast throughout the region. It consists of thinly-laminated medium-bluish-gray limestone with graded, graphitic silty partings and includes calcareous graphitic phyllite, and pyrite bearing graphitic slate. The Everona occurs dominantly as lenticular bodies immediately northwest of or within the Mountain Run fault zone. Unit thickness and degree of lateral continuity are structurally controlled, and generally ranges in thickness from 20 to 1100 feet (~<600 feet). Water-producing characteristics of this formation are considered to be good to excellent with reported yields regionally ranging from 15 to 150 gpm. Water may be moderately to strongly hard and is typically low in iron. Karst conditions may exist and therefore the formation is susceptible to producing groundwater under the influence of surface water which would require treatment as a surface water source. The Everona is the target formation on this property and should be targeted by wells east of the Mountain Run Fault where the Everona Limestone dips beneath and is more protected by confining rocks of the Mine Run Complex.

- **Mountain Run Fault Zone** is a highly fractured and sheared zone of polydeformed (mylonite) rocks of the Mine Run Complex, Everona Limestone and Candler Formation. The fault dips southeast and juxtaposes rocks of the Mine Run Complex in the hanging wall over rocks of the Everona Limestone and Candler Formation in the footwall of the fault. Movement on the fault is low angle reverse (thrust) and right lateral strike slip. The fault zone was targeted by Well 2 which does not produce as much water as Wells 1 and 4 which are located further to the east. At Well 2, it is suspected that the Everona Limestone is too shallow or not present, and that the fractures within the fault zone are likely annealed by the mylonitized fabric and the fine-grained textures of the Candler Formation.

- **Mine Run Complex (mrc)** Cambrian rocks of the Mine Run Complex lie east of the Everona Limestone and the Mountain Run fault zone and consist of Cambrian age mica schist, phyllite, meta-graywacke. Also, mapped as CZpm, metagraywacke, quartzose schist, and mélange. These rock formations have poor water-producing characteristics with typical well yields ranging from 15 to 40 gpm. Although the Mine Run Complex is mapped over most of the site, it is believed that it may have been eroded, exposing the underlying Everona Limestone over much of the central lowland portion of the site.

1.3 Scope of Work Completed

The ERI survey consisted of five ERI survey lines oriented generally west to east across the property as shown in Figure 2. The ERI survey lines were slightly over 800 feet long and consisted of 56 individual electrodes spaced every 15 feet.

1.4 Limitations of Geophysical Methods

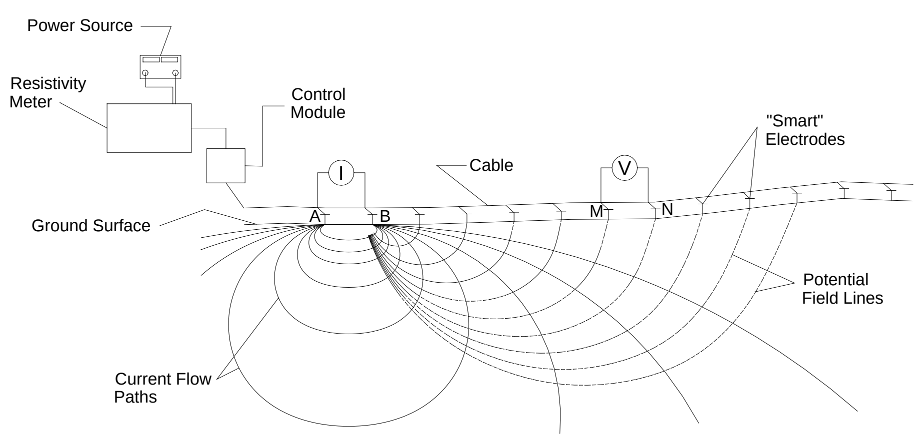
Geophysical methods provide information about the physical properties of the earth's subsurface. Accurate interpretation of geophysical data relies on the site-specific correlation of information with that obtained from drilling or other direct observation methods. The geophysical methods employed on this project may not detect all subsurface features, geologic contacts, or hydrogeologic/geotechnical features. It is possible that interpreted features may upon intrusive sampling prove to have been misinterpreted and the depth of investigation may not accurately resolve desired features at depth.

2.0 ELECTRICAL RESISTIVITY IMAGING PROCEDURES

Golder Associates conducted an electrical resistivity survey in order to identify, characterize, and attain greater precision in locating hydrogeologic features in the subsurface that may assist in a greater understanding of the interconnected groundwater system. The electrical resistivity of a geological formation is a measure of the resistance to an applied electrical current. Under saturated conditions, the resistivity is largely dependent on the density and porosity of the material and the salinity of the saturating fluids. Since water is a good conductor, electricity is transmitted more readily through a rock formation with a large concentration of open saturated fractures. As a result, fracture zones filled with water will have a lower electrical resistivity than the surrounding dry unfractured rocks.

To conduct an electrical resistivity survey, an electric current is passed into the ground through a pair of current electrodes and the potential drop is measured across a pair of potential electrodes. The apparent resistivity of the earth material between the electrodes is calculated on the basis of the measured potential drop, the applied current, and the electrode spacing. The electrodes are automatically moved down a survey line to determine the lateral variations in resistivity at a given depth of penetration. Because the electrode spacing controls the depth of penetration, the spacing can be progressively increased to determine resistivity variations with depth. By combining both horizontal and depth profiling methods, a cross-section of the lateral and vertical variations in apparent resistivity along that survey line can be constructed

Numerous configurations of electrode placement are commonly employed, each with unique data characteristics. A dipole-dipole configuration was utilized for this study (see inset). For the dipole array, a current is applied to two adjacent electrodes positioned a predetermined distance apart (distance *a*). The voltage across two other electrodes is measured simultaneously with the applied current. The two sets of electrodes are always spaced distance *a* apart and the distance between the current and voltage electrodes is always a multiple of *a* ($n \bullet a$).



"DIPOLE-DIPOLE" ARRAY

The electrical resistivity surveys were conducted using the SuperSting R8™ automatic resistivity imaging systems. With automatic resistivity systems, multiple electrodes are connected to stainless steel stakes that are pounded into the ground. The electrodes are attached to a multi-core cable, which is connected to an electronic switching unit and a resistivity meter. The switching unit automatically selects the appropriate four electrodes for each measurement. The number of electrodes used and the spacing between electrodes vary based on desired resolution, depth of penetration and the length of survey line possible on each site. Measurements are initiated at one end of the line and incrementally moved through the electrodes until readings have been taken at every position along the line.

Once the resistivity data is collected, it is downloaded to a laptop computer, processed and interpreted. The resistivity value measured in the field is not the true resistivity of the subsurface, but an "apparent resistivity" value because it is a combination of all the subsurface material and contained fluids along the entire path of the electrical current. To determine the true subsurface resistivity, apparent resistivity values have to be processed using inversion and forward modeling techniques. This was completed using the EarthImager™ computer programs, both of which uses a least-squares linear inversion techniques to generate a model of predicted two-dimensional resistivity values along the profile, which can then be contoured to evaluate spatial trends in subsurface resistivity values.

3.0 ELECTRICAL RESISTIVITY IMAGING RESULTS

The interpretative results of the electrical resistivity imaging profiles (i.e., 2-D vertical cross sections of electrical resistivity values) using the dipole-dipole array are illustrated in Figures 3 through 5. All figures have the same electrical resistivity scale for ease of comparison. ERI lines 1, 2 and 3 are oriented west to east across geologic strike and should therefore cross over subsurface exposures of the Candler Formation, the Everona Limestone, the Mountain Run Fault, and the Mine Run Complex. ERI lines 4 and 5 are oriented southwest-northeast, sub-parallel to geologic strike and should target cross-strike fault/fracture zones, the mapped diabase dike, and subcrop areas of the Everona Limestone and Mine Run Complex.

Modeled resistivity values range from less than 10 ohm-meters to over 6,000 ohm-meters. Most of the modeled ERI profiles show a three layer model with 1) surficial shallow high resistivity soil beneath upland areas, likely representing dry soil and weathered bedrock above the water table, 2) low resistivity clayey soil and weathered bedrock below the water table, and 3) moderate to high resistivity bedrock. Areas below the suspected bedrock interface with low resistivity values in the range of the overlying soil and weathered bedrock material are likely indicative of areas of increased fracture porosity, and greater water saturation (i.e., water-bearing fracture zone). Water-bearing fracture zones have higher saturated fracture porosity and therefore have a lower electrical resistivity and are more electrically conductive than the surrounding less fractured drier rock. These low resistivity zones (LRZs) are often favorable targets for locating and drilling water supply wells. Interpretations of individual ERI profiles are provide below.

<u>ERI Line 1</u> – (Figure 3) is oriented west to east across the southern most portion of the site along the wood line north of Interstate 64. This profile shows shallow low resistivity values in the central area likely underlain by weathered Everona Limestone. A deep, possibly southeast-dipping LRZ is seen at the bottom of the profile. The feature may relate to enhanced fracturing and possible solution-widening of bedding planes or faulting within the Everona Limestone and is considered a favorable target for a water supply well. A test well site, **TW1-26**, has been selected to target this feature.

<u>ERI Line 2</u> – (Figure 3) is oriented west to east across the field just south of Club Road and north of the Helipad. This profile shows a strong vertical LRZ at the mapped location of the Mountain Run Fault (MRF). This feature would be considered a potentially favorable target except that Well 2 is in this area, less than 20 feet away, and may be causing the false ERI anomaly due to interference with the steel casing of the well. Another cultural anomaly dominates the central portion of the profile between electrodes 26 and 35. No test wells were selected along ERI Line 2.

<u>ERI Line 3</u> – (Figure 4) is oriented west to east emerging from the woods in front of the treatment and controls building. A vertical high resistivity feature is observed on the ERI profile in the vicinity of where a diabase dike is mapped. A vertical LRZ is modeled just east of this feature. This could be an area of enhanced fracturing and limestone solutioning near the cooling contact zone from the diabase dike. Such contacts are often favorable locations to drill water supply wells. A test well, **TW3-45** has been selected to target this feature.

<u>ERI Line 4</u> – (Figure 4) is oriented southwest-northeast across the field east of Club Road. This ERI line follows a mapped fracture trace, which may represent an area of increased bedrock fracturing, and therefore a well located anywhere along this line may be a favorable target. There are no strong LRZs however along the line. Regardless, a test well, **TW4-36.5** targets a subtle sub-vertical LRZ and deep lower resistivity zone at the bottom of the profile.

<u>ERI Line 5</u> – (Figure 5) is oriented parallel to and approximate 60 to 80 feet southeast of the Mountain Run Fault. This line is meant to target favorable hydrogeologic features in the Everona Limestone where it subcrops beneath the fault zone and overlying confining phyllites of the Mine Run Complex. The surficial low resistivity observed in this profile suggests that there is no Mine Run Complex here and that weathered Everona Limestone is exposed near the ground surface. A moderately large circular LRZ was observed at the bottom of the profile near the beginning of ERI line 5. A test well, **TW5-14,** targets this feature.

4.0 RECOMMENDATIONS

Four recommended test well sites have been located based on the results of the geologic and geophysical analysis of this property and are shown in Figure 6. The test well sites have been ranked in descending order of favorability based on hydrogeologic attributes including topographic position, proximity to fracture traces, and the proximity and nature of the targeted low resistivity zone. The ranking is as follows:

Ranking	Test Well	Latitude	Longitude
1	TW1-26	37.999617	-78.344479
2	TW3-45	38.000579	-78.343514
3	TW4-36.5	38.000229	-78.342750
4	TW5-14	38.000118	-78.344812

It is recommended that exploratory 6-inch diameter test wells be drilled at each of these sites progressively until a well with sufficient yield to meet the needs of the development is discovered. The test well should be converted into an 8-inch Class IIB or possibly Class I public water supply well that meets the minimum Virginia Department of Health well construction requirements.

Signature Page

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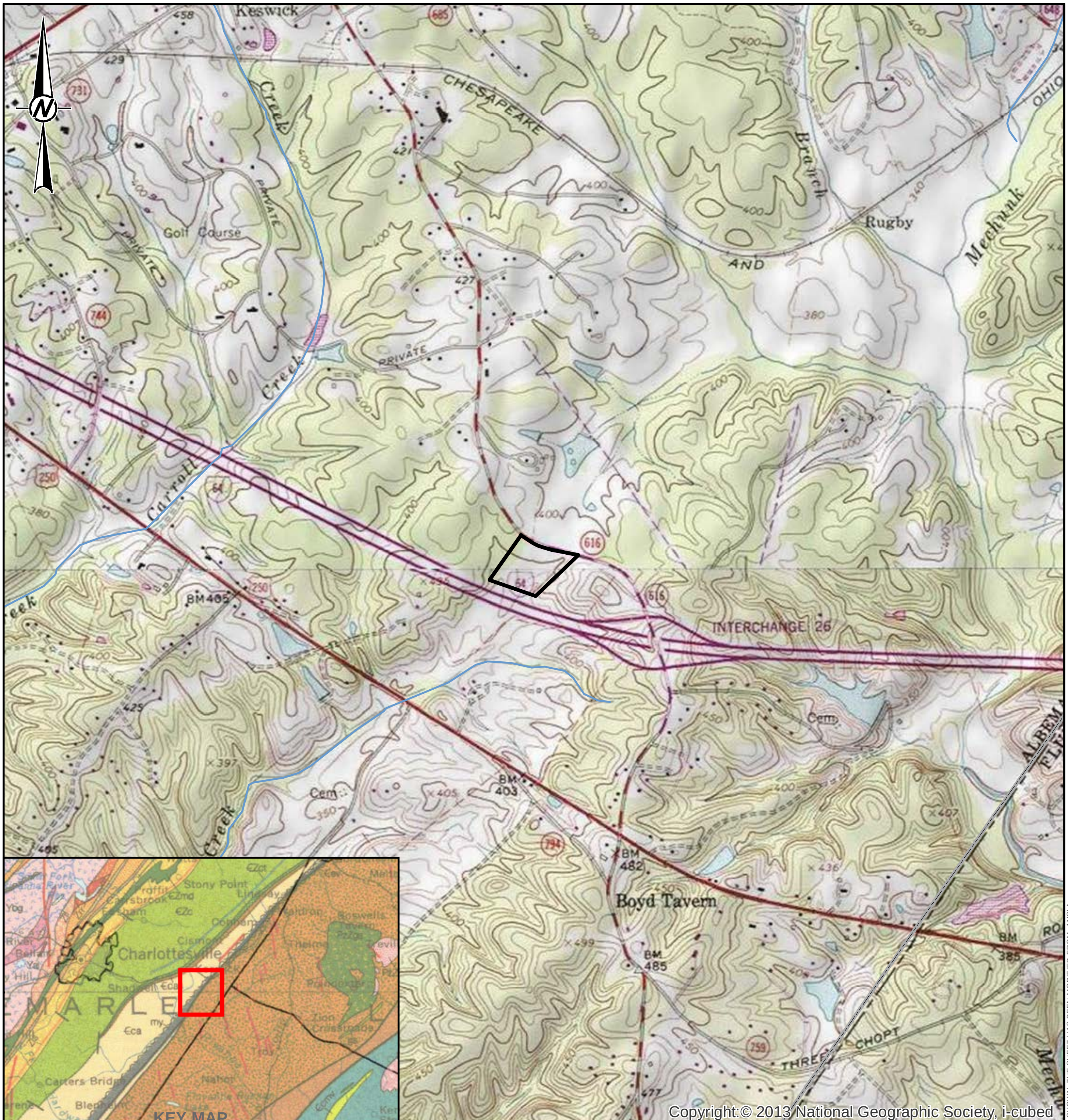

0 1,000 2,000 4,000 Feet
1 inch = 2,000 feet

LEGEND

Site Boundary

NOTES

1. SITE BOUNDARY WHERE CURRENT PUBLIC UTILITIES ARE LOCATED

REFERENCE

AERIAL PHOTO BASE MAPPING PROVIDED BY ESRI (WWW.ESRI.COM)
PROJECTION: NAD 1983 STATE PLANE VIRGINIA SOUTH FEET

CLIENT
TIMMONS GROUP &
KESWICK ESTATES

PROJECT
GROUNDWATER EXPLORATION & WELL SITING STUDY

TITLE
GENERAL LOCATION MAP
KESWICK ESTATES PUBLIC UTILITY PROPERTY

CONSULTANT	2108 W. LABURNUM AVE., SUITE 200 RICHMOND, VIRGINIA, USA, 23227	YYYY-MM-DD	2018-05-10
GOLDER		PREPARED	MGM
		DESIGN	MGM
		REVIEW	BBW
		APPROVED	BBW

PROJECT No.	PHASE	Rev.	
1792070	100	01	1

Path: G:\Projects\Timmons\1792070 Keswick\GIS\MXDs\Figure 1 - General Location Map.mxd

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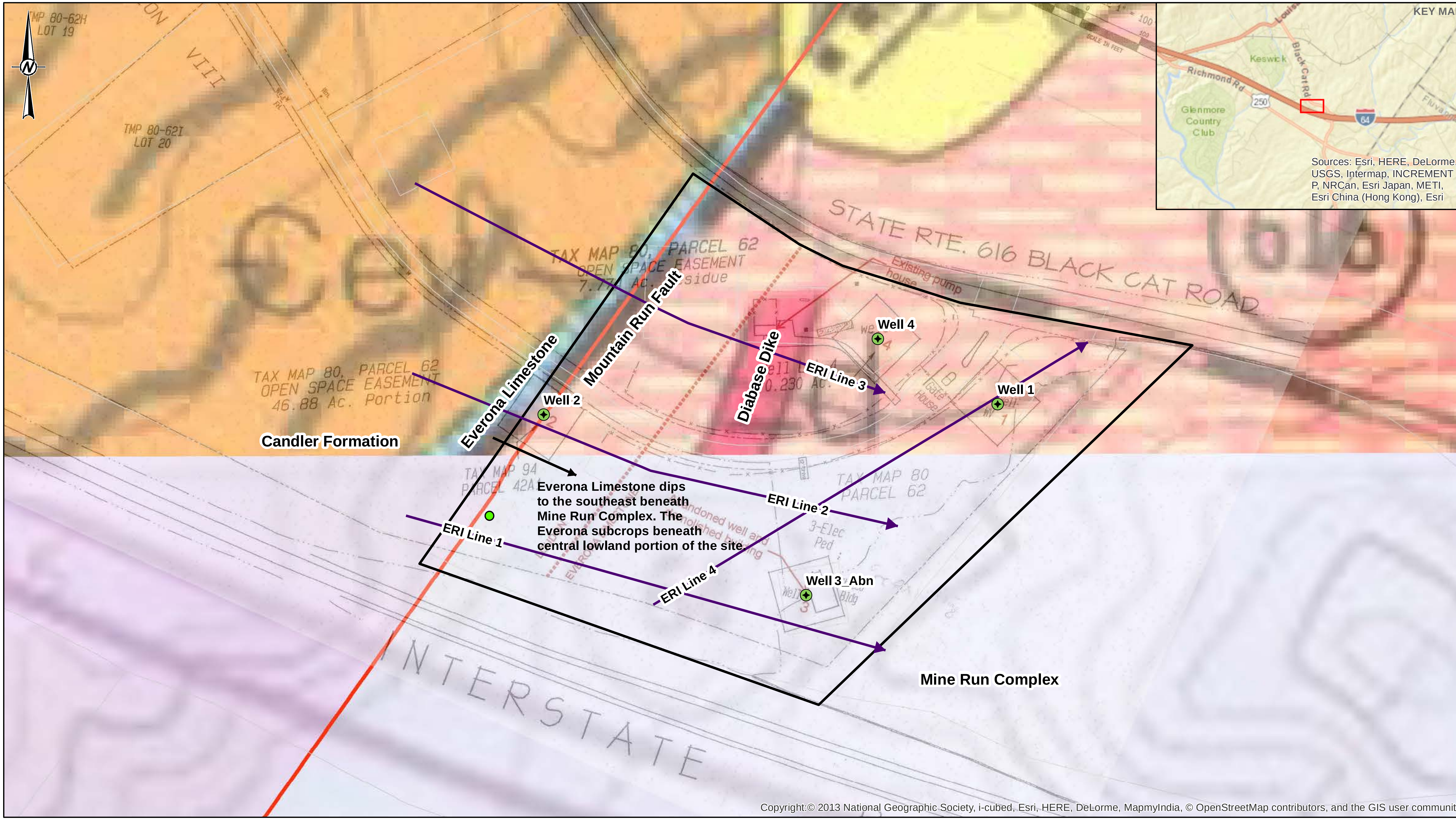

LEGEND

- Keswick Wells
- ERI Survey Lines
- Site Boundary

NOTE(S)
1. GEOLOGY FROM ROSSMAN (1991) AND VDGMR (1992)

REFERENCE(S)
SOURCE: AERIAL PHOTOGRAPHY/DIGITAL TOPOGRAPHY PROVIDED BY ESRI ONLINE SERVERS (WWW.ESRI.COM).
PROJECTION: NAD 83 STATE PLANE FOR VIRGINIA SOUTH IN FEET

0 60 120 240 360 480 Feet
1 inch = 150 feet

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PROJECT
GROUNDWATER EXPLORATION &
WELL SITING STUDY

TITLE
GEOLOGIC MAP AND GEOPHYSICAL SURVEY LINES

PROJECT NO.	PHASE	REV.	FIGURE
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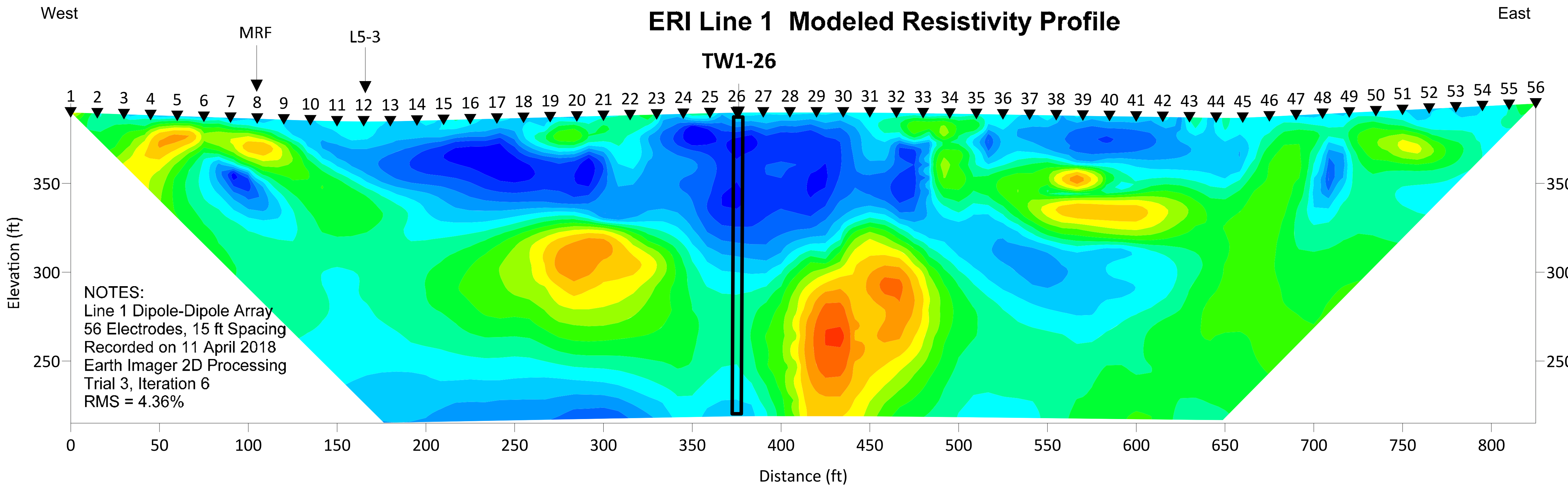

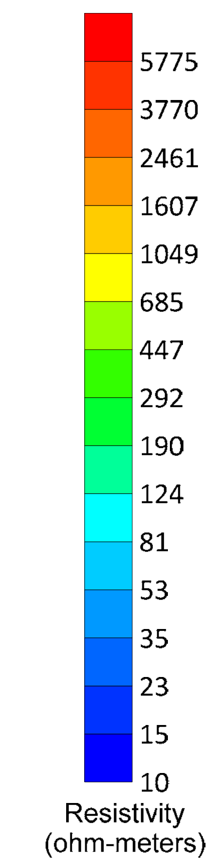

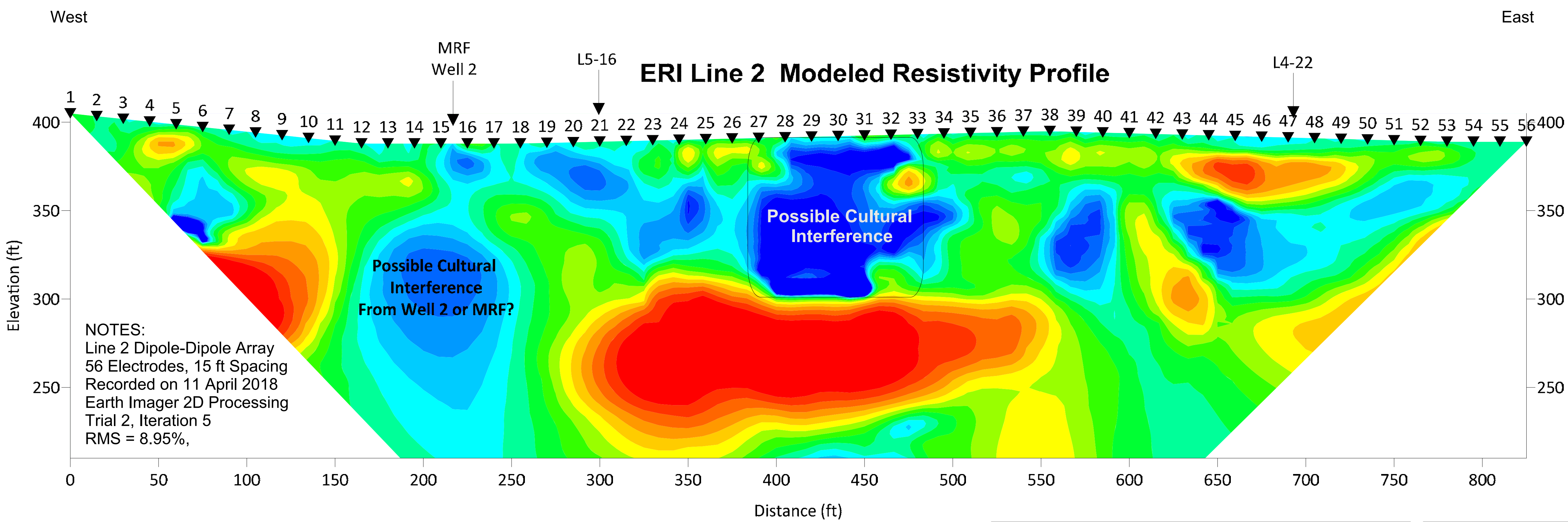

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Electrode number = ▼

NOTES: Electric resistivity profiles were derived through reverse modeling techniques using AGI's EARTHIMAGER software package. Resistivity data was collected using AGI's SuperSting R8 56 electrode automatic resistivity system.

CLIENT
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PROJECT
Well Siting Study
Keswick Estates

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PREPARED	MGM
DESIGN	MGM
REVIEW	BBW
APPROVED	BBW

TITLE
ERI Profiles 1 and 2

PROJECT No.	Phase	Rev.	Figure #
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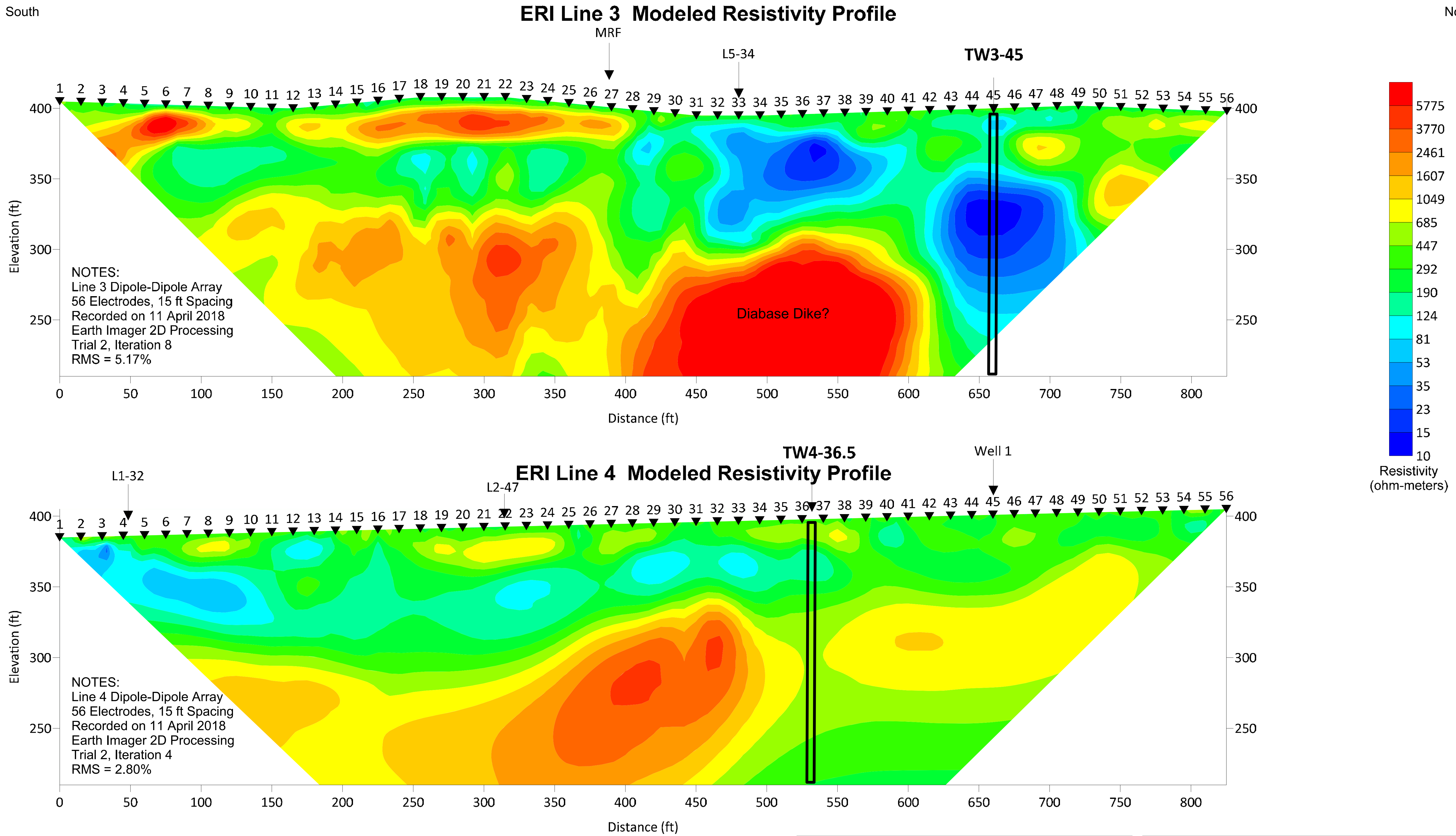

Legend

Electrode number = ▼

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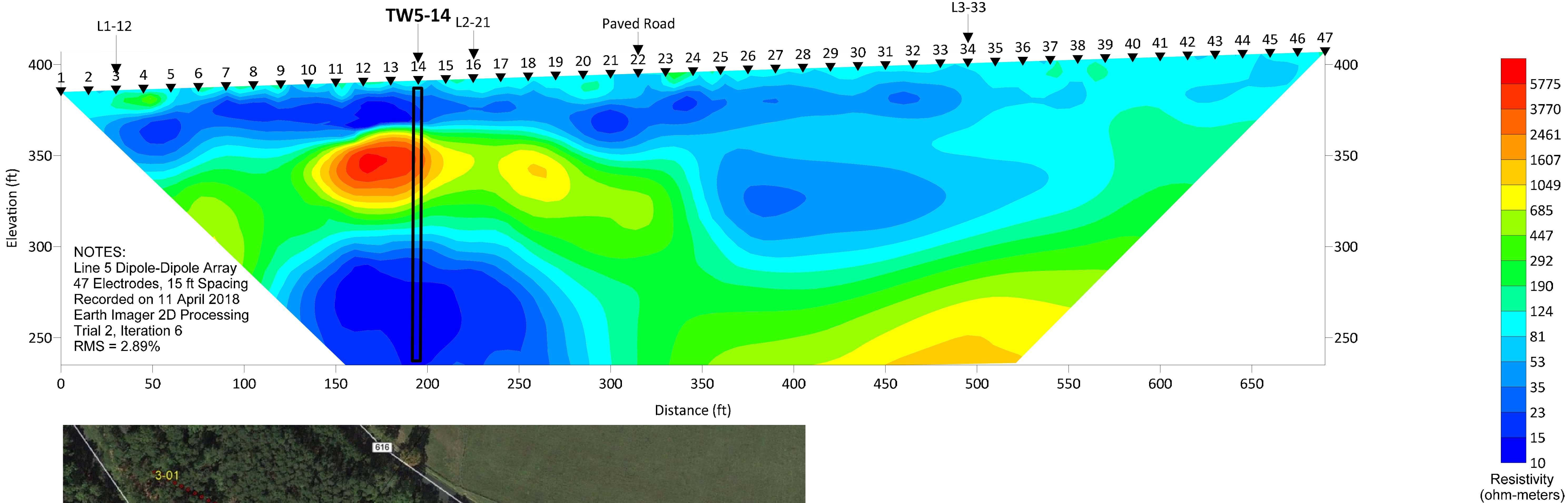
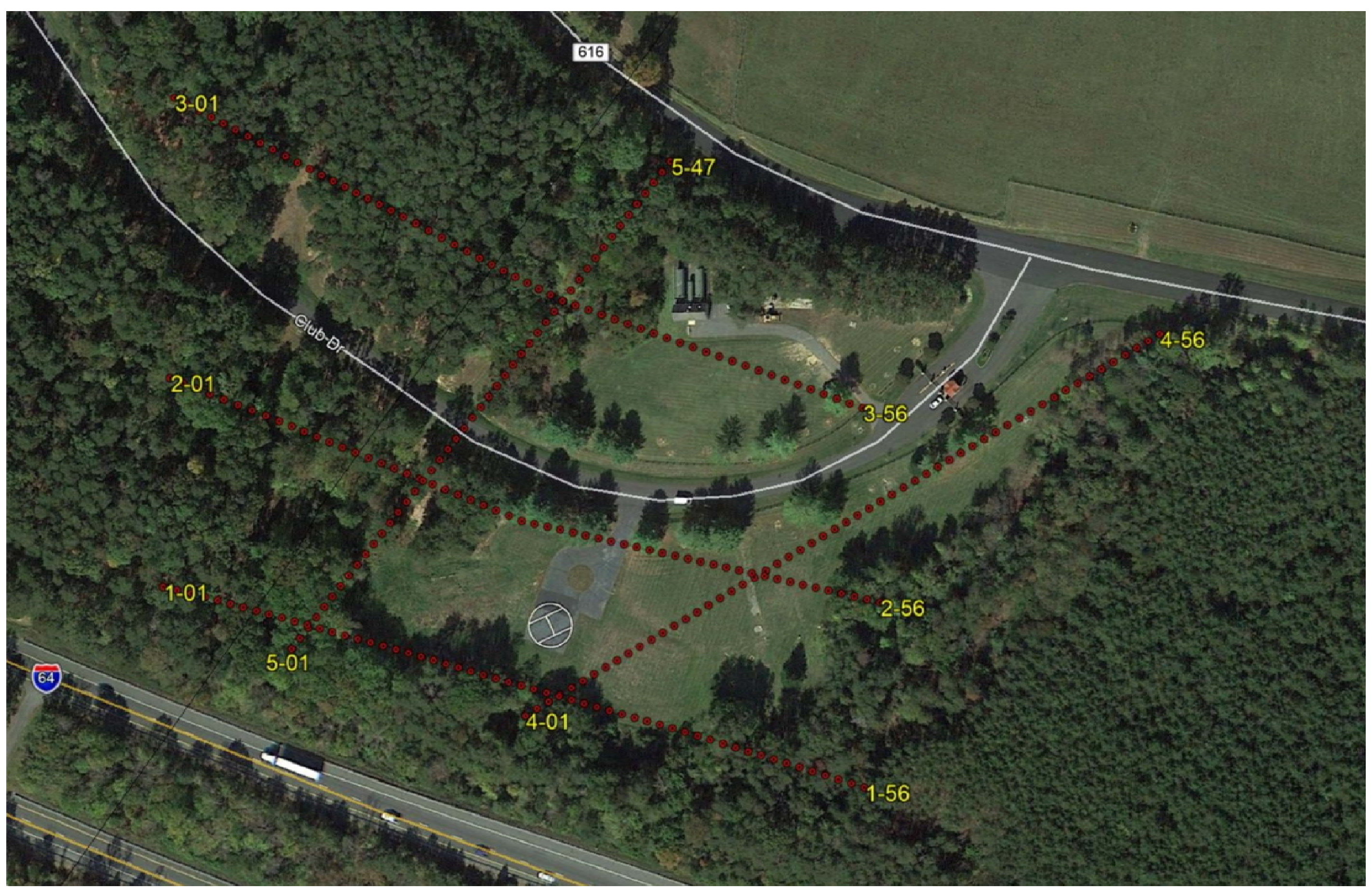
DESIGN	MGM
REVIEW	BBW
APPROVED	BBW

TITLE
ERI Profiles 3-4

PROJECT No.	Phase	Rev.	Figure #
1792070	100	1	3

ERI Line 5 Modeled Resistivity Profile





Legend

Electrode number = ▼

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PROJECT
Well Siting Study
Keswick Estates

TITLE
ERI Profile 5

PROJECT No.	Phase	Rev.	Figure #
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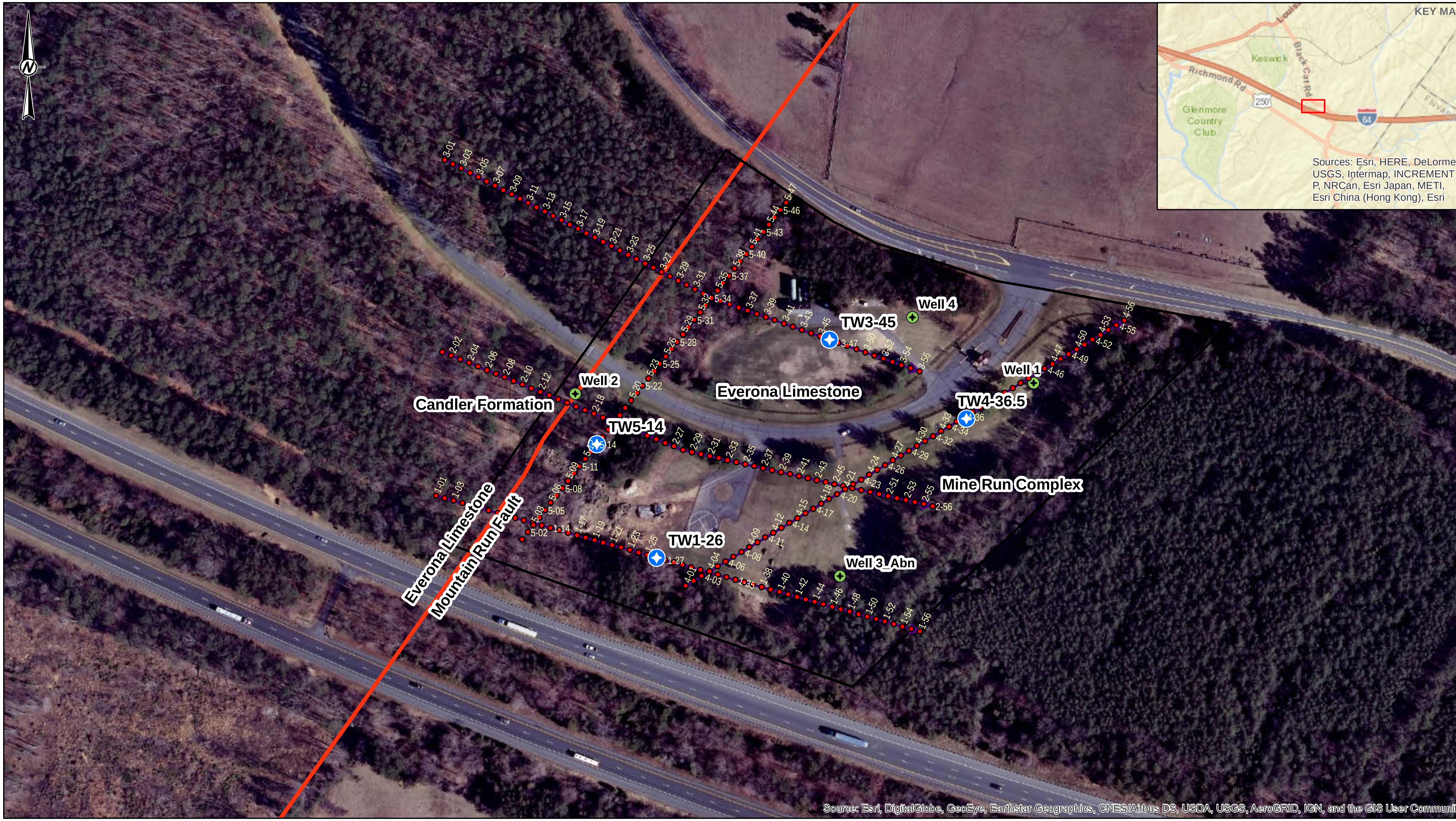

LEGEND

- Keswick Wells
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NOTE(S)

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PROJECT
GROUNDWATER EXPLORATION &
WELL SITING STUDY

TITLE
RECOMMENDED TEST WELL LOCATIONS

PROJECT NO.	PHASE	REV.	FIGURE
1792070	100	01	6

PATH: G:\Projects\Timmons\1792070 Keswick\GIS\MXDs\Figure 6 - Test Well Location Map.mxd

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