REPORT
ELECTRICAL RESISTIVITY SURVEYS FOR INVESTIGATION OF HYDROGEOLOGIC CONDITIONS AT DUCOMMUN AEROSTRUCTURES, INC.

4001 EL MIRAGE ROAD
ADELANTO, CALIFORNIA

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1.0 INTRODUCTION

This report presents the results of the electrical resistivity surveys completed by Advanced Geoscience, Inc. at the referenced Ducommun Aerostructures (DAS) site. These surveys used the transient electromagnetic (TEM) sounding method to prepare two-dimensional profiles of subsurface electrical resistivity layering.

In accordance with the recommendations in the 2016 Off-Site CPT Assessment Report prepared by Accord Environmental, subsurface electrical resistivity surveying was performed across the site and adjacent property located to the north of El Mirage Road. These geophysical measurements were recorded along a series of eight “survey lines” set up across the area (designated as Lines 1 through 8). Figure 1 shows the final positioning of these survey lines. The data from these measurements was used to prepare 2D profiles of earth electrical resistivity layering to investigate hydrogeologic conditions in the upper 300 feet. The resistivity profiles were evaluated to help 1) delineate higher electrical conductivity plumes in the upper aquifer system from 50 to 130 feet (15.2 to 39.6 meters) below the ground surface, 2) detect wider sand channels in the alluvial fan sequence of the upper aquifer, and 3) better profile the basal clay aquitard layer.

TEM resistivity surveying has been used extensively by Advanced Geoscience and others such as Taylor (1992) for investigations of hydrogeologic conditions and groundwater quality. In areas where there is mostly horizontal subsurface layering the one-dimensional, resistivity-versus-depth profiles derived from TEM soundings compare well with long-normal resistivity profiles from borehole electric logs.

The following sections summarize our field survey procedures and methods of data processing and display. The concluding sections provide a summary of area hydrogeology and a discussion our current evaluation of hydrogeologic conditions based on the electrical resistivity profiling across this area.

2.0 SURVEY PROCEDURES

Advanced Geoscience mobilized a survey crew and TEM equipment to the site and conducted the field surveys from September 12 through 21, 2018, with a total of 270 man-hours of field work. The survey crew consisted of Mr. Mark Olson, Advanced Geoscience’s Lead Geophysicist and two other geophysical survey specialists.

The TEM equipment used for these surveys was leased from the manufacturer Geonics, Ltd. in Canada. Prior to shipping, the equipment was tested to make sure it was properly calibrated and in good working order.

At the start of the field survey we walked the site and discussed the set up and positioning of the survey lines with Dr. Ian Jones of Accord Environmental. It was pointed out that the TEM survey lines planned for the area between the DAS building and El Mirage

Road would encounter galvanic interference from fencing, overhead electrical power lines, pipelines, and other near surface metal objects. To avoid this interference it was decided that the down gradient survey lines would be positioned north of El Mirage Road to investigate hydrogeologic conditions associated with the off-site groundwater contaminant plumes. It was also decided that the TEM soundings should be set up and recorded along the survey lines to provide the best possible lateral resolution for delineation of sand channels within the saturated alluvium. This required that the TEM soundings be conducted at 50-foot (15.2-meters) or less intervals along the survey lines.

The TEM soundings were conducted using a Geonics TEM47 transmitter and Protem digital receiver. Square wire "transmitter loops" measuring 20 by 20 meters (65.6 by 65.6 feet) were set up along the survey lines at each sounding point to transmit an on-off pulsed current pattern into the wire loop. This pulsed current pattern induced electrical "eddy" currents into the earth that were measured by a receiver coil positioned outside the transmitter loop. Following procedures recommended by Geonics, the TEM data were recorded from various receiver coil positions offset from the edge of the transmitter loop, using various transmitter current frequency rates and output current settings. Based on this testing on Line 1 we decided to use the following recording parameters for the TEM soundings.

Receiver Coil Position on Transmitter Loop Center Line (from Tx Center)	**Transmitter Frequency Rates (Hertz)**	**Type of Geonics Receiver Coil Used**	**Current Output (Amps)**
21 meters (68.9 feet)- Outside loop on the survey line	75 and 285	High Frequency	2.7

The TEM soundings were first conducted along Line 1. Line 1 was positioned to the south of the DAS building and located up gradient from the groundwater contaminant plumes. The TEM soundings were recorded at 50-foot (15.2-meter) intervals (stationing points) along this 1,100-foot (335.3-meter) long survey line shown in Figure 1. After discovering a north-south pipeline near station 0 it was decided to begin recording the soundings on Line 1 at station 100 to avoid interference from this pipeline.

The down gradient surveys north of El Mirage Road were continued along Lines 2 through 7 shown in Figure 1. The TEM soundings along these 1,000 to 1,250-foot (304.8 to 381-meter) long survey lines were recorded at 25 and 50-foot (7.62 and 15.2-meter) intervals. On the last day of the field surveys we attempted to record TEM soundings along Line 8 positioned near El Mirage Road; however, the presence of the overhead power lines and subsurface utility lines running along both sides of El Mirage Road caused galvanic interference in all of these soundings. This interference was visible in the data displays shown on the Protem receiver. Similar interference (in various degrees of severity) was also observed in the TEM soundings located at the beginning and ends of Lines 2 through 5. A Geonics EM-31 terrain conductivity meter was used to detect the metal pipelines positioned along the dirt road causing the interference near stations 0 and

50 on Lines 2 through 5. Lines 6 and 7 also showed some interference from the above ground irrigation watering system crossing over these lines.

During the TEM surveys the distance stationing along the survey lines was staked on the ground and mapped on to a site map with a Brunton pocket transit compass and 300-foot (91.4-meter) measuring tape. In addition a WAAS-corrected, global positioning system (GPS) was also used to measure the State Plane coordinates of distance stationing along the survey lines at 100-foot (30.5-meter) intervals.

3.0 DATA PROCESSING AND DISPLAY

The data from the TEM soundings on each survey line underwent computer processing using specialized, commercially-tested software to prepare 2D earth resistivity profiles along each line. These 2D resistivity profiles were based on more accurate 1D models of earth resistivity layering calculated for each TEM sounding position. The following steps were used in this data processing.

Step 1

The TEM field data from each survey line were first pre-processed using the Geonics program PROTIX64 to edit the voltage "decay curves" recorded at each sounding point with different receiver gain settings and transmitter frequency rates. These voltage decay curves from each sounding were converted to sets of "apparent resistivity" versus time curves. The apparent resistivity curves were selected and averaged together for the 285, 75, and 30 Hertz transmitter rates and were complied together into a set of Universal Sounding Format (USF) files for each survey line.

Step 2

The TEM sounding data in these USF files underwent computer modeling using the program IX1D developed by Interpex, Ltd. (www.interpex.com/ix1dv3/ix1dv3.htm). The apparent resistivity curves from each sounding point underwent several rounds of computer modeling with IX1D to simulate various 1D models of resistivity layering to fit the apparent resistivity curves. Initially, a smoothed, 10-layer model of resistivity layering was calculated for each sounding point on each survey line. This smoothed model was then used to calculate more detailed 18-layer resistivity models that were further refined until a set of 1D resistivity profiles consistent with known subsurface geology and groundwater conditions was obtained for all of TEM measurement points on each survey line. Figure 2 shows two of the 1D resistivity profiles used to simulate the apparent resistivity curves on Lines 6 and 7 at stations 950 and 750.

Step 3

The program IX1D used these 1D resistivity profiles to prepare 2D earth resistivity profiles along each survey line showing resistivity layering in the upper 100 meters (328 feet). Appendix A displays these color contour resistivity profiles generated for Lines 1 through 7. The vertical elevation scale on these profiles is based on our interpolation of the ground surface elevations at each sounding point using a topographic map of the area.

It is noted that not all of the 1D resistivity models generated from the TEM soundings were used to prepare these 2D resistivity profiles. Lines 1 through 7 had a few TEM sounding points that showed greater degrees of interference from nearby buried pipelines and the above ground irrigation watering system. The profiles in Appendix A show the areas where this interference was encountered, and the areas where there are some missing 1D profiles at the beginning and ends of Lines 1 through 5 and in the middle of Lines 6 and 7 where valid 1D resistivity models could not be generated. The 2D resistivity profile along Line 8 was not generated due to the strong interference previously mentioned.

Step 4

To prepare more detailed 2D resistivity profiles of the upper 170 feet (51.8 meters) the set of valid 1D resistivity profiles for each survey line were input into the program Surfer developed by Golden Software (www.goldensoftware.com/products/surfer). Surfer was used to grid and contour the data from the 1D resistivity profiles using the Kriging procedure with a grid cell x=50 feet and y=2 feet (x=15.2 meters and y=0.61 meters). The resulting scaled, west-to-east, color contour earth resistivity profiles for Lines 2 through 7 are shown in Figures 3 through 9. Note that the distance stationing and elevations relative to mean sea level (MSL) are in feet.

It is emphasized that Steps 2 through 4 were repeated several times until the 2D resistivity profiles in Step 4 showed resistivity layering consistent with the known water table depth in the upper aquifer and the elevation profile of the clay aquitard layer. The positions of these surfaces were used as constraints in the IX1D modeling. This hydrogeologic information was made available from the cross sections, lithologic logs, and groundwater data generated from the cone penetrometer tests (CPTs). The resistivity modeling process was first started on Line 5 because it was positioned along a line of several CPTs. Once the basic profile of the resistivity layering was established on Line 5 the IX1D modeling was continued for the other survey lines. Line 5 was therefore used as a control line to help the modeling be consistent with known hydrogeologic conditions based on the CPT data.

The 2D resistivity profiles in Figures 3 through 9 show an overlay of the recent CPT locations, with estimated water table depths, clay and silt layer aquitard depths, and measured “groundwater” resistivity values converted from water sample electrical conductivity measurements. In the saturated alluvium these groundwater resistivity values are always less than the “formation” resistivity layering shown on the profiles.

4.0 EVALUATION OF HYDROGEOLOGIC CONDITIONS

4.1 Summary of Area Hydrogeology

The following provides a brief summary of "known" hydrogeologic conditions beneath the area. This information is summarized from the 2016 Off-Site CPT Assessment Report prepared by Accord Environmental.

The upper groundwater aquifer in this area is an unconfined, perched groundwater system that occurs within the alluvial fan sequence known as the Sheep Creek Fan. In this area the Sheep Creek Fan is mostly finer-grained and formed by large-scale mud flows from the San Gabriel Mountains, which were later incised by surface streams that deposited coarser-grained, sandy material within the finer-grained matrix. A smaller portion of this alluvial sequence was also deposited by valley-axial streams and aeolian processes. Beneath these alluvial deposits an extensive 100 to 150-foot (30.5 to 45.7-meter) thick clay and silt layer exists that was formed by the El Mirage Lake during wetter periods in the past.

The three main hydrogeologic units beneath the area are described below:

1) An upper groundwater aquifer occurs in the alluvial fan sequence to a depth of about 130 feet (39.6 meters) below ground surface (BGS). The water table within this alluvial sequence is approximately 50 to 60 feet (15.2 to 18.3 meters) BGS. This alluvial fan sequence is subdivided into three descending units designated as Qa1, Qa2, and Qa3. Unit Qa2 is further subdivided into units Qa2a, Qa2b, and Qa2c. The depth range and hydrogeologic conditions of these units are described in detail in the 2016 Off-Site Assessment Report.

2) An extensive layer of clay and silt forms a basal clay aquitard beneath the alluvial fan sequence. This aquitard layer extends from approximately 130 to 250 feet (39.6 to 76.2 meters) BGS.

3) A regional groundwater aquifer occurs within a deeper alluvial sequence from approximately 250 to 700 feet (76.2 to 213 meters) BGS.

The natural groundwater gradient in the upper Qa1 and Qa2 units of the aquifer is to the north. The chlorinated hydrocarbon and nitrate contaminant plumes emanating from the DAS facility follow this gradient.

The Qa1 groundwater near the water table has higher concentrations of total dissolved solids (TDS) with electrical conductivities generally between 2,500 to 5,500 µS/cm (micro-Siemens per centimeter). Where irrigation recharge and other anthropogenic inputs are present the TDS and electrical conductivity are often higher. TDS and electrical conductivity generally decrease with depth in units Qa2 and Qa3. The groundwater in the deeper regional aquifer is known to have much lower TDS and electrical conductivity levels.

4.2 Evaluation of Electrical Resistivity Profiles

The deeper 2D resistivity profiles for Lines 1 through 7 in Appendix A show resistivity layering in the upper 300 feet (91.4 meters) BGS that is consistent with the positioning of the three main hydrogeologic units beneath this area. The 1D resistivity models for these profiles all show 1) a lower resistivity (higher conductivity) upper alluvial aquifer layer, 2) a middle, very low resistivity clay aquitard layer, and 3) a deeper regional aquifer layer, as depicted in Figure 2. It is not surprising that the resistivity of this clay aquitard layer is lower than 10 ohm-meters, this is because clays often exhibit electronic conduction in additional to electrolytic conduction and are reported to have resistivity values approaching 1 ohm-m as discussed in Telford (1977).

The detailed 2D resistivity profiles of the upper 170 feet (51.8 meters) in Figures 3 through 9 also show this resistivity layering consistent with the depth of the water table and top of the clay aquitard as determined by CPT data. These resistivity profiles also overlay the approximate positioning of the alluvial fan units Qa1, Qa2a, Qa2b, Qa2c, and Qa3 as interpreted from the hydrogeologic cross sections in the 2016 Off-Site CPT Assessment Report.

Based on the 2D resistivity profiles for Lines 1 through 7 the following evaluation of hydrogeologic conditions is provided.

The electrical conductivity (and hence TDS) of groundwater near the water table in the upper aquifer is higher down gradient of the DAS site on Lines 2 through 7. The up-gradient Line 1 shows formation resistivity layering near the water table in the range 10 to 15 ohm-meters, which is higher than the less than 10 ohm-m water table resistivity layering on Lines 2 through 7. This conclusion is also supported by the CPT measurements of groundwater electrical conductivity which are lower on Line 1. (Note that electrical resistivity in Ohm-m is the mathematical reciprocal of electrical conductivity in S/m.)

Down-gradient of the site the electrical conductivity of groundwater near the water table is mostly similar in value based on the resistivity profiles for Lines 2 through 7. There is no clear evidence of separate, anomalous higher conductivity plumes near the water table, except for some slight decrease in the water table resistivity near the centers of Lines 2 though 7 which indicates higher electrical conductivity associated with infiltration from irrigation. The profiles for Lines 3 through 7 also show deeper lower, resistivity zones (less than 10 ohm-m) in the Qa2 units just below elevation 2,830 feet (60 to 70 feet BGS) that suggests some deeper infiltration from this irrigation. The center of Line 6 from station 350 to 550 appears to show the deepest area of this higher conductivity (higher TDS) groundwater infiltration in the Qa2 units. This deeper area of higher conductivity infiltration is shown by the resistivity modeling and also supported by the CPT measurements of groundwater electrical conductivity in this area.

The resistivity layering shown on the profiles within the Qa1-Qa3 alluvial sequence cannot resolve the thinner sand, silt, and clay layering displayed on the interpreted CPT logs. This is largely due to the narrow range of resistivity variations in this earth layering (within 6 to 45 ohm-meters) and the averaging effect in the IX1D modeling process. However, the resistivity layering shown on Line 5 is consistent with the thicker groupings of sand, silt, and clay units shown on the CPTs logs in hydrogeologic cross section EW3 positioned on Line 5 (Accord Environmental, 2017). Where groundwater resistivity is mostly the same value, clays and silts show lower formation resistivity layers and the sands show higher resistivity layers. Based on this valid assumption, we interpret the following larger-scale lithologic conditions within the Qa1-Qa3 aquifer units:

1) The Qa3 layer is always the highest resistivity layer within the alluvial sequence, which indicates it contains the largest amount of coarser-grain, sands and silty sands, and the lowest electrical conductivity groundwater. However, there are lateral, lower-resistivity variations at this depth level (above the basal clay layer) that suggest a pinch out of the Qa3 unit or transition to a finer-grain, silty area with less permeability. This is shown by the lower resistivity layering below elevation 2,800 feet (90 to 100 feet BGS) on the west side of Lines 2, 3, and 4, and the lower resistivity layering on the east end of Line 6.

2) There are also lateral, higher-resistivity variations at the Qa2 depth level near elevation 2,810 feet (80 to 90 feet BGS) that indicate the presence of wider sand channels. This interpretation is clearly made in areas where lateral increases in formation resistivity layering occur and groundwater resistivity values from CDP measurements stay within a similar range or decrease slightly. This condition indicates that the cause of this lateral resistivity increase is due to transition from finer-grained, clays, and silts to coarser-grained, sands and silty sands. Line 5 shows the best example of two areas (between stations 200 to 500 and 950 to 1150) where lateral formation resistivity increases occur along elevation 2,815 feet (indicating sand channels) and groundwater resistivity values remain within the range 2.8 to 3.7 ohm-m. Based on similar conditions we interpret several other areas of sand channels on the resistivity profiles in Figure 3 through 9. The lateral bounds of these areas are also shown on the site map in Figure 10. North of Line 3 there appears to be an alignment of these sand channels to the northwest. This alignment is consistent with the movement of the Qa2 groundwater contaminant plumes in this area based on the recent CPT data.

The resistivity profiles for Lines 1 through 7 also support the existence of an extensive layer of clay and silt that forms a basal clay aquitard beneath the upper aquifer. The resistivity profiles show the estimated thickness of this layer to be greater than 100 feet.

5.0 REFERENCES

Accord Environmental, 2107, 2016 Off-Site CPT Assessment Report

Taylor, et al., 1992, Use of Transient Electromagnetics to Define Local Hydrogeology in an Arid Alluvial Environment, Kendrick Taylor, Micheal Widmer, and Matthew Chesley, Geophysics, Vol. 57, No. 2, 1992

Telford, et al., 1977, Applied Geophysics, Cambridge University Press, Chapter 5

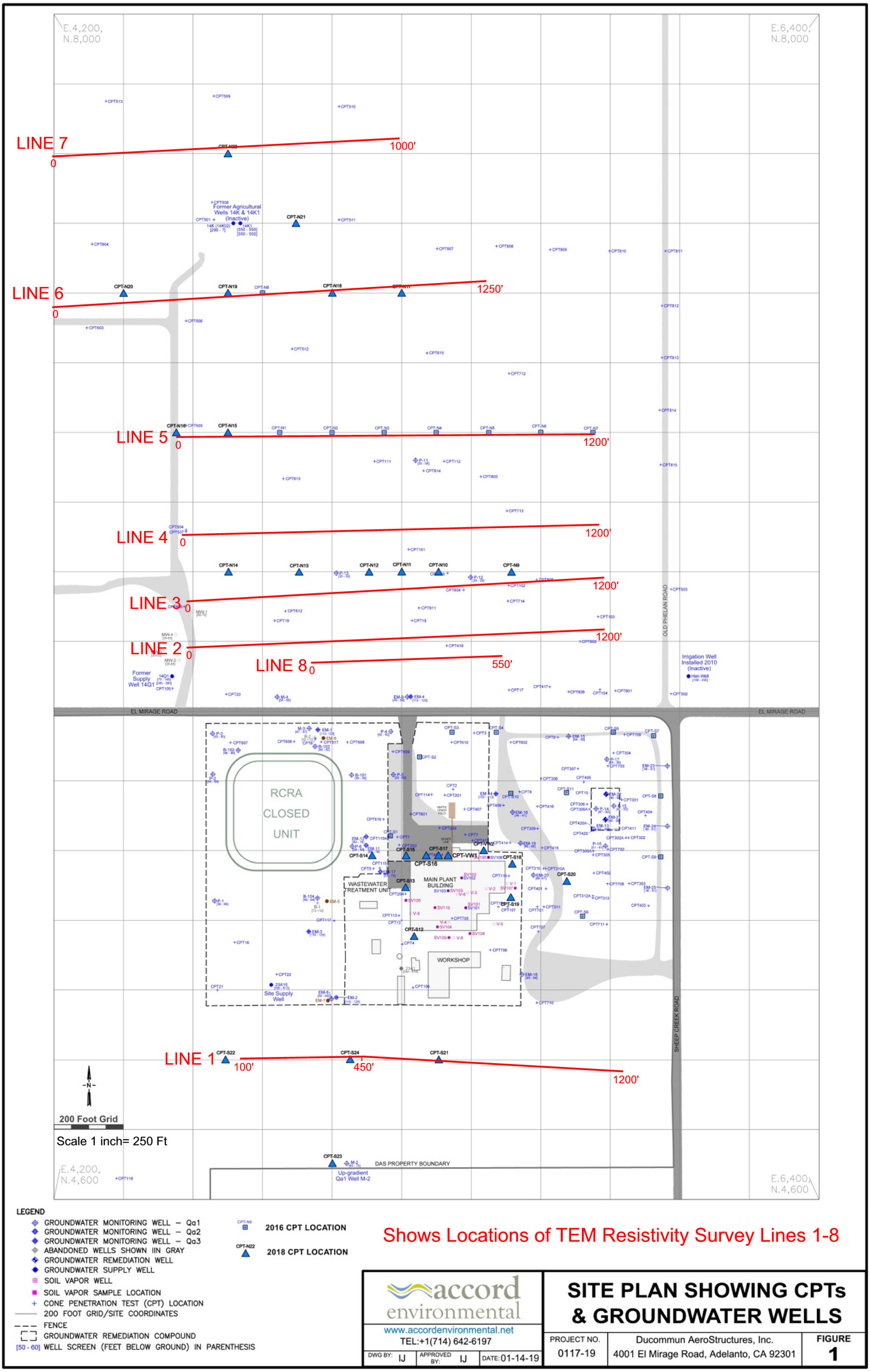

Figure 1
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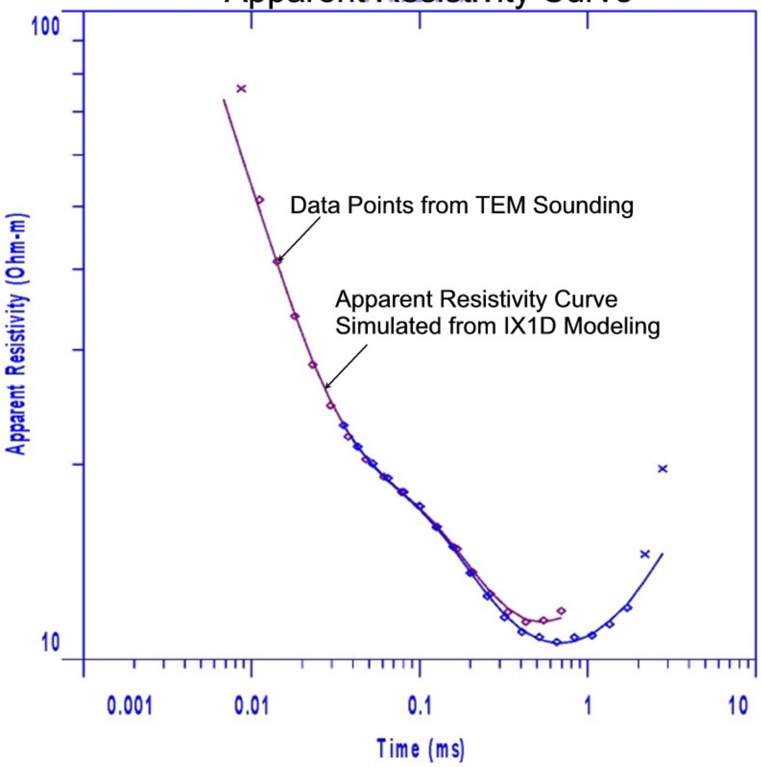
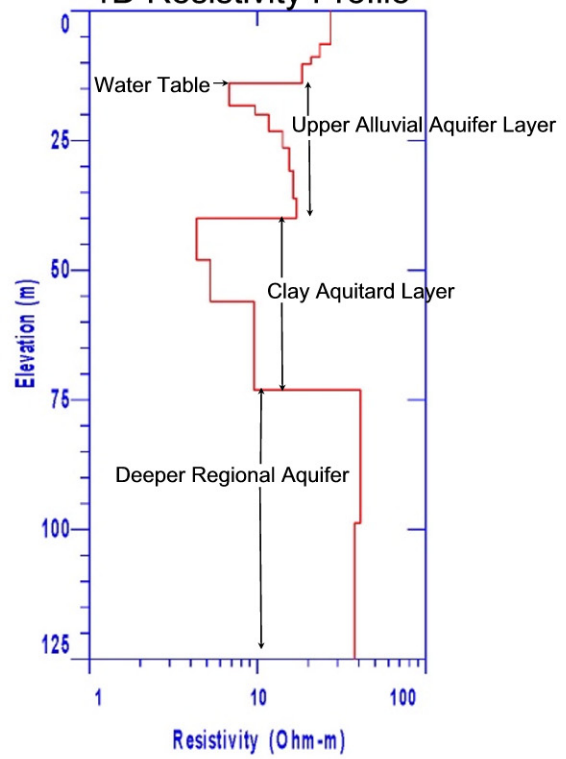
Line 6 Station 950

Apparent Resistivity Curve

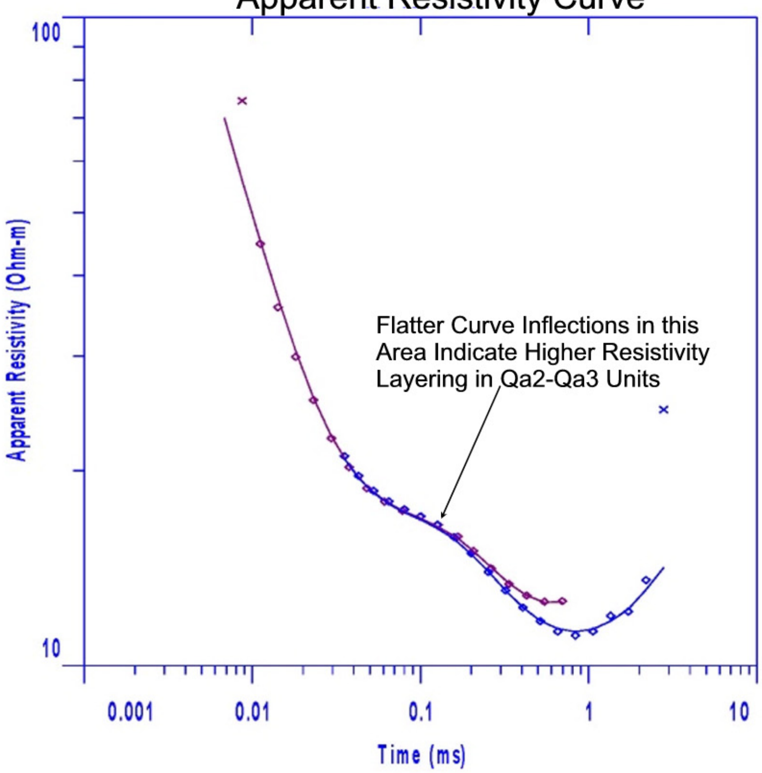


1D Resistivity Profile

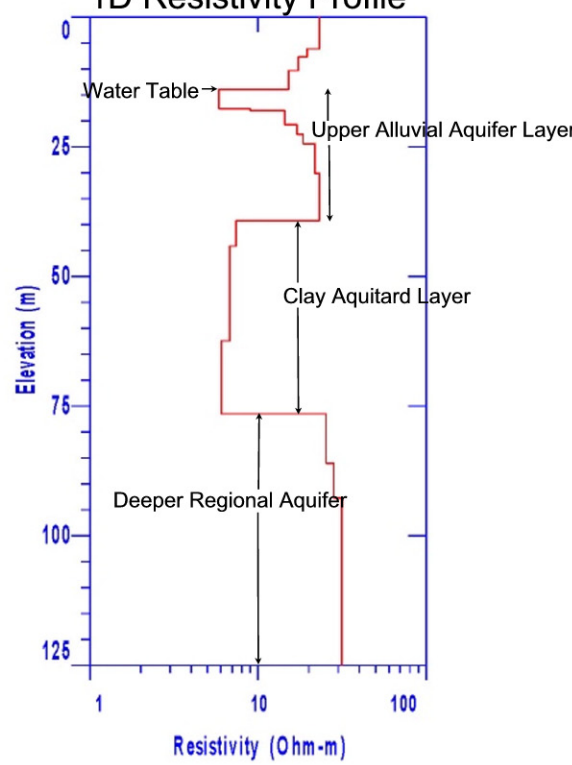


Line 7 Station 750

Apparent Resistivity Curve



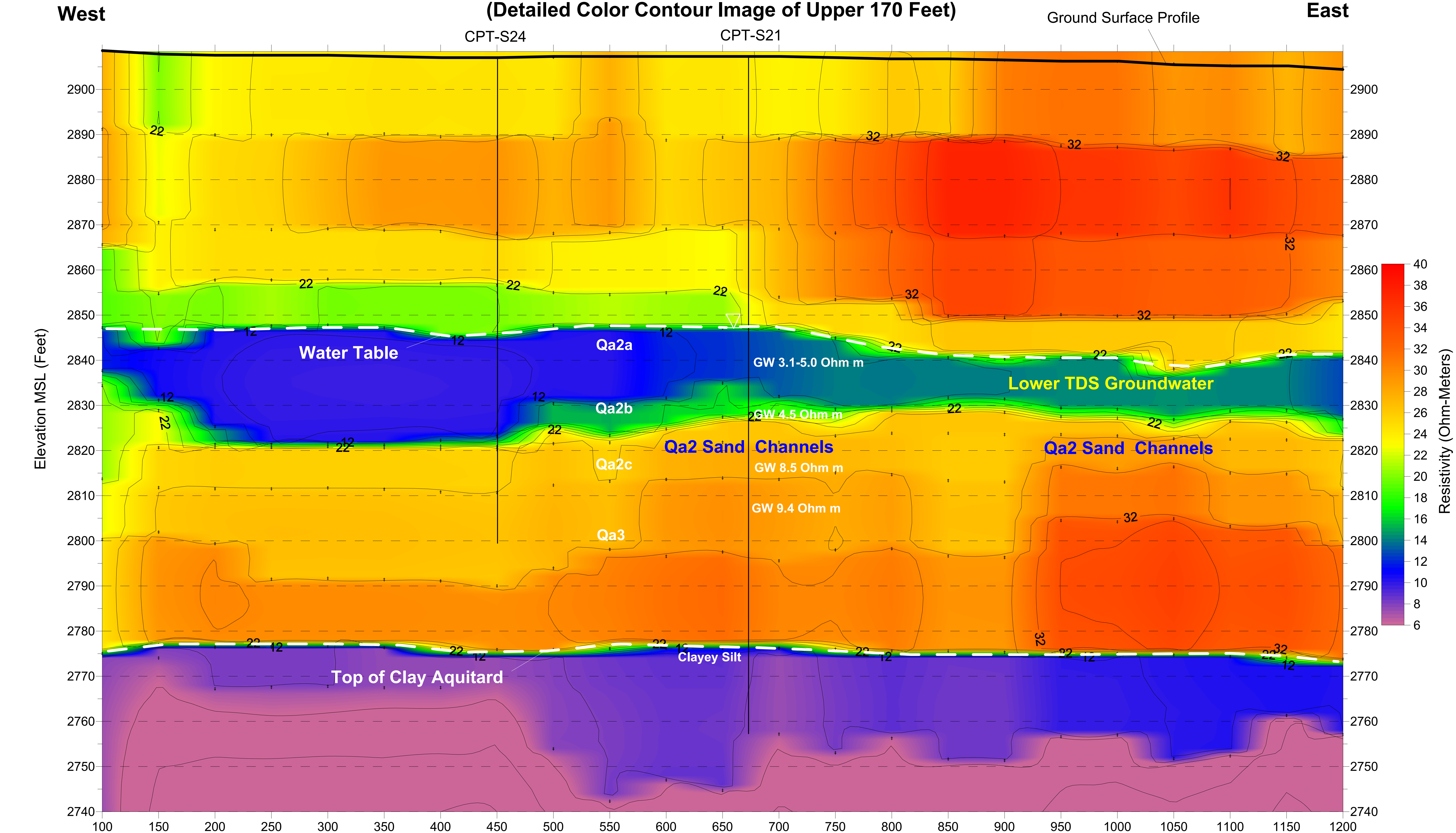
1D Resistivity Profile



Example 1D Resistivity Profiles from
IX1D Modeling of Apparent Resistivity Curves
on Lines 6 and 7 at Stations 950 and 750

Figure 2
ADVANCED GEOSCIENCE, INC.

Line 1 Earth Electrical Resistivity Profile
(Detailed Color Contour Image of Upper 170 Feet)

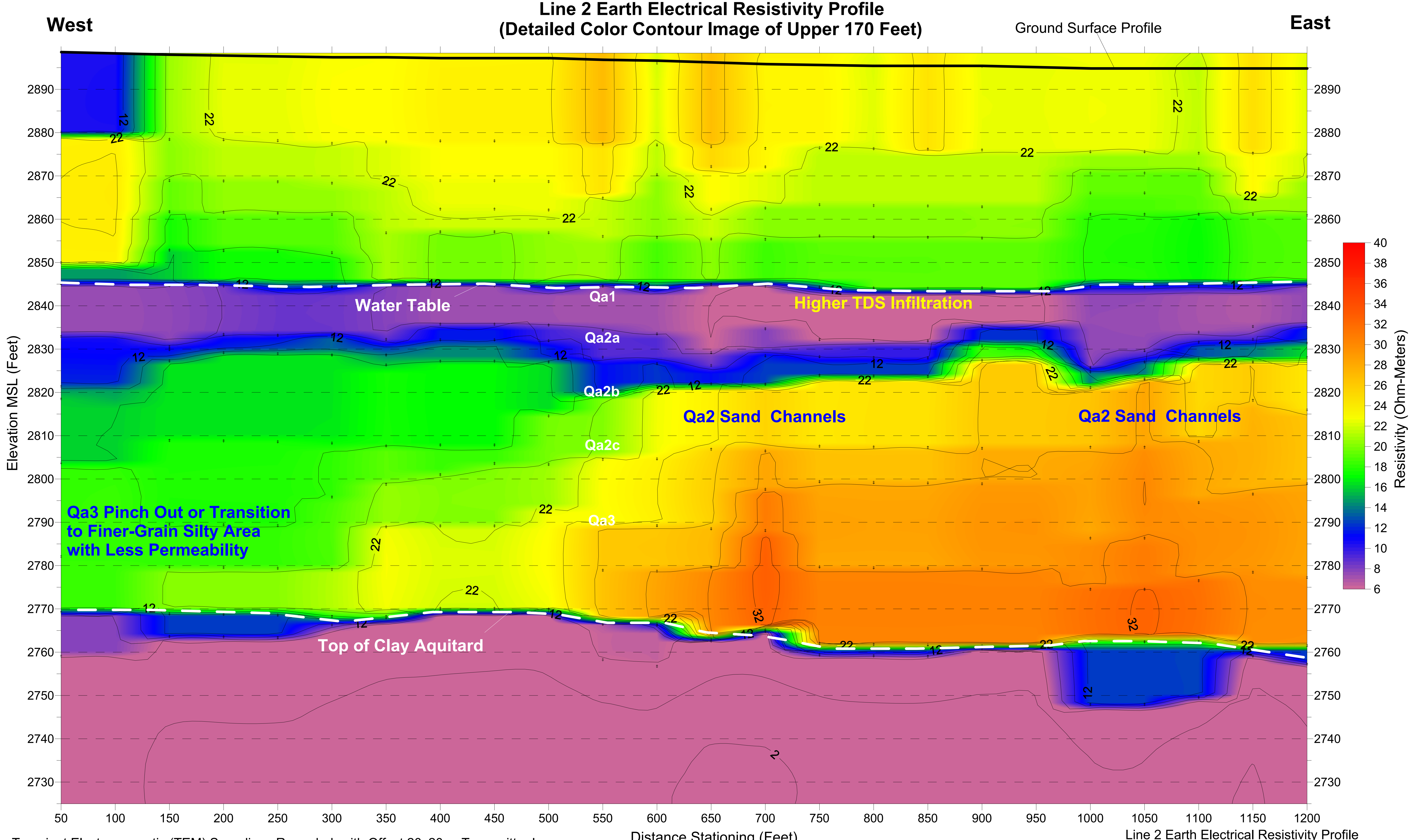


Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
Profile Based on 1D 18-Layer Resistivity Models Generated by Interpex IX1D Inversion Software
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 1 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 3
ADVANCED GEOSCIENCE, INC.

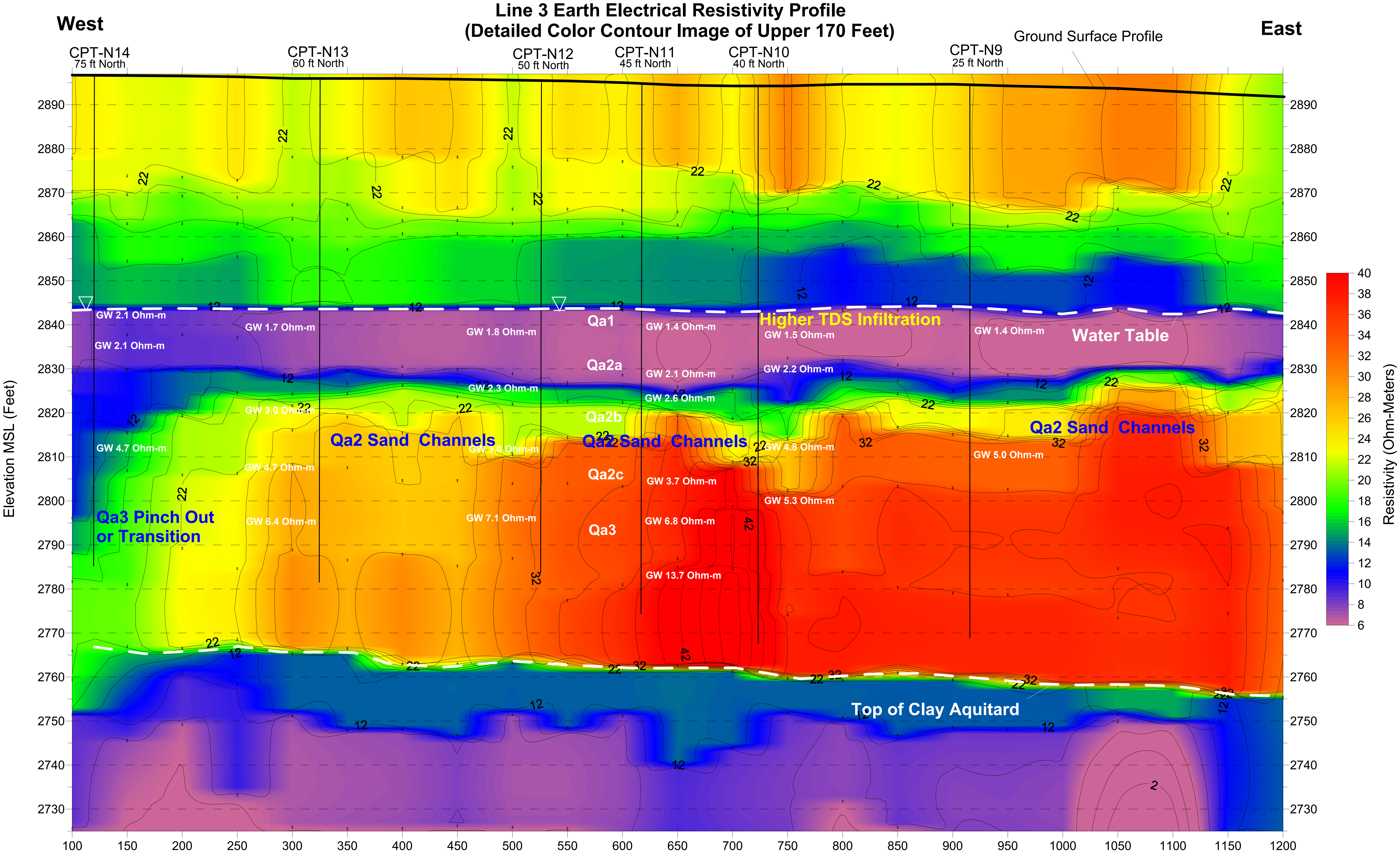
Line 2 Earth Electrical Resistivity Profile
(Detailed Color Contour Image of Upper 170 Feet)



Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
Profile Based on 1D 18-Layer Resistivity Models Generated by Interpex IX1D Inversion Software
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 2 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 4
ADVANCED GEOSCIENCE, INC.



Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
Profile Based on 1D 18-Layer Resistivity Models Generated by Interpex IX1D Inversion Software
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 3 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 5

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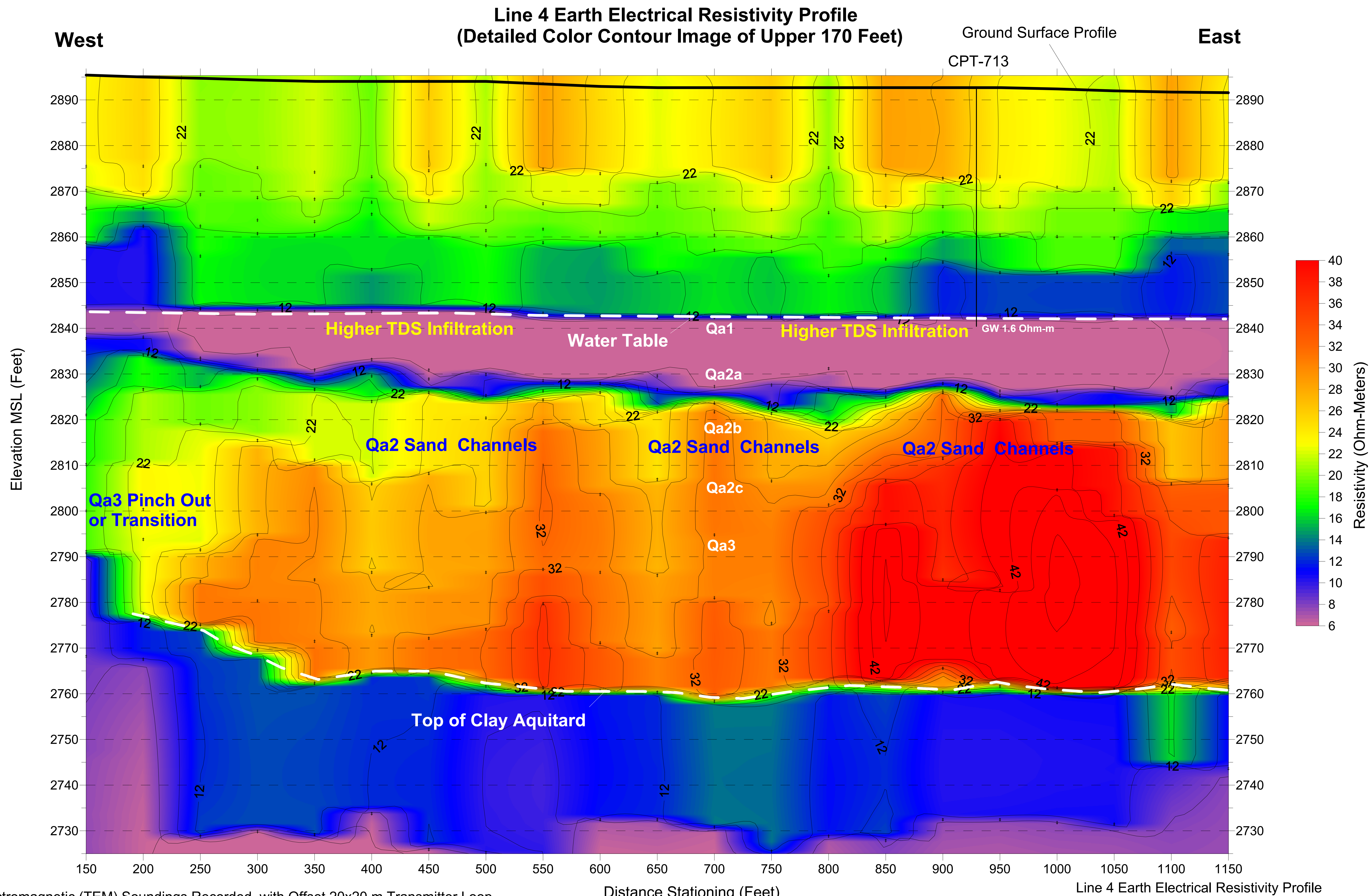

Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
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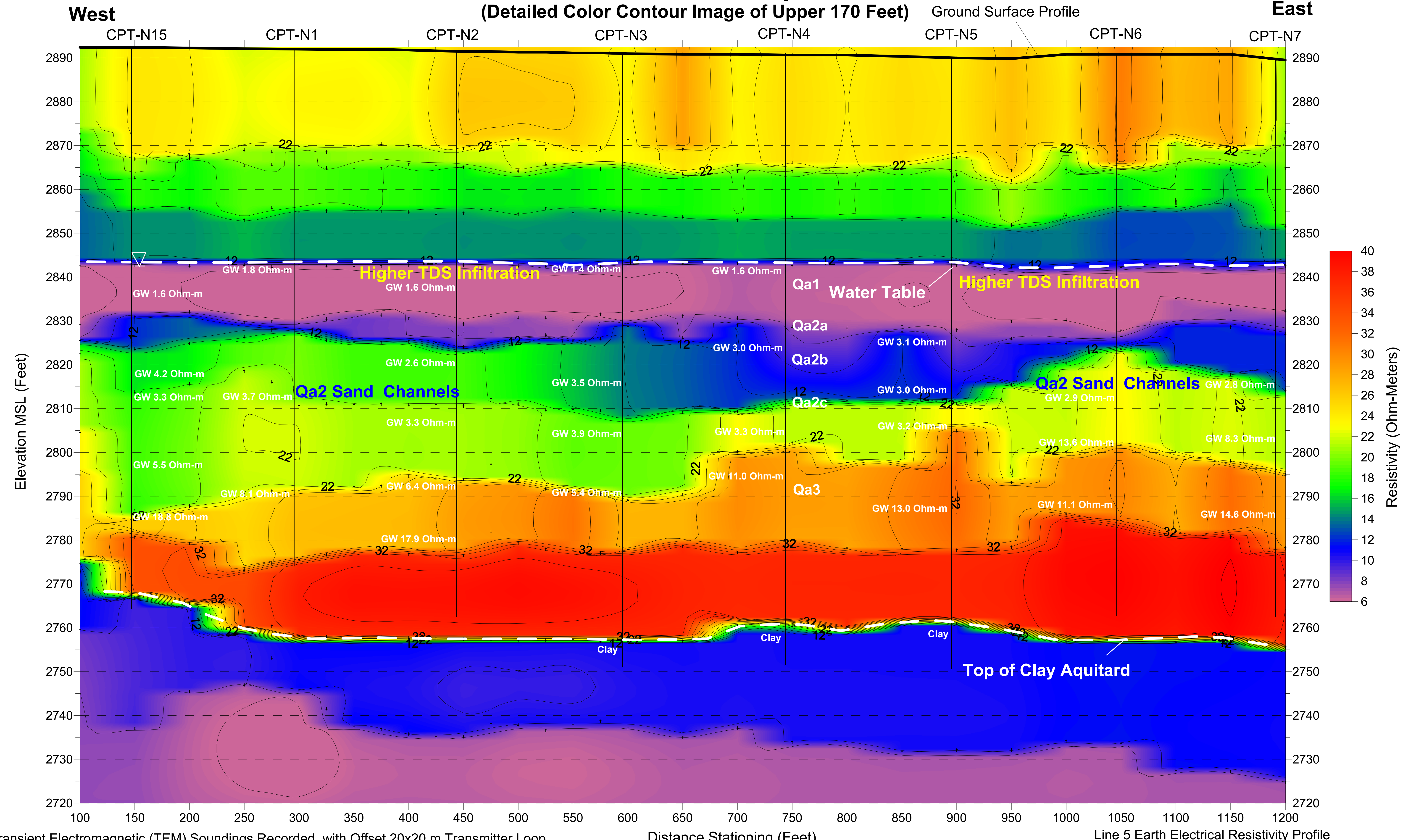
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 4 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 6
ADVANCED GEOSCIENCE, INC.

Line 5 Earth Electrical Resistivity Profile
(Detailed Color Contour Image of Upper 170 Feet)

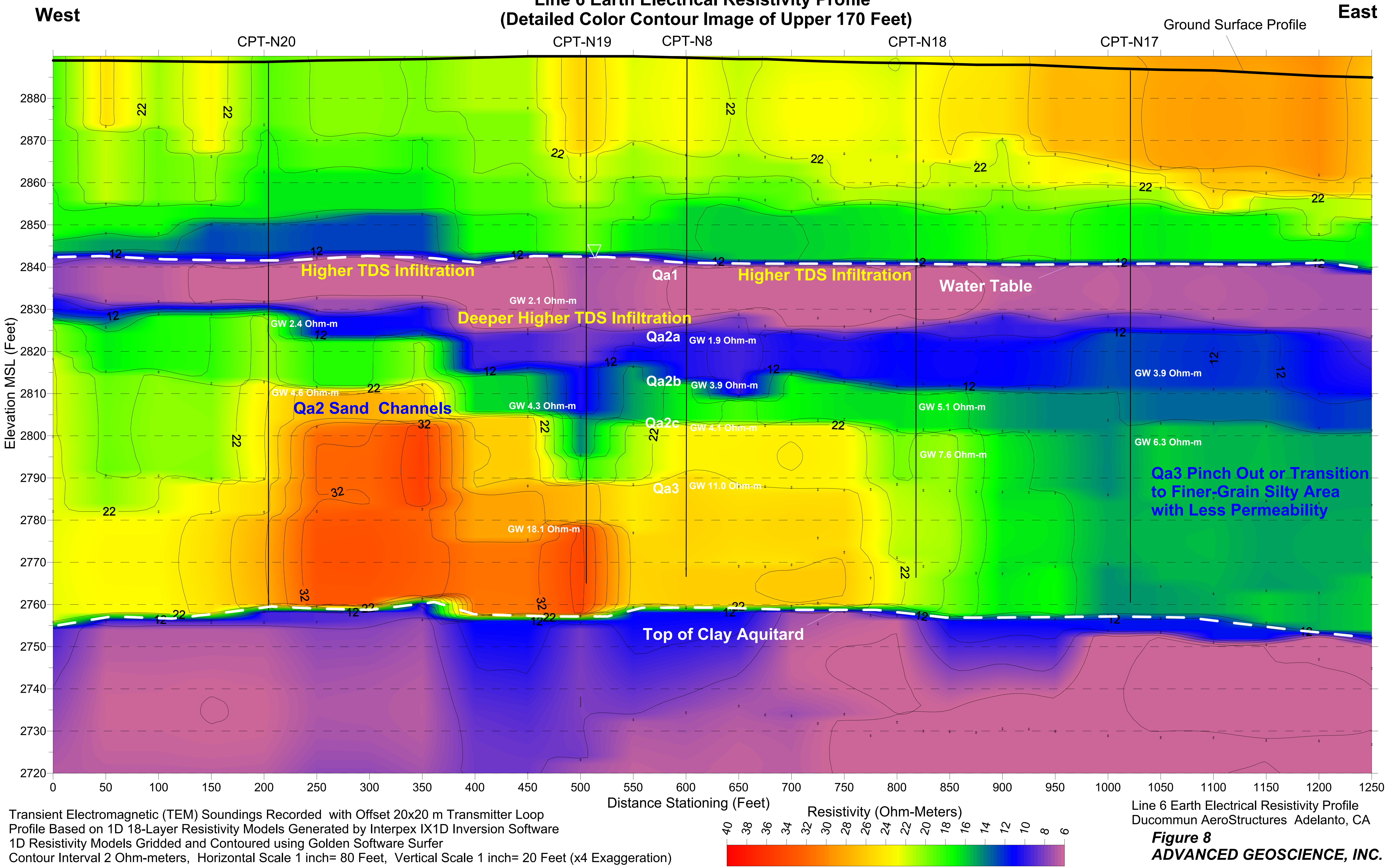


Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
Profile Based on 1D 18-Layer Resistivity Models Generated by Interpex IX1D Inversion Software
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 5 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 7
ADVANCED GEOSCIENCE, INC.

Line 6 Earth Electrical Resistivity Profile
(Detailed Color Contour Image of Upper 170 Feet)

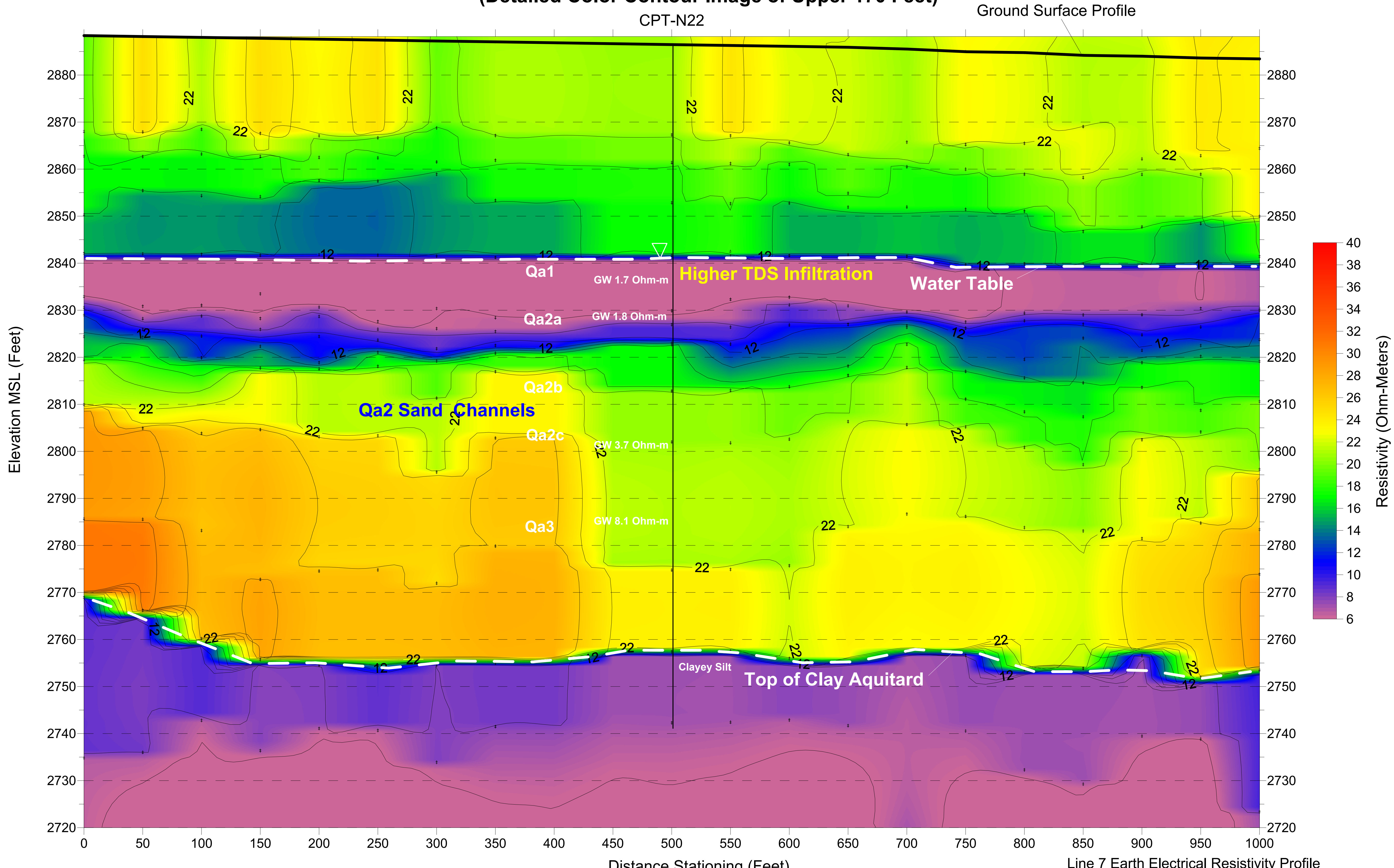


Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
Profile Based on 1D 18-Layer Resistivity Models Generated by Interpex IX1D Inversion Software
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 6 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 8
ADVANCED GEOSCIENCE, INC.

Line 7 Earth Electrical Resistivity Profile
(Detailed Color Contour Image of Upper 170 Feet)



Transient Electromagnetic (TEM) Soundings Recorded with Offset 20x20 m Transmitter Loop
Profile Based on 1D 18-Layer Resistivity Models Generated by Interpex IX1D Inversion Software
1D Resistivity Models Gridded and Contoured using Golden Software Surfer
Contour Interval 2 Ohm-meters, Horizontal Scale 1 inch= 80 Feet, Vertical Scale 1 inch= 20 Feet (x4 Exaggeration)

Line 7 Earth Electrical Resistivity Profile
Ducommun AeroStructures Adelanto, CA

Figure 9
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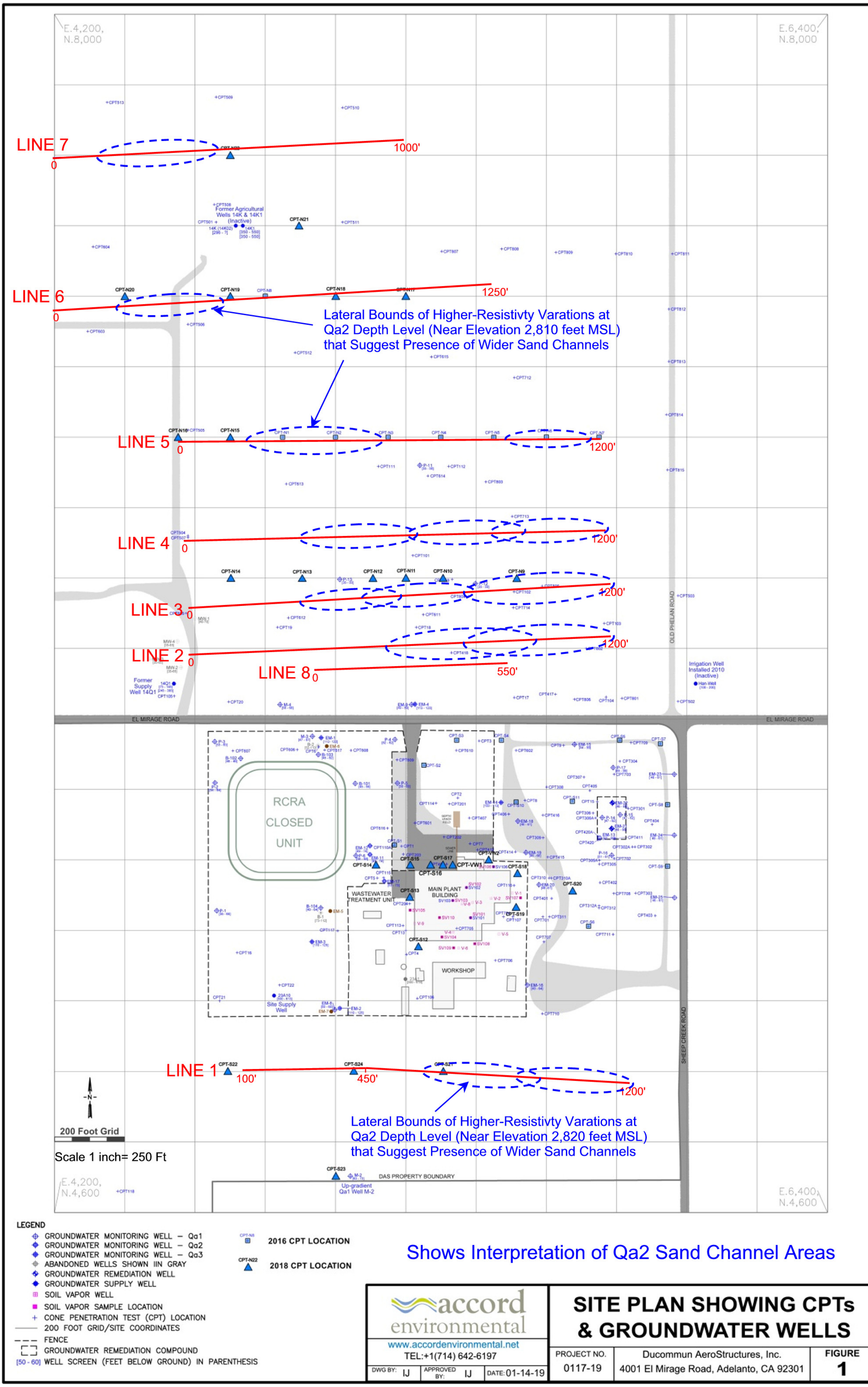

Figure 10

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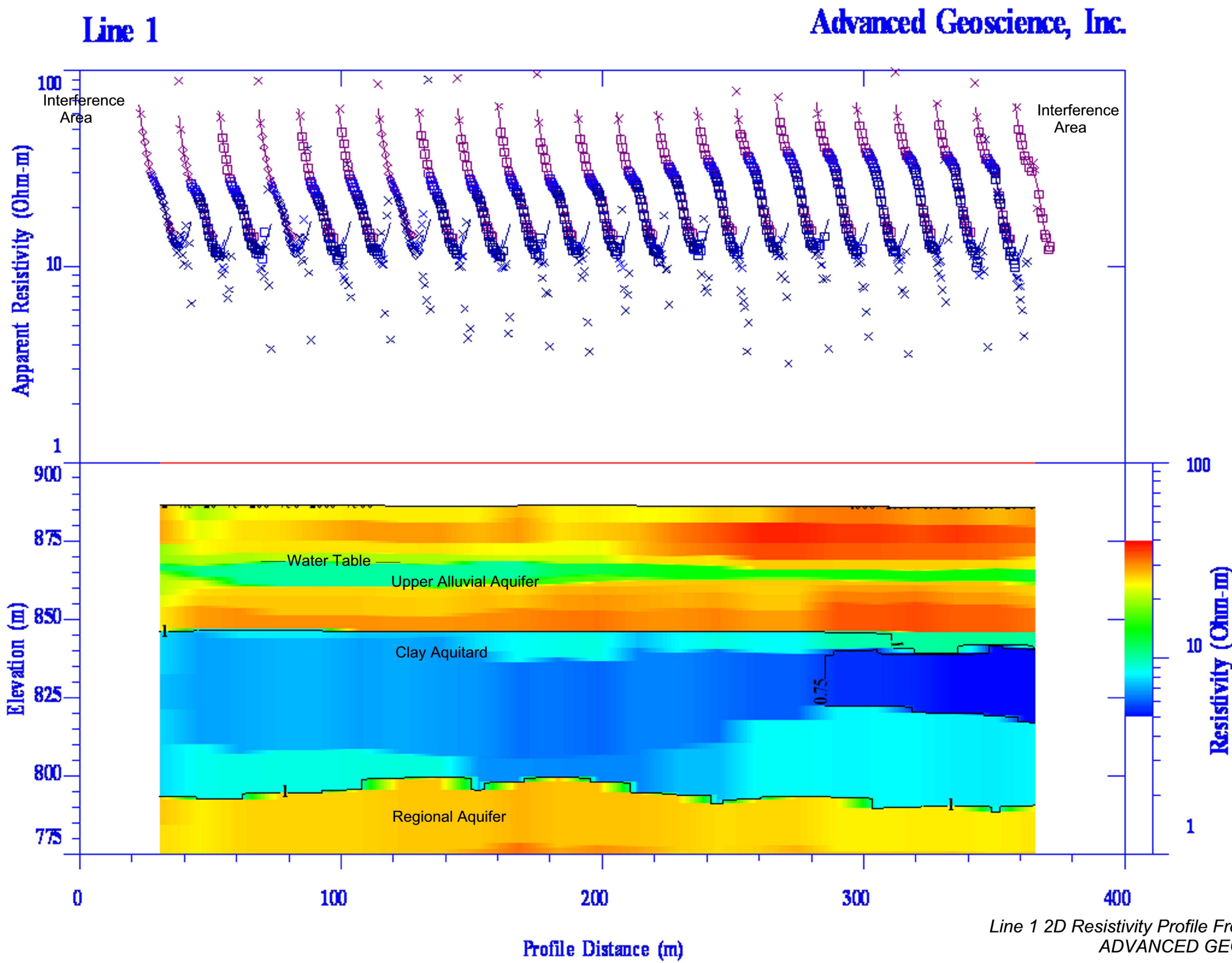
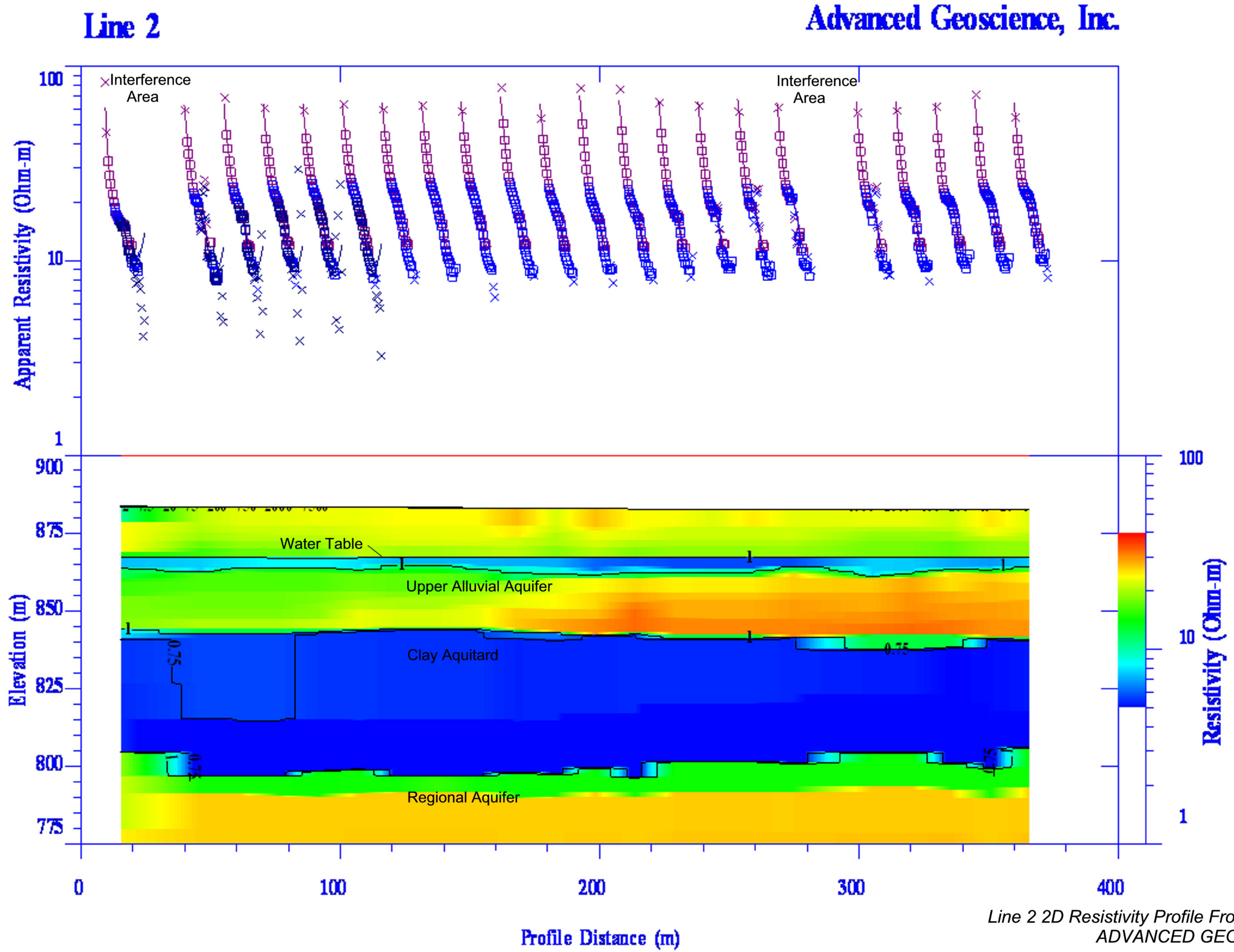
APPENDIX A

PROGRAM IX1D 2D RESISTIVITY PROFILES
AND
APPARENT RESISTIVITY CURVES



Line 1 2D Resistivity Profile From Program IX1D
ADVANCED GEOSCIENCE, INC.



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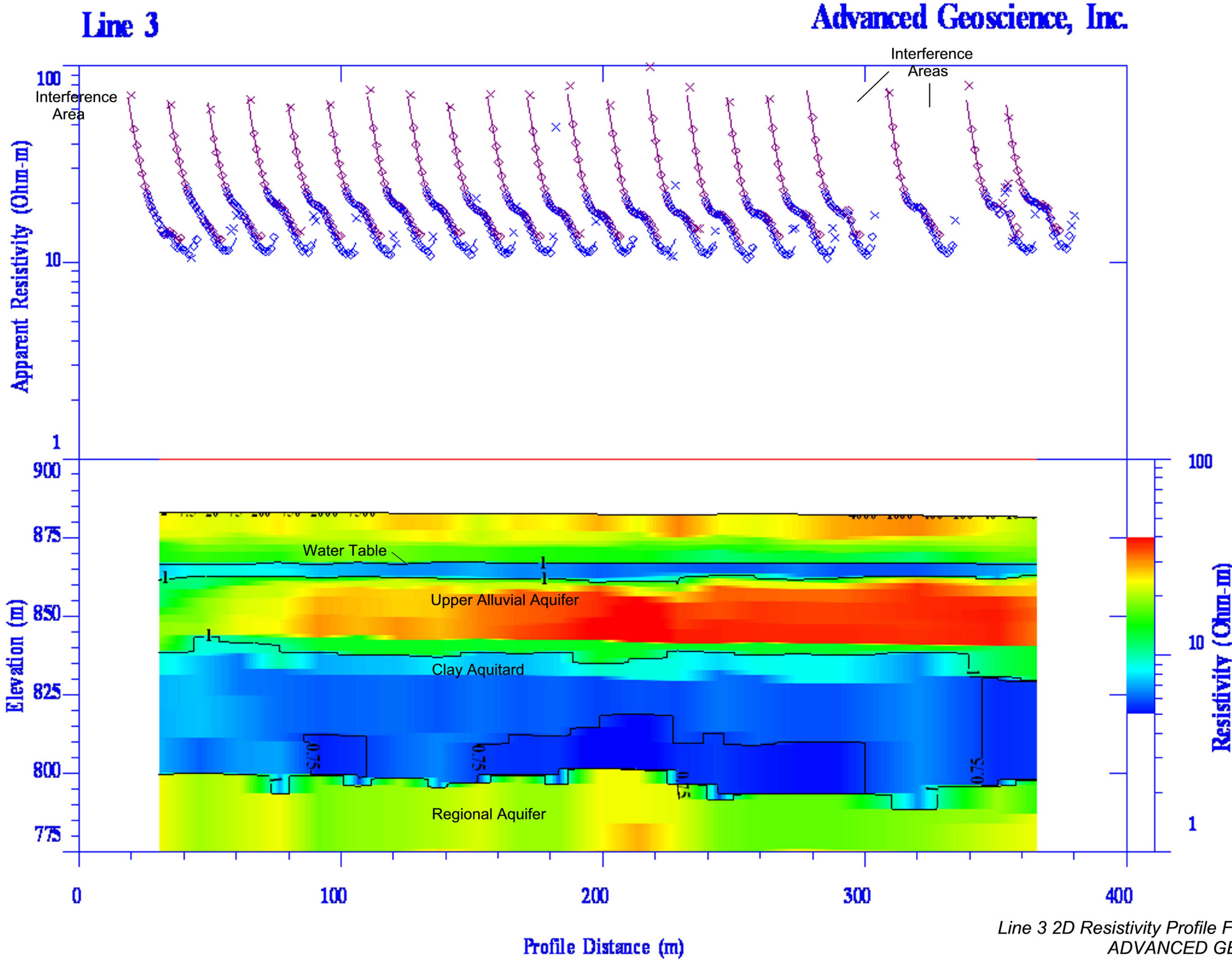

Line 3 2D Resistivity Profile From Program IX1D
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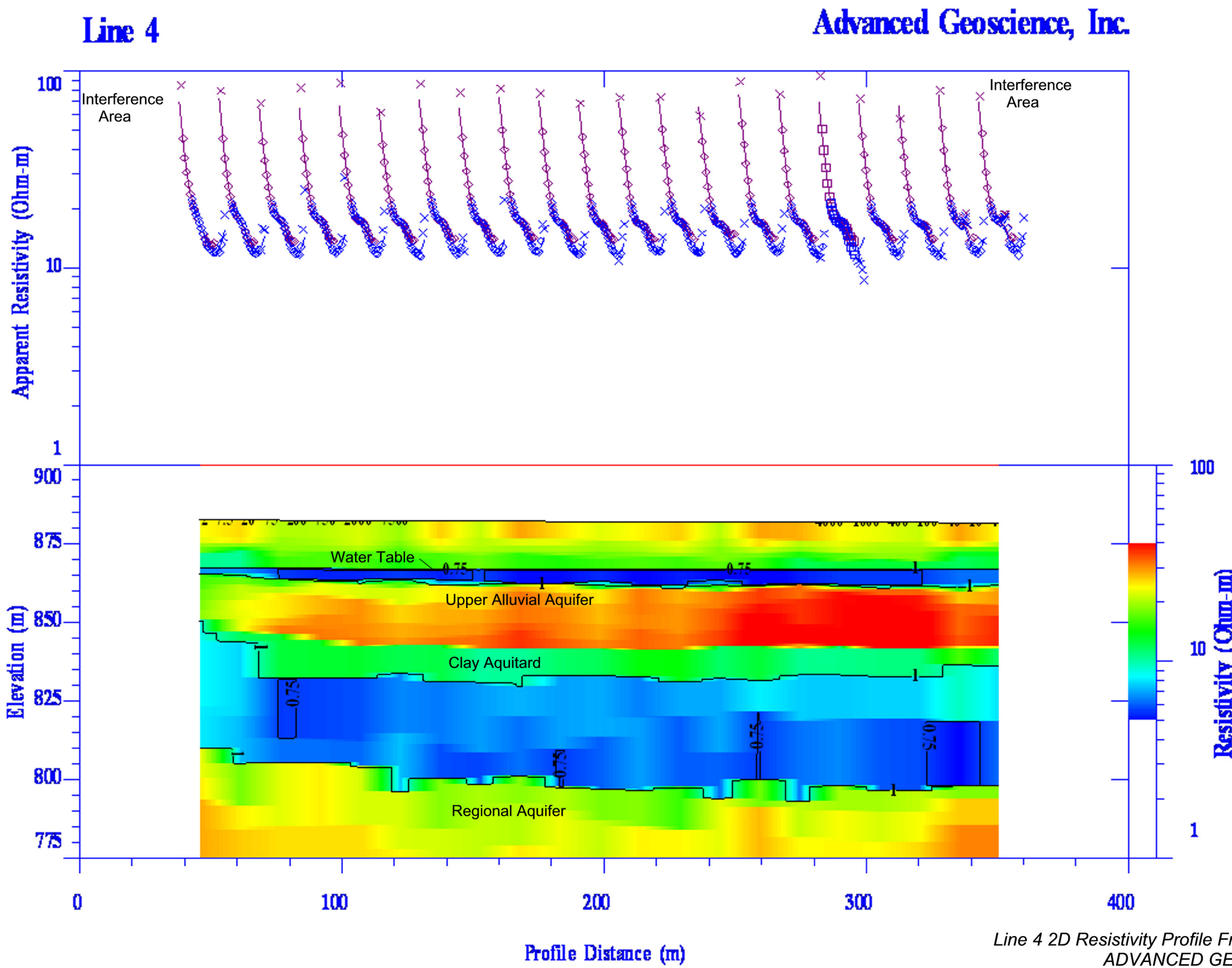

Line 4 2D Resistivity Profile From Program IX1D
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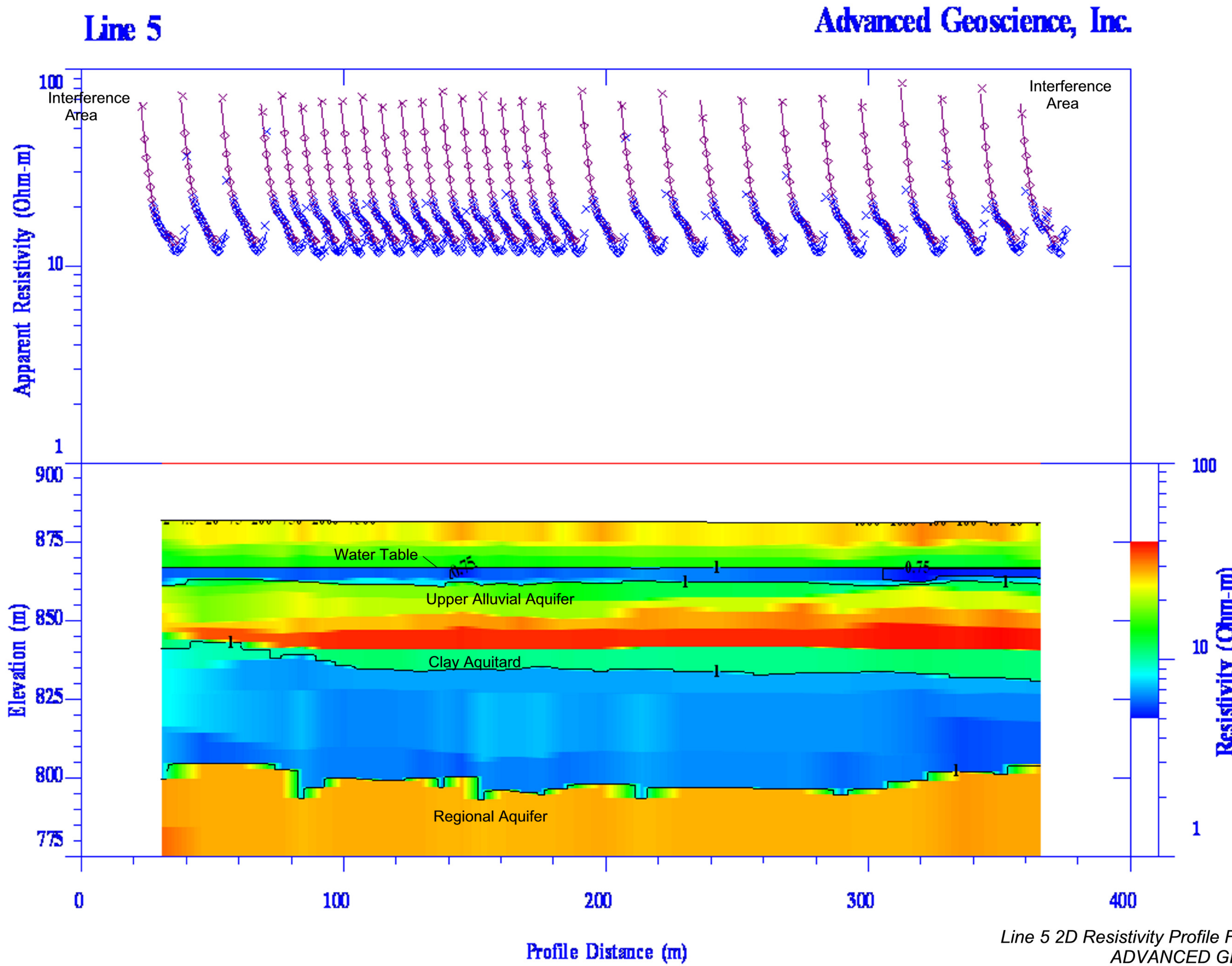
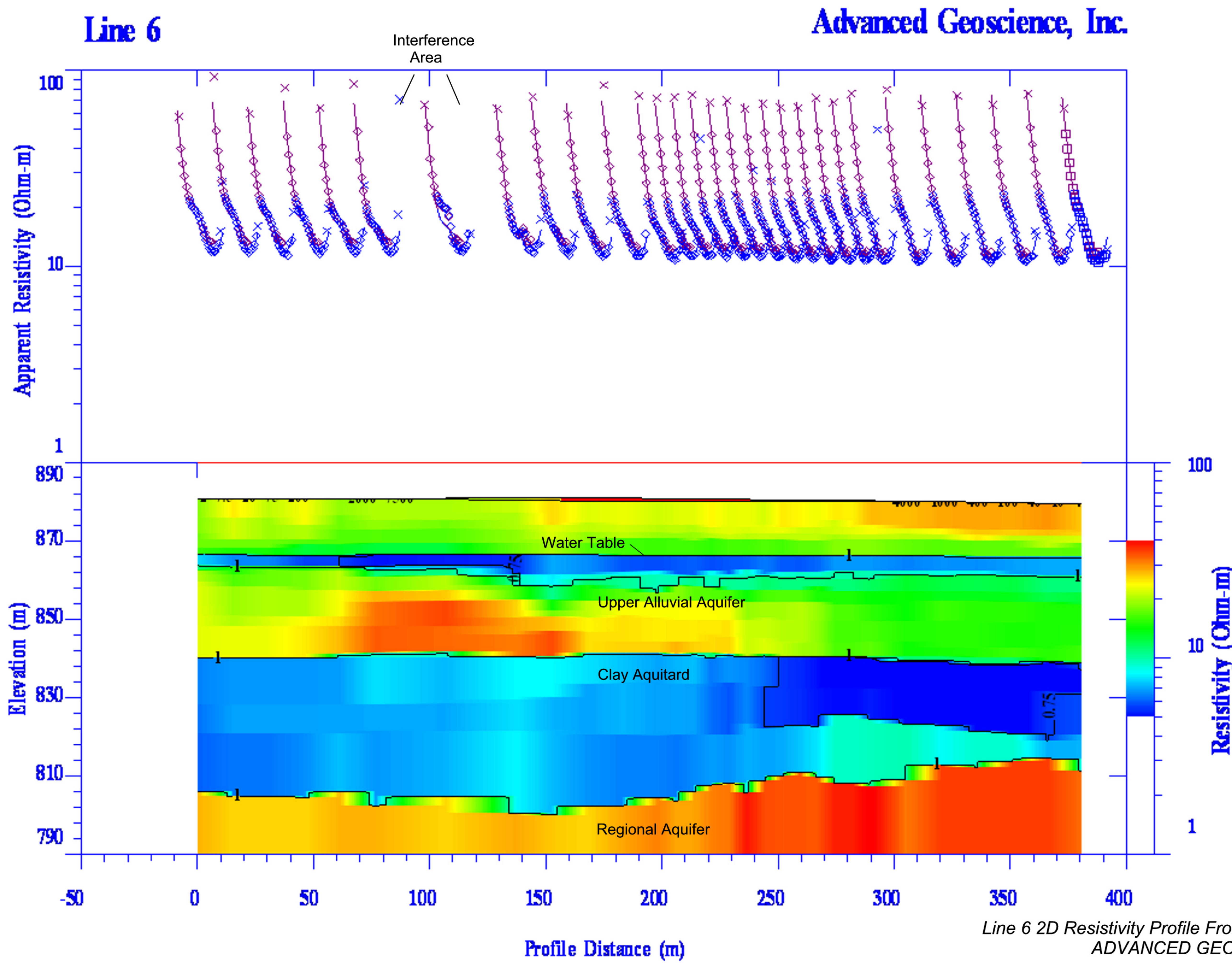
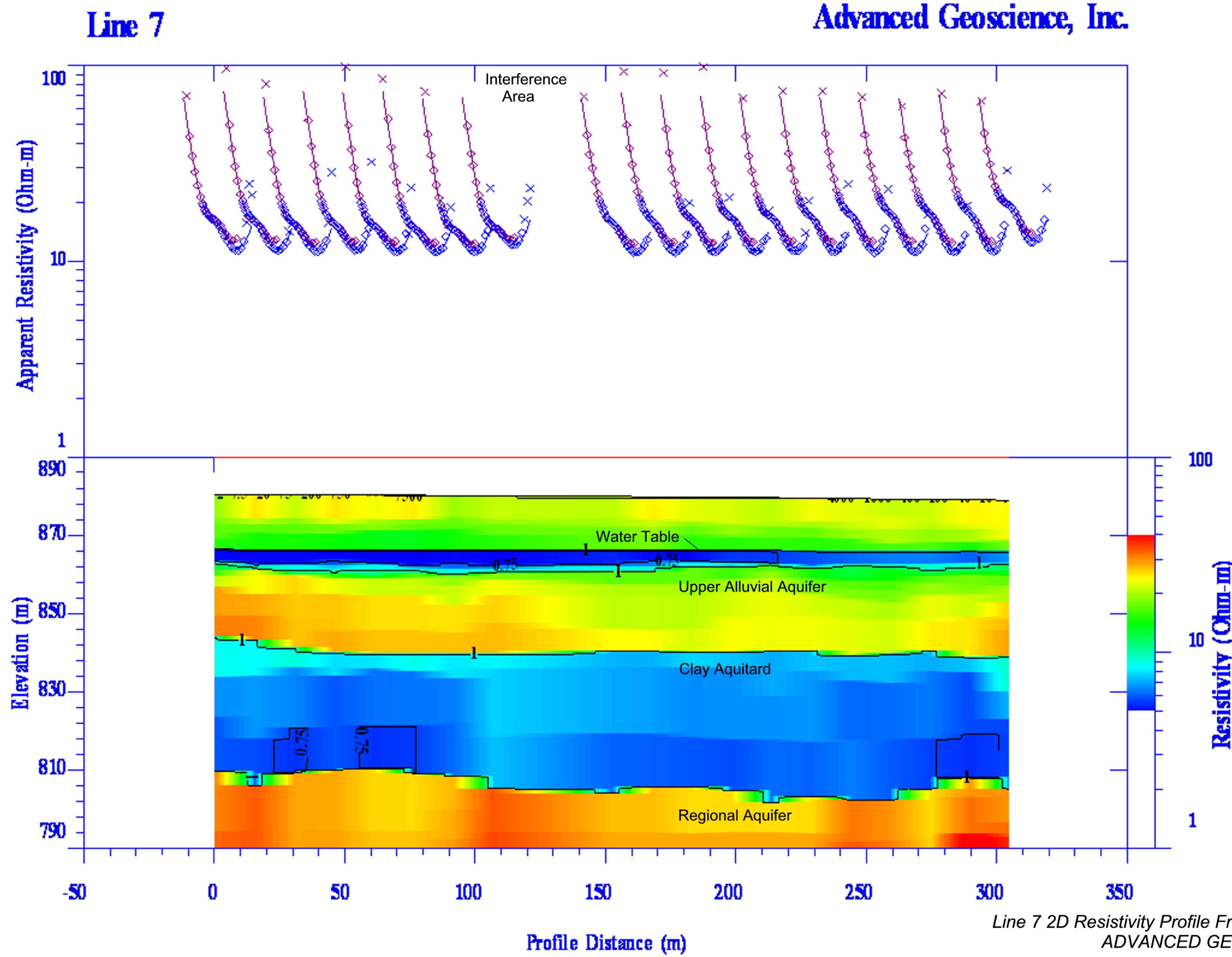


Line 5 2D Resistivity Profile From Program IX1D
ADVANCED GEOSCIENCE, INC.



Line 6 2D Resistivity Profile From Program IX1D
ADVANCED GEOSCIENCE, INC.



Line 7 2D Resistivity Profile From Program IX1D
ADVANCED GEOSCIENCE, INC.