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Ventura River Water District
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Attn: Mr. Bert J. Rapp, P.E.
General Manager

**DRAFT REPORT**
**Geophysical Surveys for**
**Investigation of Subsurface Geologic Conditions**
**Near Well Numbers 1-4 at VRCWD Facility**
**Ojai, California**

## 1.0 INTRODUCTION

This report presents the results of the subsurface geophysical surveys recently completed by Advanced Geoscience, Inc. These surveys were conducted in general accordance with our proposal dated July 10, 2014 to investigate subsurface geologic conditions along the west property line of the Ventura River Water District's (VRCWD) facility adjacent to existing Wells 1 through 4 (shown on the site map in Figure 1). The main objective was to provide a continuous profile of alluvial and bedrock conditions to locate the faulting which was approximately shown on a geologic map of this area. The resulting data was also used to help evaluate groundwater conditions and position a new groundwater test well.

Seismic reflection, refraction tomography, multi-channel analysis of surface waves (MASW) data were first recorded along a 1,550-foot long survey line, designated as Line 1 (Figure 1). The resulting data underwent computer processing to prepare three separate profiles showing: 1) seismic reflection patterns from subsurface layering in the upper 300 feet, 2) seismic compressional-wave velocity variations in the upper 150 feet, and 3) seismic shear-wave velocity variations in the upper 150 feet. The seismic reflection profile was used to image the structure of the upper surface of the Sespe Formation bedrock and the orientation of its bedding. This reflection profile was also used to interpret the location of subsurface faulting where sharp vertical offsets or changes in the slope of bedrock layering were detected. The refraction compressional-wave velocity and MASW shear-wave velocity profiles were used to help interpret the structure of the bedrock surface and the lithologic conditions within the overlying alluvium.

Transient electromagnetic (TEM) electrical resistivity surveys were also performed along Line 1. The 2D resistivity-versus-depth profile generated from this TEM data processing provided additional evaluation of the hydro-stratigraphy along Line 1 and the location of potential higher-permeability groundwater zones within the alluvium.

The seismic and TEM resistivity profiles were correlated to borehole logs and information available from Wells 1 through 4 to interpret bedrock structure and groundwater conditions within the alluvium and to help select a location for the proposed groundwater test well.

The following sections summarize our field data collection program and data processing and display procedures. The concluding sections discuss our current interpretation of subsurface geologic conditions and recommendations for the groundwater test well. This interpretation may be revised once the geophysical profiles are correlated to subsurface data available from the new groundwater test well.

## 2.0 FIELD DATA COLLECTION

Advanced Geoscience began the field surveys on Monday, July 21, 2014. The seismic MASW surveys were performed first on Line 1, and followed by the seismic reflection and refraction surveys which were completed on July 24. The TEM resistivity surveys were completed on the last day of field work on Friday, July 25.

Line 1 was set up along a 1,550-foot long traverse positioned west of the VRWD property line on land owned by Ojai Valley Land Conservancy. Figure 1 shows the distance stationing set up along Line 1 which was mapped using Goggle Earth based on the locations of the sewer line manhole vaults. This west positioning of Line 1 was used to provide the longest possible, continuous straight-line traverse across accessible terrain. This positioning also placed the center of Line 1 near the mapped projection of faulting shown on the geologic map in Figure 2.

### 2.1 Seismic Reflection, Refraction and MASW Surveys

The MASW seismic data were recorded first on Line 1 using a 60-channel Seistronix EX-6 data acquisition system. This recording system was connected to 60 lower-frequency, 4-Hertz geophones (seismic vibration transducers) placed in the ground at 10-foot intervals along Line 1. These geophones are commonly used for the recording of seismic surface waves (such as Rayleigh waves) with frequencies below 10 Hertz.

The active-source, MASW data were recorded along Line 1 in an end-on recording configuration, with the seismic energy source positioned off the north end of a pattern of 36 geophones (with an active recording line length 350 feet). The energy source was positioned a fixed distance of 30 feet from the first geophone position (at station 1,580 feet) to record surface waves into the 36-channel geophone array. After each recording the energy source was moved to the south at 20-foot intervals as the 36-channel geophone recording array was also shifted to the south in 20-foot increments. When southernmost geophone position on this 36-channel array reached the last available geophone position the first 24 geophone positions were picked up and moved to the south to build on to the geophone line and continue the data recording. The last 36-channel geophone array was recorded with the southernmost geophone positioned at station 0 on Line 1. (This movement of seismic recording equipment to the south was used to facilitate set up for the next phase of reflection and refraction data recording.)

The seismic energy source for MASW data was generated using 85-pound, accelerated weight-drop (AWD) mounted on a 4WD Polaris Ranger. The AWD was used to make multiple impacts on a metal plate placed on the ground surface. Three or more impacts were recorded and summed together at each source point to increase the signal to noise ratio. In areas where the AWD could not gain access a 20-pound sledge hammer was used to strike the metal plate to generate the seismic vibrations.

The MASW data were recorded into a total of sixty-one 36-channel field records. The recording length for each record was 2.0 seconds with a 0.5 millisecond sample rate.

The seismic reflection and refraction data were recorded next on Line 1 using a 108-channel Seistronix EX-6 data acquisition system. This recording system was connected to 108 higher-frequency, 40-Hertz geophones placed in the ground at 10-foot intervals along Line 1.

The reflection and refraction data were recorded from seismic energy source points positioned on Line 1 at mostly 10-foot intervals. These source points were positioned between the geophones, starting at the south end of the line and continuing to the north end of the line. The seismic waves generated at each source point were recorded into all 108 channels of the geophone array. The geophone array was shifted to the north along Line 1 in increments of 240 feet (24 channels) after the source point was advanced beyond the center of each 108-channel geophone array.

The seismic energy source for the reflection and refraction data was also generated using the 85-pound AWD. Five to ten impacts with the AWD were recorded and summed together at each source point to increase the signal to noise ratio. In areas where the AWD could not gain access a 20-pound sledge hammer was used to strike the metal plate to sum together 15 or more impacts. Periodic background noise vibrations from well pumping operations caused some degradation to the quality of these data recordings. However, the overall data quality was judged to be good and sufficient for the purposes of this investigation.

The reflection and refraction data were recorded into a total of one hundred and twenty-five 108-channel field records. The recording length for each record was 0.8 seconds with a 0.25 millisecond sample rate.

**2.2 Transient Electromagnetic (TEM) Resistivity Surveys**

The TEM resistivity data were recorded at various "sounding points" set up along Line 1. The locations of these sounding points (designated as TEM-1 through TEM-11) are shown in Figure 1. Most of these sounding points were positioned slightly west of Line 1 to place the square wire transmitter loops along the property line to avoid interference from crossing the metal fence.

The TEM surveys were performed using a Geonics, Ltd. TEM-47 transmitter and Protem digital receiver equipped with a high frequency receiver coil. This system was used to transmit an on-off pulsed electrical current pattern (at repetition rates of 285, 75, and 30 Hertz) into a square wire transmitter loop laid on the ground surface. During the off time periods of this pulsed current pattern the rapidly-decaying currents induced in the earth were measured versus shut-off time at the position of the receiver coil by the Protem receiver. The measurements of these "voltage decay curves" were repeated several times for each repetition rate.

The TEM data were recorded using two sounding configurations. At TEM-1 through TEM-7 a central-loop sounding was used with the receiver coil positioned in the center of a 120 by 120-foot square wire transmitter loop with a supplied current of 2.5 amps. At TEM-8 through TEM-11 offset-loop soundings were used with the receiver coil positioned outside of a smaller 70 by 70-foot square wire transmitter loop with a supplied current of 3.1 amps. The smaller offset-loop soundings were used in areas where the larger transmitter loops could not be set up.

The data recording from higher frequency repetition rates of 285 and 75 Hertz showed good quality voltage decay curves which were mostly repeatable. The 30-Hertz decay curves showed some interference and degradation from surface sources of electromagnetic noise. To help avoid a strong source of this interference a TEM sounding was not conducted near station 900 feet where the overhead power line to the abandoned well crossed this area. The clay sewer pipeline crossing beneath the survey area was not judged to be a source of interference.

## 3.0 DATA PROCESSING AND DISPLAY

### 3.1 Seismic Reflection, Refraction, and MASW Data Processing

Prior to starting the seismic data processing an elevation profile of the ground surface was generated along Line 1. These elevations were estimated at various distance stations from a topographic map of the area prepared by the County of Ventura.

The seismic refraction data processing was completed first. The field records from selected source points were used for seismic refraction tomography imaging using the RAYFRACT computer program written by Intelligent Resources, Inc. (Vancouver, Canada). A total of 27 field records were selected at 50 to 70-foot intervals along Line 1 for the tomography imaging of seismic compressional-wave velocities.

The field records were used to pick first arrival times (first breaks) for seismic waves traveling through the surface layer and refracted along deeper higher-velocity layers. These time picks were plotted as a series of travel time curves for each source point and evaluated for reciprocal time consistency. The final time picks were input together with their geophone and source point coordinates and elevations into the program RAYFRACT. RAYFRACT was used to generate an initial velocity-depth model using the Delta-TV method. This initial model was then refined to produce a closer fit to the first breaks using the Wavepath Eikonal Traveltime (WET) inversion method with 20 iterations. This best-fit velocity-depth model was then gridded and color contoured with the program SURFER (Golden Software, Inc.) to show estimated vertical and lateral velocity variations. The resulting compressional-wave velocity profile for Line 1 is shown in Figure 3.

The seismic reflection processing was conducted using the computer program Visual SUNT (developed by W_Geosoft in Geneva, Switzerland). The complete set of 125 field records together with source point and geophone coordinates and elevations were input into this program to generate seismic reflection time and depth profiles for Line 1.

Visual_SUNT was used to perform a specialized sequence of editing, data trace sorting, and digital processing to first prepare a common mid-point (CMP) stacked, reflection time profile. Digital filtering such as band pass filtering, deconvolution, and time-space (FK) filtering were applied in the beginning stages of this processing to attenuate ground roll on the field records and reduce the amplitude of lower-frequency noise. Elevation differences along Line 1 were also accounted for in the processing by applying datum static shifts to the field record traces. These time shifts reduced the reference time (t=0) on the reflection time profile to a flat datum elevation of 580 feet. Several analyses of normal moveout (NMO) velocity corrections were then performed and applied together with residual static corrections to prepare a CMP-stacked reflection time profile.

The reflection time profile was converted to a depth profile using a smoothed seismic velocity-time profile generated for Line 1. The resulting reflection depth profile for Line 1 is shown in Figure 4.

The MASW data processing was performed using the computer program SURFSEIS developed by the Kansas Geological Survey. The complete set of 61 field records together with source point and geophone coordinates were input into this program to generate a shear-wave velocity profile for Line 1.

The 36-channel, active-source MASW records were used in SURFSEIS to perform a specialized sequence of processing to prepare dispersion curves showing Rayleigh wave (or ground roll) phase velocity versus frequency for each 36-channel field record. These curves were used to calculate 1-D models of shear-wave velocity layering for the center of each 36-channel geophone array. The resulting 1-D models generated along Line 1 were then gridded and color contoured by SURFER to prepare the 2D shear-wave velocity profile shown in Figure 5.

**3.2 Transient Electromagnetic (TEM) Resistivity Data Processing**

The TEM data recorded at sounding points TEM-1 through TEM-11 were processed using the computer modeling program IX1D developed by Interpex, Ltd. (Golden, Colorado). IX1D was first used to edit the voltage decay curves recorded from several receiver gain settings and repetition rates. For each sounding point a set of final decay curves for the three repetition rates was converted to a set of "apparent resistivity" versus time curves.

These apparent resistivity curves underwent several rounds of 1D modeling with IX1D using seven to twelve-layer resistivity models until a consistent set of modeling parameters was selected for generating a final set of 1D resistivity versus depth profiles for all eleven sounding points. During this modeling process, the 1D resistivity profiles from the sounding points to the north were compared with the borehole logs of 64-inch long-normal resistivity and 6-foot lateral resistivity from Well 1.

Two different types of apparent resistivity curves and 1D resistivity profiles were generated along Line 1. South of station 800 feet the apparent resistivity curves showed 1D resistivity profiles with decreasing resistivities to the maximum depth. North of this point, the apparent resistivity curves showed 1D resistivity profiles with decreasing resistivities and a deeper higher-resistivity layer. Figure 6 shows the two types of resistivity profiles generated at the sounding points TEM-3 and TEM-5.

Figures 7 also shows the resistivity profile at sounding point TEM-8 and the borehole resistivity logs in Well 1 which show similar resistivity layering in the upper 300 feet.

The 1D resistivity profiles at sounding points TEM-1 through TEM-11 were converted to resistivity elevation profiles and gridded and color contoured with the program SURFER to show estimated vertical and lateral resistivity variations. The resulting 2D resistivity profile along Line 1 is shown in Figure 8.

North of station 400 feet on Line 1 the TEM sounding points were positioned further to the west of Line 1. Therefore, north of this point the resistivity profile in Figure 8 is located to the west of Line 1.

### 3.3 Display of Geophysical Profiles

The seismic compressional-wave velocity profile, reflection depth profile, shear-wave velocity profile, and TEM resistivity profile (in Figures 3, 4, 5, and 8) are all displayed at the same horizontal scale 1 inch= 100 feet. The vertical elevation scales for the two seismic velocity profiles and TEM resistivity profile are 1 inch= 50 feet (showing 2x vertical exaggeration). The vertical elevation scale on the seismic reflection profile is approximately 1 inch= 80 feet (showing 1.25x vertical exaggeration).

The profiles in Figures 3, 4, 5, and 8 also show the approximate projected positions of Wells 1 through 4 located to the east of Line 1 on the VRWD property. Each of these projected well locations shows the elevations of the actual or expected "well shutoff" pumping water levels.

## 4.0 SUBSURFACE INTERPRETATION

The seismic refraction and reflection profiles in Figures 3 and 4 show the current interpretation of the structure of the Sespe Formation bedrock surface beneath Line 1. These two elevation profiles of the bedrock surface were derived from separate data processing procedures and are very similar to one another. Some revisions may be made to these elevation profiles once borehole data is available from the new groundwater test well.

The seismic reflection profile in Figure 4 also shows the interpretation of bedding planes within the Sespe Formation and the positioning of the east-west trending faulting expected to intersect Line 1. South of station 500 feet, reflections from bedding planes in the Sespe Formation indicate that bedding is dipping to the north as shown on the geologic map. Between stations 500 and 800 feet, a stronger pattern of reflections indicates bedding is abruptly dipping to the south. This abrupt change in the dip of bedding was used together with patterns of diffracted seismic waves to interpret the orientation of these fault planes.

The site map in Figure 9 shows the approximate near-surface location of subsurface faulting beneath the area based on the positioning of the fault planes shown on the reflection profile in Figure 4 and the trend of faulting shown on the geologic map in Figure 2.

The shear-wave velocity and resistivity profiles in Figures 5 and 6 support the above interpretation of bedrock structure; however, these profiles show less detailed images of this structure. The shear-wave velocity profile shows a deeper, north-sloping, greater than 2,000 ft/sec velocity layer similar to the bedrock profile in Figure 3 and 4 between stations 200 and 800 feet. North of station 800 feet this profile shows different shear-wave velocity layering within both the bedrock and alluvium which supports the interpretation of the north fault plane near station 800 feet. The resistivity profile also shows a deeper, north-sloping, less than 20 ohm-meter resistivity layer between stations 100 and 800 feet which is interpreted as the bedrock layer. In addition, north of station 800 feet an abrupt change in resistivity structure occurs which also indicates this faulting.

As mentioned above, starting to the north from station 400 feet the resistivity profile in Figure 8 is located to west of Line 1; therefore, the subsurface conditions shown on this profile are also located to the west of Line 1. This west positioning would explain the shallower less than 20 ohm-meter resistivity layer in Figure 8 between stations 600 and 1,350 feet which is interpreted as the bedrock layer. This interpretation of a shallower bedrock surface immediately to the west of Line 1 is supported by the geologic map which shows that the bedrock rises to the ground surface and outcrops further to the west of Line 1 (Figure 2). This east-west structure indicates there is a bedrock channel beneath the area that could extend on to the VRWD property north of the fault zone.

The site map in Figure 9 shows our current interpretation the orientation of the axis of this bedrock channel which extends on to the VRWD property. This interpretation is based on the approximate alignment of the channel-like depressions of the bedrock surface shown on the seismic refraction and reflection profiles in Figures 3 and 4 and the resistivity profile in Figure 8. This interpretation now suggests that this ancient river channel is cut off by the faulting intersecting Line 1, which would imply the faulting in the deeper alluvium is younger than the bedrock channel.

The shear-wave velocity and resistivity profiles in Figures 5 and 8 can be used to interpret lithologic and groundwater conditions within the alluvium. Both of these profiles show sequences of lithologic layering north of the fault zone (near station 800) feet which indicate zones of higher groundwater permeability. North of 800 feet, a greater than 2,100 ft/sec shear wave velocity layer below elevation 510 feet indicates there is a layer of cobble to boulder-size material in the saturated alluvium. The resistivity profile west of Line 1 in this area also shows resistivity layering greater than 50 to 60 ohm-meters near elevation 500 feet which indicates increased groundwater permeability within these coarse-grain deposits. This reasoning is based on the 6-foot lateral resistivity log for Well 1 (Figure 7) which shows saturated, permeable alluvium in the range of 60 to 70 ohm-meter above the expected well shutoff pumping water level.

The shear-wave velocity profile in Figure 5 also indicates there are deeper, older alluvial deposits beneath Line 1 north of station 800 feet which could be less permeable than the coarse-grain alluvium between elevations 450 to 510 feet. These deposits are shown in this area by the less than 2,000 ft/sec velocity layer below elevation 450 feet. Based on the geophysical profiles, which indicate an east-sloping bedrock surface and the migration of a bedrock channel further to the east beneath the VRWD property, these older alluvium deposits may be thinning to the east beneath a thicker layer of coarse-grain, more permeable alluvium within the axis of the bedrock channel. This interpretation is also supported by the lower elevation of 443 feet for the expected Well 1 shutoff pumping water level which we interpret could be close to the base of this more permeable alluvium.

## 5.0 RECOMMENDATIONS

The recommended locations for the proposed groundwater test well on the VRWD property are shown in Figure 9. These locations were positioned to place the well within the interpreted bedrock channel. The well boring should be drilled and continuously cored to a depth within the bedrock. Considerations should be given to possibly extending the depth of this borehole to test the deeper higher-resistivity zone below elevation 350 feet shown in Figure 8. This higher-resistivity zone may indicate permeable groundwater conditions within the deeper bedrock units.

It is also recommended that a detailed geologic log be prepared for the groundwater test well and that borehole resistivity logs be run before well completion.

Before the new groundwater production well is constructed it is also recommended that considerations be given to conducting one additional seismic refraction profile along a survey line positioned on the VRWD property that crosses the groundwater test well. This seismic refraction profile could be directly correlated to the borehole log from the test well to provide a more accurate interpretation of bedrock structure for the positioning of the production well.

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Advanced Geoscience appreciates this opportunity to be of service to the Ventura River Water District.

Please call the undersigned for any additional information or requests concerning this geophysical investigation. Thank you.

Sincerely,

**Advanced Geoscience, Inc.**

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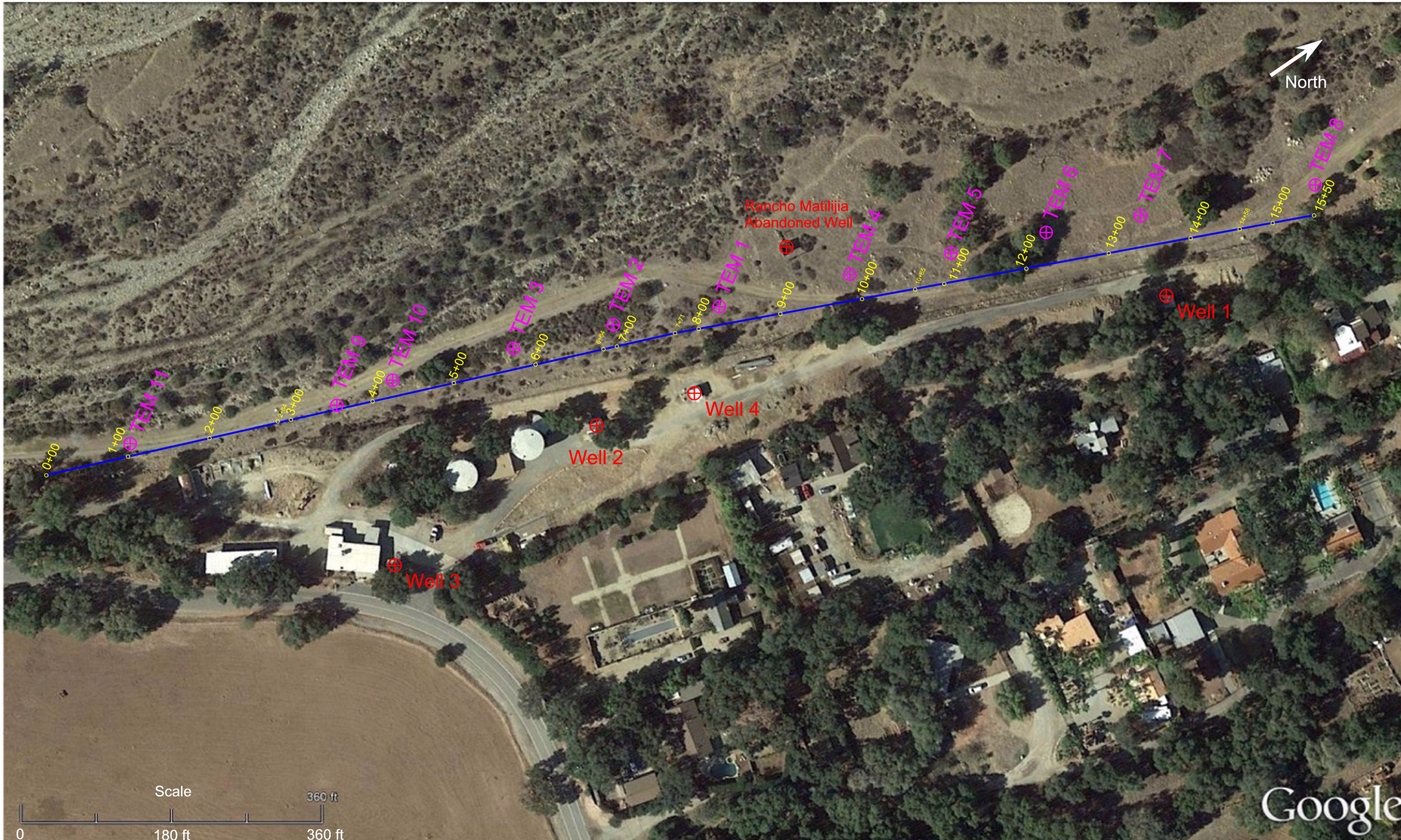
List of Attachments:

Figure 1- Site Map Showing Locations of Seismic Line 1 and TEM Resistivity Soundings
Figure 2- Geologic Map of Area
Figure 3- Line 1 Seismic Refraction Compressional-Wave Velocity Profile
Figure 4- Line 1 Seismic Reflection Depth Profile
Figure 5- Line 1 MASW Shear-Wave Velocity Profile
Figure 6- TEM 1D Resistivity Profiles for TEM-3 and TEM-5
Figure 7- TEM 1D Resistivity Profile for TEM-8 and Well 1 Resistivity Logs
Figure 8- TEM 2D Resistivity Profile
Figure 9- Site Map Showing Interpretation of Subsurface Faulting and Orientation of Possible Bedrock Channel




Site Map Showing Locations of
Seismic Survey Line 1 and TEM Resistivity Soundings
Ventura River Water District Facility Ojai, California

Figure 1
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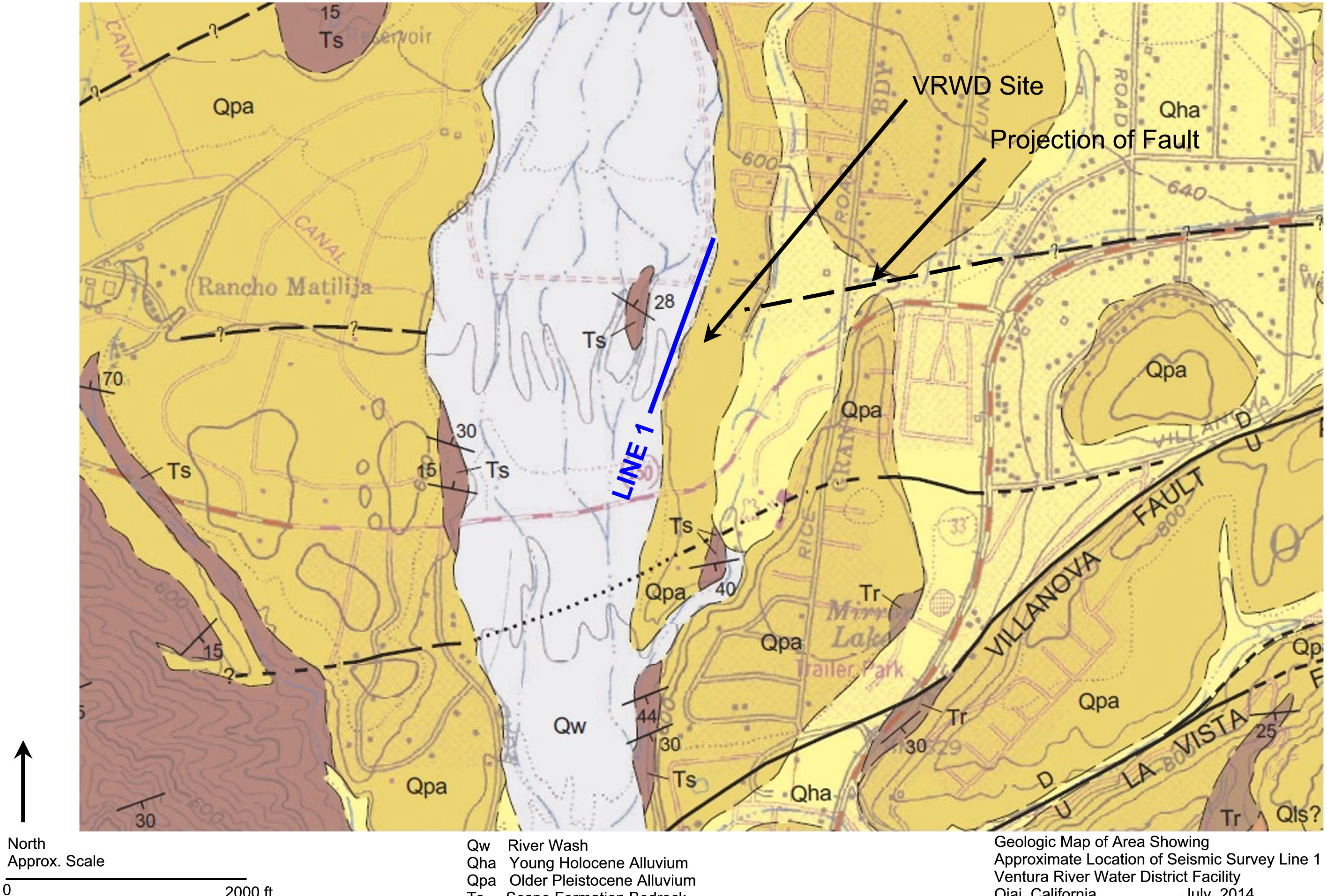
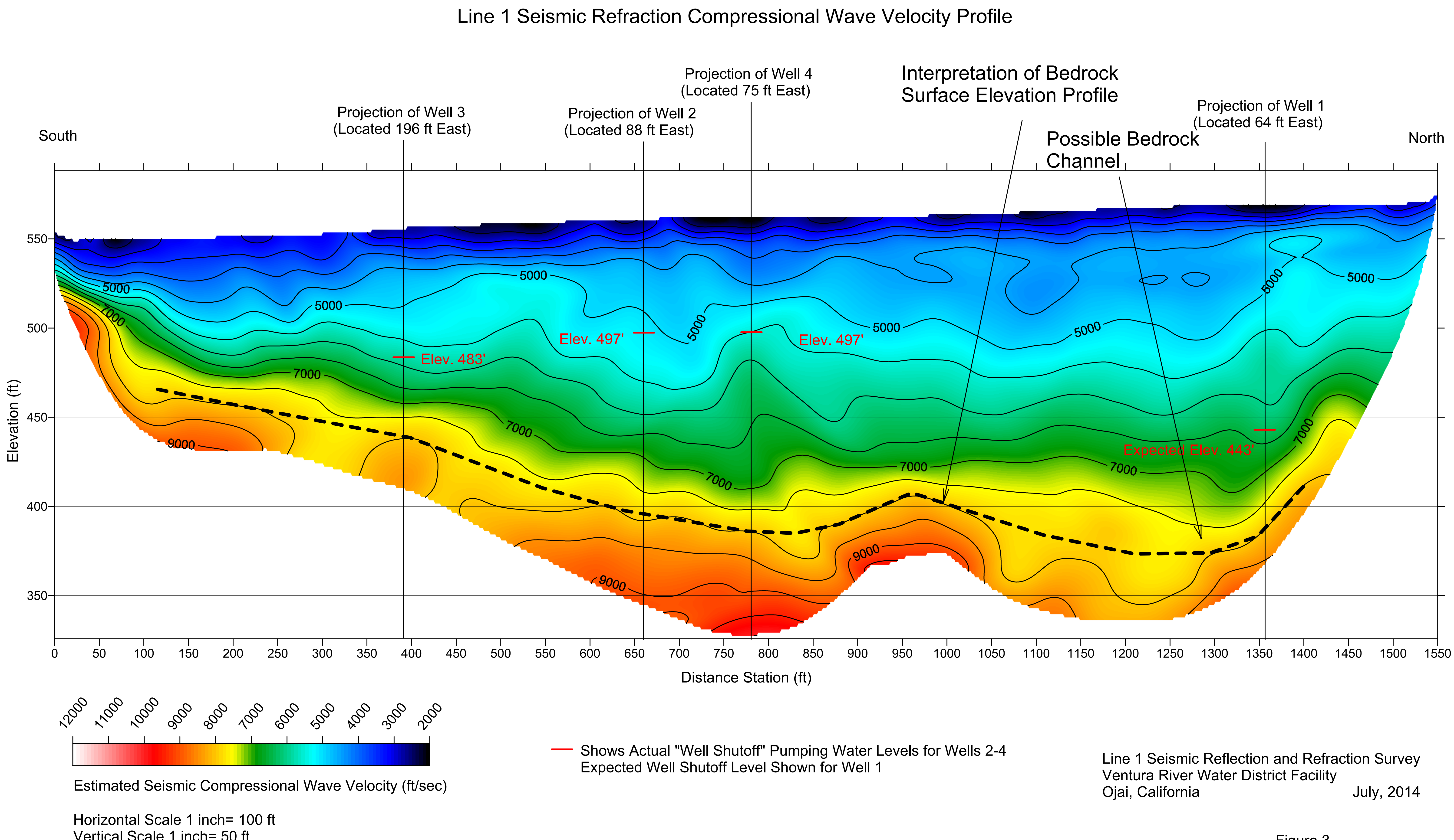



Qw River Wash
Qha Young Holocene Alluvium
Qpa Older Pleistocene Alluvium
Ts Sespe Formation Bedrock

Geologic Map of Area Showing
Approximate Location of Seismic Survey Line 1
Ventura River Water District Facility
Ojai, California July, 2014

Figure 2
Advanced Geoscience, Inc.




Line 1 Seismic Reflection and Refraction Survey
Ventura River Water District Facility
Ojai, California July, 2014

Figure 3
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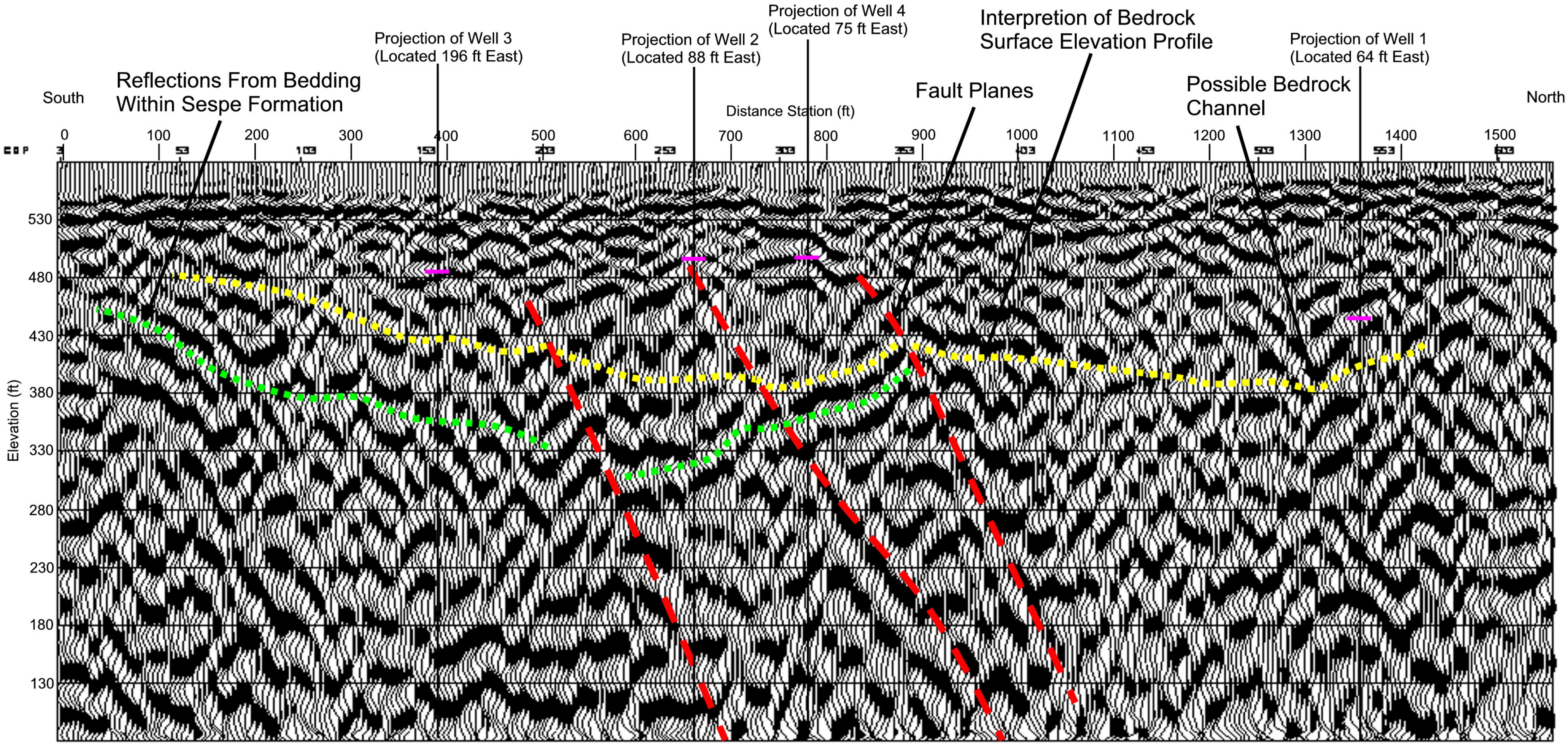
Line 1 Seismic Reflection Depth Profile




Horizontal Scale 1 inch= 100 ft
Vertical Scale Approx. x 1.25

Shows Actual "Well Shutoff" Pumping Water Levels for Wells 2-4
Expected Well Shutoff Level Shown for Well 1

Line 1 Seismic Reflection and Refraction Survey
Ventura River Water District Facility
Ojai, California July, 2014

Figure 4
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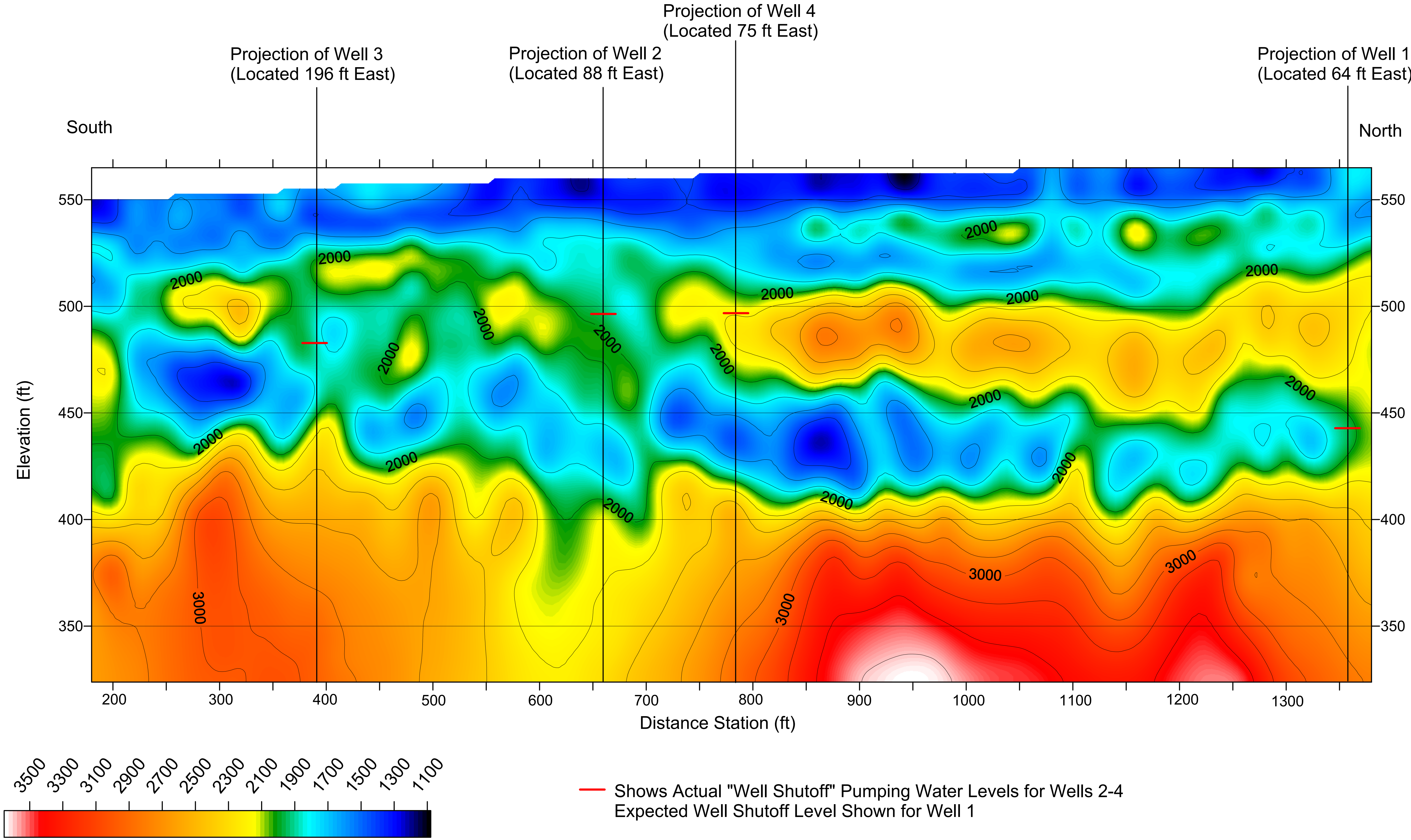
# Line 1 MASW Seismic Shear-Wave Velocity Profile




Shows Actual "Well Shutoff" Pumping Water Levels for Wells 2-4
Expected Well Shutoff Level Shown for Well 1

Horizontal Scale 1 inch= 100 ft
Vertical Scale 1 inch= 50 ft

Line 1 Multi-Channel Anaysis of Surface Waves (MASW)
Seismic Shear-Wave Velocity Survey
Ventura River Water District Facility
Ojai, California July, 2014

Figure 5
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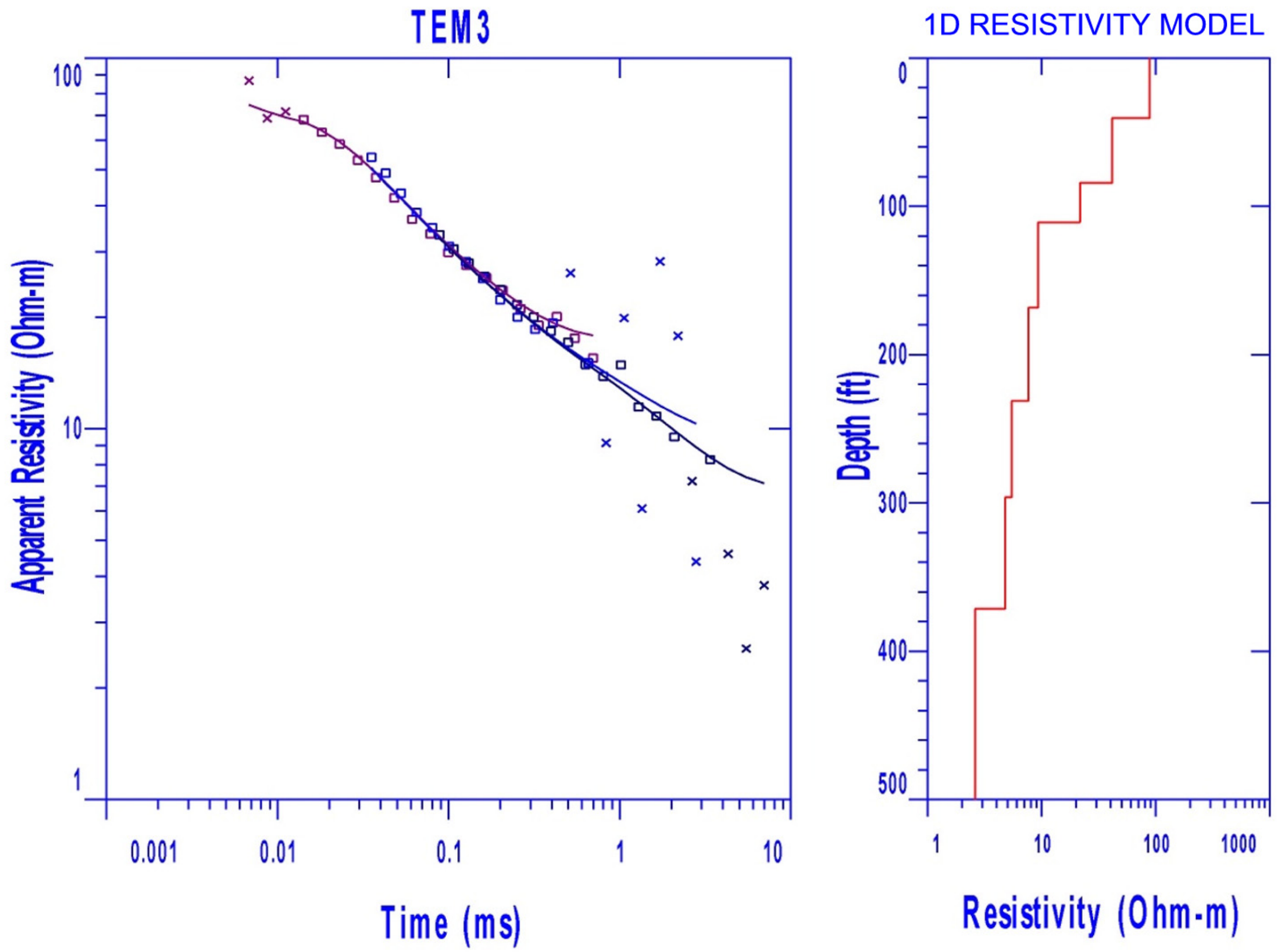
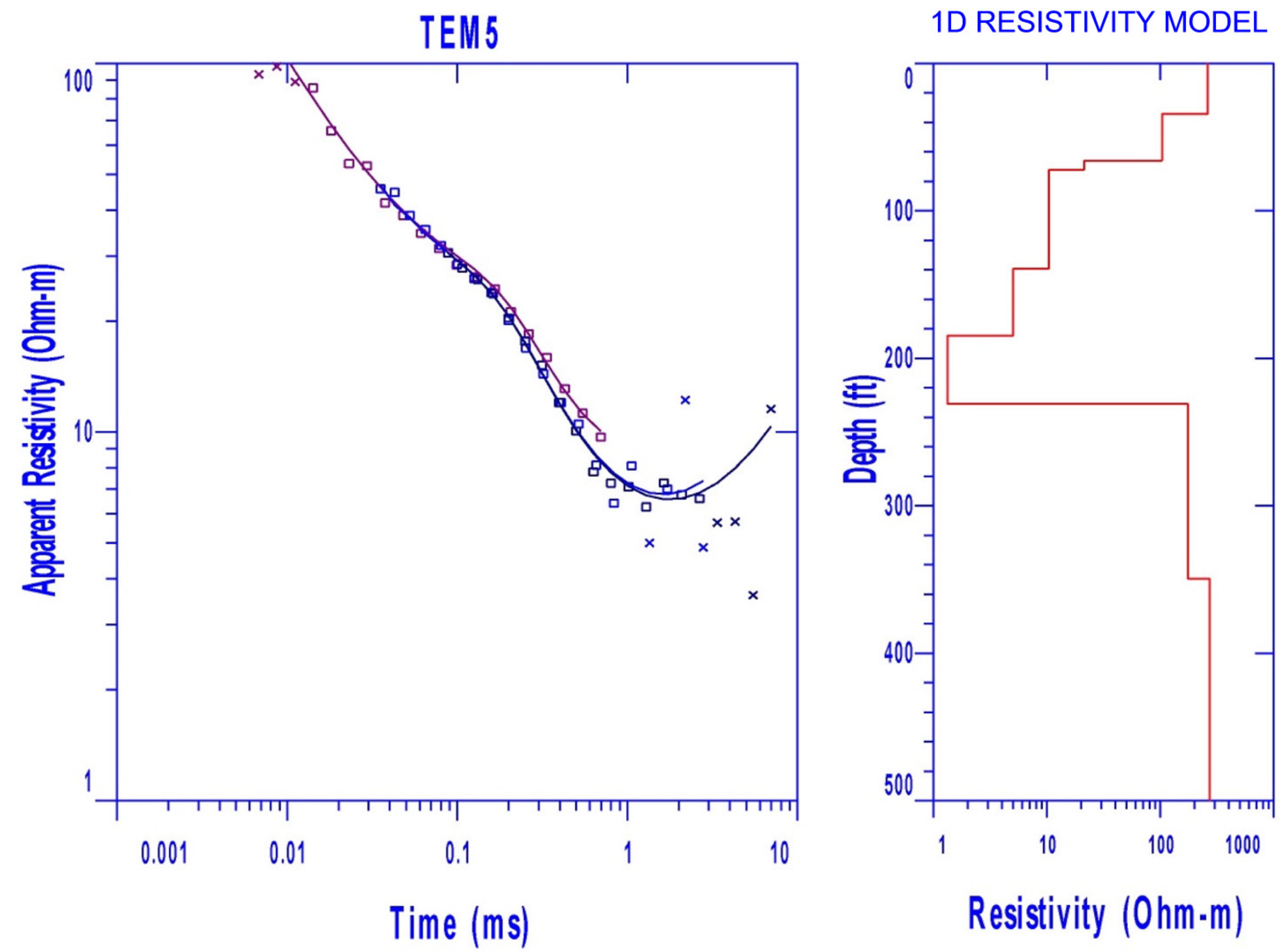
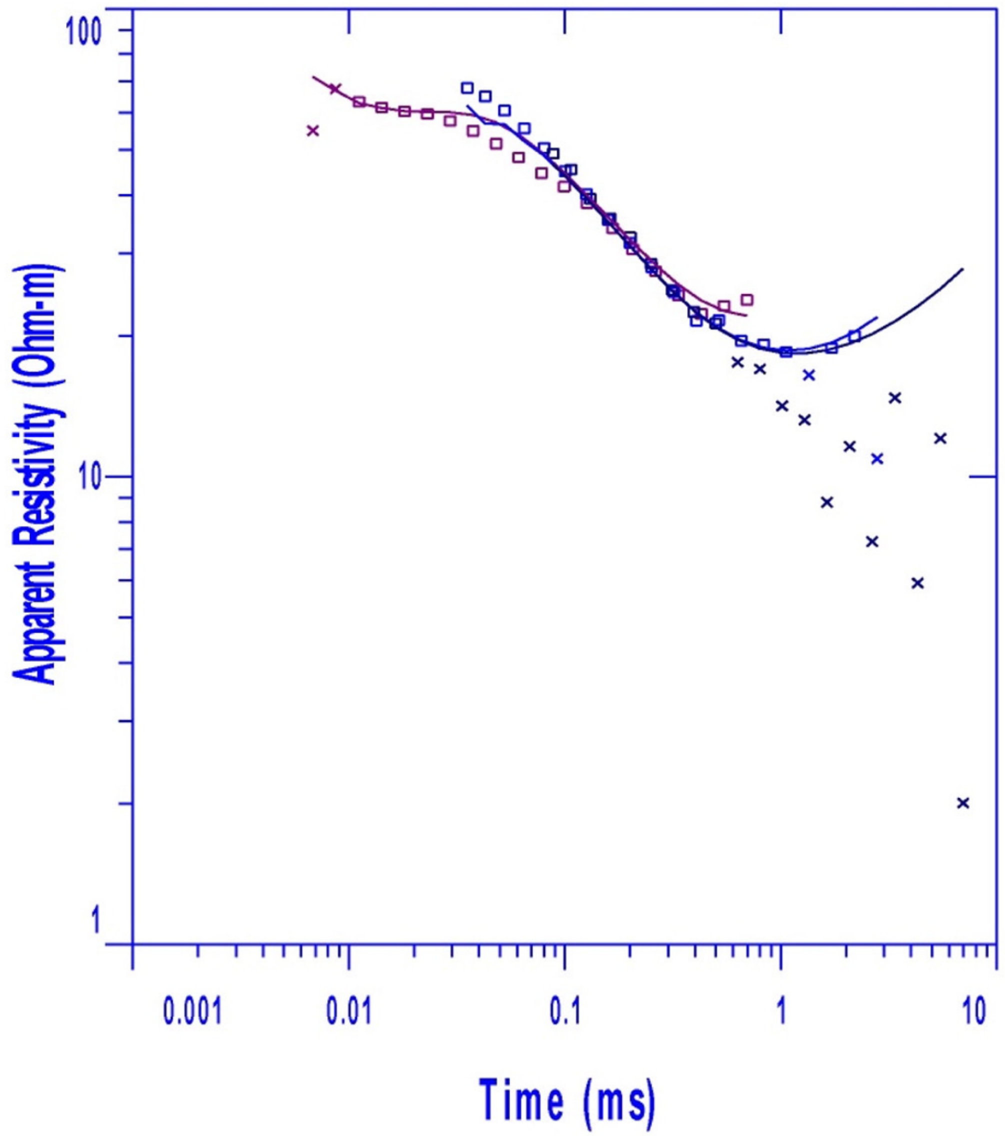


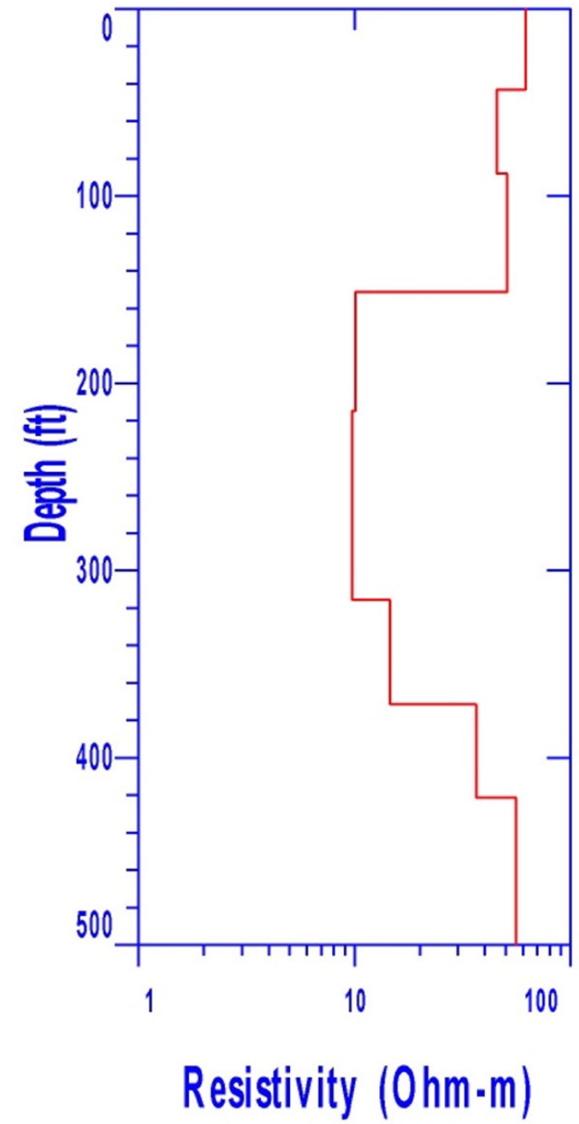

TEM 1D Resistivity Profiles for
Sounding Points TEM-3 and TEM-5
Ventura River Water District Facility
Ojai, California July, 2014

Figure 6
Advanced Geoscience, Inc.

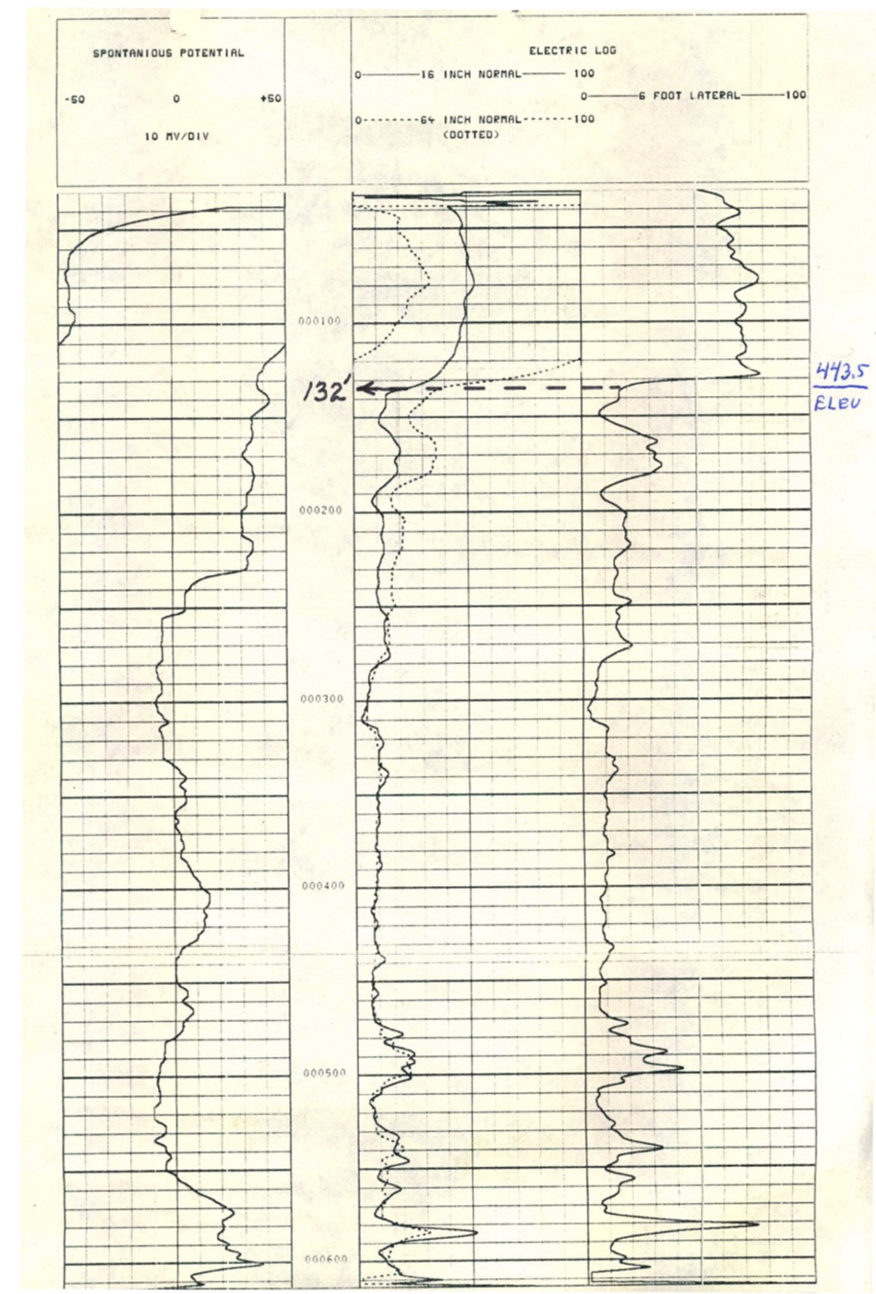
TEM8




1D RESISTIVITY MODEL




WELL 1 BOREHOLE RESISTIVITY LOGS




TEM 1D Resistivity Profile for
Sounding Point TEM-8 and Well 1 Borehole Resistivity Logs
Ventura River Water District Facility
Ojai, California July, 2014

Figure 7
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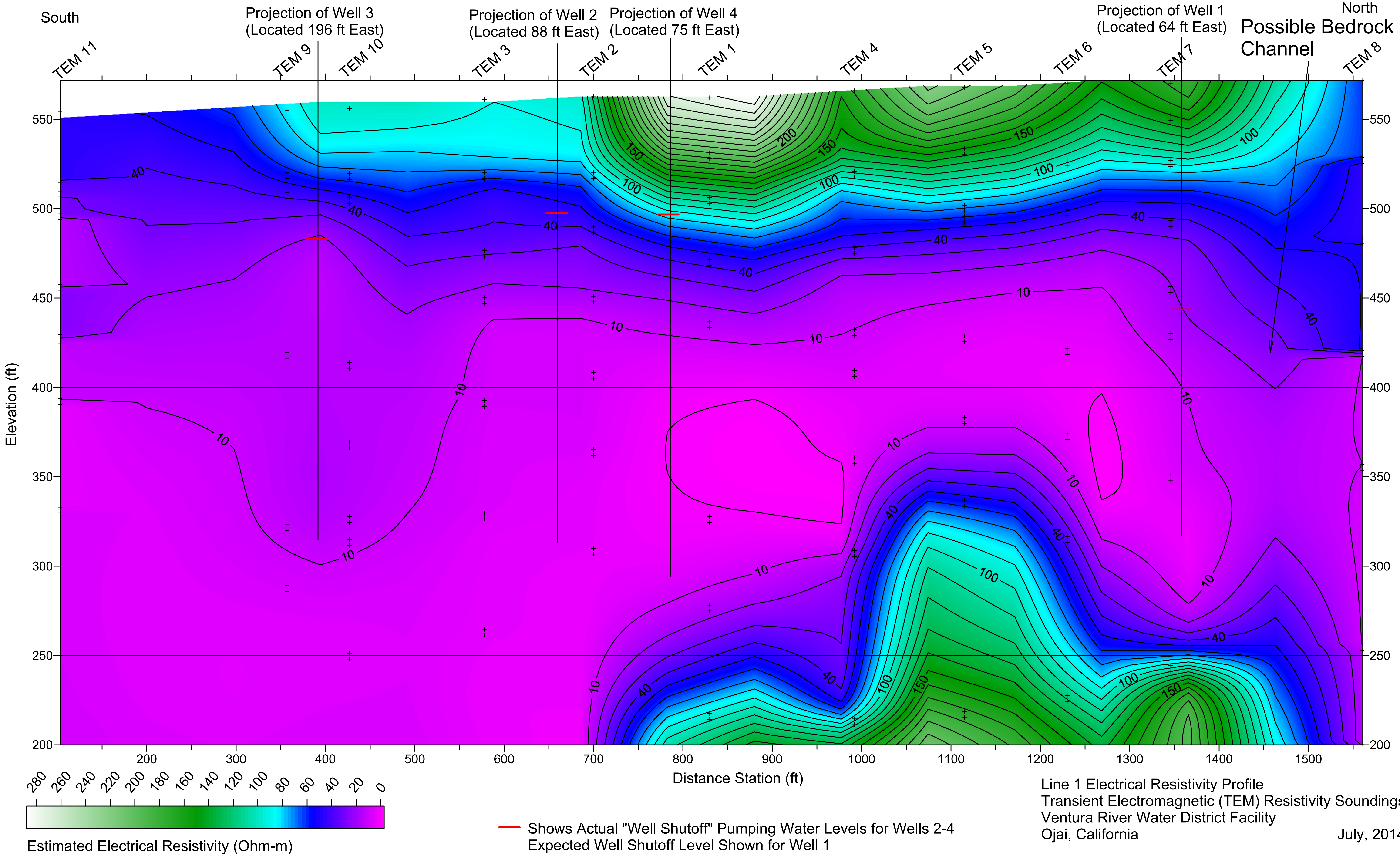
TEM Electrical Resistivity Profile




Horizontal Scale 1 inch= 100 ft
Vertical Scale 1 inch= 50 ft

Line 1 Electrical Resistivity Profile
Transient Electromagnetic (TEM) Resistivity Soundings
Ventura River Water District Facility
Ojai, California
July, 2014

Figure 8
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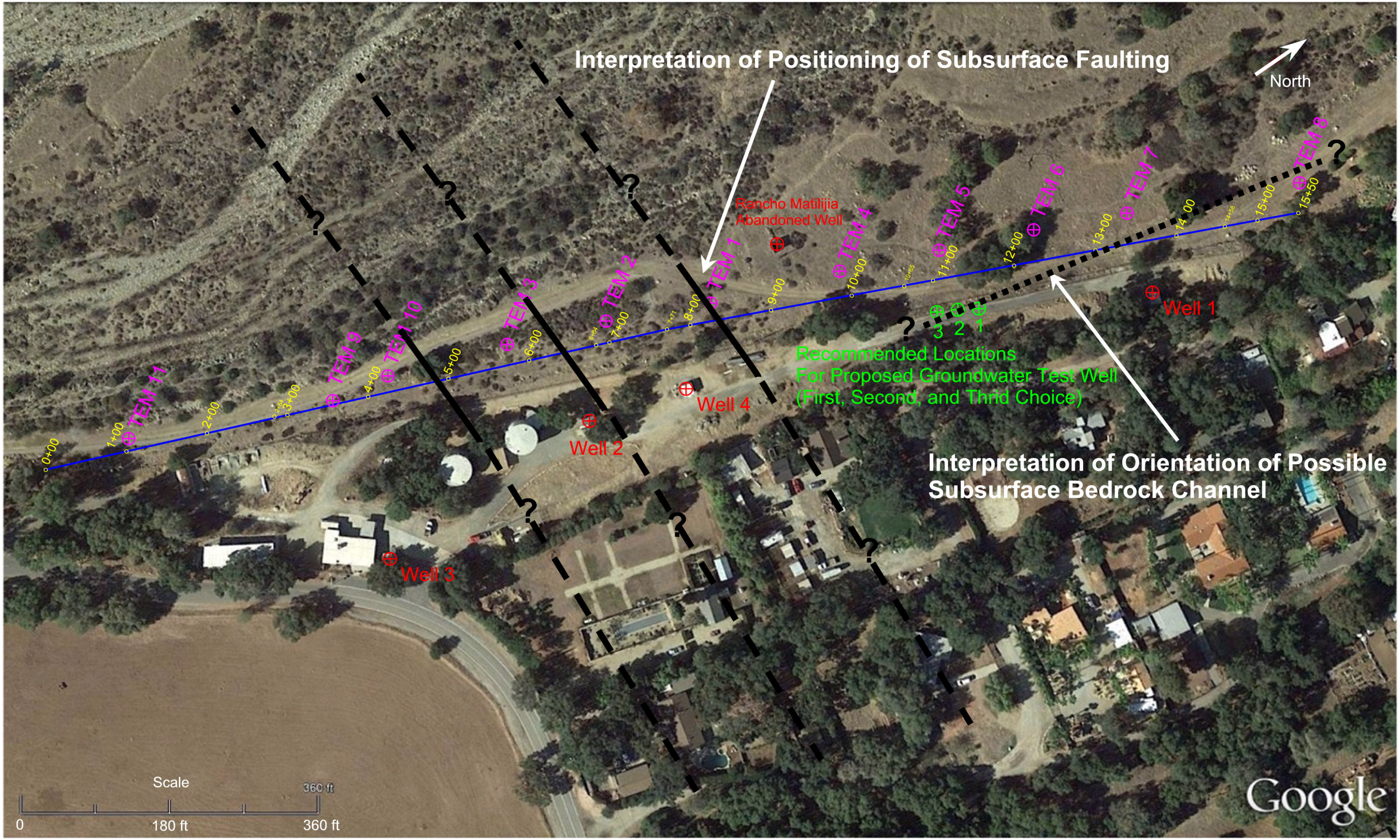


Site Map Showing Interpretation of
Subsurface Faulting and Possible Bedrock Channel
Ventura River Water District Facility Ojai, California

Figure 9
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