# Investigation of Pervasive Clay Layers and Their Effect on Groundwater Flow Using Electrical Resistivity Tomography in the San Antonio Groundwater Basin

A Senior Project Presented to

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## Abstract

The United States Geological Survey is developing an integrated hydrologic model of the San Antonio Creek Groundwater Basin to better understand and simulate the integrated surface water and groundwater system. An abrupt 60 meter offset in groundwater depth over a distance of less than one kilometer is observed in well readings within the Cañada De Las Flores region of the groundwater basin. Abrupt changes in groundwater levels are often explained by the presence of a fault in the subsurface vertically offsetting sedimentary units. However, observations of the structural geology of this region indicates that faulting is unlikely and suggests an alternative hypothesis: subsurface folds of the sedimentary units may provide distinct groundwater pathways to separated groundwater sub-basins. To test the two hypotheses Electrical Resistivity Tomography profiles were collected to image the subsurface and constrain the geologic structure responsible for the offset in groundwater levels. The subsurface imaging results do not support the fault model, but instead image a layer interpreted as impermeable clay that may be extensive throughout the folded structure of the region. The folded clay structure provides a plausible geologic model for diverting the subsurface flow of water producing the abrupt offset in groundwater well levels. The correct identification of the geologic structure in Cañada De Las Flores is important because each model significantly changes the characteristics and predictions of a groundwater model with respect to predicted subsurface flow, groundwater distribution, and recharge.

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# 1. Introduction

The United States Geological Survey (USGS) is developing an integrated hydrologic model model to assist stakeholders in the San Antonio Creek Groundwater Basin plan for future water use. The San Antonio Creek Valley is characterized by rural agriculture that predominantly relies on groundwater (Fig. 1). An increased demand for groundwater has resulted in a measured decline of groundwater levels since the 1950s, and there is a concern among stakeholders that continued declines could negatively affect the groundwater supply (“San Antonio Creek Water Availability,” last accessed 06-12-2019). The USGS has identified two important objectives in solving this problem: (1) developing a hydrogeologic framework model for the basin, and (2) characterizing the surface/groundwater interactions.

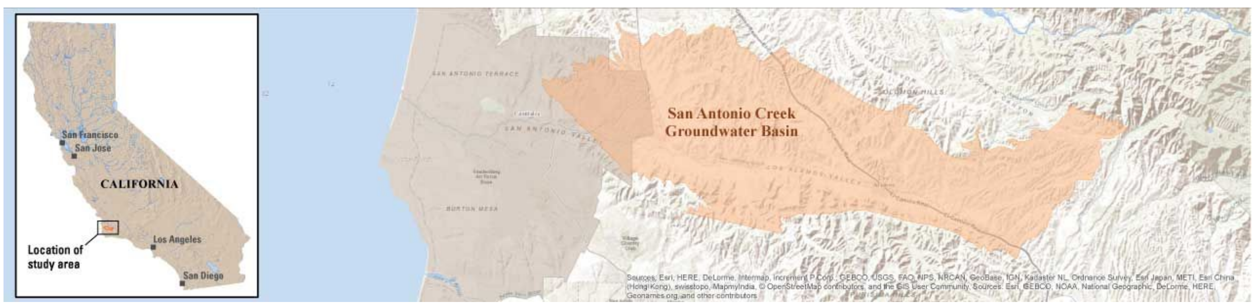


**Figure 1.** Regional overview of study area. The region of the US Geological Survey groundwater basin modeling study is shown in orange. Figure from https://ca.water.usgs.gov/projects/san-antonio-creek/index.html (last accessed on 2019-06-12).

The aim of this paper is to improve the hydrogeologic understanding of the San Antonio Groundwater Basin by identifying the subsurface geologic structure of Cañada De Las Flores region of the basin. The Cañada De Las Flores contains two nearby (~1 kilometer) groundwater wells that display an abrupt 60 meter offset in depth to water over a short distance of less than one kilometer (Fig. 2). Drastic changes in groundwater levels such as this are often explained by the presence of a fault in the subsurface that vertically offsets impermeable units. In this location the topography suggests that the fault, if present, would likely be a normal fault. However, observations of the regional geology indicates that the extensional faulting necessary to produce such an offset is unlikely within the basin. Regional geology suggests an alternative hypothesis, that due to the region being composed of a series of anticlines and synclines, subsurface folds of the impermeable sedimentary units may provide distinct groundwater pathways to separate groundwater sub-basins (Fig. A1). To test the Fault Model (Hypothesis 1), vs. the Subsurface Fold Model (Hypothesis 2), Electrical

Resistivity Tomography (ERT) was used to image the subsurface and constrain the geologic structure responsible for the offset in groundwater levels.

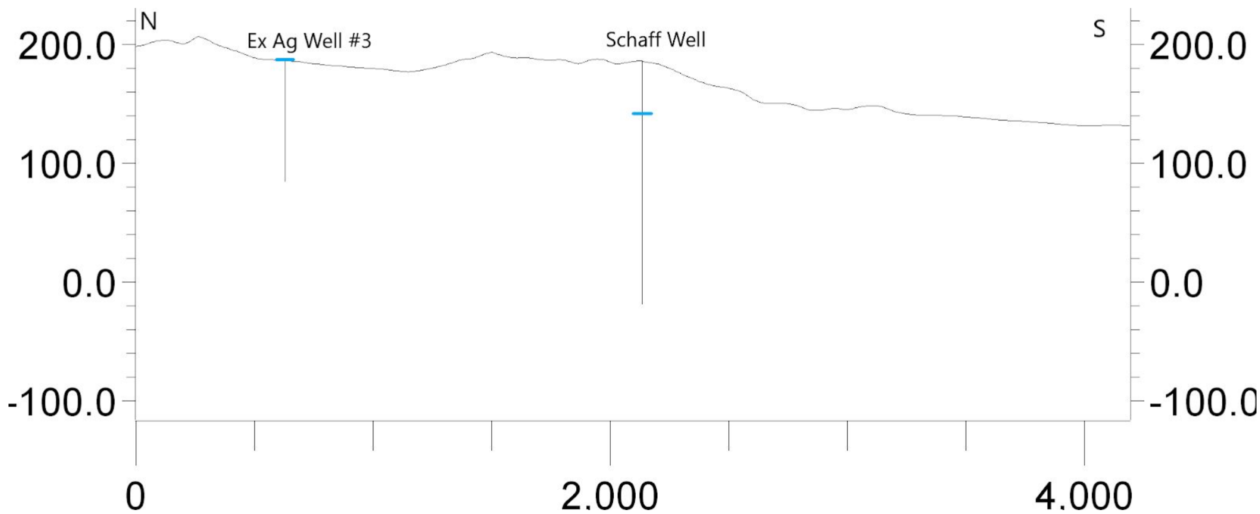


**Figure 2.** Cross-section of depth to water in wells the San Antonio Groundwater Basin. The offset in water levels in the Ex Ag Well #3 (008N033W09H002S) and the Schaff Well (008N33W16H) is shown to be approximately 60 meters. The Y-axis is elevation above sea level in meters and the X-axis is distance along the profile in kilometers. Profile is shown in Figure A2. Modified from original image provided by G. Cromwell.

## 2. Site Description

### 2.1 Study area

The San Antonio Groundwater Basin is located in western Santa Barbara County approximately 24 kilometers south of Santa Maria and 88 kilometers north of Santa Barbara. The basin is about 48 kilometers long and 11 kilometers wide paralleling the drainage of San Antonio Creek. The San Antonio Groundwater Basin is situated between Santa Maria Basin to the north and Santa Ynez Basin to the south. To the north of the basin lies the Casmalia Hills and the Solomon Hills, and to the south lies the Purisima Hills and Burton Mesa. The basin is bounded on both the east and the west by uplifted consolidated sedimentary rocks. San Antonio Creek provides the main surface drainage for the area, flowing generally from east to west into the Pacific Ocean. The study focuses on an area of approximately 0.62 square kilometers around Cañada De Las Flores within the San Antonio Groundwater Basin. Cañada De Las Flores is located approximately 6.7 kilometers northwest of Los Alamos, California (Fig. 3). Cañada De Las Flores is a roughly north-south trending canyon that is approximately 2 kilometers long and 0.5 kilometers wide and is situated about 1.5 kilometers to the north of Highway 135. Water flows into the canyon from the northeast and is drained to the south by a tributary to the San Antonio Creek.

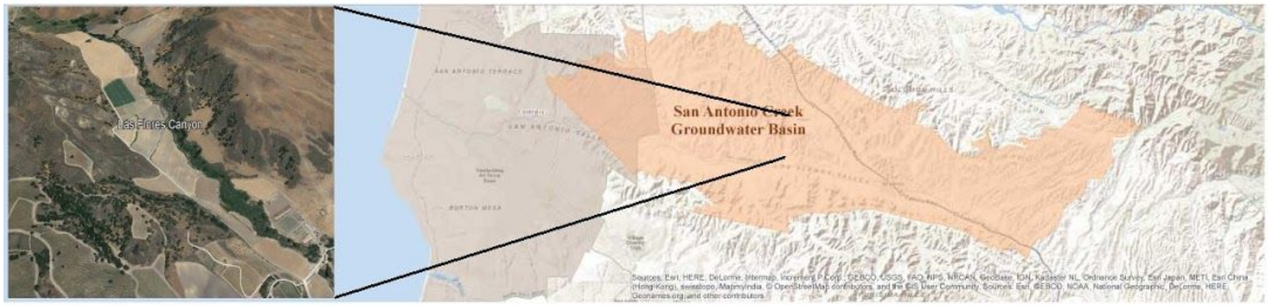


**Figure 3.** Location of Cañada De Las Flores within the San Antonio Groundwater Basin. Figure modified from original figure provided by the US Geological Survey. https://ca.water.usgs.gov/projects/san-antonio-creek/index.html (last accessed on 2019-06-12).

## 2.2 Local Geology

The study area has been subjected to considerable Quaternary shortening and uplift as evidenced by extensive folds, thrust faults, angular unconformities, mountain building, and syngenetic deposits (Namson & Davis, 1990). Local examples of these shortening features are the Los Alamos Syncline, Solomon Anticline, and the Los Alamos Fault (Fig. 4) (Tennyson, 1992). Quaternary erosion has led Cañada De Las Flores to be incised into an anticline to the north of the Los Alamos Syncline by a tributary to the San Antonio Creek. The valley floor of Cañada De Las Flores comprises Quaternary alluvial gravel, sand, and clay. Underlying the Quaternary alluvium and composing the canyon walls is the Paso Robles Formation. The Paso Robles Formation consists of weakly consolidated valley alluvial sediments deposited from streams (Dibblee, T.W., Ehrenspeck, H.E., and Bartlett, 1994). The Paso Robles Formation lies stratigraphically above the Careaga Sandstone which composed of two members: the Graciosa Member and the Cebada Member. The Graciosa Member of the Careaga Sandstone consists of massive gray-white to tan sandstone or sand which is in part, nonmarine and wind-deposited and pebbly at the base. The Cebada Member of the Careaga Sandstone consists of massive tan to yellow, soft, fine-grained sandstone or sand that locally contains small marine shell fragments. The Careaga Sandstone then unconformably overlies the Foxen Claystone which is composed of dark gray soft claystone that is approximately 270 to 365 meters thick (Dibblee, T.W., Ehrenspeck, H.E., and Bartlett, 1994).

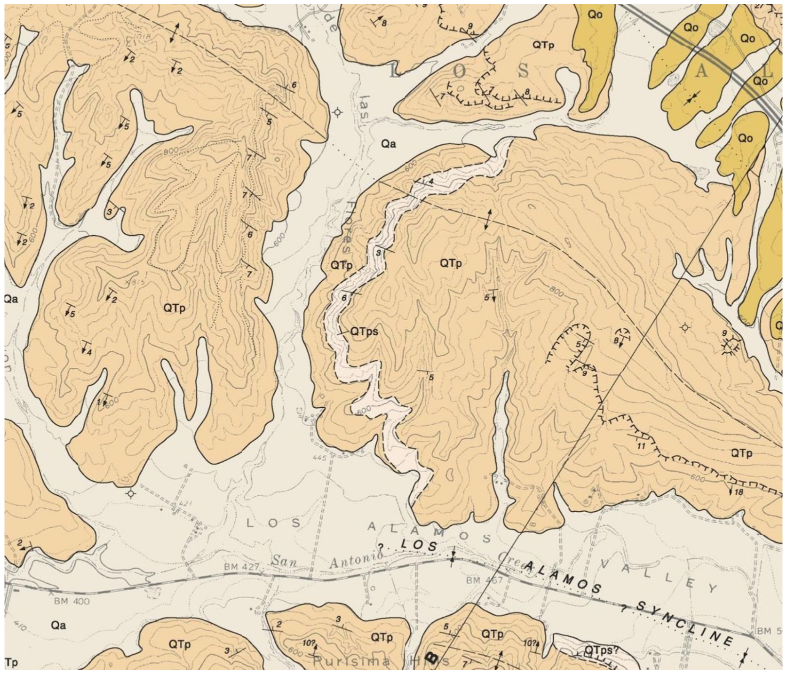


**Figure 4.** Geologic map of Cañada De Las Flores modified from the Geologic map of the Sisquoc quadrangle, Santa Barbara County, California provided by the USGS and Dibblee Geological Foundation. (https://ngmdb.usgs.gov/Prodesc/proddesc_228. htm).

# 3. Methods

## 3.1 Electrical Resistivity Tomography

Electrical resistivity surveys measure variations in the electrical resistivity of the subsurface by injecting current (I, in Amps) into the ground through two electrodes and measuring the resulting electric potential (V, in Volts) across other pairs of electrodes (Fig. 5). The resistivity meter acts as both a voltmeter to measure voltage (V) and an ammeter to measure current (I). The resistivity meter can automate user selected patterns of measurements along a profile to efficiently collect two-dimensional data. Each measurement initially calculates calculates resistance values (R = V/I, in Ohms), and is then converted to resistivity values (Ω*m) by multiplying resistance values by a geometric factor *K* that is dependent on the array style (Burger, Sheehan, & Jones, 2006). Resistivity is an inherent material property, whereas resistance is a function of a material and its geometry. Resistivity data collected in the field is initially considered as apparent resistivity because variations in geologic material along a current path all contribute to the measured value. The field data are then inverted for a true model of electrical resistivity in the form of a two-dimensional cross section as in this study, or in the case of a three-dimensional survey a subsurface volume. Resistivity values can be interpreted for subsurface geologic structure, composition, and conditions such as degree of soil saturation. Multiple array collection styles exist, each with trade-offs in either the vertical or horizontal direction. In this study, a Schlumberger style array was used (Burger, Sheehan, & Jones, 2006) which attempts to balance horizontal and vertical resolution. This was chosen since the subsurface structure was not constrained by prior investigations, and therefore the data collected would not be biased to either horizontal or vertical structures.

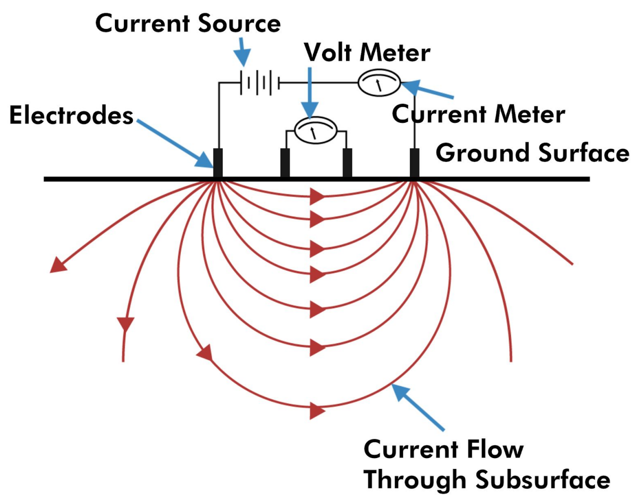


**Figure 5.** Schematic of a single electrical resistivity measurement. Measurements are done along a profile in an automated way with the AGI SuperSting R8 field equipment used. Figure from http://edtech.engineering.utoronto.ca/object/electrical-resistivity.

**Table 1.** Summary range of resistivity values for common geologic materials (Burger, Sheehan, & Jones, 2006).

| Material | Resistivity (Ω•m) |
|---|---|
| Wet to moist clayey soil and wet clay | 1s to 10s |
| Wet to moist silty soil and silty clay | Low 10s |
| Wet to moist silty and sandy soils | 10s to 100s |
| Sand and gravel with layers of silt | Low 1000s |
| Coarse dry sand and gravel deposits | 1000s |
| Fractured rock with moist, soil-filled cracks | 100s |
| Slightly fractured rock with dry, soil-filled cracks | Low 1000s |
| Massively bedded rock | High 1000s |

## 3.2 Electrical Resistivity Profile Locations

The location of the Las Flores and Four Deer profiles (Fig. 6) were chosen to best image the geologic structure in Cañada Las Flores causing the offset in groundwater levels and were collected August 8th and 9th., 2018. These locations are further reinforced by their proximity to groundwater wells used to check and correlate the collected resistivity values to local lithology and depth to water. The 008N33W16H well, from here on referred to as the Schaff well, is located at the southern extent of the Las Flores profile (Table. A1). The 008N033W09H002S well, here on referred to as the Ex Ag Well #3, is located at the northern extent of the Four Deer profile and displays artesian properties (Fig. 6, Table. A1). If the offset in groundwater levels is a product of faulting, the Four Deer and Las Flores profiles would be able to detect this subsurface structure. However, if the offset is not caused by faulting and is a product of a folded subsurface impermeable clay layer the Highway 135 profile, collected on August 11th, 2018 serves a way to image the corresponding syncline of the fold, which would add confidence to the structural fold interpretation. A possible confining unit (QTps) mapped at the surface in Cañada De Las Flores by Dibblee and Ehrenspeck (1994) continues out of the canyon and parallels the San Antonio Creek to the east (Fig. 4). If a folded subsurface clay layer similar to the mapped surface clay layer is present, the three chosen profiles should image the layer in the Cañada De Las Flores and exiting the canyon to the east along the San Antonio Creek.

**Table 2.** Summary of geometry for acquired profiles. Coordinates given represent location of resistivity meter.

| Profile | Latitude | Longitude | Orientation | Location of Resistivity Meter | Date Aquired |
|---|---|---|---|---|---|
| Four Deer | 34.7825° | -120.3472° | 332° | End of Profile | 8-8-2018 |
| Las Flores | 34.77917° | -120.3492° | 0° | Center of Profile | 8-9-2018 |
| Highway 135 | 34.75056° | -120.3506° | 72° | End of Profile | 8-11-2018 |

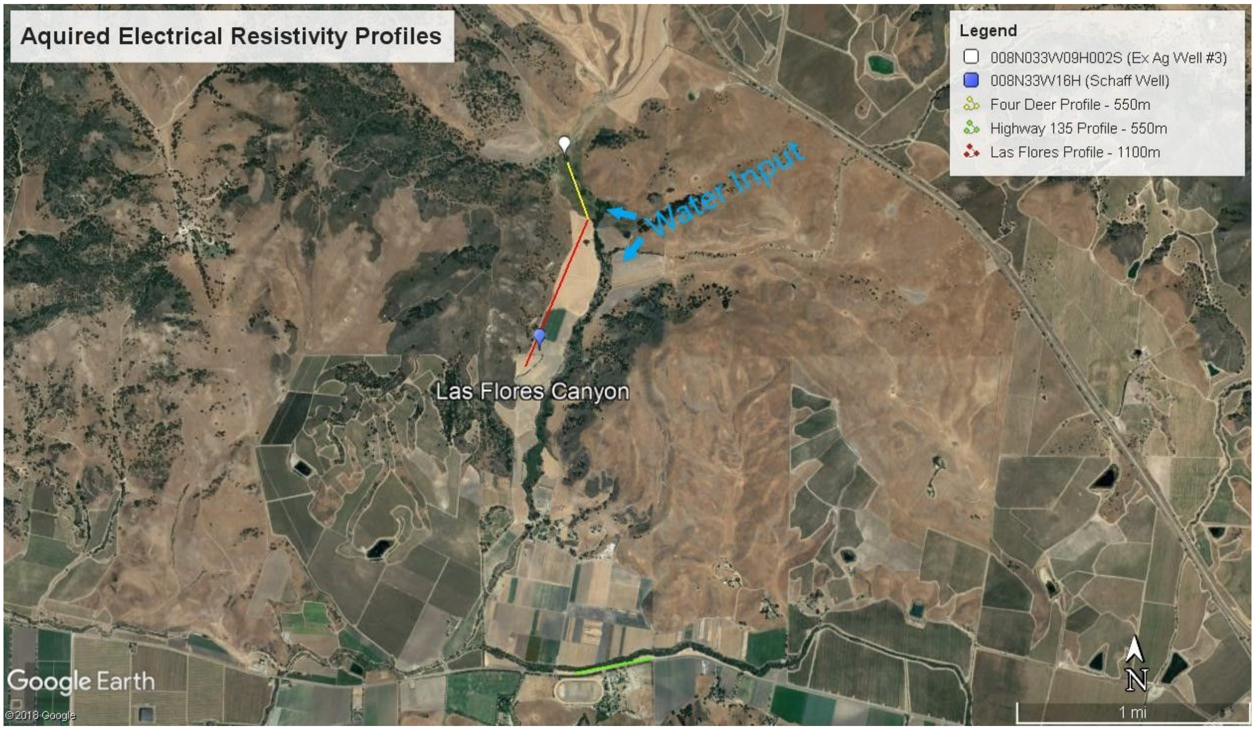


**Figure 6.** Locations of electrical resistivity profiles within the study area. Four Deer profile was 550 meters(yellow), Las Flores profile was 1100 meters(red), and Highway 135 profile was 550 meters (green).

**Table 3.** Summary of acquisition parameters for acquired profiles.

| Profile | Array | Max AB/MN | Expansion Factor | Length (m) | No. electrodes | Electrode Spacing (m) | Measure Time (s) | Measurements |
|---|---|---|---|---|---|---|---|---|
| Los Flores | Schumberger Inverse | 11 | 28 | 1100 | 112 | 10 | 1 | 1359 |
| 4 Deer | Schumberger Inverse | 11 | 14 | 550 | 112 | 10 | 1 | 455 |
| Highway 135 | Schumberger Inverse | 11 | 14 | 550 | 112 | 10 | 1 | 455 |

## 3.3 Synthetic Forward Models

Numerical simulations of two plausible geological scenarios in Cañada De Las Flores were conducted (Fig. 7, 8). The first scenario represents a low resistivity impermeable clay layer (modeled as ~10-15 Ω*m) within the Paso Robles Formation that is pervasive throughout the folded structure of the region. This layer is then overlain by quaternary alluvium that comprises the unconfined aquifer (~50-100 Ω*m) and the shallower dry unconsolidated sediments (~200-400 Ω*m) in the canyon. The second scenario also represents a low resistivity impermeable layer (~10-15 Ω*m) within the Paso Robles Formation, but one that is offset by a normal fault. Mechanical failure of the layer during faulting was modeled by including low resistivity elements between the offset layers. The offset impermeable layers are then overlain by quaternary alluvium (~40-100 Ω*m) that comprises the unconfined aquifer and the dry unconsolidated sediments (~200-400 Ω*m) above the water table. Electrical resistivity values of around 400 Ω*m for the dry unconsolidated are used in the numerical simulation, however actual field electrical resistivity values these sediments could be much larger depending on soil moisture conditions, e.g. ~1000 Ω*m. These numerical simulations were inverted using the same parameters as the actual field data. A commonly used measure of goodness for the inversion is the root-mean-squared (RMS) misfit between modelled and measured resistances (Uhlemann, Kuras, Richards, Naden, & Polya, 2017). Both the numerical simulations and field data inversions included both root-mean-squared (RMS) misfit and L2-norm statistics to monitor the inversion progress and convergence. The inversions of each set of electrical resistivity data are stable and accurately reproduce the field data (Fig. A3, A4, A5).

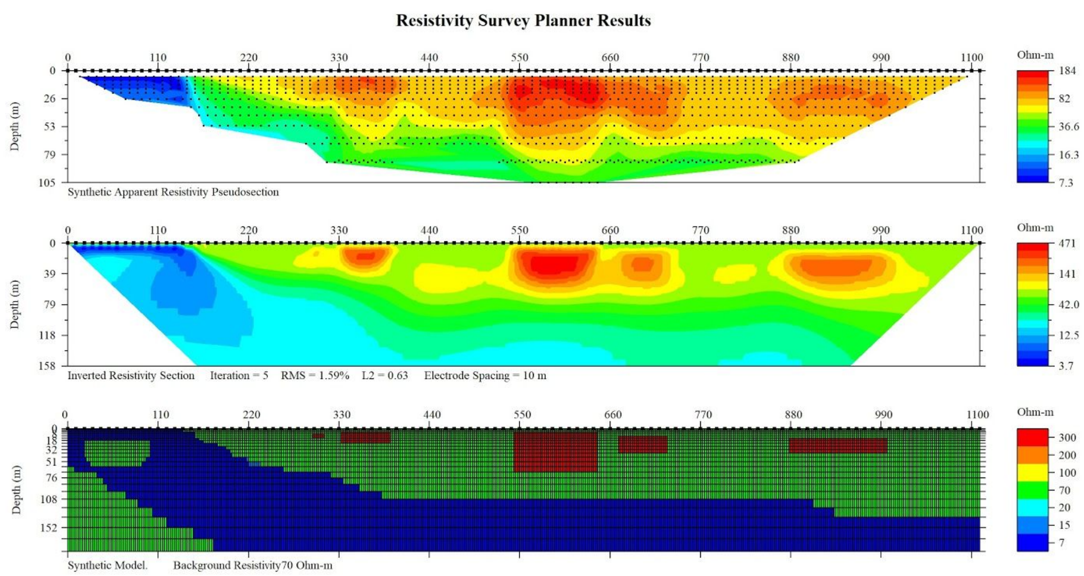


**Figure 7**. Synthetic modeling of a geologic scenario involving the subsurface folding of an impermeable clay layer that is pervasive throughout the folded structure of the region. Bottom panel: resistivity model expected in the geologic scenario. Top panel: the corresponding measured apparent resistivity data to the model. Middle panel: inverted resistivity section. The blue color represents the folded clay layer and is overlain by sediments that compose the unconfined aquifer represented by the green color. Near surface red colors indicate unsaturated sediments above the water table. RMS = 1.59% and L2 normalization = 0.63.

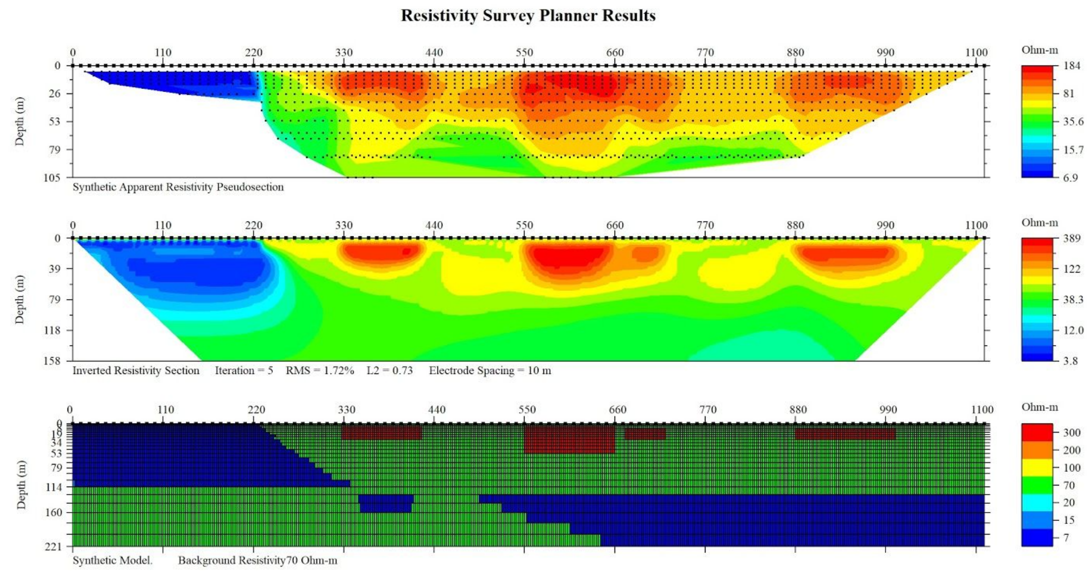


**Figure 8**. Synthetic modeling of a geologic scenario where an impermeable layer is offset by a normal(extensional) fault. Bottom panel: resistivity model expected in the geologic scenario. Top panel: the corresponding measured apparent resistivity data to model. Middle panel: inverted resistivity section. The blue color represents the offset impermeable layer and is overlain by sediments that compose the unconfined aquifer represented by the green color. Near surface red colors indicate unsaturated sediments above the water table while the green color below the impermeable layer represents sediments that predate the impermeable layer. RMS = 1.72% and L2 normalization = 0.73.

# 4. Results and Interpretations

## 4.1 Four Deer Ranch Profile

The low electrical resistivity values (15-20 Ω*m) are consistent with a shallowing impermeable clay layer at or near the surface. The shallow higher values of electrical resistivity (~70 Ω*m) are also consistent with the presence of a confined aquifer near the hinge of the fold that the Ex Ag Well #3 on Four Deer Ranch utilizes (Fig. 8). While this well is approximately 100 meters and 315° to the northwest of the end of the electrical resistivity profile, it is projected onto the profile in Figure 8. We are assuming that the subsurface structure beneath the well is represented by the structure imaged by this profile. The overlying low resistivity layer (15 Ω*m) above the confined aquifer is likely composed of recently deposited sediments by a tributary to the San Antonio Creek. The impermeable clay layer then begins to deepen to the right as Cañada De Las Flores is approached which is also consistent with the interpretation of a folded subsurface layer.

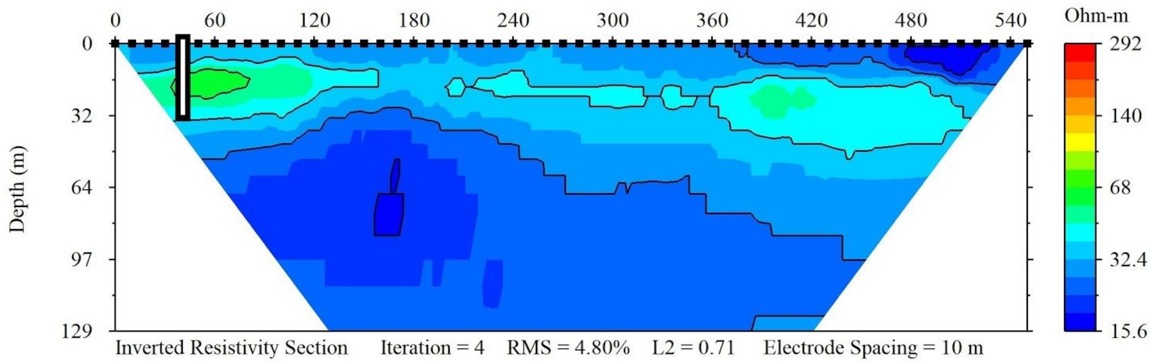


**Figure 8**. Four Deer Ranch Profile. The profile ran in is near the Domestic Artesian well on Four Deer Ranch. The well diagram on the figure is projected from its actual location to the electrical resistivity profile. Low values of electrical resistivity 15-20 Ohm*m are consistent with a shallowing clay layer at or near the surface. The clay layer deepens to the right as Cañada De Las Flores is approached. RMS = 4.80% and L2 normalization = 0.71.

## 4.2 Las Flores Profile

The layer interpreted as the shallowing impermeable clay layer (~15-20 Ω*m) within the Paso Robles formation in Figure 8 is seen to continue across the full 1,100 meters of the Las Flores profile, following the surficially mapped QTPs, and to a depth of almost 240 meters below the reference surface (Fig. 9). This is again consistent with the interpretation of a folded subsurface layer as the depth to the impermeable layer would increase with distance away from the hinge of the anticline near Four Deer Ranch. The shallower electrical resistivity values (~70 Ω*m) indicate quaternary alluvium that comprises the unconfined aquifer. The higher values (250-600 Ω*m) of electrical resistivity near the surface indicate unsaturated sediments above the water table in Cañada De Las Flores.

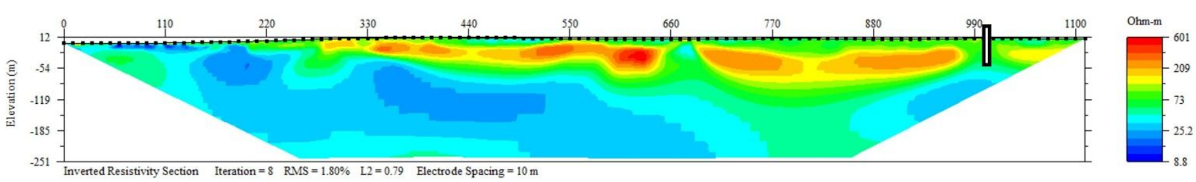


**Figure 9**. Las Flores Profile with surface topography. The well diagram on the figure shows the approximate location of Schaff well. The interpreted clay layer in Figure 8 is seen to continue to deepen to 240 m below the reference surface elevation. Shallower green and yellow colors indicate the aquifer water contained in the sedimentary basin. Near surface red colors indicate unsaturated sediments above the water table. RMS = 1.80% and L2 normalization = 0.79.

## 4.3 Highway 135 Profile

The layer interpreted as the impermeable clay layer in the previous two cross-sections begins to approach the surface as the layer exits Cañada De Las Flores (Fig. 10). The low resistivity values (~15 Ω*m) at a depth of approxiamtely 70 meters corresponds to the clay found at similar depths in nearby wells (The California Department of Water Resources, last accessed 06-13-2019). This clay is interpreted as the same clay layer in the Four Deer and Las Flores profiles. This correlation to the same clay layer in Cañada De Las Flores and the presence of the previously mapped surficial QTps along Highway 135 supports the model of a clay layer pervasive throughout the folded structure of the region. As this profile was collected adjacent to San Antonio Creek, the overlying higher electrical resistivity values most likely represent fine/saturated sediment deposited by the creek.

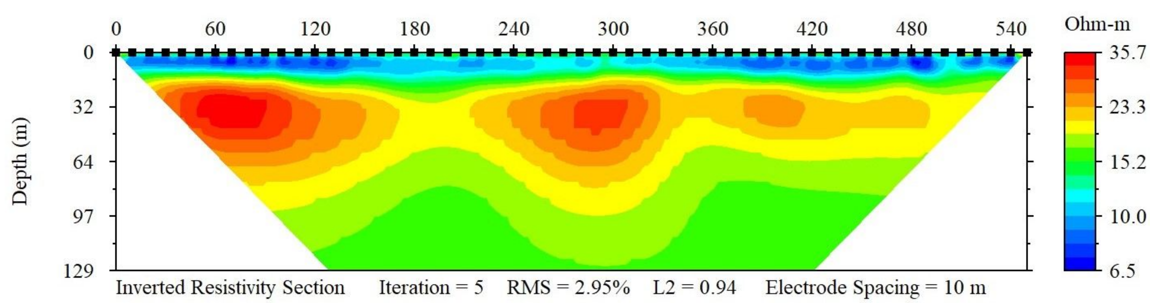


**Figure 10**. Highway 135 electrical resistivity cross-section. This profile images an interpreted clay layer in the syncline between outcropping clay layers along Highway 135. The resistivity values of around 15 Ohm*m in this image correspond to the clay layers in Figures 8 and 9. Figures are not on a common color scale so that contrasting values in each image are more clearly shown. RMS = 2.95% and L2 normalization = 0.94.

The continuity of the subsurface fold structure in Cañada De Las Flores can clearly seen by adjoining the electrical resistivity profiles from Four Deer and Cañada De Las Flores (Fig. 11). The interpreted clay layer can be seen to come to the near surface at the hinge of the anticline, and descend down Cañada De Las Flores to the syncline along the Highway 135 profile (Fig. 10).

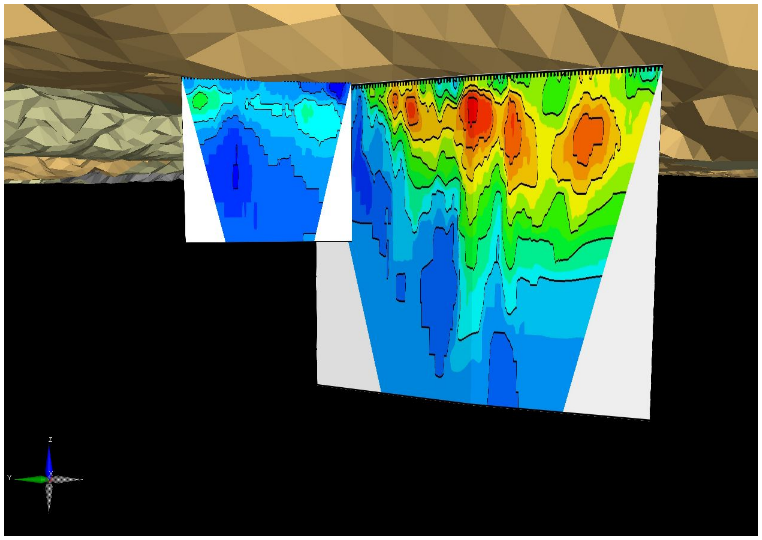

**Figure 11.** Resistivity profiles hung from land surface looking east. Left: Four Deer Profile. Right: Las Flores Profile. The Las Flores profile is shown here inverted without terrain data for accurate correlation with the Four Deer profile. See Figure 5 for location. Simplified geologic map (Jennings, 2010) draped over digital land surface elevation grid.(Figure courtesy of G. Cromwell).

## 5. Conclusion

The 2D electrical resistivity cross sections of the Las Flores and Four Deer profiles (Fig. 8, 9) clearly indicate the continuity of a folded structure. The fold structure continues to the syncline underneath the Highway 135 profile (Fig. 10), following the previously mapped QTps unit (Fig. 3). No evidence for a normal fault is indicated by the electrical resistivity data. This deeper, folded, confining layer stratigraphically below the QTps unit mapped at the surface (Fig. 3) presently outcrops at the top of Cañada De Las Flores. The present groundwater input reaches the anticline of the fold near the top of Cañada De Las Flores and is thus diverted into (1) a shallow pressurized aquifer beneath shallow clay layers that the Ex Ag Well #3 well utilizes (Fig. 6, 8), and (2) down the limb of the fold where the clay layer forms the base of the unconfined aquifer in Cañada De Las Flores that the 008N33W16H Well utilizes (Fig. 6, 9). Well completion report from Ex Ag Well #3 from Katherman Exploration Co., LLC, indicate a clay layer at a depth of approximately 45 meters, possibly creating artesian conditions in the formations south of Four Deer Ranch. This direct observation of a confining layer supports the model of a clay layer within the folded formations creating the conditions for a confined aquifer at Four Deer Ranch, but an unconfined aquifer in Cañada De Las Flores (Katherman Exploration Co., LLC, 2009). It must be noted that Electrical Resistivity Tomography inversions are non-unique and more than one inversion can generate plausible geologic interpretations (Olayinka and Yaramanci, 200). However, based off knowledge of local geology, stratigraphy, and numerical modeling the subsurface fold model is preferred to the normal fault model as the explanation for the offset in measured groundwater levels. Assuming land access could be obtained again, additional shallower high-resolution electrical resistivity profiles in the Ex Ag Well #3 well area on Four Deer Ranch would greatly clarify the details of the pathway groundwater takes into the shallow aquifer system as it branches off from waters that descend into the Cañada De Las Flores unconfined aquifer.

# 6. References

Burger, R. H., Sheehan, A. F., & Jones, C. H. (2006). *Introduction to Applied Geophysics, Exploring the Shallow Subsurface*. W.W. Norton & Company, Inc.

Jennings, C.W., with modifications by Gutierrez, C., Bryant, W., Saucedo, G., and Wills, C., 2010, Geologic Map of California: California Geological Survey, Geologic Data Map No. 2, scale 1:750,000, https://maps.conservation.ca.gov/cgs/gmc/.

Katherman Exploration Co. LLC. (2009). Water Well Drilling Project - Hunter Four Deer Ranch. Los Alamos Area, Santa Barbara County, CA.

Namson, J., & Davis, T. L. (1990). Late Cenozoic Fold and Thrust Belt of the Southern Coast Ranges and Santa Maria Basin, California. *The American Association of Petroleum Geologists Bulletin*, *74*(4), 467–492.

Olayinka, A. I., & Yaramanci, U. (2000). Assessment of the reliability of 2D inversion of apparent resistivity data. *Geophysical Prospecting*, *48*(2), 293-316.

Tennyson, M. (1992). *Preliminary geologic map of Santa Maria 30' x 60' quadrangle, California, U.S. GEOLOGICAL SURVEY Open-File Report 92-189*. Retrieved from https://pubs.usgs.gov/of/1992/0189/report.pdf

San Antonio Creek Water Availability. (n.d.). Retrieved May 1, 2019, from https://ca.water.usgs.gov/projects/san-antonio-creek/index.html

Dibblee, T.W., Ehrenspeck, H.E., and Bartlett, W. L. (1994). Geologic map of the Sisquoc quadrangle, Santa Barbara County, California. Dibblee Geological Foundation.

Uhlemann, S., Kuras, O., Richards, L. A., Naden, E., & Polya, D. A. (2017). Electrical resistivity tomography determines the spatial distribution of clay layer thickness and aquifer vulnerability, Kandal Province, Cambodia. Journal of Asian Earth Sciences, (147), 402–414.

The California Department of Water Resources. (n.d.). Well Completion Report. Retrieved from https://dwr.maps.arcgis.com/apps/webappviewer/index.html?id=181078580a214c0986e2da28f8623b37

# Appendix

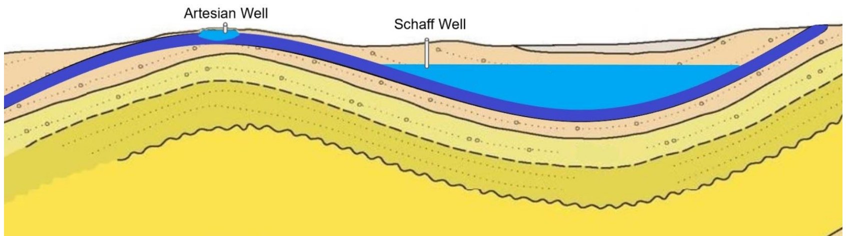


**Figure A1.** Conceptual model of a folded clay layer creating both the unconfined aquifer beneath the Schaff Well and the shallow confined aquifer beneath Ex Ag Well #3. Groundwater input is diverted from the northeast to the unconfined aquifer in the southeast and to the confined aquifer in the northwest due to the subsurface fold being nearly exposed in the north of Cañada De Las Flores.

**Table. A1** Summary of referenced groundwater wells.

| Well ID | Latitude | Longitude |
|---|---|---|
| 008N033W09H002S | 35.2375° | -120.3483° |
| 008N33W16H | 34.7756° | -120.3508° |
| 08N33W22 | 34.753° | -120.333° |


**Figure A2.** Location of cross section profile shown in Figure 2 within study area.

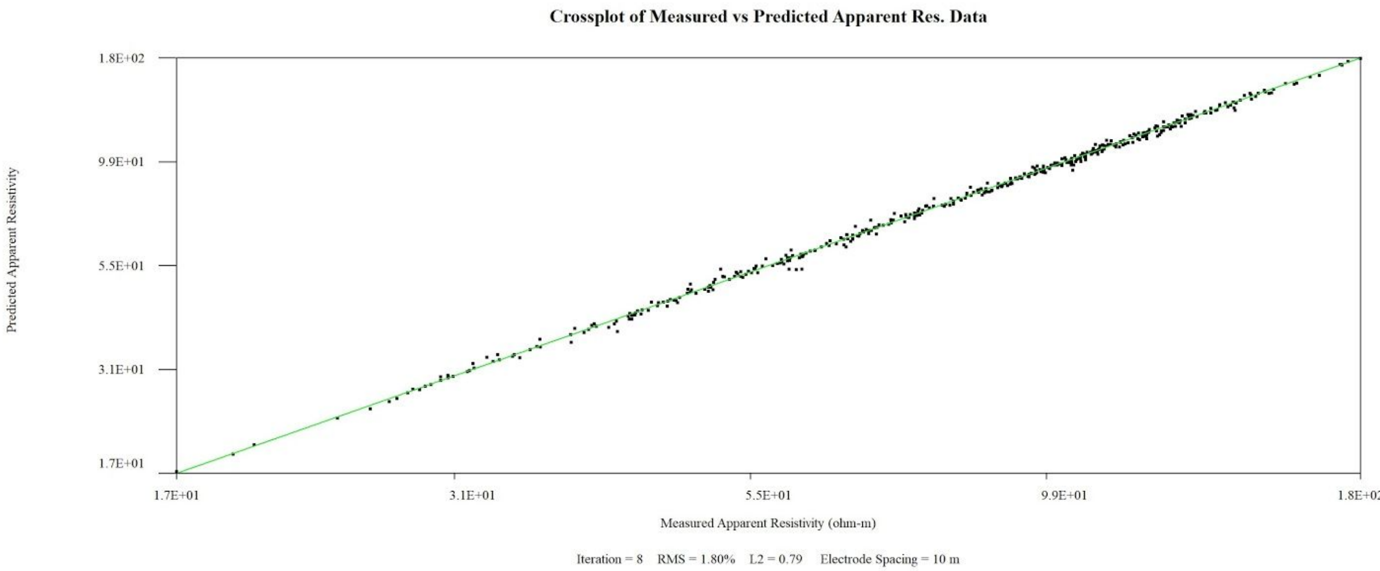


**Figure A3.** Convergence curve and Misifit Crossplot of the Las Flores profile inversion.

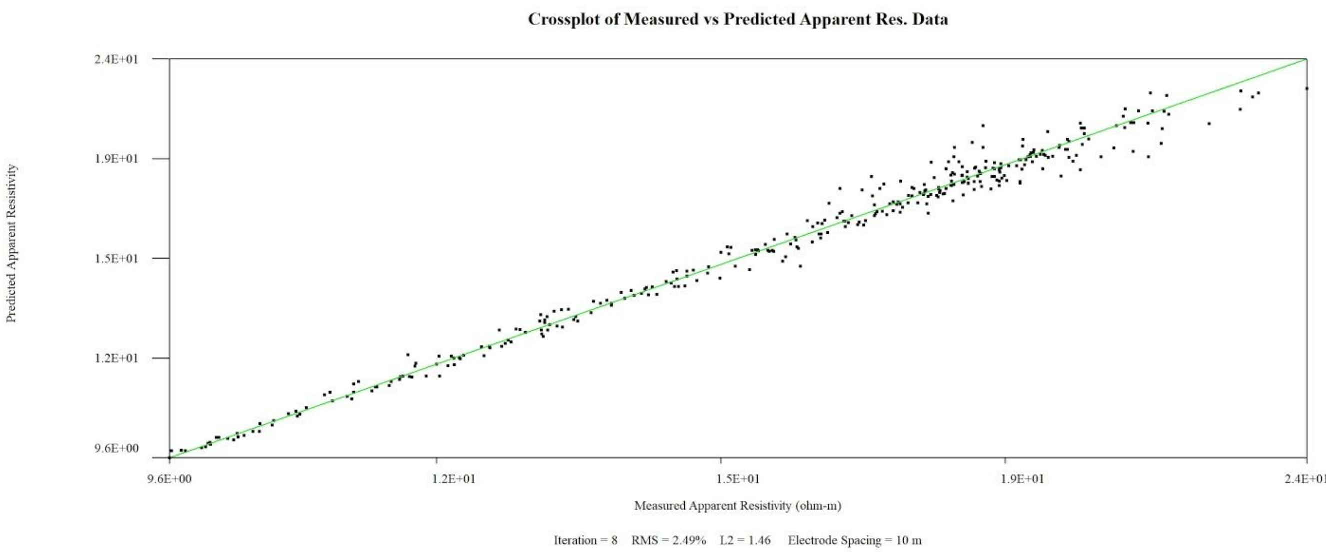


**Figure A4.** Convergence curve and Misifit Crossplot of the Highway 135 profile inversion.

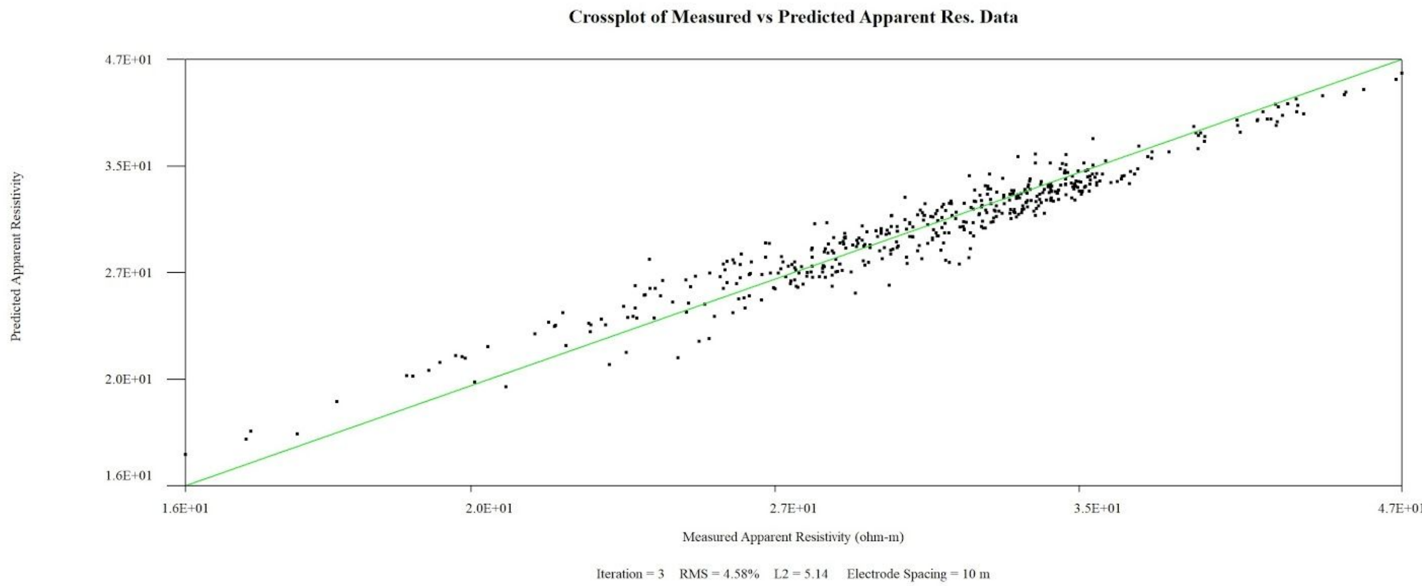


**Figure A5.** Convergence curve and Misfit Crossplot of the Four Deer profile inversion.