Geoelectrical Detection of Water Table Depth at two Locations in the Los Osos Groundwater Basin

A Senior Project

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By

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Abstract

The city of Los Osos sits on top of a coastal groundwater aquifer which is the sole supplier of all its residential, agricultural, and industrial water needs. Lacking a sewer system, the upper aquifer became progressively contaminated with nitrates over several decades. Groundwater pumping eventually shifted to the lower aquifer, however seawater intrusion of the lower aquifer caused by over-pumping has further degraded water quality. The Los Osos groundwater basin provides an excellent field region to examine the utility of geophysical methods for characterizing aquifer structure. In this study shallow (<20 m) electrical resistivity imaging methods were performed at two locations in Los Osos to assess depth to water table. The goals of the electrical resistivity surveys were to assess the depth to the water table in each area and compare with water table depths from nearby well data. If accurate and sufficient data are found, the resistivity surveys might be a plausible way to monitor the areas of contamination in a non-invasive manner.

Introduction

Los Osos, CA, is a coastal community located on the western edge of San Luis Obispo County, north of San Luis Obispo and south of Cambria (Fig. 1, 2).

Figure 1. Location of Los Osos. Los Osos is a coastal town in central California near San Luis Obispo, CA.

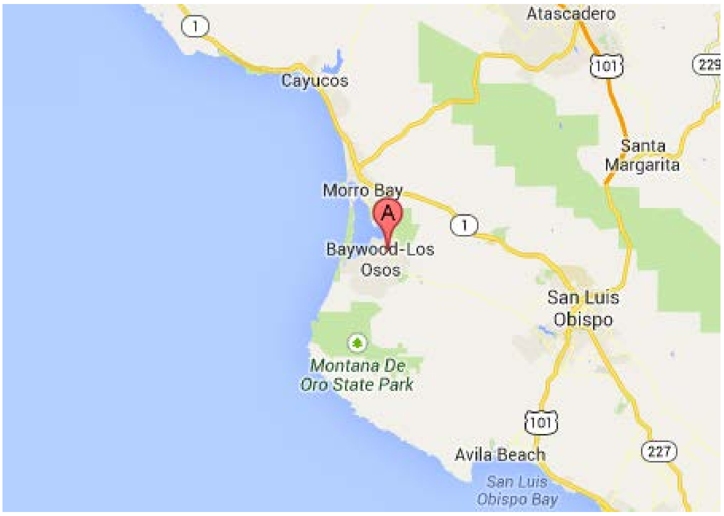

Figure 2. Detail of Los Osos field site. Los Osos sits on the Morro Bay estuary and Pacific Ocean. Overpumping of the Los Osos aquifer has caused seawater intrusion into the lower aquifer.

Originally a sparsely populated agricultural town, Los Osos underwent a huge population spike between 1970 and 1985 [*Yates and Wiese*, 1988]. With this change, the town shifted from being a small scale agricultural town to providing residential and suburban neighborhoods with a higher demand for public amenities, such as clean water. The town itself rests on top of its own aquifer, with outlets to Morro Bay, and an extending distance of 3 miles from the coast [*Yates and Wiese*, 1988].

The Los Osos aquifer is the sole provider of water to the towns of Los Osos, Baywood Park, and Cuesta-By-The-Sea, Los Osos being the largest of the three. The aquifer itself is comprised of multiple layers, with the importance being placed on the top four – from top to bottom, the First Water, Upper Aquifer, Lower Aquifer, and Alluvial Aquifer (Fig. 3) [*City of Los Osos Community Services District*, 2013]. The two main causes of degradation to the aquifer are by nitrate accumulation in the Upper Aquifer (Fig. 4), primarily by agricultural use as well as the lack of a sewer system, and by seawater intrusion from the bay in the Lower Aquifer. The Upper Aquifer was depleted first, which caused the city to start pumping from the Lower Aquifer. By 1983, shallow groundwater was tested for nitrate levels and gave a reading of 45 mg/L, which is well above the national standards for clean drinking water [*City of Los Osos Community Services District*, 2013].

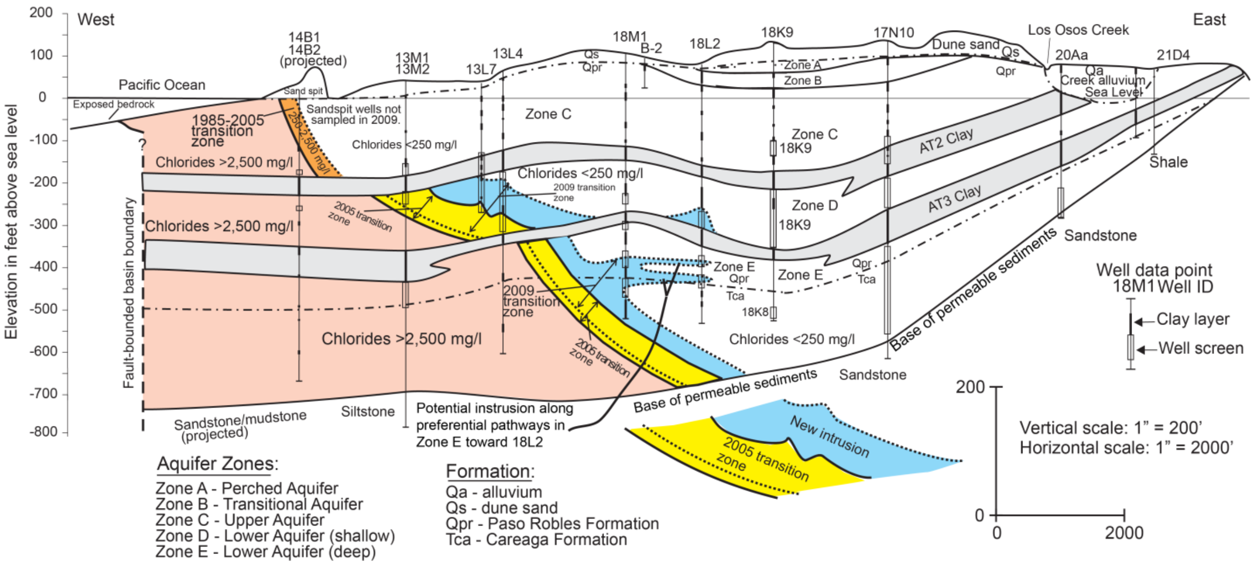

Figure 3. Cross section of the Los Osos Aquifer. The aquifer is divided into Zones. Zones A,B are perched aquifers not used for water extraction presently. Zones C-E are separated by thick clay layers. The extens of seawater intrusion is seen to be increasing rapidly inland over time.

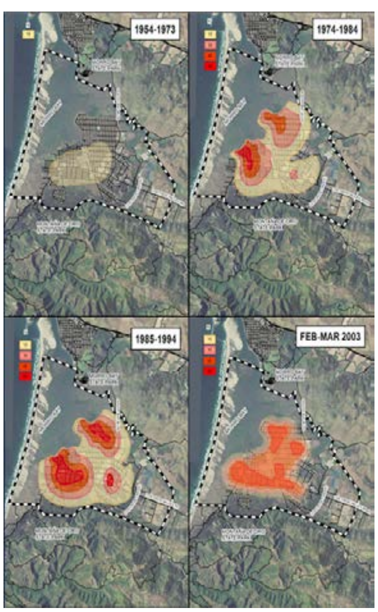

Figure 4. Nitrate contamination in the Los Osos aquifer. The concentration and extent of nitrate contamination has been steadily increasing over several decades. Installation of a sewer system is hoped to correct this problem over the next few decades.

Over-pumping of the lower aquifer, however, dropped water levels low enough so that sufficient pressure (head) no longer existed to keep the freshwater/saltwater interface offshore. Parts of the western portion of the aquifer have been deemed unusable by means of too low of a water and too high a level of seawater contamination, as indicated by chloride leves exceeding 250 mg/l [*City of Los Osos Community Services District*, 2013].

Aquifer degradation sparked protracted legal battles between the city of Los Osos, the three water purveyors, and the California state government, resulting in a court-ordered legally mandated long-term aquifer remediation and monitoring plan (ARMP) [*City of Los Osos Community Services District*, 2013]. The ARMP includes periodic monitoring of nitrate concentration levels in the upper aquifer, and chloride concentration levels in the lower aquifer (Fig. 4) with the goal of reducing nitrate concentrations to <10 mg/l and chloride concentrations to < 250 mg/l. Monitoring at water wells has the advantage of direct sampling of water for contaminant analysis. However, it is disadvantaged by only providing a zero-dimensional view (a point sample) of contaminant distribution. A complementary and non-invasive method of assessing contaminant distribution can be achieved with electrical resistivity imaging (ERI). While ERI does not directly measure contaminant levels, the distribution of contaminants in two- and three- dimensions can be imaged and monitored over time [*Telford et al.*, 1989].

In this study, preliminary electrical resistivity surveys in the eastern aquifer are performed to assess (1) depth to the water table in the First Water aquifer, and (2) compare the ability of the Wenner array to resolve shallow aquifer structure and to see how well the data aligns with local well depth data. These results will be used to inform the design of future larger scale electrical resistivity surveys of the Los Osos aquifer.

Geology of the Los Osos Groundwater Basin

The city of Los Osos is located within the Los Osos Valley, whose geology controls groundwater recharge into the aquifer. This valley is triangular in shape, with a portion along the coastline and another 7 miles inland (Fig. 5) [*Smith et al.*, 2010]. The northern boundary is delineated by Park Ridge, with a maximum altitude of 1,409 feet, while Morro Bay rests at the western boundary, separated by the ocean by a 4 mile long sandspit [*Yates and Wiese*, 1988]. There is a drainage divide inland to the south separating the Los Osos Valley from nearby San Luis Valley. Within the San Luis drainage basin runs San Luis Creek, with it being the main source of drainage for the approximate 31 miles it contains [*Yates and Wiese*, 1988]. There are several floodplains in the area that allow for proper drainage.

The Los Osos Valley basin consists of the Paso Robles Formation and Careaga Sandstone. The majority of the basin rises 4 to 5 degrees over a sheet of Cretaceous and Jurassic Franciscan Complex. The Franciscan Complex is found throughout the area, however underneath multiple depositions of Miguelito shale and Careaga Sandstone during the Miocene and Pliocene periods, respectively. These depositions were faulted and eroded over time, especially along the Los Osos fault and Edna fault zones. Over the years, windblown eolian sand has been deposited as well as Holocene alluvium (Yates and Wiese, 1988).

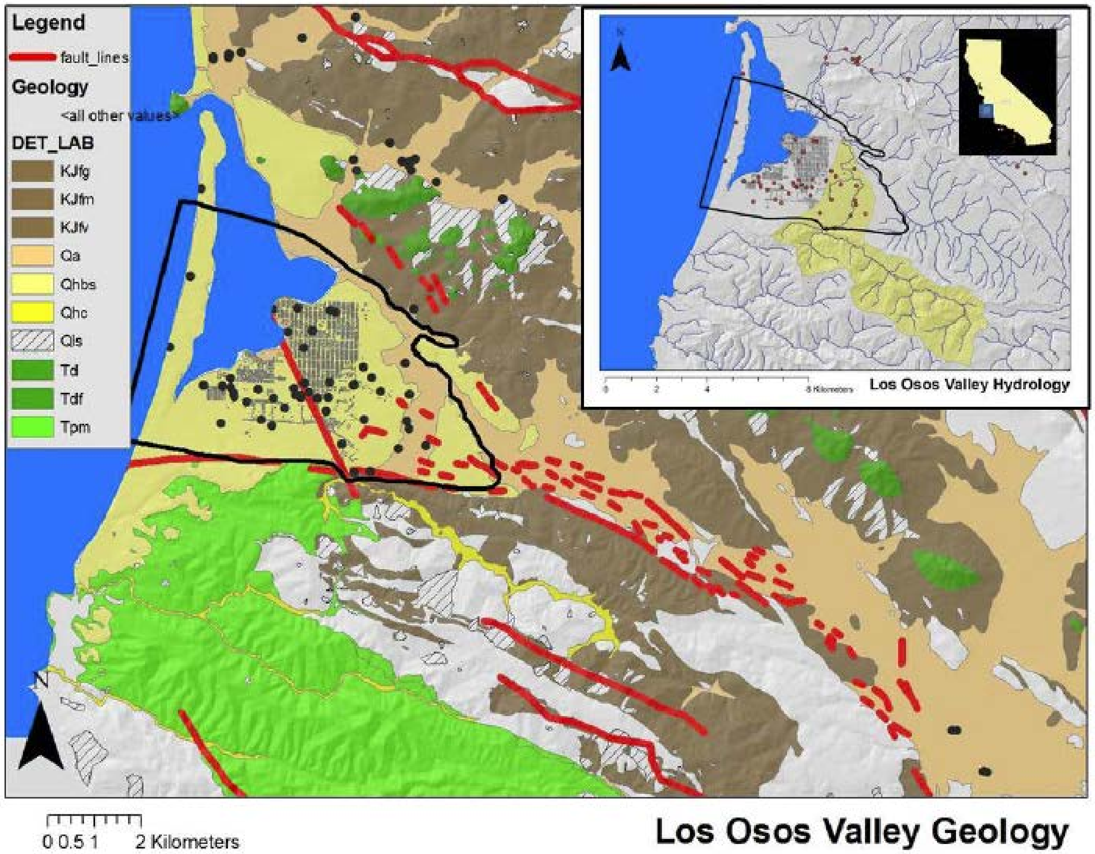

Figure 5. Los Osos Valley Geology. (Taken from [*Smith et al.*, 2010]). The groundwater basin is largely overlain by quaternary dune sands. The Los Osos Valley Fault projects underneath the town and through the aquifer, possibly offsetting clay aquitards separating aquifer zones (Fig. 3).

Direct Current Electrical Resistivity Imaging

Direct current electrical resistivity (DCER) imaging is a common geophysical method in groundwater studies. It has been applied to groundwater depth, seawater intrusion, and monitoring of contaminant plumes [*Mills et al.*, 1998; *Sherif et al.*, 2005; *Luján and Romo*, 2010].

To collect DCER data a DC voltage source and four electrodes (e.g. stainless steel stakes) are needed. Two stakes act as current injection points while the other two stakes measure electric potential. The locations of the stakes can then be moved along a profile to build up a sequence of image points at different depths and locations along the profile.

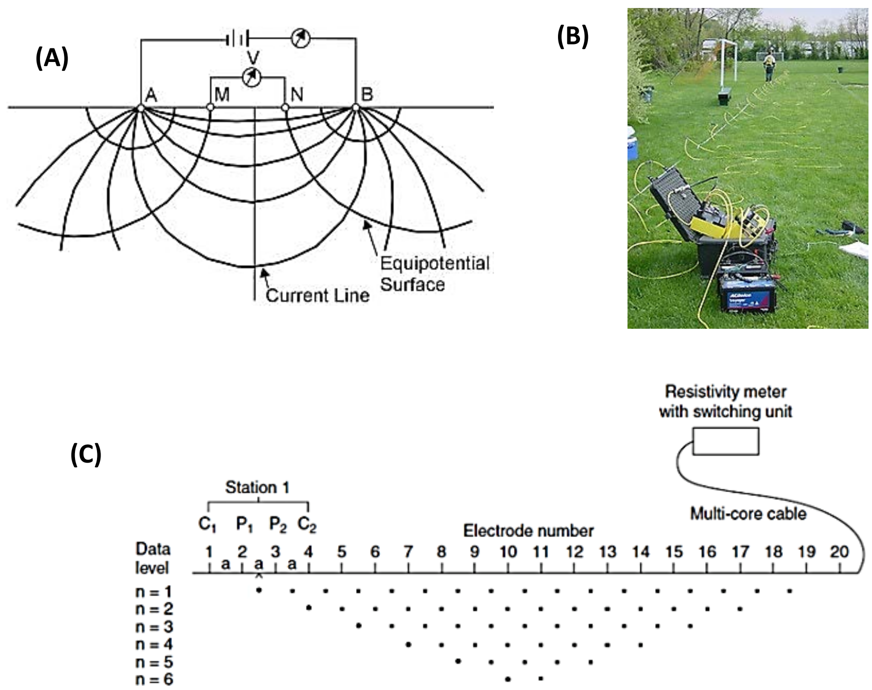

Figure 6. Direct Current Electrical Resistivity Survey Principle. **(A)** Electrodes (A,B) function as current injection points; electrodes (M,N) measure resulting voltage. (http://www.epa.gov/nerlesd1/cmb/GeophysicsWebsite/pages/reference/_img/fig270.jpg).

(B) 2-D DCER field survey profile. (http://water.usgs.gov/ogw/bgas/toxics/images/NAWC-2Dres.jpg).

(C) Subsurface sampling of apparent resistivity imaging points. (http://www.landviser.net/sites/default/files/enc_4_er-multielectrode.png).

All figures accessed on 2013-12-15.

In this study the geologic target is the depth to the water table, or saturated zone. Because of previously known data about the aquifer, the depth to the water is not expected to exceed 10 meters in our study area [*City of Los Osos Community Services District*, 2013]. The Wenner array [*Telford et al.*, 1989] was used on both the Lazy Q Ranch site and the Los Osos Middle School site. The calculation of resistance from the voltage and current measurements is converted to a resistivity measurement with a geometric correction factor depending on the spacing of the electrodes. The field measurement is referred to as apparent resistivity because the current path may travel through non-uniform geologic materials and thus the measurement of resistivity represents a combination of materials. After the field data is collected, computer software can calculate a subsurface true resistivity model that best reproduces the field data. In this study the resistivity meter used was a Syscal Kid Switch 24, and the software used to process the field data was RES2DINV by Geotomo Software.

In order to most accurately interpret the data given by the RES2DINV model, upon inversion, there needs to be manipulation of the given range of resistivity values. The reason behind this is because in order to accurately interpret two different models, the axis ranges must be the same otherwise the comparison would be misleading as different colors on each graph would correspond to different resistivity values.

In our case, the Los Osos Middle School model was first compared to the Lazy Q Ranch site. This was done for several reasons. If there were any obvious discontinuities between the models, such as large gaps in the resistivity values or obstructions not following the actual landscape surveyed, than more testing could be necessary. With our preliminary model results, we compared these two models.

Site Descriptions

The locations of the Lazy Q Ranch are shown in Figures 7, 8 and Los Osos Middle School in Figure 9. Table 1 summarizes the electrical resistivity survey parameters.

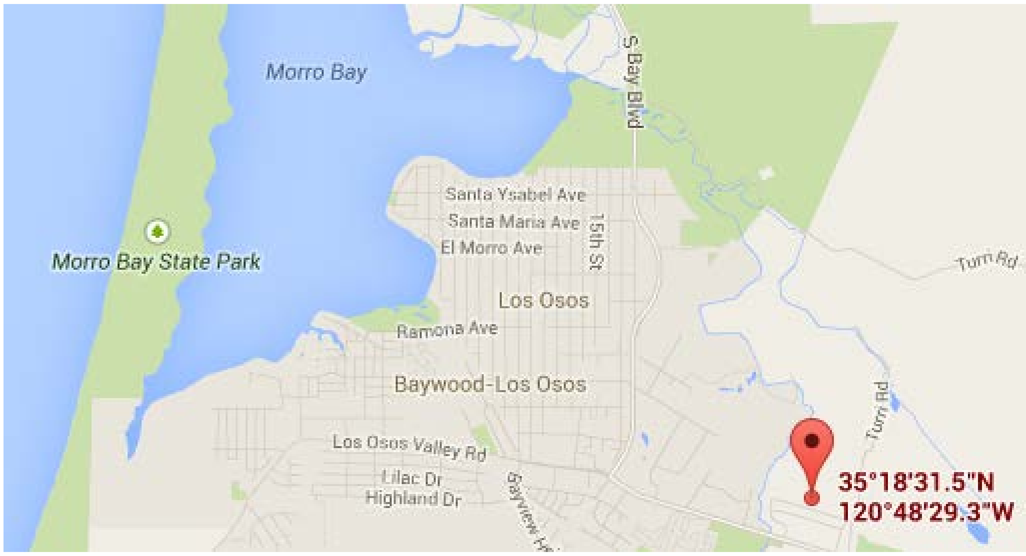

Figure 7. Map view of Los Osos. Shown are the GPS coordinates of the Lazy Q Ranch (35.308740, -120.808128).

Figure 8. Close up of Lazy Q Ranch. The two lines show the electrical resistivity profiles taken at this location. The longer profile line is 120 meters in length.

Table 1. Summary of electrical resistivity survey parameters.

Date	Profile Center (Lat , Lon)	Location	Profile Strike (to Node 1)	Array Type	Nodes (24) spacing (m)
2013-09-07	35.30858, -120.80830	LazyQ Ranch	S15W	Wenner	5
2013-09-15	35.30844, -120.80834	LazyQ Ranch	S70E	Wenner	3
2013-10-24	N/A	Los Osos Middle School	S85E	Wenner	5

The first set of data was taken on September 7th, 2013, at the Lazy Q Ranch. The center of the line was at 35.30858 , -120.80830, with an altitude of 19 m. The lines were then extended to go perpendicular to the walking path down the property. The second set of data was taken on September 15th, 2013, and the center of the line was at 35.30844 N , 120.80834 W, with an altitude of 21.6 meters. The lines were then extended out parallel to the walking path down the property.

In addition to the Lazy Q Ranch site, we also took measurements on the athletic fields of Los Osos Middle School (Fig. 9). We used this property because it was an area with known water table measurements from nearby wells. This would allow us to easily interpret the resistivity data and see if that specific method gave accurate measurements that correlated with known data. We also knew that there were no geologic irregularities in this area that might skew our resistivity data.

Figure 9. Los Osos Middle School. Electrical resistivity survey was taken in the middle of the running track, running EW (shown by the red line).

We took several lines from this property in a similar fashion as from the Lazy Q Ranch. This gave us the ability to look at the area in a perfect cross section and examine the resulting data for water table depth.

Results

Figures 10 and 11 display representative electrical resistivity profiles at the Lazy Q Ranch and Los Osos Middle School field sites. The results are consistent with shallowing of the groundwater basin inland (to the east). Lazy Q Ranch is in the eastern part of the groundwater basin where the aquifer begins to pinch out [*City of Los Osos Community Services District*, 2013]. It is therefore expected that the saturated zone is very close to the ground surface, except for locations where shallow modifications of the soil profiles have been made by human activity. As seen in Figure 10, low resistivity (<20 Ohm-meters) values are observed throughout almost the whole electrical resistivity profile.

Los Osos Middle School is closer to the main aquifer and the ocean, and sits above the perched aquifers A, B, and well 18L2 (Fig. 3). This site is situated almost exactly on a 50 foot water elevation contour line (relative to sea-level) extrapolated from well data (Fig. 12) [*Cleath-Harris Geologists*, 2013]. The elevation of the electrical resistivity survey was 72 feet above sea-level, and the water table from the electrical resistivity cross section (Fig. 11) is ~5.5 m (18.2 feet). Thus, the 72 feet above sea level elevation of the survey *minus* the 18.2 interpreted water table depth closely matches the 50 ft water height from well data, only being off by a few feet.

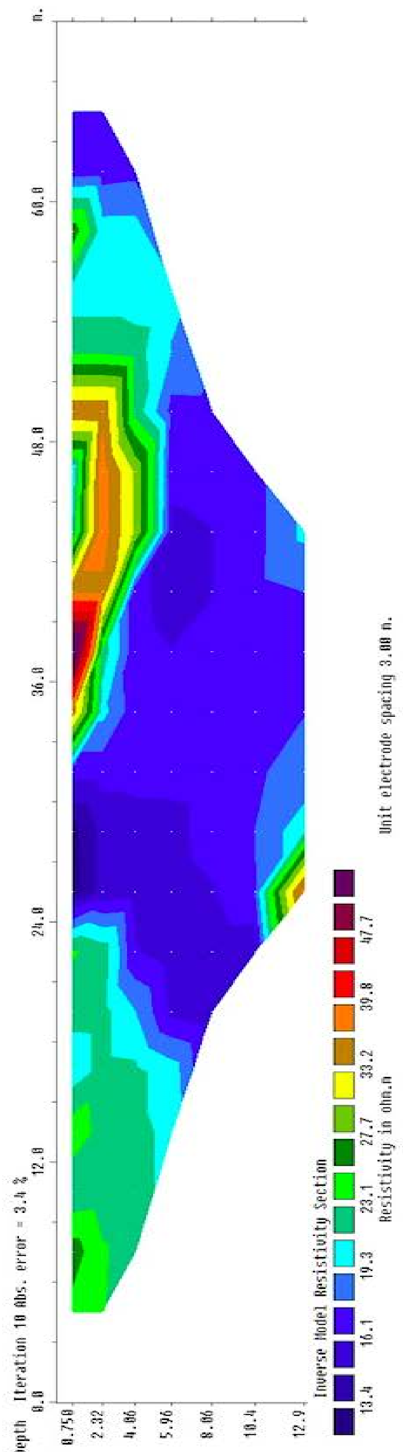

Figure 10. Electrical Resistivity Imaging at Lazy Q Ranch. The NW-SE electrical resistivity profile is shown from Figure 8.

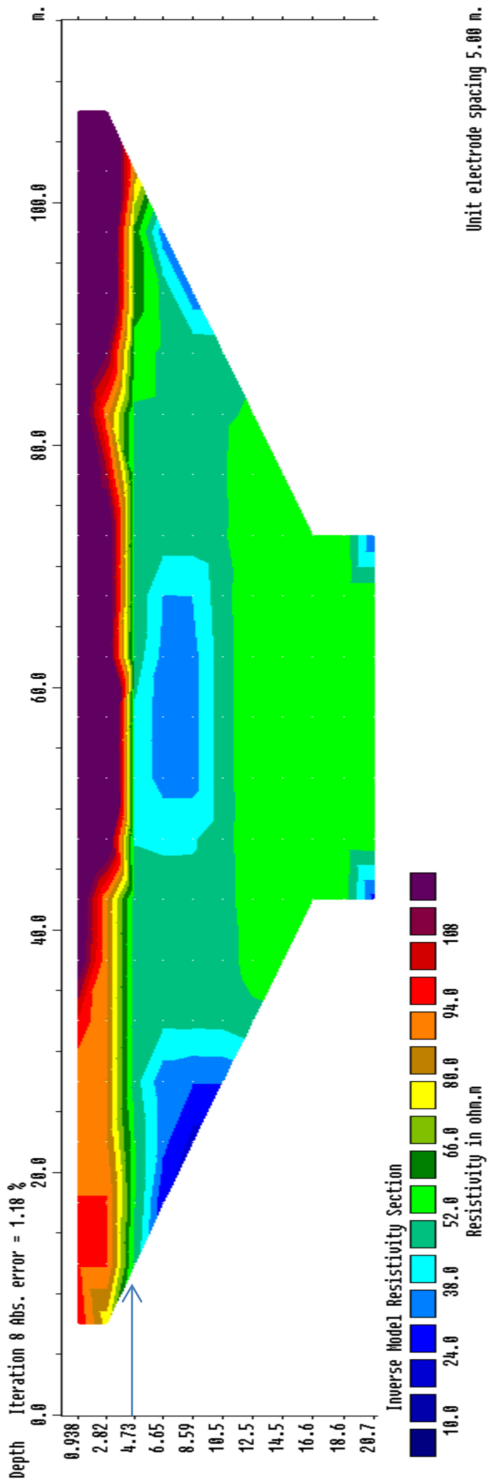

Figure 11. Los Osos Middle School Electrical Resistivity Profile. Location shown in Figure 9. Water table depth is seen by the transition from high resistivity in the upper layer to much lower resistivity values below. The water table is interpreted to be at ~5.5 meters depth.

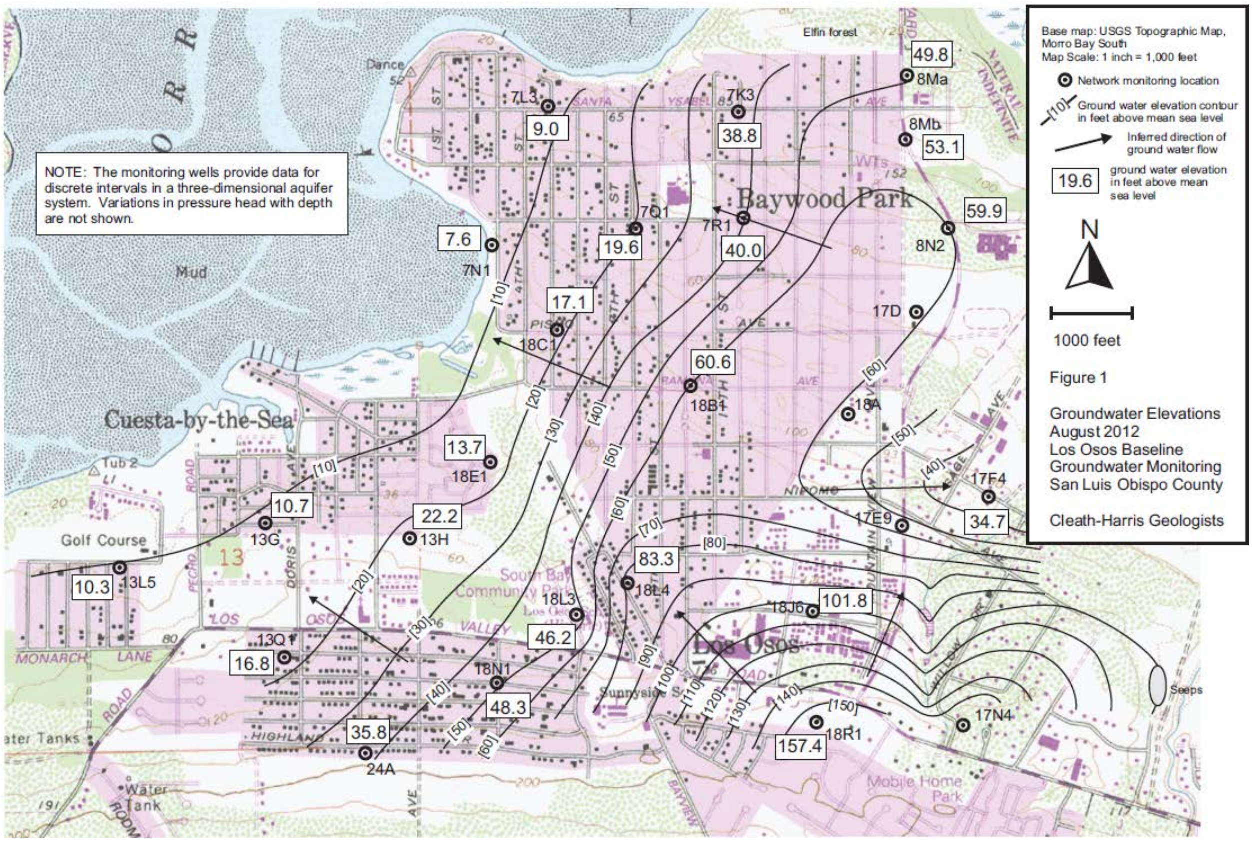

Figure 12. Comparison of well data to electrical resistivity data. The Los Osos Middle School site is close to the 50 foot water elevation (form sea level) contour line. Electrical resistivity data interpreted for water table is consistent with this water elevation. Figure from [*Cleath-Harris Geologists*, 2013].

Conclusion

With the comparison of the two testing sites, we can firmly conclude that the method of Direct Current Electrical Resistivity (DCER) is an accurate measurement when trying to determine the depth of the water table in the Los Osos Valley. With the accurate delineation of the water table depth given by the DCR method, when compared to known depth levels from point sources (wells), the levels were within 4 feet of each other. We can use this data to conclude that the DCER method can be applied with confidence to larger scale monitoring and characterization of Los Osos Aquifer as the ARMP plan goes into effect.

The benefits of the DCR when looking at large scale monitoring plans outweigh the benefits of point source sampling of wells, which has been the norm for decades. The DCER method allows for there to be a two- or three-dimensional view of the aquifer to delineate the spatial extent of contaminants, and allows for more accurate remediation decisions to be made.

For Los Osos, time is of the essence. Since the city is under a court ordered mandate to start a remediation plan for the aquifer, non-invasive and accurate methods of monitoring remediation progress accuracy is valuable. The DCER method provides accuracy, efficiency as well as providing a multi-dimensional view of aquifer state.

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