Electrical Conductivity Logging To Determine Control Of Hydrocarbon Flow Paths In Alluvial Sediments

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ABSTRACT

A field investigation using electrical conductivity logging at a former underground storage tank (UST) facility located on alluvial deposits was undertaken to study how changes in lithology can affect movement of hydrocarbons or other LNAPLs in the subsurface. Electrical conductivity logging can be completed using direct push methods. In general, higher electrical conductivities are representative of finer grained sediments, such as silts or clays, while sands and gravels are characterized by distinctly lower electrical conductivities. Site specific core samples, either from discrete depths or a continuous core, can be used to verify the lithology represented by electrical conductivity values at a site. The electrical logs are then correlated across the site to show changes in thickness or elevation of lithologic units of interest. Contacts between different units may show a significant change in conductivity, and these contacts can be mapped.

Electrical conductivity logs are used to define zones of lower conductivity, equivalent to coarser grained, more permeable sediments, which will allow the movement of hydrocarbons in the subsurface. Cross sections of the alluvial deposits, based on the electrical logs, can be used to determine possible migration pathways for hydrocarbons. When elevations are measured at each log location, the elevations of contacts between a sandy aquifer and overlying clays can be mapped for the area investigated. This contour map of the contact will show the presence of any linear or sinuous features in the surface of the sand along which hydrocarbons may travel on the groundwater surface. This contour map will also show the presence of any dome-like or nose-like structures where hydrocarbons can be trapped. The cross sections and contour maps constructed, based on electrical conductivity, can be used to aid the investigator in understanding the movement and location of hydrocarbons in the subsurface. This information will also assist in the proper placement of monitoring or extraction wells.

INTRODUCTION

Direct push electrical conductivity logging is a rapid, cost effective way to conduct geohydrologic investigations with minimal sampling and disturbance of the surface and subsurface. A study was conducted at a former underground storage tank (UST) facility in central Kansas (Figure 1) to look at the applications of direct push electrical conductivity (EC) logging as a method to determine potential flow paths for free-product hydrocarbons (light non-aqueous phase liquids [LNAPL]) in alluvial sediments. Other geohydrologic applications for EC logging were also studied and are presented.

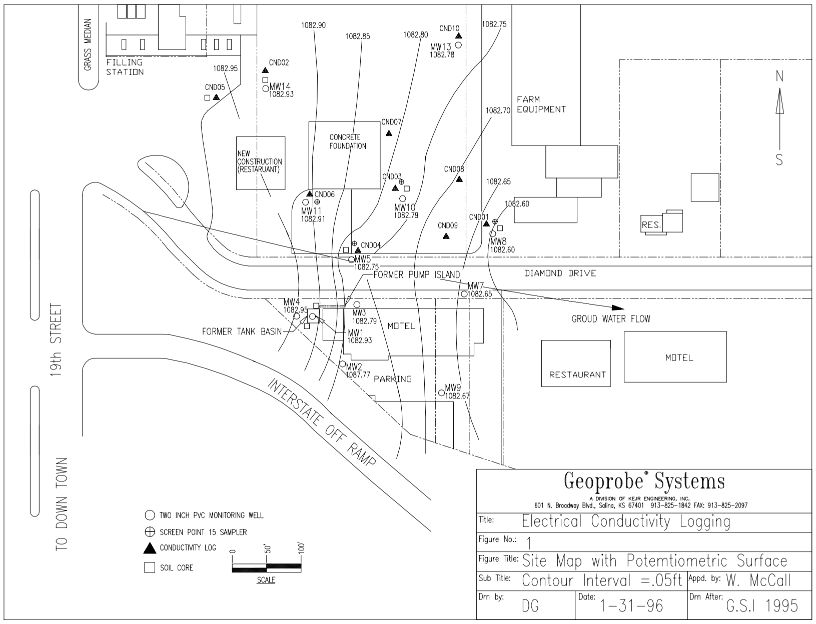

FIGURE 1
Site Map with Potemtiometric Surface

Electrical conductivity has been used by soil scientists for many years to investigate soils. Geologists are typically more familiar with the inverse of electrical conductivity, that is electrical resistivity, for conducting geologic investigations, especially in petroleum exploration.

OBJECTIVES

The primary focus of this paper is to look at the application of EC logging to geohydrologic investigations, especially at environmental sites where the movement of contaminants is of primary interest. Electrical conductivity logs, such as the one shown in Figure 2, are used to provide detailed definition of the subsurface geology. This log shows that the electrical conductivity of the unconsolicated materials varies from less than 10 milliSiemens per meter (mS/m) to more than 250 mS/m in the first ten feet logged. The log also shows that there are abrupt changes in the electrical conductivity of the materials penetrated at about 46 and 52 feet (14 m and 16 m) below ground surface (bgs). EC logs such as the one shown in Figure 2 will be used in this paper to define and correlate lithologies across a site.

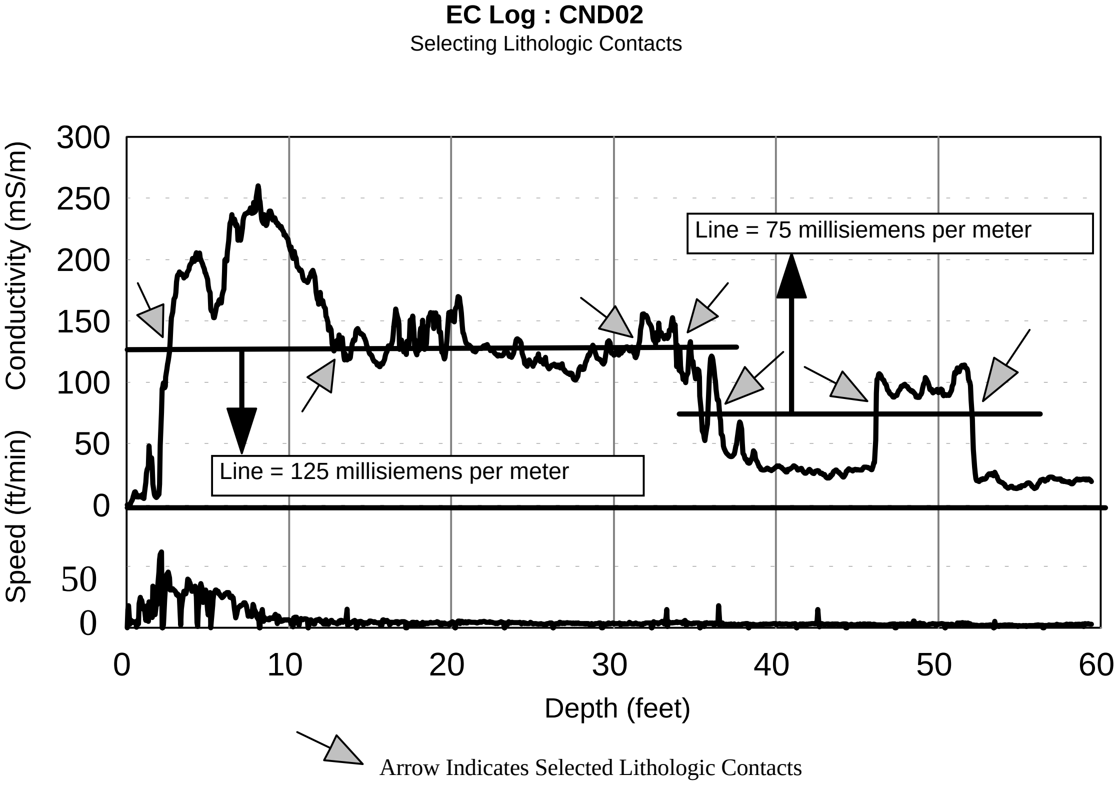

FIGURE 2
EC Log: CND02
Selecting Lithologic Contacts

Several examples of field applications for EC logging to geohydrologic investigations will also be discussed. These examples include:

- Site specific lithologic logging based on EC logs and limited soil core sampling.
- Construction of geologic cross sections based on EC logs.
- Delineation of aquifers and aquitards in the subsurface based on EC logs.
- Determination of the thickness and lateral extent of aquifers, aquitards, and other lithologic units based on EC logs.
- Use of EC logs to assist in locating appropriate lateral and veritcal placement of wells and well screens.
- Use of EC logs to construct contour maps on the upper surface of a sand formation.
- Construction of contour maps on the surface of an aquitard or impermeable bedrock contact based on EC logs to determine potential DNAPL flow paths and collection points.
- Construction of isopach maps (thickness) for lithologic units based on EC logs.

SITE BACKGROUND AND GEOHYDROLOGIC SETTING

Figure 1 is a current map of the area studied. A new motel was recently constructed over the location of a former filling station near the south end of the investigated area (GSI, 1994). The location of the former UST basin and pump island is shown in Figure 1. Contamination was detected during an initial environmental investigation and the site was entered into the Kansas Department of Health and Environment (KDHE) Underground Storage Tank (UST) Program. KDHE utilized an independent drilling contractor to conduct soil borings and install two-inch PVC monitoring wells which are also shown on Figure 1. The EC logging study was initiated shortly after the wells were installed. For the purposes of this study, access was available only to the area north of Diamond Drive.

The area investigated is located on the alluvial flood plain of the Saline River in central Kansas. The subsurface geology consists of Pliestocene alluvial deposits overlying the bedrock which is the Permian Age Wellington Formation (Latta, 1949). The alluvial deposits consist of clays and silty clays that grade into sands with interbedded gravels and silt or clay lenses with depth. The Wellington Formation is comprised primarily of gray and greenish shales with some maroon and purple beds (Latta 1949) and serves as a dependable aquitard throughout the area.

As noted above, the fine-grained soils and sediments grade downward into coarser-grained alluvial deposits of sands and fine gravels. The overlying fine-grained soils and sediments appear to form a hydraulic barrier. When a well screen is set above 22 to 24 feet (7 to 7.3 m) below ground surface (bgs), the well will not yield water. But, when well screens are set to a depth of approximately 28 feet (9 m) bgs, the static water level will rise in the well casing to about 18 feet (5 m) bgs. Also, measurement of static water levels in the PVC monitoring wells showed groundwater flow is to the east (Figure 1). Contrary to the groundwater flow direction LNAPL contamination was observed in monitoring wells (MW) No. 5, No. 10, and No. 11, north of the source area (GSI, 1994).

After the EC logs were obtained, continuous soil cores were collected by direct push methods at locations CND02, CND03, and CND04. Samples for analysis were taken at two-foot (0.6 m) intervals from two of the continuous cores. These samples were analyzed by gas chromatography using the flame ionization detector to quantify concentrations of gasoline range organics (GRO). The results of these analyses, shown in Table 1, reveal that significant contamination was not encountered until depths of approximately 25 feet (8 m) bgs. This is significantly below the static water level of approximately 18 feet (5 m) bgs observed in the existing monitoring wells and direct push groundwater samplers installed at the study area.

TABLE 1
Soil Sample Analytical Results
(Gasoline Range Organics)

Depth (feet bgs)	Location CND03 (mg/kg)	Location CND04 (mg/kg)
1	< 1.0	< 1.0
3	< 1.0	< 1.0
5	< 1.0	< 1.0
7	< 1.0	< 1.0
9	< 1.0	< 1.0
11	< 1.0	< 1.0
13	< 1.0	< 1.0
15	< 1.0	< 1.0
17	< 1.0	< 1.0
19	< 1.0	< 1.0
21	< 1.0	1.2
23	< 1.0	< 1.0
25	55	70
27	255	104
29	8.1	2.7
31	9.7	2.7
33	8.1	< 1.0
35	< 1.0	2.4
37	7.3	5.6
39	< 1.0	< 1.0

EQUIPMENT AND PROCEDURES

Conductivity Probe and Logging

Soil conductivity logging at the study site was conducted using Geoprobe® Systems Direct Image® Soil Conductivity System. The system was operated in the Wenner array configuration. The electrical conductivity probe itself consists of a steel shaft that runs through the center of four stainless steel contact rings (Figure 3). An engineering grade plastic isolates the contact rings form the steel shaft. The probe is about eight inches long with a one inch diameter at the drive point and 1.125 inch diameter just above the top ring. This geometry provides a one degree taper angle to assure contact with the soil as the probe is advanced into the subsurface. The shielded cable for transmission of the signal is attached to the probe by a watertight rubber seal (KEI, 1994).

The conductivity probe is advanced to depth (logging is conducted) using a hydraulically driven percussion probing machine. Depth and the speed of advancement of the probe is measured with a string pot system. The signals from both the conductivity probe and string pot are carried to the instrumentation box by the cordsets. A notebook PC is connected to the instrumentation box and the Direct Image software provides a real time display of the conductivity signal, probe depth, and speed of advancement as logging is conducted. Figure 2 shows the EC log obtained at location CND02 at the study area. Hard copies of the log can be printed in the field if desired.

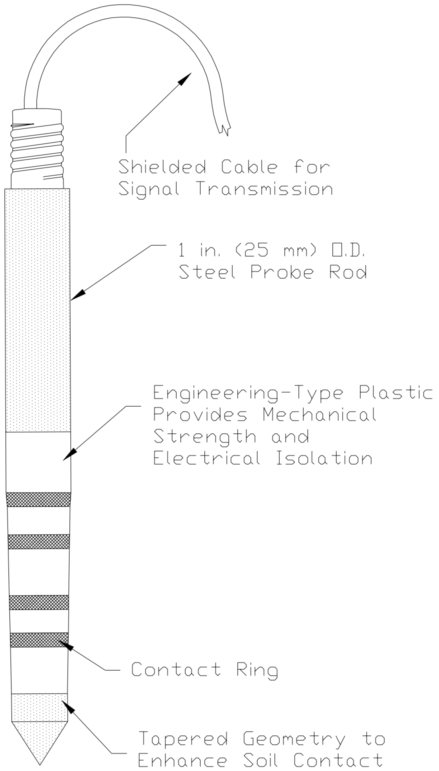

Figure 3
Conductivity Probe Construction

Units of Electrical Conductivity and Factors Influencing the Electrical Conductivity of Unconsolidated Materials

Most geologists are more familiar with electrical resistivity logging than electrical conductivity logging. Units of measurement reported for resistivity logging is the Ohm-meter (Milsom, 1989; Keys, 1989). Since electrical conductivity is the inverse of electrical resistivity, the units of measurement are reported in Siemens/meter. The Siemen is the inverse of the Ohm. Because of the low conductivity of earth materials, the units used for electrical conductivity here are milliSiemens/meter (mS/m). The electrical conductivity of unconsolidated soils and sediments is a function of their grainsize. Fine-grained materials such as clays have a higher conductivity than silty materials, which in turn have a higher conductivity than sands or gravels. Most soils and sediments are mixtures of clays, silts and sands and the conductivity of any bulk soil or sediment will be influenced by this fact. Some other major factors influencing the conductivity of unconsolidated materials are the chemical composition, moisture content, and salinity of pore fluids (brines). Because clay minerals are ionically active, they will conduct well even if only slightly moist (Milsom, 1989). Of course, if brine fluids are present, they will greatly increase the conductivity of the formation. Because of these factors, soil and sediment samples at a particular area must be collected to verify what a particular conductivity value represents.

Interpretation of Electrical Conductivity Logs

Definition of Lithologic Units

A total of ten conductivity logs were obtained across the study site for this project (Appendix I). The location of each log is shown on Figure 1. A continuous core was collected at the CND02 location to a depth of 40 feet. The lithologic log is summarized in Table 2. Discrete interval samples were also collected at 46 to 48 feet (14 to 15 m) and 54 to 56 feet (16 to 17 m) bgs at the CND10 location to sample the distinct lithologic units detected at those depths. Brief descriptions of these units are also provided in Table 2. Comparing the lithologic descriptions from the CND02 and CND10 locations to the electrical conductivity logs from these locations reveals the correlations summarized in Table 2. These correlations show that a certain range of conductivity is representative of a particular lithologic unit. As one example, the conductivity range of approximatley 125 to 240 mS/m, observed in the CND02 EC log (Figure 2) between approximately 3 and 12 feet (1 and 4 m) bgs correlates with the brown clays observed in the core samples at the same depth interval. The conductivity range of 20 to 40 mS/m, observed at a depth of about 36 to 46 feet (11 to 14 m) bgs on the CND02 log, correlates with the medium- to coarse-grained granitic sands and gravels sampled at that interval in the continuous core samples.

TABLE 2
Correlation of Lithology with Electrical Conductivity

Approximate Conductivity Range (mS/m)	Approximate Depth Range (feet bgs)	Location of Lithologic Samples	Generalized Lithologic Description
0 to 75	0 to 2	CND02	Organic rich topsoil and gravel fill
125 to >240	2 to 13	CND02	Clays, brown, with some caliche development
70 to 140	13 to 32	CND02	Silty to fine sandy brown clays
125 to >240	32 to 34	CND02	Clays, brown, with some caliche development
20 to 40	36 to 46	CND02	Medium to coarse grained granitic sands with sparse fine gravels, water saturated
80 to 100	46 to 52	CND10	Gray clay-silt
20 to 40	52 to 60	CND10	Medium to coarse grained granitic sands with sparse fine gravels, water saturated

The conductivity ranges given in Table 2 for each lithology vary slightly from location to location at this site. The depth at which the different lithologies and related conductivities are encountered at each location also varies. Furthermore, the electrical conductivity range observed for the brown silty to sandy clays (70 to 140 mS/m) completely overlaps the range of the gray clay-silt (80 to 100 mS/m). This demonstrates that a certain range of electrical conductivity is not unique to one specific type of sediment or lithologic unit even at one site. This is why selected samples must be collected at least at one location at each site investigated to confirm what the different electrical conductivity values represent. Once the electrical log has been 'calibrated' in this manner additional logs can be obtained across the area under investigation to observe lithologic changes and formation contacts.

Selecting Formation Contacts

The EC logs and soil core samples show that the upper 35 to 40 feet (11 to 12 m) of the unconsolidated materials consist primarily of clays and silty to sandy clays along with the top soil (Appendix I and Table 2). The contacts between these three fine-grained units at each location were selected based on the change in electrical conductivity relative to the ranges given in Table 2. On log CND02 (Figure 2) at a depth of 10 to 14 feet (2 to 4 m) bgs, there is a distinct drop in conductivity from over 200 mS/m to less than 125 mS/m. And from a depth of about 13 to 30 feet (4 to 9 m) bgs, the conductivity stays in the range of about 70 mS/m to 140 mS/m. Therefore, the contact between the overlying clays and the silty to sandy clays was placed at approximately 13 feet (4 m) bgs where the conductivity drops below 140 mS/m and stays consistently below that value.

At a depth of 36 to 46 feet (11 to 14 m) bgs at location CND02, the electrical conductivity stays in the range of about 20 to 40 mS/m (Figure 2). As discussed above, the core samples from this depth and location (Table 2) show that this electrical conductivity range correlates with a layer of relatively clean granitic sand with fine gravels. At a depth of approximately 46 feet (14 m) bgs on the EC logs from both locations CND02 and CND10, the conductivity abruptly increases from the range of 20 to 40 mS/m to approximately 100 mS/m. The conductivity stays near 100 mS/m for the next 6 to 8 feet (2 to 2.5 m) at both locations. A discrete core sample collected at location CND10 at a depth of 46 to 48 feet (14 to 14.5 m) bgs shows that the abrupt increase in electrical conductivity correlates with a very distinctive gray clay-silt formation. Therefore, the contact between the upper sand and the gray clay-silt formation is placed at 46 feet (14 m) bgs where the abrupt increase in conductivity occurs.

Again at the CND10 location, the conductivity drops from around 100 mS/m back to the range of 20 to 40 mS/m between the depth of 54 to 56 feet (16 to 17 m) bgs (Appendix I, Log CND10), and then stays in that range to the bottom of the log. Another discrete core sample was collected at a depth of 56 to 58 feet (17 to 18 m) bgs at the CND10 location. This sample was found to consist of coarse granitic sands and gravels. Based on this, the contact between the clay-silt formation and underlying sands and gravels at the CND10 location was placed at approximately 52.5 feet (16 m) bgs where the conductivity drops abruptly from almost 100 mS/m to about 20 mS/m.

The examples discussed above show how the formation contacts are selected based on the EC logs and limited sampling. As seen from the contacts between the gray clay-silt and the granitic sands above and below this unit, the lithologic and electrical conductivity contacts can be very sharp while the contact between the brown clay and silty-to-sandy clay is more transitional and requires some interpretation.

RESULTS

A total of ten EC logs were obtained from the study site for this project (Appendix I). The location of each EC log is shown on Figure 1. These logs are used in the following discussion to provide examples of how electrical conductivity can be used to facilitate the geohydrologic investigation of the subsurface. These examples are specifically related to the investigation of unconsolidated alluvial sediments where LNAPLs or DNAPLs may be present.

Correlation of Lithologic Units and Geologic Cross Sections Based on Electrical Conductivity Logs

Initially, two electrical coductivity logs (CND01 and CND02) were obtained to depths of approximately 60 feet (18 m) at the southeast and northwest corners of the study area (Figure 1). Later, a third EC log (CND10) was obtained to a depth of about 60 feet (18 m) near the northeast corner of the study area. Figure 4 provides a geologic cross section based on these three EC logs. As described above and summarized in Table 2, these logs indicate the presence of five basic lithologic units. The formation contacts shown on each log of the cross section in Figure 4 were selected using the methodology discussed above. The lines of correlation connecting lithologic units from log to log were drawn simply by connecting the contacts between the same two units on each successive log.

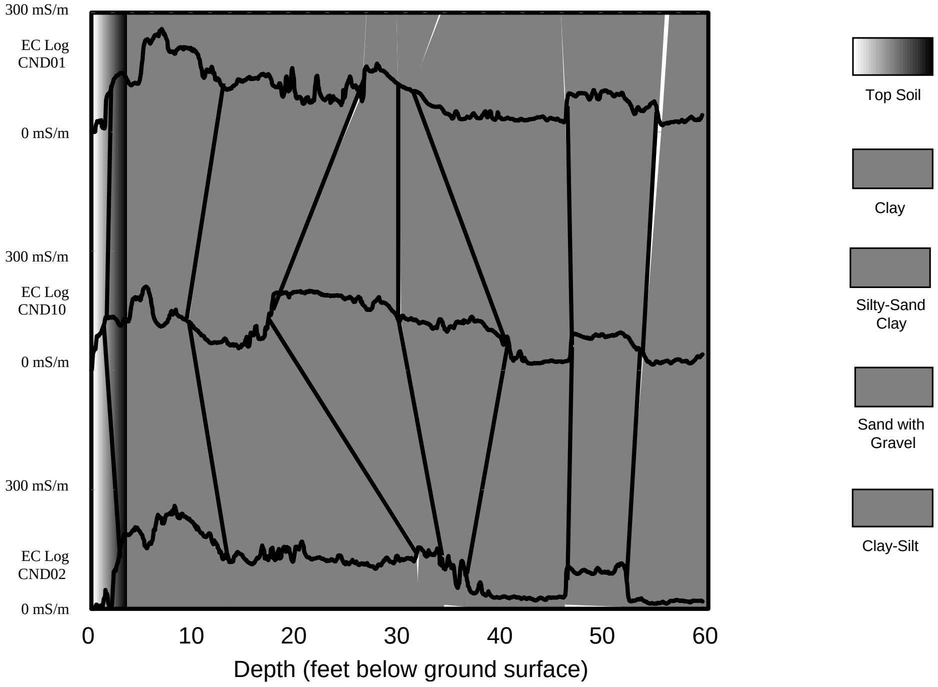

FIGURE 4
Geologic Cross Section Using EC Log

Preliminary Definition of Aquifers and Aquitards Using Electrical Conductivity Logs

Static water levels in the monitoring wells and Screen Point 15 Groundwater Samplers were measured at approximately 18 feet (5 m) bgs across the study area. By definition, the saturated sediments below the water table yet above any low permeablity confining layer that are capable of yielding sufficient quantities of water constitute an aquifer (Bates, 1983; EPA, 1986). The saturated silty to sandy clays and granitic sands and gravels that overlay the gray clay-silt unit are therefore considered an aquifer. This aquifer is seen as the sediments below the water table yet above the gray clay-silt unit shown on the geologic cross section (Figure 4). Inspection of all of the EC logs (Appendix I) from the site shows that the units forming this aquifer can be correlated beneath the entire site and so form a laterally continuous aquifer. This aquifer is equivalent to the **uppermost aquifer** as defined by the Resource Conservation and Recovery Act (RCRA) (CFR 40 Part 264 subpart f) and in EPA guidance documents for groundwater investigations at RCRA facilities (EPA, 1986; EPA, 1992).

The discrete sample collected at a depth of 46 to 48 feet (14 to 14.5 m) bgs at location CND10 shows the layer beneath the uppermost aquifer to be a very distinctive gray clay-silt layer. As discussed earlier, this layer has a distinctly higher electrical conductivity than the sands and gravels which lie both above and below it. As such, this unit is easily distinguishable from the surrounding sands and gravels. This unit begins at about 46 feet (14 m) bgs on the three logs shown on the geologic cross section (Figure 4) and ranges in thickness from about six to nine feet (2 to 2.5 m). Inspection of each of the EC logs in Appendix I shows that the upper portion of this layer was detected at each location and is therefore areally continuous beneath the site.

In general, the hydraulic conductivity of silts and clayey silts will range from 10^{-5} to 10^{-6} cm/sec while the hydraulic conductivity of medium to coarse sands and gravels will range form 10^{-1} to 10^{-3} cm/sec (Fetter, 1980). Considering the thickness of the clay-silt unit, the fact that it is areally extensive beneath the site, and the differences in the hydraulic conductivty of the clay-silt from the overlying and underlying sands and gravels indicates that this unit forms a **confining layer or aquitard.** This aquitard will seperate the uppermost aquifer from the underlying sand and gravel aquifer. Additional field and/or laboratory testing of the hydraulic conductivity would be required to confirm that this aquitard meets all of the requirements as defined under RCRA to constitute a confining layer (EPA, 1989; EPA, 1992). Beneath this aquitard, the lower sand and gravel layer will form a lower aquifer.

Tracing Conductivity Zones to Determine Potential LNAPL Flow Paths

Groundwater flow was determined to be almost due east at this site by measurements taken from the two-inch PVC wells shown in Figure 1 (GSI, 1994). In a simple groundwater flow system, any dissolved and free-phase hydrocarbons (LNAPLs) would be expected to migrate away from the source area (former tank basin) toward the east along with groundwater flow. Contrary to what the groundwater flow suggests, the highest levels of contaminants are found in monitoring wells No. 5, No. 10, No. 11 and No. 14 which are north-to-northeast of the source area (Figure 1). Also, free product was measured in MW No. 10 and in a direct push groundwater sampler installed approximately ten feet (3 m) north of MW#5. Analysis of soil core samples from these locations confirmed the presence of contamination (Table 1) at the depth interval of about 25 to 30 feet (8 to 9 m) bgs.

As analysis of the EC logs was conducted, it became apparent that the highest levels of contamination were encountered in zones where the EC for the sandy to silty clays dropped near or below 100 mS/m at a depth of 25 to 30 feet bgs (CND03, CND04). It would be possible to trace such lower EC zones from log-to-log across a site under investigation and conduct targeted sampling (soil or water) to verify the presence or abscence of contamination. Becoming aware of the less than obvious details of the EC logs may be a useful tool in deciphering the complex subsurface environment. This example shows how EC logs may be used to determine potential flow paths for hydrocarbons or other LNAPLs in the subsurface by tracing electrical conductivity zones.

Top of Aquifer Contouring Using Electrical Conductivity Logs

The contact between the overlying clays and top of the sand layer in the uppermost aquifer was determined by inspection of the EC logs. This contact was fairly sharp at some locations (CND04 and CND09, Figure 5) but more transitional or gradational at other locations (CND01, Figure 5). Because this contact was transitional at some locations, the point at which the EC dropped below 75 mS/m going from the clays into the upper sand layer was chosen to define the ‘contact’ on each log. The depth of this contact on each EC log is read off of the depth scale on the log. The cross section in Figure 5 also shows there are significant changes in the depth to the upper surface of the sand formation.

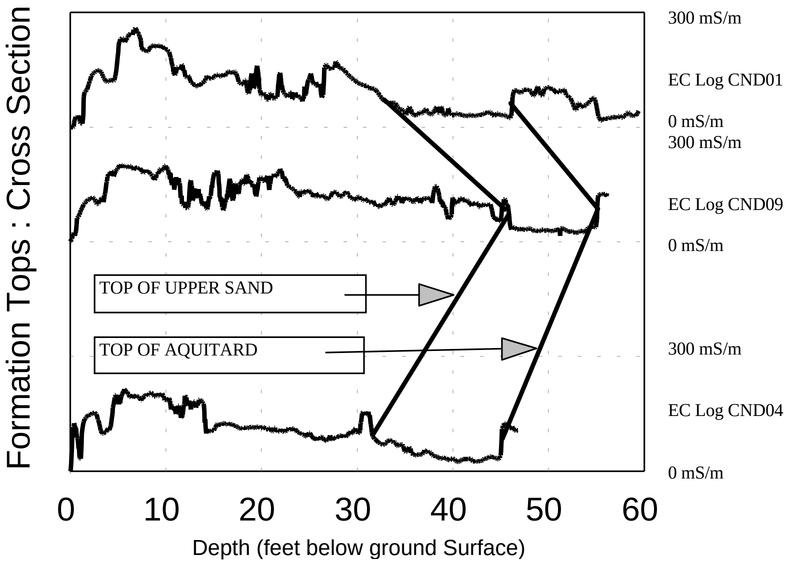

FIGURE 5
Formation Tops: Cross Section

After the EC logs were completed surface elevations were obtained at each location. Knowing these elevations, it is then possible to calculate the elevation of any formation contact at depth below the surface. The elevations calculated for the top of the upper sand at each location were then plotted on the site map. These elevations were contoured by hand to create a contour map of the contact surface. This contour map (Figure 6) shows that the contact between the upper sand layer and overlying clays forms a complex saddle-like shaped surface.

This example shows that EC logs can be used to construct maps on the surfaces of sand layers or other formations that can be defined by electrical conductivity. In turn, these mapped surfaces can then be used to determine potential migration pathways for LNAPLs in the subsurface.

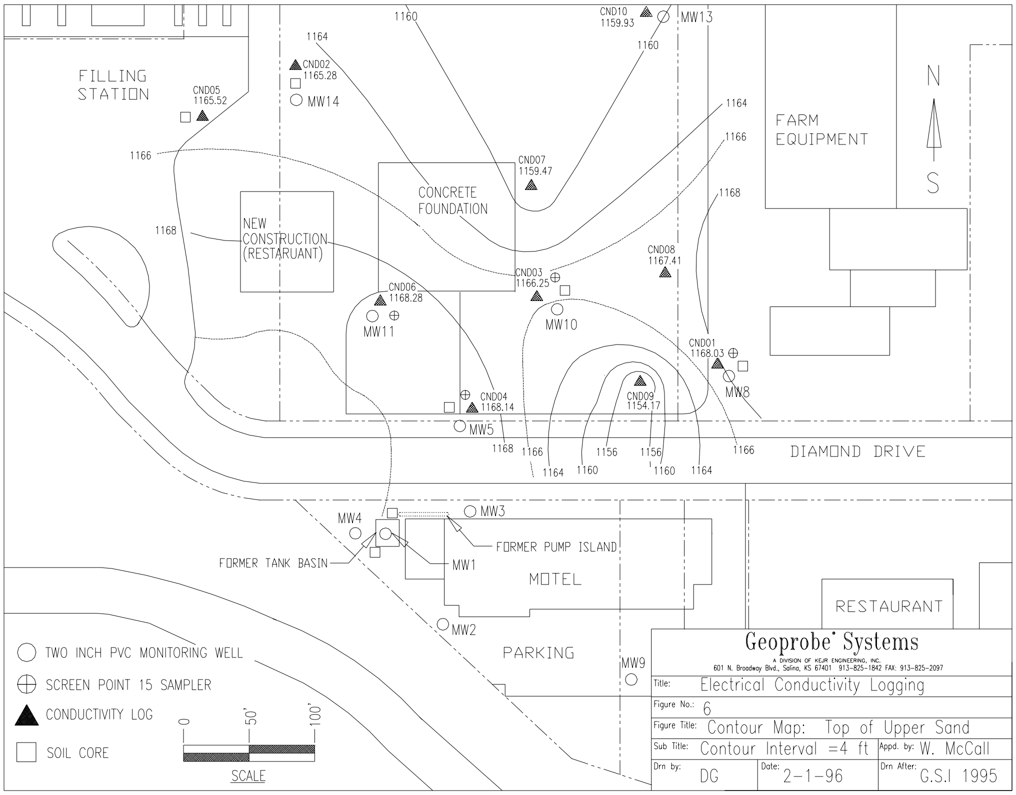

FIGURE 6
Contour Map: Top of Upper Sand

Top of Aquitard Contouring and Potential DNAPL Flow Paths

All of the EC logs from the site were obtained to a depth at which the aquitard dividing the uppermost aquifer from the lower aquifer(s) was encountered. This assured that the aquitard was continuous beneath the entire study area. The aquitard was not completely penetrated in areas of suspected contamination. Not penetrating the aquitard assured that a pathway was not created for contaminants from the upper aquifer to enter the lower aquifer(s). The cross section in Figure 5 also reveals that there are significant changes in the depth to the top of the aquitard.

Following the procedure described above, the elevation on the top of the aquitard was determined by subtracting the depth to the top of the aquitard from the surface elevation at each EC log location. These elevations were again plotted on the site map and contoured by hand (Figure 7). This map shows that the upper surface of the aquitard slopes gently toward the southeast over much of the study area. Then, near the southeast corner of the study area, a deep trough or depression is present in the surface of the aquitard. If any dense nonaqueous phase liquids were present in the subsurface at this study area they would be expected to flow across the sloping surface of the aquitard and collect in the trough or depression at the southeast corner of the mapped area.

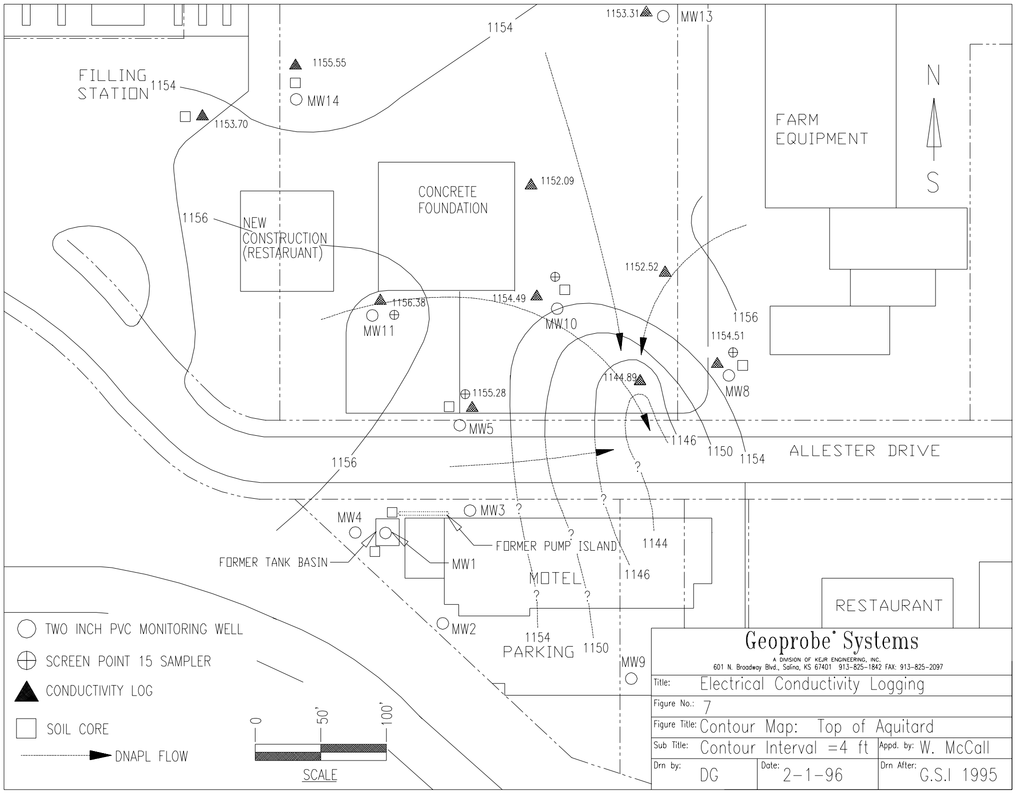

FIGURE 7
Contour Map: Top of Aquitard

This example illustrates how EC logging can be used to map the surface of an aquitard (or bedrock contact) to locate potential flow paths and collection points for DNAPLs. This type of information can be very useful during groundwater investigations and remedial actions to determine appropriate locations for placement of monitoring wells, extraction wells, sparging wells, or soil vapor extraction wells.

Determining Thickness and Volumes of Sand Layers or Aquifers

Using the elevations calculated for the upper surface of the sand layer and for the upper surface of the aquitard (which is equal to the lower surface of the sand layer), the thickness of the sand layer may be determined at each EC log location. The thickness of the sand layer calculated at each EC log location was plotted on the site map and then contoured by hand (Figure 8). This map of the thickness of the sand layer is called an isopach map. This informtion can be used to calculate the volume of the sand layer in the uppermost aquifer. If the average porosity of the sand layer were determined then the volume of pore fluids (water + contaminants) could be calculated to determine the approximate volume of fluids and mass of contaminants requiring treatment or remediation.

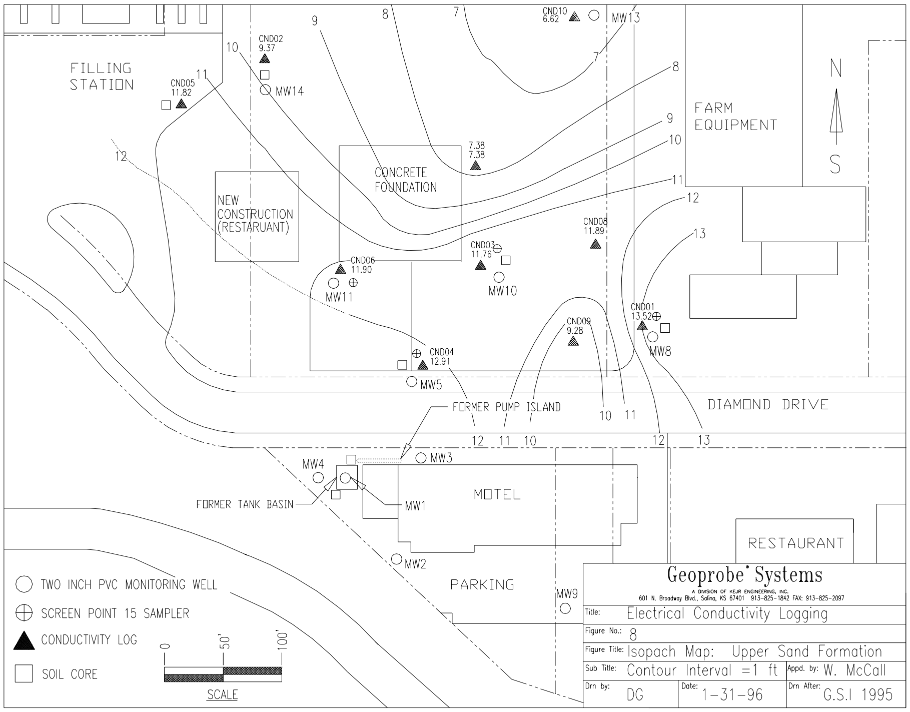

FIGURE 8

Isopach Map: Upper Sand Fromation

SUMMARY AND CONCLUSIONS

After site specific verification of electrical conductivity, log response to different formations with limited soil sampling (site specific calibration) EC logs can be used during environmental investigations or for other geohydrologic investigations to:

- Trace lithologic units across the site.
- Construct geologic cross sections.
- Trace specific conductivity zones which may form flow paths for LNAPLs.
- Define sand formations based on EC response to defined lithology.
- Define aquitards based on EC response to defined lithology.
- Define thickness and lateral continuity of aquifers, aquitards, or other defineable lithologic units (such as clay lenses or sand lenses) based on EC response.

When accurate surface elevations are obtained at each EC log location, the depths to formations or formation contacts can be translated to elevations. When this is done, EC logs can be used to:

- Construct contour maps on formation contacts.
- Construct contour maps on upper surfaces of permeable units to define potential flow paths for LNAPLs.
- Construct contour maps on upper surfaces of aquitards or impermeable bedrock to define potential flow paths for DNAPLs.
- Construct isopach maps to define the thickness and volumes of specific formations.

In conclusion, it is seen that electrical conductivity logging by direct push technology is a cost-effective and rapid method for defining subsurface geology in unconsolidated materials. It required approximately two 8-hour days for two people to complete the ten logs for this study. An additional three to four hours was required to collect the necessary soil core samples at two locations to verify the logs. In comparison, using traditional hollow-stem auger drilling and continuous samplers to log these ten locations (up to 60 foot depth) could have required as much as five to seven days for a two-person drilling crew, plus a geologist to log the samples. Since EC logging minimizes the sampling required to define subsurface geology, it also greatly minimizes the potentially hazardous waste generated during subsurface investigations. By reducing the time required for the geohydrologic investigation and minimizing the waste generated, EC logging will reduce the overall cost of the project significantly while providing more detailed information for the investigator and regulator.

ACKNOWLEDGEMENTS

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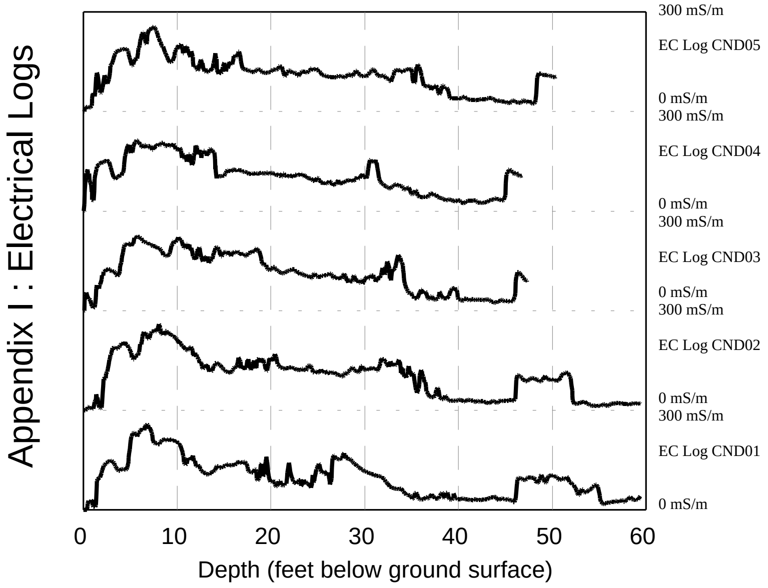
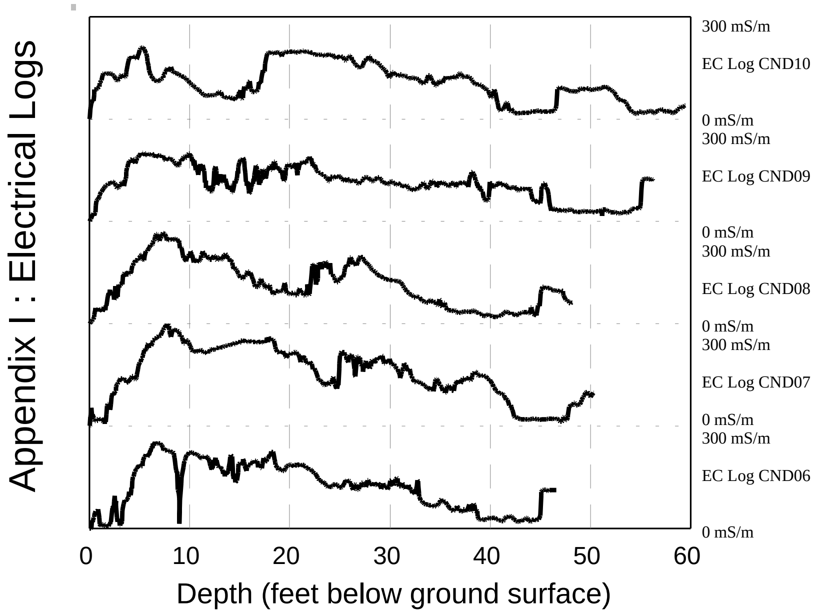
APPENDIX I: Electrical Logs





Biographical Sketch

Wesley McCall, Environmental Geologist
Mr. McCall earned his B.S. in Geology from Clemson University in 1982 and his M.S. in Geology from the University of Missouri-Columbia in 1987. Shortly after completing his M.S., he began work as an environmental consultant on federal, state, and private contracts. Mr. McCall joined Geoprobe Systems in May of 1995 where he is involved with applications research and technical support.

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