3.7 Electrical Conductivity (EC) Probe

EC is the ability of a particular material (for example, soil, sediment) to conduct an electrical current measured in milli-Siemens per meter (mS/m) using an EC probe. The EC probe is typically deployed by direct-push methods (static or percussion) to measure the apparent EC of the bulk formation (solids and fluids) located adjacent to the advancing probe. The term "apparent conductivity" is used because the probe measures the bulk or average conductivity of materials near it.

As the probe is advanced, it produces a continuous log of apparent conductivity versus depth. Measurements of EC can be used to infer the presence of more highly conductive subsurface materials such as clays; but because EC can be influenced by several factors, EC probes are typically used in conjunction with other tools such as the HPT to better determine the true nature of the subsurface materials being investigated (USEPA 2016b).

Finer-grained soils, such as silts or clays, tend to produce higher EC signals than coarser-grained sands and gravels. While specific values cannot be assigned to each soil type, each soil type typically provides a different response. Figure 3-30 shows the typical EC measurements for sand, silt, and clay.

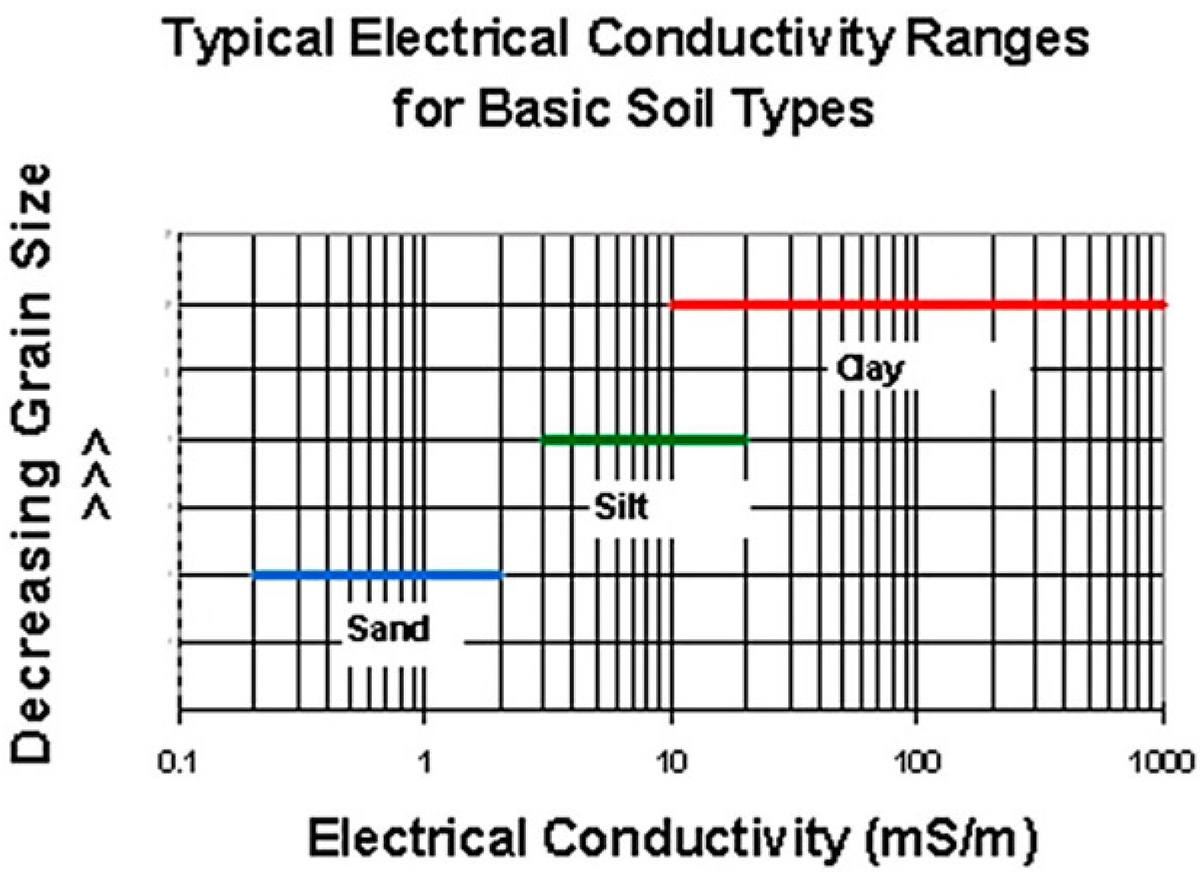


Figure 3-30. Typical EC measurements for sand, silt, and clay.
Source: Geoprobe 2015b, Used with permission

An EC probe is frequently used to map potential contaminant pathways. Zones of lower EC usually indicate coarser-grained, more permeable materials. These more permeable zones allow contaminants to migrate in the subsurface (path of least resistance). Finer-grained sediments (for example, clays) can trap and store contaminants. The EC gives the investigator real-time, on-screen logs for on-site decision making. Once multiple logs are generated, a cross-sectional view of a series of logs is helpful to visualize how these preferential pathways connect across a site (see Figure 3-31*)*. Courser-grained sediments are located near 10 ft to 11 ft and 16 ft to 24 ft below ground surface and are also present near the bottom of the logs. More conductive finer-grained sediments are present elsewhere in the logs.

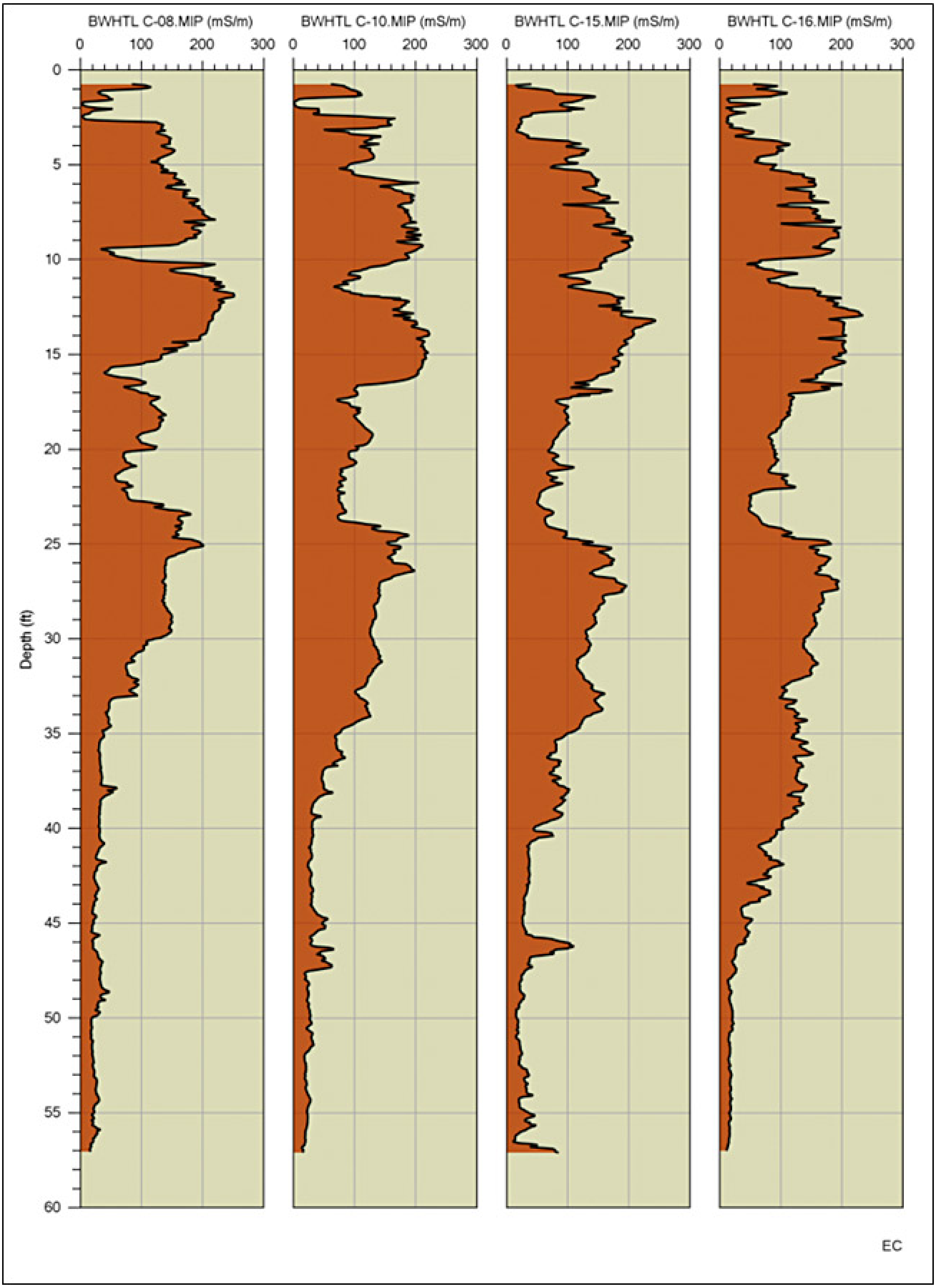
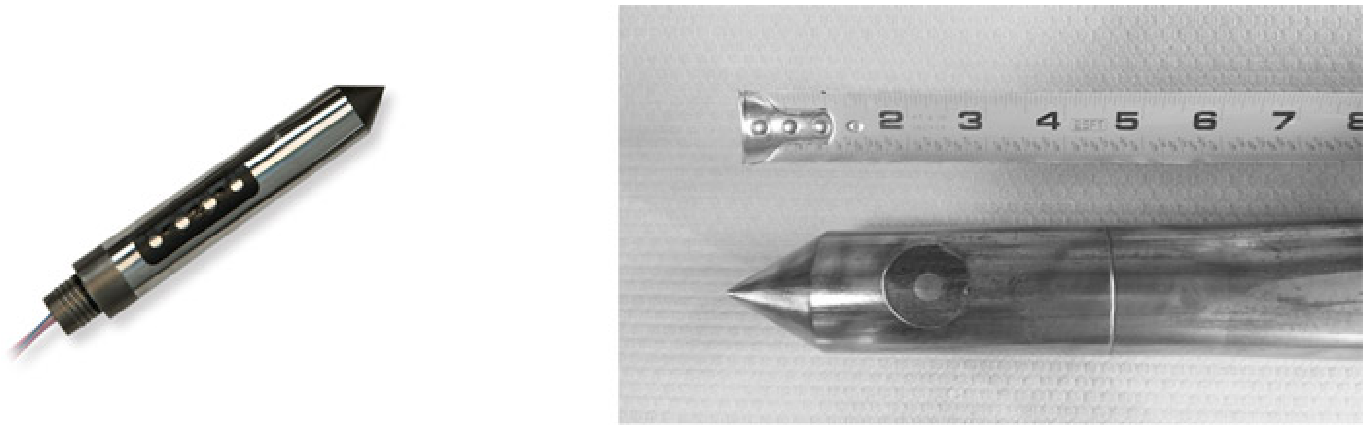


Figure 3-31. Example of EC logs along a cross section.

Source: Geoprobe Systems®, Used with permission

3.7.1 Tool Description

EC probes typically use either a four-pole Wenner array (see Figure 3-32) or a simple dipole array to measure apparent conductivity. Similar arrays are used during surface electrical resistivity surveys except that the probe electrodes in a downhole tool are fixed along the probe’s surface. Consequently, the volume of material being measured is also fixed and does not extend far from the probe’s surface. Of the two electrode configurations, the Wenner array measures a somewhat larger volume of the formation proportional to the length of the array. Using this configuration, more averaging is necessary to obtain the output signal in the log, so small-scale features, such as a 1-inch-thick clay lens in a sand body, may not be clearly distinguishable. Conversely, dipole arrays sample a smaller volume of the formation and therefore more easily distinguish the smaller-scale lithologic features. These probes measure bulk formation EC; thus, they provide a measure of the combined EC of the formation solids and any contained fluids and dissolved ions (Milsom and Eriksen 2011).



A B

Figure 3-32. EC probe with four-pole Wenner array (left) and simple dipole EC array (right).

Source: Geoprobe Systems®, Used with permission

The EC tool consists of the probe, a trunk line to connect the probe to the field instrument (see Figure 3-33), a string pot to measure sensor depth, and a laptop to process and view the EC versus depth and probe advancement rate logs. The field instrument provides current to the probe and senses both downhole current and potential difference values. The probe is used in concert with a direct-push-type rig operated in either push or percussion mode.

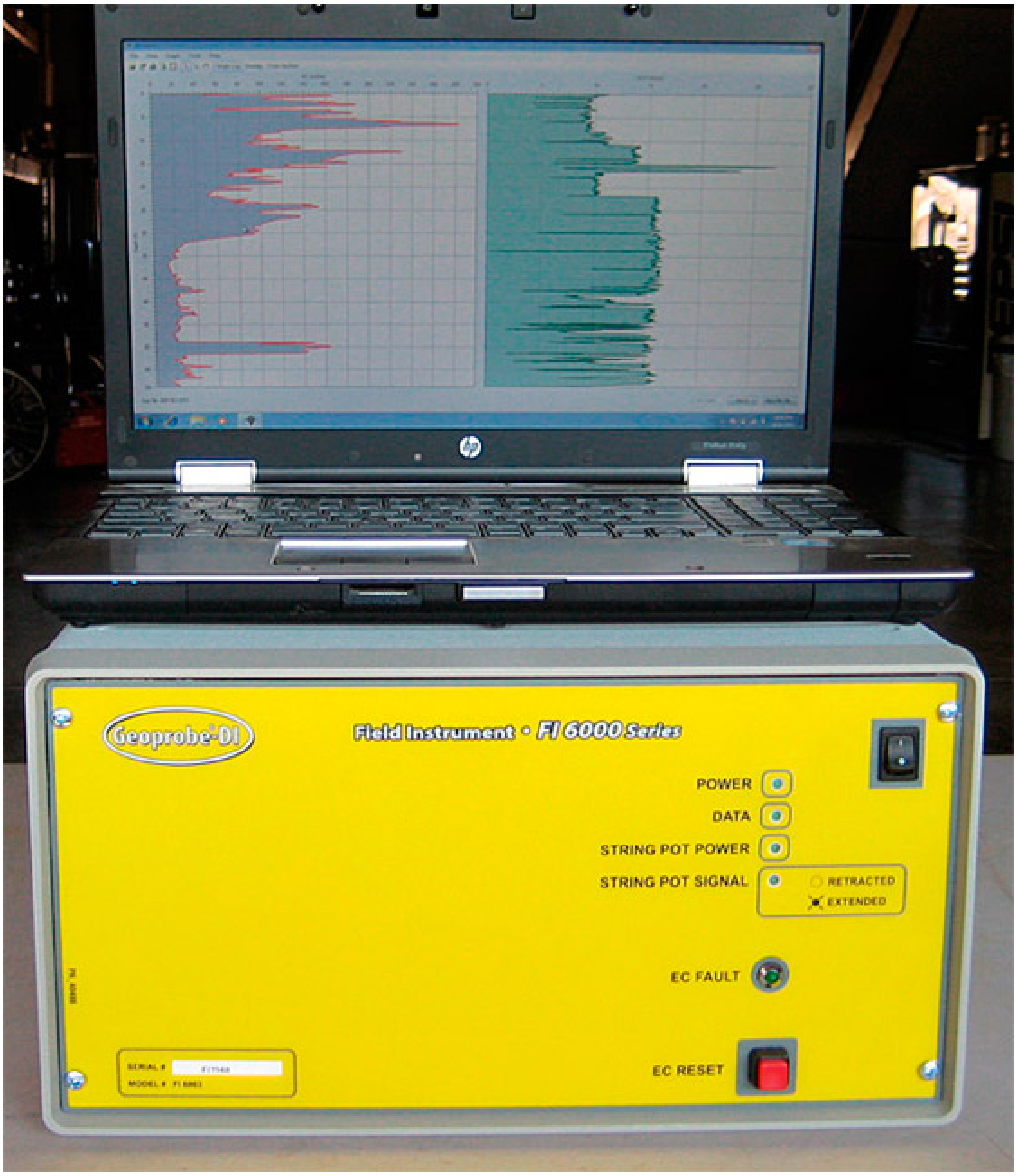


Figure 3-33. Geoprobe FI 6000 field instrument and laptop display.

Source: Geoprobe Systems®, Used with permission

EC probe operation is straight forward; using the Wenner configuration, the probe is positioned with two poles in the ground and the other half aboveground as the starting position for the log. Just prior to beginning the first subsurface push, a trigger is activated using the provided software, initiating logging for that particular boring. If needed, logging can be paused by using the software to switch the trigger off, which allows the user to disconnect the probe wires and add new rods as needed. As the probe is advanced into the ground, information from the field instrument is relayed to the field computer, which displays EC (in mS/m) and probe advancement rate (see Figure 3-33). Once downhole logging is complete, the trigger is set to "off" and the probe is extracted from the ground. A rubber sleeve at the ground surface removes soil residue from the probe as it is being extracted (Geoprobe 2015a). The log can then be used in concert with other information (for example, sediment logs, injection flow logging data) to map site hydrostratigraphy.

3.7.2 Technical Limitations

In fresh-water formations, elevated EC readings often indicate increased clay content, but not all clays exhibit high EC. The presence of elevated dissolved ions (such as sodium, calcium, chloride, or ionic remediation fluids like sodium persulfate) can further complicate EC log interpretation. High concentrations of dissolved ions can completely overwhelm and mask changes in EC due to lithologic variations. Because of these limitations, targeted soil and sometimes groundwater sampling should be conducted to verify log interpretation (McCall, Christy, and Evald 2017). The EC probe can also be used in conjunction with HPT (see Section 3.6) as a means of addressing these limitations.

3.7.2.1 Detection Limits

EC logging resolution may depend upon several factors. The type of array configuration used (Wenner vs. dipole) may have some affect with respect to resolution, with the dipole configuration providing somewhat higher resolution (Geoprobe 1994); using the Wenner configuration, clay layers as thin as 2.5 cm have been identified. Clay type can also be a factor. Clays with high cation-exchange capacity such as smectite and montmorillonite are more conductive and therefore more easily resolvable than kaolinite clays. Probes measure conductivity every 1.5 cm as the probe is advanced (Schulmeister et al. 2003). The instrument measures the bulk conductivity of soils, sediments, pore fluids, or other materials located in the proximity of the probe, generally within 5 cm to 10 cm (Beck, Clark, and Puls 2000).

3.7.2.2 Interferences

The EC probe may be subject to certain interference that may hinder or prevent it from detecting stratigraphic changes. It is possible that highly mineralized or otherwise conductive pore waters may overwhelm the ability of the EC probe to detect discrete changes in lithology that may be of interest. For instance, a thin conductive clay layer surrounded by sands or gravels filled with saline pore water may not be resolvable. If work is being performed in a disturbed area, buried debris could affect readings if the debris were to come into direct contact with the probe array. Because the alternating current delivered to the probe's current electrodes is in the low hertz (Hz) range, the field instrument is designed to effectively filter out signal noise caused by underground electrical lines (60-Hz signals).

3.7.3 Data Collection Design

3.7.3.1 Identify Project Goals

Direct sensing survey design should always begin with a basic understanding of what is unknown and what the investigator hopes to learn by deploying a given technology. Once the goal of a survey is well understood, the investigator can begin to tailor use of the technology to the given need.

EC surveys are commonly used to help identify subsurface stratigraphic features that may be helping to control contaminant transport. If fine-grained deposits exist in the form of discontinuous lenses or as laterally continuous layers, then an EC survey combined with limited soil coring could be useful in helping to refine the CSM. The amount of heterogeneity present determines the density of survey boreholes required at a given site. In many cases, a gridded approach to survey design may be used, especially little is known about a particular site.

Alternatively, EC surveys can be used to better identify the location or width of a conductive groundwater plume. In this case, a courser-grained, relatively nonconductive sandy or gravelly sedimentary environment may be ideal because EC would be mainly a function of the ionic content of the pore water. Under such circumstances, laying out a series of borings in the form of a transect(s) downgradient plume source may be advantageous. Regardless of the survey goal, using other tools or methods as multiple lines of evidence is often advantageous to support survey conclusions.

3.7.3.2 Determine Verification Requirements

EC probe logs should not be taken at face value. Because EC can be affected by multiple factors, it is common to collect at least a single sediment core near an EC boring to confirm log interpretation and allow correlation with strata identified in the core. Ideally several core logs are available for a given site; other tools can be used in tandem with EC to assist with EC log interpretation.

3.7.4 Quality Control

Diagnostic tests should be run on the EC probe before and after each boring log. An EC load test confirms that the actual measured EC values are within 10% of the target values for three separate conductivity values. If the EC probe passes the load test, then the tool is ready for logging. If the EC probe fails the load test, then a separate set of tests must be run to troubleshoot the problem. If the EC probe is functioning as designed, then only pre- and post-load tests are required (Geoprobe 2015a).

3.7.5 Data Interpretation and Presentation

Interpretation and presentation of EC logging data is fairly straightforward. In many instances, elevated EC values indicate the presence of finer-grained sedimentary layers (for example, silts or clays). Other tools can be used in conjunction with EC logging to identify situations where this relationship does not hold true. Figure 3-34 shows an EC log obtained from the Arkansas River alluvial aquifer. From the interpretation provided (verified by targeted sampling), increasing EC values in fresh water formations typically indicate increasing clay content. Yet this is not always true, as clay mineralogy and the presence of brines can affect EC log response. Here the water table is visible where clean sand goes from dry to saturated at about 9 ft below ground surface. In finer-grained materials, the water level is typically not discernable. When combined with the HPT, the HPT pressure correlates with the EC response unless ionic interferences are present (see Figure 3-34). Various data presentation options are available, with the most common being to display individual EC logs side by side.

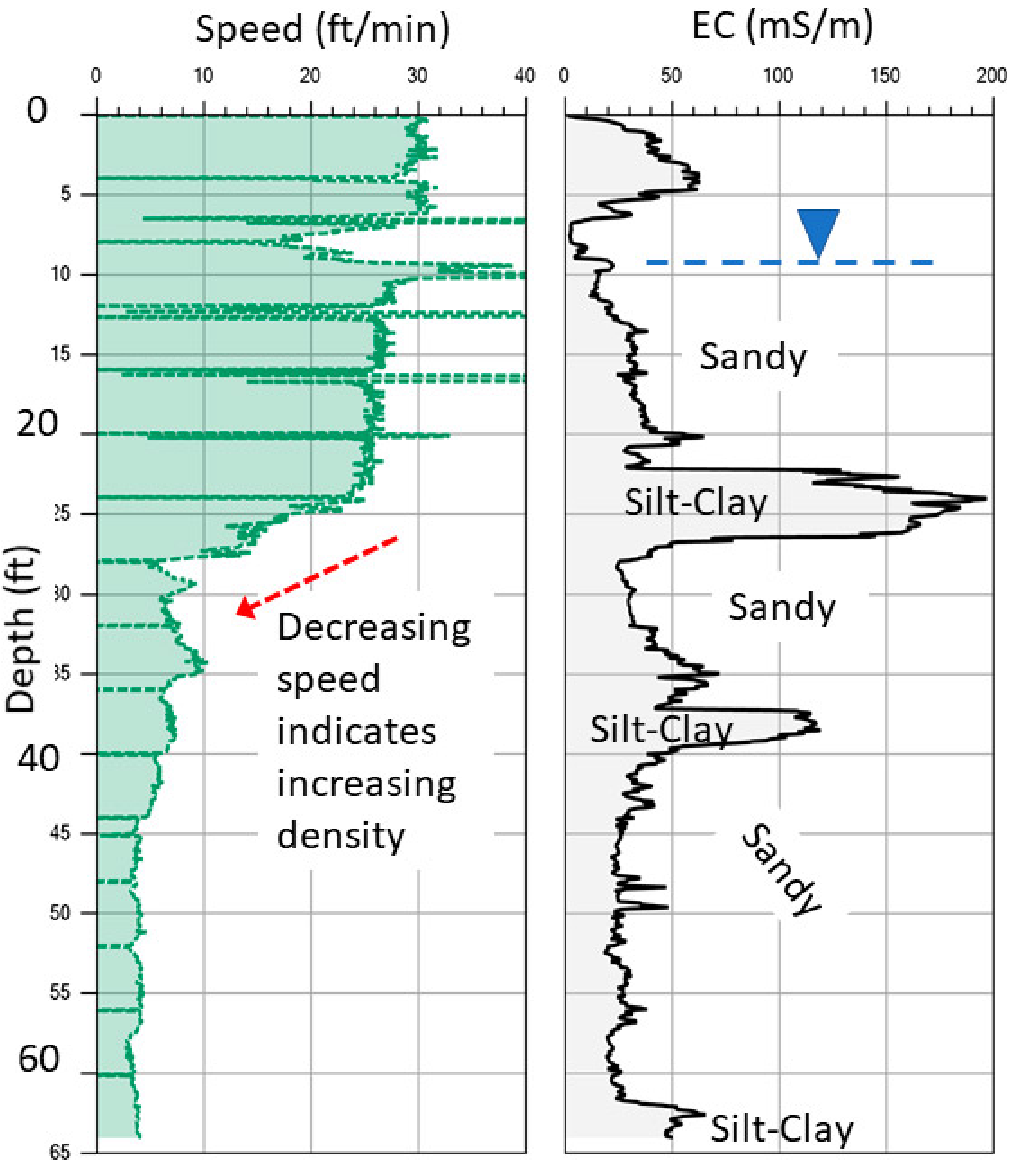
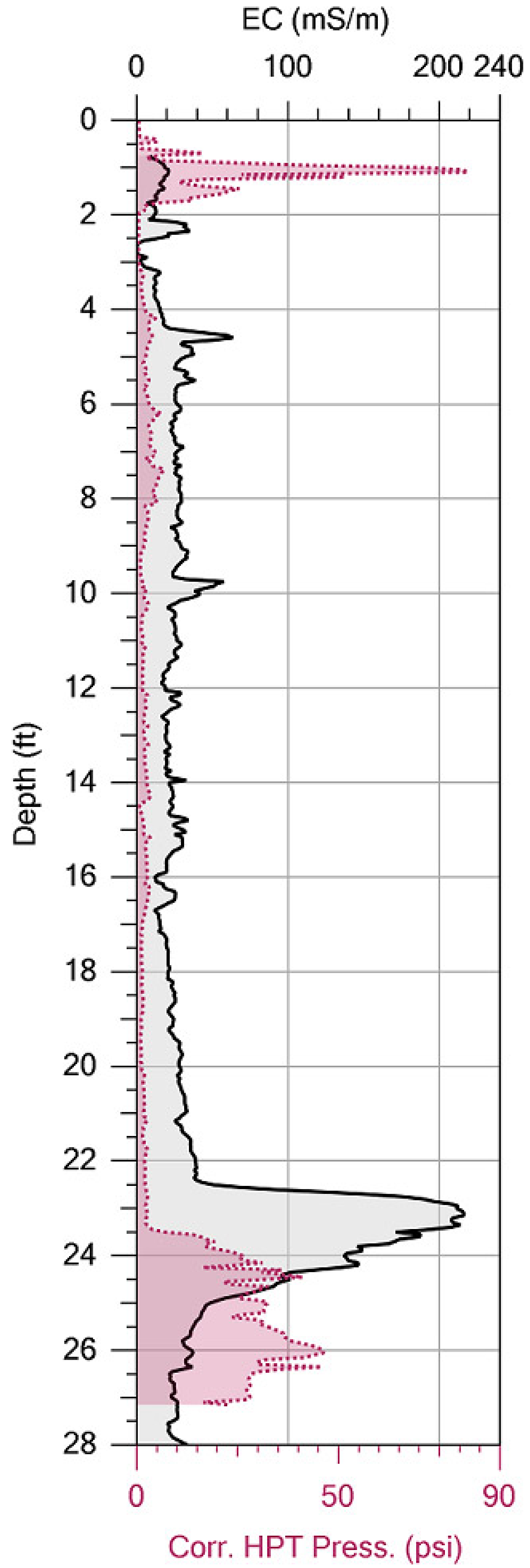


Figure 3-34. EC log (right) with associated probe advancement rate log (left).

Source: Geoprobe Systems®, Used with permission

EC field logs are initially displayed on a laptop computer as conductivity versus depth. A separate log indicating probe advancement rate is also displayed, primarily for field use and may or may not be included in a final report. The EC probe should be advanced at a rate of approximately 2 cm/sec through the logging process to ensure adequate contact between the probe and sediment and consistent results between adjacent boreholes. Because the probe is commonly used in tandem with other sensors that are more sensitive to advancement rate, advancement rates for each log should be confirmed to be close to the 2 cm/sec value.

If the ionic content of pore waters is believed to be fairly consistent at a given site, then EC should be primarily a function of grain size and clay content, with higher EC values being associated with smaller grain size and more conductive clays. Silts and clays are less permeable than coarser-grained sediments, which is why it is often advantageous to plot EC logs alongside hydraulic profiling logs obtained from the same borehole. When using this approach, a low-permeability clay should exhibit a similar signature on both the EC and hydraulic profiling logs. An inverse relationship (for example, high EC and low pressure) may indicate that higher EC values reflect coarser-grained materials containing conductive pore water. Figure 3-35 provides an example EC log that shows mostly sands and gravels present above approximately 23 ft and a clay till layer below this depth based on the abrupt rise on the HPT log below 23 ft. Note that the EC log peaks above the clay till layer. This effect is produced by the presence of sodium persulfate in the more permeable material located above the clay till.



EC (mS/m)
0
100
200 240
Depth (ft)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0
50
90
Corr. HPT Press. (psi)

Figure 3-35. EC log (solid black line) and superimposed HPT pressure log (dashed purple line) corrected for hydrostatic pressure.

Source: Modified from McCall et al., 2014, Used with permission

There are several different options when it comes to displaying EC data. Typically, EC probe data are simply presented as a log of conductivity versus depth with multiple logs being displayed in a cross-section format (see Figure 3-31). If HPT is used in concert with the EC array, both sets of data (EC and corrected pressure curves) can be plotted on the same log or on adjacent logs to aid in data interpretation. While perhaps less common, plot plan view slice maps or even 3-D images of EC can be created using appropriate software. Whatever the presentation style, EC data should not be viewed in isolation but should be presented with some form of supporting information (for example, hydraulic profiling, natural gamma log).

3.7.6 Tool and Data Misuse

Using the EC probe in areas known to contain mainly coarser-grained, nonconductive soils (for example, coastal plain environments) may be of little benefit unless the survey goal is to map a zone of highly conductive pore water (for example, a salt-water intrusion zone). The EC probe is likely to be most useful in more heterogeneous unconsolidated environments where greater understanding of hydrostratagraphic relationships is required. It can also be useful for defining (in high resolution) acidic buried wastes, high-concentration total dissolved solid plumes in groundwater, and buried material that has an EC different from the deposits that contain the buried waste.

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