# A Permeable Membrane Sensor For The
# Detection of Volatile Compounds in Soil

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## INTRODUCTION

The large volume of site investigation work being performed since 1980 has spurred numerous attempts to improve field methods of data collection. As part of this effort, Geoprobe Systems has developed two soil logging tools which can be driven into soil to determine either lithology or contaminant concentration. These two tools are the soil conductivity logging tool and the membrane interface probe. Both of these methods can be combined into the same probe giving the site investigator a powerful means of collecting subsurface information. The soil conductivity log of this probing tool is used to interpret lithology while the membrane interface probe is used to determine the position and approximate concentration of volatile organic compounds (VOCs).

This paper will describe the principle of operation of the combined soil conductivity (SC) and membrane interface probe (MIP). Data is presented in this paper from actual field use of the MIP/SC logging system on fuel hydrocarbon and chlorinated solvent contamination and comparisons are made to soil core analyses.

## SYSTEM DESCRIPTION

The basic parts of the MIP/SC probe are shown on Figure 1. The probe is 1.5 inches (3.8 cm) in diameter and approximately 12 inches (30 cm) in length. The probe is driven into the ground at a rate of one foot per minute using the Geoprobe GH-40 hammer which can develop forces up to 50,000 pounds per blow and operates at a rate of 30 blows per second. Normal operating depth for this tool is 60 feet. (18m).

The soil conductivity portion of the tool utilizes a dipole measurement arrangement (Figure 2). An alternating electrical current is passed from the center, isolated pin of the SC probe to the probe body. The voltage response of the soil to the imposed current is measured across the same two points. This probe is reasonably accurate for measurement of soil conductivities in the range of 5 to 400 mS/m. In general, at a given location, lower conductivities will indicate sands while higher conductivities are indicative of silts and clays.

Figure 3 shows a schematic of the MIP portion of the probe. This probe has been developed and patented by Geoprobe Systems and tested in numerous settings of VOC contamination.
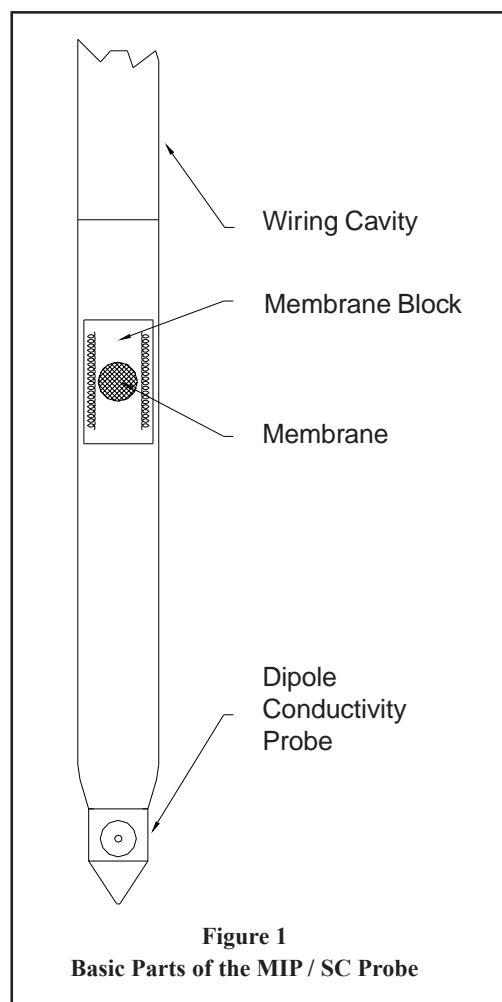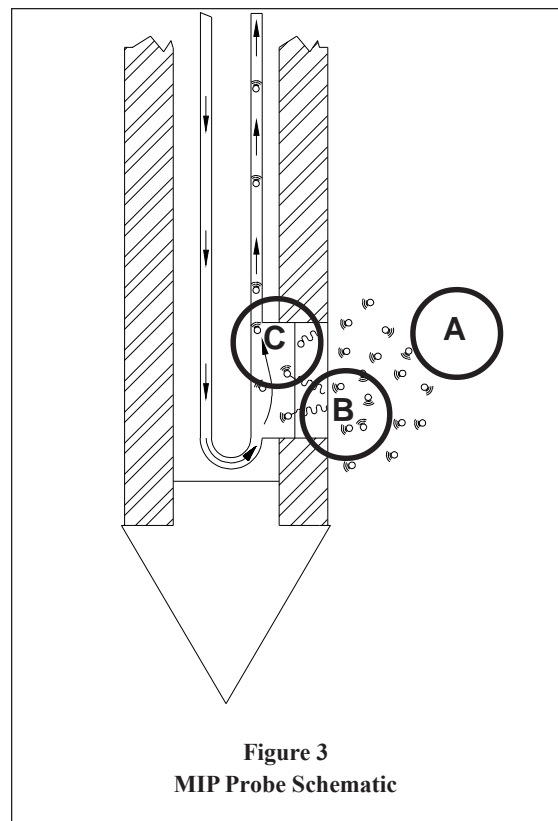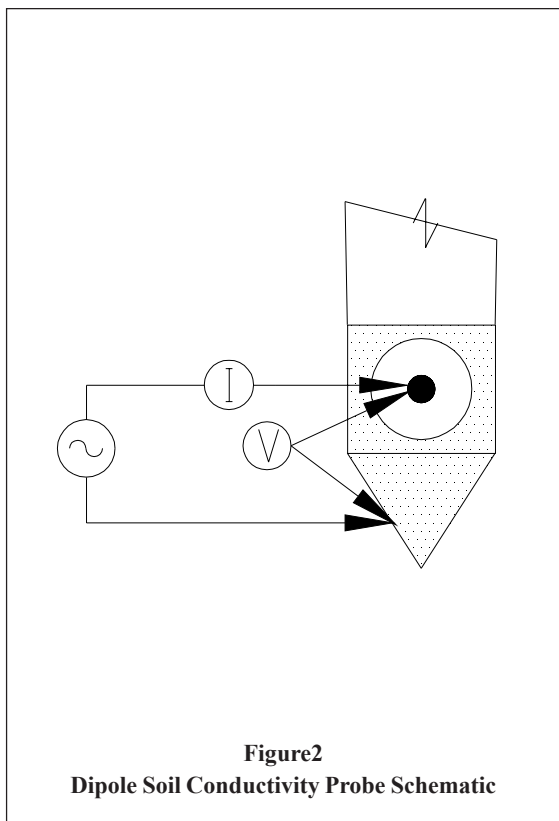


**Figure 1**
**Basic Parts of the MIP / SC Probe**

**Figure2**
**Dipole Soil Conductivity Probe Schematic**

**Figure 3**
**MIP Probe Schematic**

The operating principle of the MIP is illustrated in Figure 3.  Volatile organic compounds (VOCs) in the subsurface (Region A of Figure 3) come into contact with the heated surface of the MIP polymer membrane (B).

Upon contact, the VOCs will partition (adsorb) into the polymer membrane.  The membrane is actually a composite of metal and polymer.

VOCs in Region A in the gaseous, dissolved, solid, or free product phases can partition into the membrane.  Bulk fluids, either gases or liquids, do not travel across the membrane.  This allows the MIP tool to be used in both saturated and unsaturated soils.

Once they are sorbed into the membrane, VOC molecules will move by diffusion across the membrane to regions where their concentration are lowest.  Because the membrane is heated (80 to 125 deg. C operating temperature) and the membrane is thin, this movement across the membrane is very rapid.

After diffusing across the membrane, the VOC's partition into the carrier gas which sweeps the back side of the membrane (C).   It takes about 35 seconds for the carrier gas stream to travel through about 100 feet of inert tubing and reach the detectors used in the system.

A number of detectors have been used to measure VOC concentration in the MIP permeate gas stream. The data shown in this paper was made using an FID detector.  Data is therefore designated "MIP-FID".  However, sevral different detectors could be used.  Geoprobe Systems has used PID and XSD type detectors with good success.   The detectors must be low dead volume gas chromatography detectors and must be heated to avoid condensation of water vapor which crosses the membrane.

REPRESENTATIVE MIP/SC LOGS.

The MIP/SC tool is driven into the ground at a rate of one foot (30 cm) per minute.  Normally, driving the tool one foot will only require 15 to 30 seconds of time.  However the tool is not moved again until the one minute increment from the start of driving is complete.  Driving at this rate allows the tool to maintain its operating temperature.

A typical log of both soil conductivity and MIP response data is shown in Figure 4.  The soil conductivity data is shown at the top of the graph with the soil conductivity scale being the right hand axis.  The MIP log is shown at the bottom of the graph and its scale shown on the left hand axis.  Data output for the MIP is the output voltage of the detector connected to the MIP gas stream.  In this case the detector is an HP-5890 FID
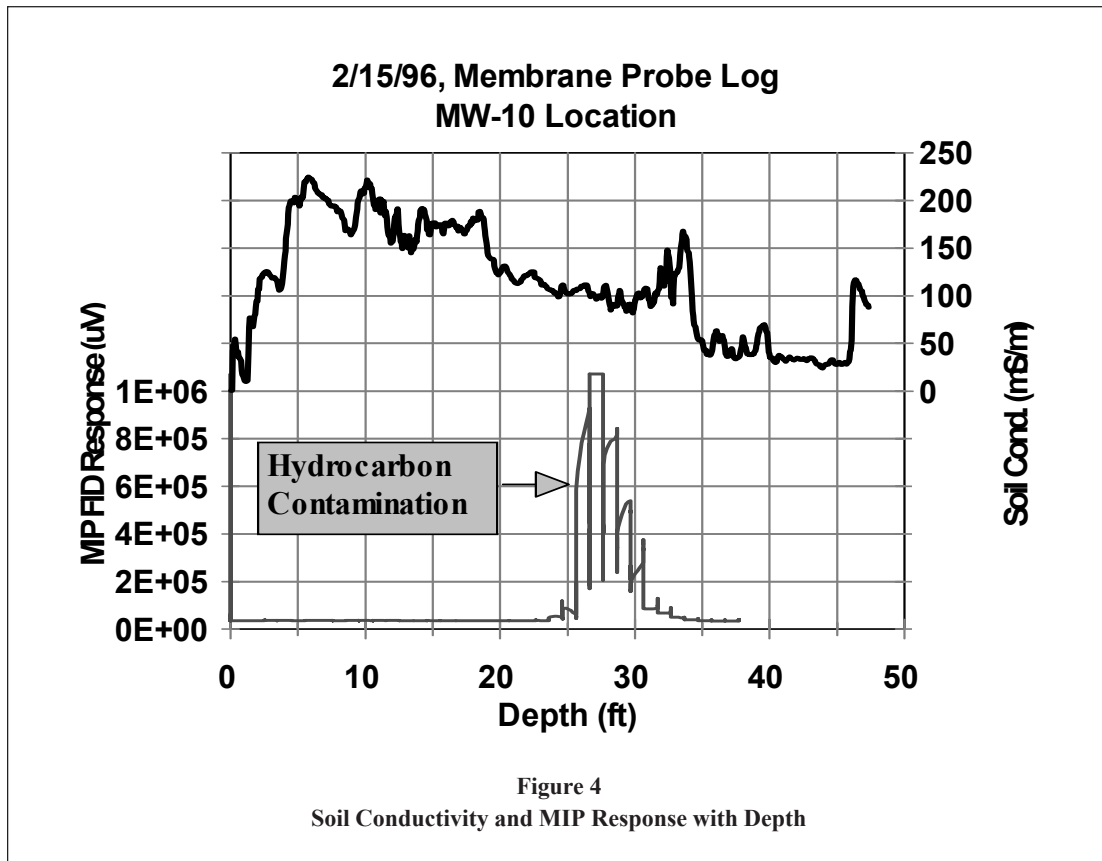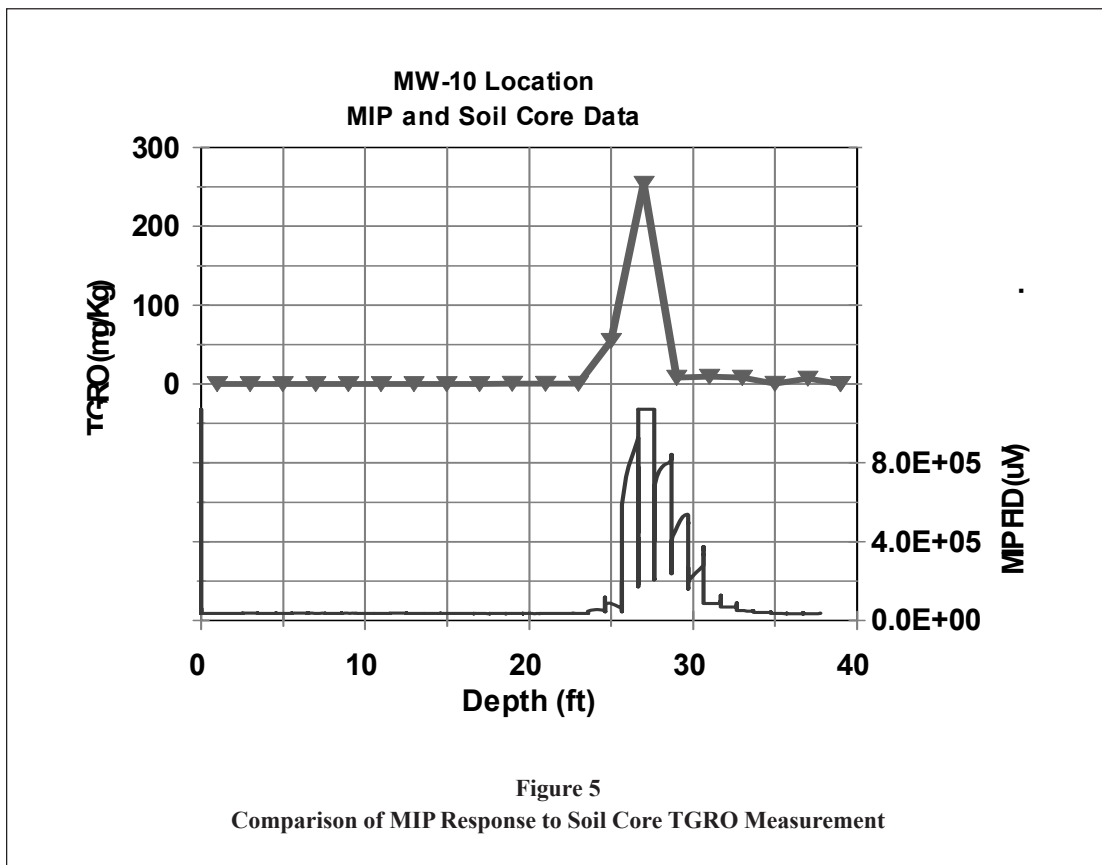


**Figure 4**
**Soil Conductivity and MIP Response with Depth**

detector and the detector response is given in micro-volts (uV).  The MIP is not quantitative; however, this detector response can be used at a particular site to estimate soil concentrations.

The MIP log in Figure 4 shows hydrocarbon contamination occurring in a the 25 to 31 foot interval.  The soil conductivity log shows a corresponding dip in conductivity in this interval that subsequent soil coring showed to be a sandy silt.  There is a clay barrier at approximately 38 feet which forms the lower boundary for the hydrocarbon contaminant.

A comparison of MIP data to soil core analyses at this same location is shown in Figure 5.  Soil Cores were recovered at this location using Geoprobe closed piston samplers.  The comparison of soil core analyses to MIP response in this figure is typical  for gasoline range organics.  Geoprobe Systems in the U.S. has found that for gasoline range organics we attain an MIP response of 4,000 to 10,000 uV of MIP-FID response per

**Figure 5**
**Comparison of MIP Response to Soil Core TGRO Measurement**

mg/Kg in soil (ppm). Studies by Michel Rogge and Pascal Carlier of Geoprobe Environmental Technologies, s.a., n.v., Waterloo, Belgium, have found a typical response of 50,000 uV per ppm in clay soils, and 10,000 uV/ppm in sandy soils.

CROSS SECTIONS
All of the data obtained with the MIP/SC system is stored in columnar form in standard ASCII format files. These files can be imported into common spreadsheet programs for graphing of data. For example, figures 4 and 5 of this paper were made using the depth, soil conductivity, and MIP response columns of the data in a Quattro Pro spreadsheet.

Another use of the data is to import several logs in sequence into a 3-D graphing program and constructing a cross section of either soil conductivity or MIP response. Geoprobe Systems has constructed numerous cross sections using Surfer® for Windows, version 6 (Golden Software, Golden, CO).

Figure 6 shows a soil conductivity cross section made using 11 MIP/SC logs along a 500 foot (154 m) alignment. Clays in this figure are represented by dark color, while sands are light. Of particular interest in this section is a clay zone at 25 feet which decreases in thickness from left to right across the page. Note also that the sand at the base of the section generally increases in thickness and elevation as we move to the right across the figure.
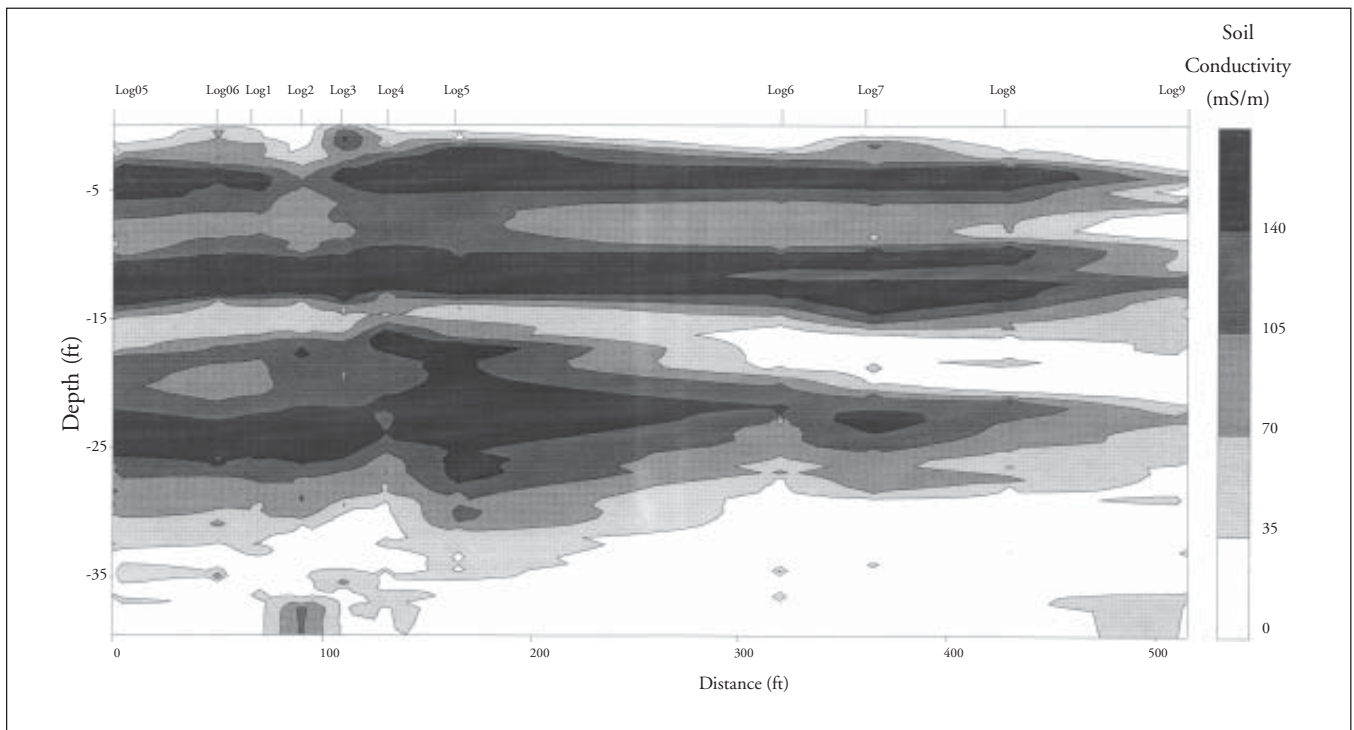
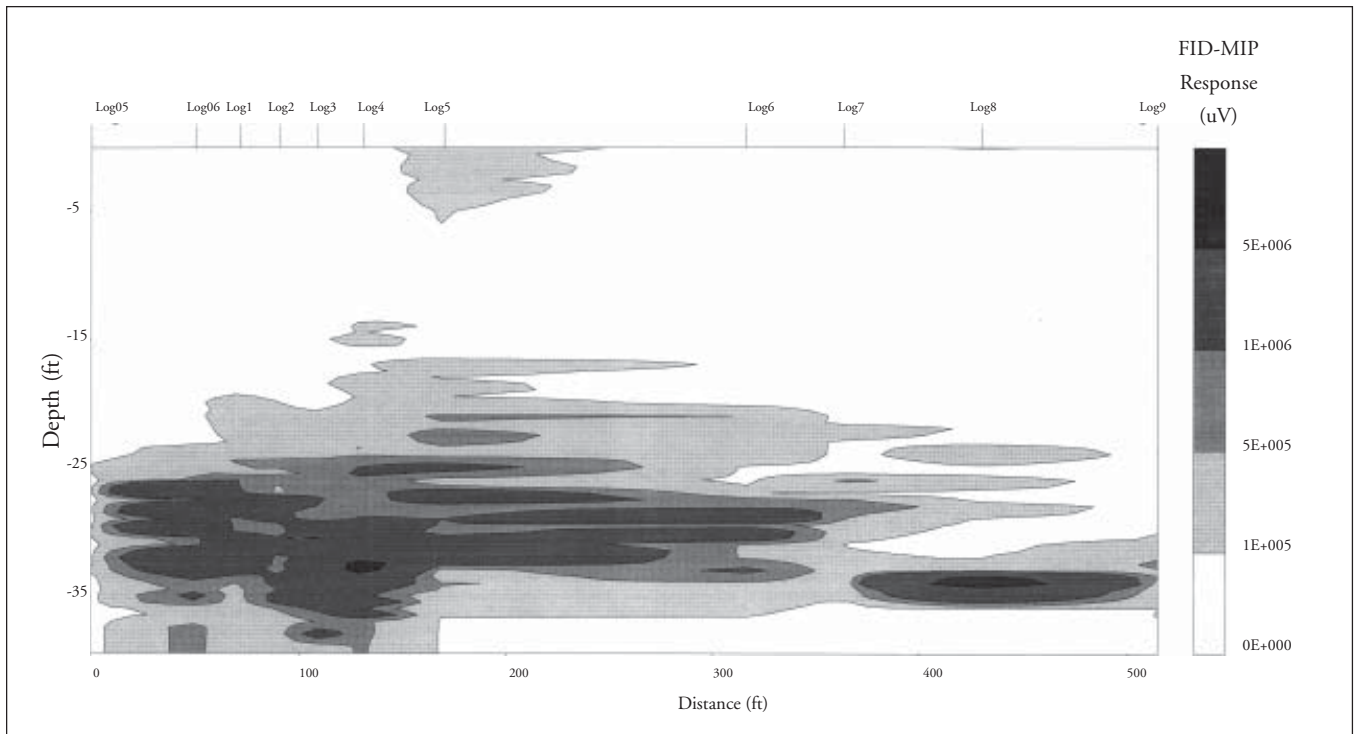**Figure 6**
**Soil Conductivity Cross Section**



**Figure 7**
**MIP Cross Section**

Figure 7 shows a cross section through the same log locations using MIP response data. The contaminants at this site are fuel hydrocarbons. The water table at this location is at approximately 25 ft. bgs. Flow in the subsurface is generally in a direction pointed into the figure. In this case, MIP response increases with intensity of color. Note that the highest concentrations of hydrocarbon contamination are found well below the water table in the sand zone of the section at a depth of approximatel 35 feet. Two distinct areas of contamination are found, one on the left side of the figure, and one on the right.

MIP AND CHLORINATED SOLVENTS:
The MIP has been used in determining the distribution of chlorinated solvents in source areas. The detection limit for most chlorinated species using conventional PID and FID detectors is approximately 5 ppm, limiting the use of this logging tool to the important task of delineation of DNAPL source areas.

Data from a DNAPL investigation in Europe is shown in Figures 8, 9, and 10 which follow. This data was collected by Geoprobe Environmental Technologies, s.a., n.v. of Waterloo, Belgium. The chlorinated solvent species being measured include PCE, TCE, and their degradation products. Concentrations in groundwater samples collected at the site after MIP logging ranged as high as 70 ppm of total chlorinated species.
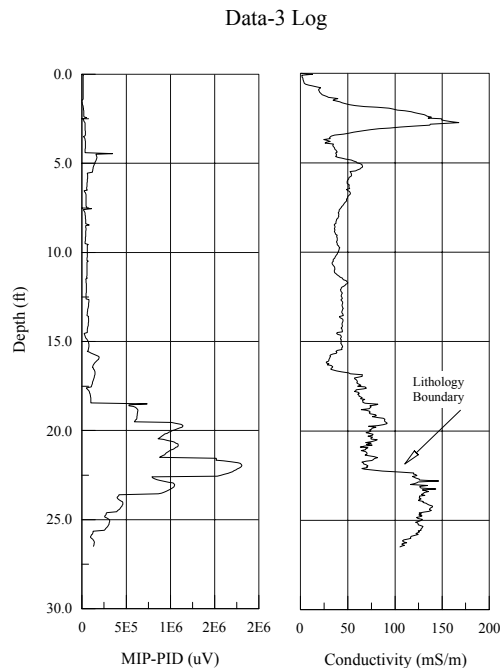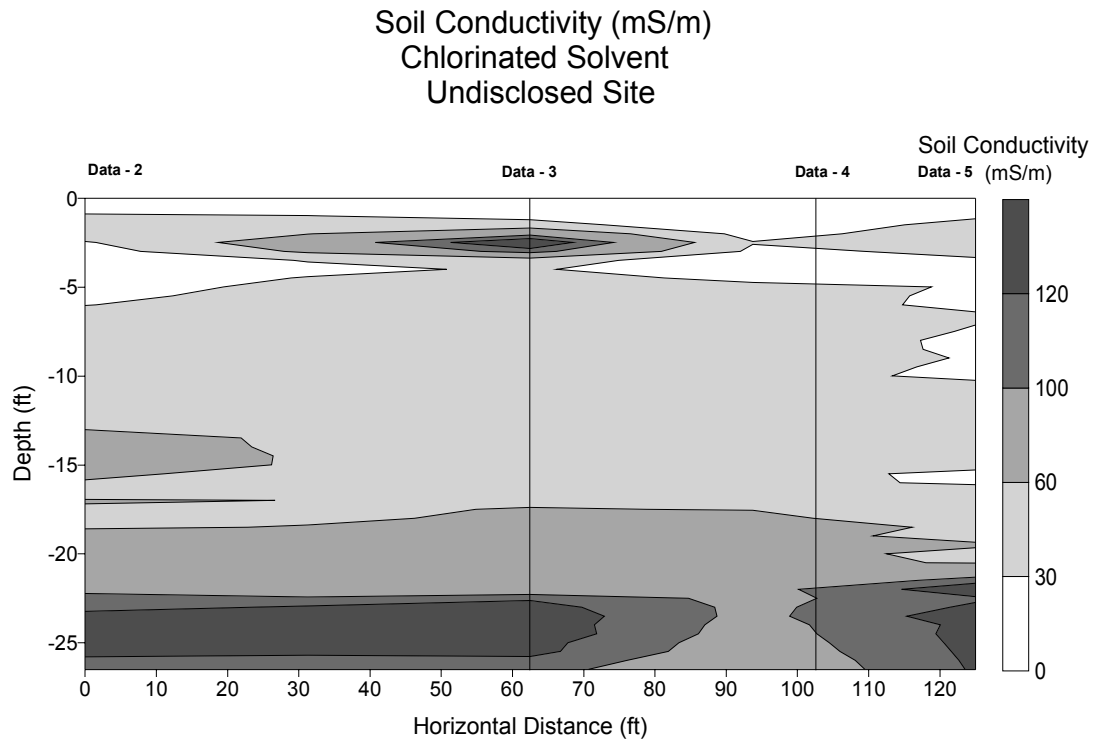


Data-3 Log

**Figure 8**
**MIP Log: Soil Conductivity and PID Response**
**DNAPL Site - Europe**

Figure 8 shows a typical MIP log at the site. The water table at this location is known to be shallow, occurring at approximately 6 to 8 ft. below ground surface. An obvious lithologic boundary is noted on the log at a depth of approximately 22 ft. At this point soil conductivity changes from a value of approximately 75 mS/m or less to a value of approximately 125 mS/m, indicating a change to a finer grained, lower permeability formation.

The MIP-PID log shows significant contamination beginning at approximately 16 ft. and peaking at a maximum value at the point of change in lithology at 23 ft.  Signal below this point must be interpreted as a combination of degrading signal (bleed) from the massive amount of contaminants that have entered the MIP system, and some new contaminants being introduced from the formation.
Cross sections of both soil conductivity and MIP-PID data from 4 logs run across the site are shown in Figures 9 and 10.  The soil conductivity cross section shows a consistent pattern of layered lithology across the site, including a persistent lithologic boundary at 23 ft.

## Soil Conductivity (mS/m)
### Chlorinated Solvent
### Undisclosed Site



**Figure 9**
**Soil Conductivity Cross Section**
**DNAPL Site - Europe**

The MIP-PID cross section shows the movement of the DNAPL plume from a point of entry near the log Data-4 point and moving downgradient towards the Data-2 location.  Note that the highest concentrations of the DNAPL are found above the lithologic boundary indicated by the soil conductivity log.

MIP-PID Response
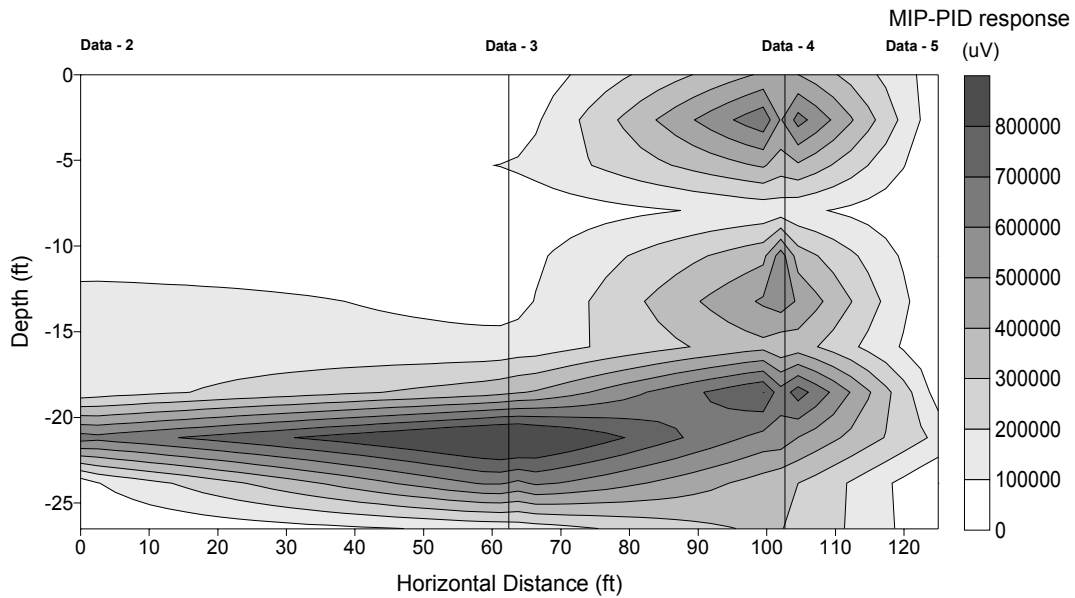Chlorinated Solvent
Undisclosed Site



**Figure 10**
**MIP-PID Cross Section**
**DNAPL Site - Europe**

CONCLUSIONS
The membrane interface probe combined with soil conductivity is a new logging tool that yields a wealth of information about subsurface lithology and VOC contaminant distribution. From the examples given in this paper it is evident that these logging tools allow us to form images of the subsurface which were unobtainable using conventional sampling and analysis methods.

REFERENCES
Kejr, Inc., 1995, "A Percussion Probing Tool for the Direct Sensing of Soil Conductivity", Geoprobe Systems Technical Paper No. 94-100.

Christy, T.M., May 1996, "Driveable Permeable Membrane Sensor For the Detection of Volatile Compounds in Soil," presented at the 1996 National Outdoor Action Conference, Las Vegas, Nevada.

BIOGRAPHICAL SKETCH
Thomas M. Christy, P.E.
Mr. Christy earned his B.S. in Civil Engineering from the University of Missouri-Rolla in 1980. Upon graduation he worked as a consultant performing numerous site characterization studies for industrial clients. In 1987 Mr. Christy co-founded Geoprobe Systems, a manufacturer of percussion soil probing machines, sampling tools, and logging tools.

*This paper was presented at the National Ground Water Association's Outdoor Action Conference in Las Vegas, Nevada, in May 1996.*