

**BOREHOLE GEOPHYSICS  
 FOR GROUNDWATER  
 INVESTIGATIONS AND  
 WATER WELL DESIGN**

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**INTRODUCTION**

Borehole geophysics is the science of recording measurements of the physical properties of the soil and water in a drilled borehole or well casing. Graphs or logs are generated from the data and are used in various ways to understand the subsurface hydrogeology, to help design water wells, and to address ongoing water supply challenges.

Geophysical logs have been used in these ways for over 100 years largely in the petroleum industry but also in the groundwater field to supplement traditional data collection methods such as logging soil cuttings and core samples.

Borehole geophysical logging is performed using a tool or sensor suspended on an electric wireline which is raised and lowered within a borehole or well casing from a special spool called a drawworks. **Figure 1** shows a cable drawworks mounted in the back of a logging truck. At the drawworks the top of the wireline is connected to logging devices such as a chart recorder or computer with processing software.

**BASIC BOREHOLE LOGS**

The “basic” geophysical logs include spontaneous potential, resistivity, and natural gamma. Individual logs provide limited information by themselves, but when analyzed together with soil cuttings can provide a good interpretation of geologic layers, aquifers, and water quality.

Spontaneous Potential (SP) is a measure of the electrochemical voltage difference between the formation



**Figure 1** Borehole logging truck with wireline and drawworks.

water and the drilling fluid. The measurement works best when there is a significant contrast between the two fluids, such as a saline aquifer in a borehole drilled with fresh water mud. In water wells drilled in fresh water aquifers with fresh water drilling mud, there may be little to no contrast on the SP curve.

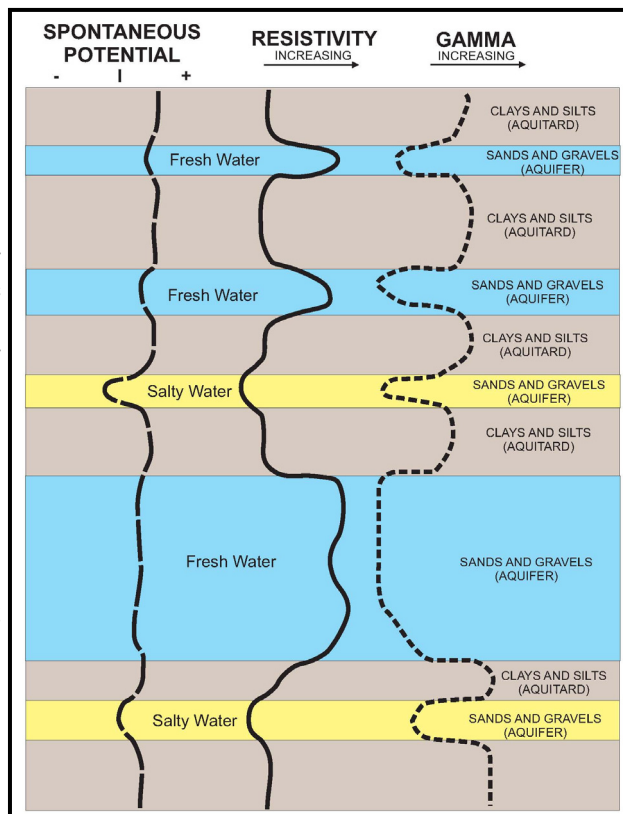
Resistivity (apparent) is a measure of the electrical resistance or conductance within formations. The resistivity of a formation is affected by its lithology, water quality, and pore geometry. Sand with fresh water will have a higher resistivity than clay with fresh water. Sand with salt water, however, may have a resistivity lower than a fresh water clay since the salt water is highly conductive. Because of the factors influencing resistivity,

the log should not be used on its own to interpret lithology or water quality.

Gamma is a measure of the natural gamma radiation emitted by the formation adjacent to the borehole. The gamma log is affected by the presence of potassium, uranium, and thorium isotopes naturally present in the earth materials. In general, finer grained materials (silts and clays) emit higher levels of gamma radiation than coarser grained materials (sands and gravels), making gamma a useful tool to help determine the lithology of a borehole.

**Figure 2** shows a simulated basic geophysical log which might have been collected in the Central and West Coast Basins (CWCB). Generally, resistivity plotting right (increasing), and gamma plotting left (decreasing) indicate permeable aquifer material like fresh water sands and gravels indicated by blue layering. Alternatively, resistivity low

and gamma high indicates lower permeability sediments such as silt and clay aquitards shown as tan layers. SP will generally plot similar to gamma, however poor water quality zones are pronounced (yellow layer) while good water quality zones have a muted SP response. The common basic borehole logging tools are shown on **Table 1**.



**Figure 2** Basic Borehole Geophysical Log.

## ADVANCED BOREHOLE LOGS

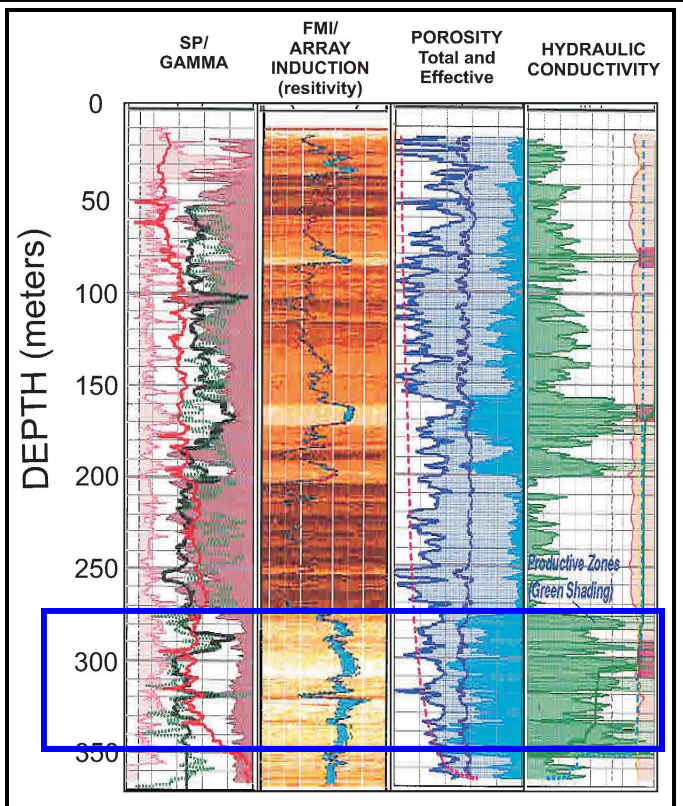
Transfer of oilfield technology to the water resources field is improving our understanding of the groundwater resources. Beyond the basic logs described above, new logging technology includes techniques to determine porosity and permeability and highly refined versions of the basic logs such as resistivity and gamma. **Figure 3** shows some advanced borehole logs used to design and construct a well. Computer processing and analysis of these advanced logs can also produce information on clay mineralogy, grain-size distribution, and hydraulic conductivity. Another advanced borehole log is the Formation Micro-imager which logs geologic structure. Many other specialized geophysical logging tools are available and new ones are being developed. **Table 1** lists the common advanced geophysical logging tools used in groundwater investigations and in design of wells.

## GROUNDWATER INVESTIGATIONS

Geophysical logs provide continuous vertical records which help with correlation to other locations and input to hydrogeological models. The continuous logs are helpful in generating cross-sections because they can provide subtle details for correlation between boreholes not available from soil samples. Often, borehole logs within a region share a common "signature" which is another correlation technique to match related hydrogeologic layers or sequences.

## WELL DESIGN

Geophysical logs are a powerful tool when designing and constructing monitoring wells and water supply wells. Logs can indicate permeable zones where groundwater flow is substantial and where to place perforated intervals. They can also show poor water quality zones which could be avoided in a production well. Perforations for wells are generally placed where logs indicate greatest permeability and meet desired water quality objectives. For example the blue rectangle plot on **Figure 3** shows the greatest continuous free water porosity at depths from 270 to 350 meters based on the combination of logs. This zone might be screened when designing a well.



**Figure 3** Advanced borehole geophysical log shows a productive water zone from 270 to 350 meters outlined by the blue rectangle based primarily on calculated hydraulic conductivity (green), supported by high effective porosity (blue), SP, gamma, FMI, Array Induction, and Salinity.

## Sources of Information for this Technical Bulletin:

- Driscoll, F.W., 1986, Groundwater and Wells, 2nd Edition, Published by Johnson Filtration Systems, Inc.
- Heath, Ralph C., Basic Groundwater Hydrology, United States Geological Survey Water Supply Paper 2220, 1987.
- Keys, W. Scott, Borehole Geophysics Applied to Ground-Water Investigations, National Groundwater Association, 1989 .

**TABLE 1: COMMON BOREHOLE GEOPHYSICAL LOGS**

TOOLS	WHAT IS MEASURED	INFORMATION PROVIDED
<b>Basic Borehole Logs</b>		
Resistivity (Many Variations)	Electrical Resistivity/Conductivity	Porosity, grainsize, general water quality
Spontaneous Potential	Voltage	General water quality, salinity of pore fluids
Gamma Radiation	Gamma Radiation Counts	Presence of clay
Caliper	Borehole Diameter	Borehole swelling/washouts/collapse/mud invasion
Temperature	Temperature	Recent recharge water/flow pathways
<b>Advanced Borehole Logs</b>		
Array Induction	Better electrical resistivity tool	Porosity, grainsize, general water quality
Combinable Magnetic Resonance	Quantitative porosity and permeability	Porosity, Permeability
Natural Gamma Spectroscopy	Better gamma tool	Potassium, Uranium and Thorium
Fullbore Formation Micro-Imager	Geologic Structure	Strike and dips, formation fractures
Electromagnetic Induction	Salinity	Water quality in open borehole or non-metal casing
Flow Logs	Rate of flow between zones in borehole	Flow between layers, hydraulic conductivity