



# Chap VII: Borehole geophysics for Hydrogeology and log analysis

Borehole geophysics includes all methods for making continuous profiles or point measurements at discrete depth stations in a borehole. These measurements are made by lowering different types of probes into a borehole and electrically transmitting data to the surface, where they are recorded as a function of depth or distance along the borehole. The measurements are related to the physical and chemical properties of the rocks surrounding the borehole, the properties of the fluid saturating the pore spaces in the formation, the properties of fluid in the borehole, the construction of the well, or some combination of these factors.

Note that many geophysical logging techniques were developed in the petroleum industry, which differ markedly from groundwater and environmental applications. In addition, the characteristics (probe weight and diameter, pressure rating, and sensor configuration) of the equipment used for nonpetroleum logging is generally different from that used to log oil and gas wells.



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**Borehole geophysics principles and benefits:** Borehole geophysics methods has different physical principals (nuclear, acoustic, electrical, etc.) but all have the same purpose to obtain more information than can be obtained from conventional drilling, sampling, and testing. Drilling a borehole or well is an expensive procedure, but the borehole provides access to the subsurface for geophysical probes. Logs may be interpreted in terms of lithology, thickness, and continuity of aquifers; porosity and bulk density; resistivity; moisture content; specific capacity; groundwater chemical and physical characteristics and parameters of water movement; and integrity of well construction.

Borehole logs provide continuous records that can be analyzed in real time at the well site. Thus, they can be used to guide completion or testing procedures. Logs also aid the lateral and vertical extrapolation of geologic and water sampling data or hydraulic test data obtained from wells. In contrast, samples of rock or fluid from a borehole provide data only from sampled depth intervals and only after laboratory analysis. Data from some geophysical logs, such as acoustic velocity and resistivity, are also useful in interpreting surface geophysical surveys.



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## Most Common Borehole geophysics methods for groundwater:

These methods are widely applied to characterize aquifers, determine water quality, estimate hydraulic properties, and improve the interpretation of surface geophysical surveys ( used as a support to well understand result from surface geophysics) see the below table.

Rank	Method	Common Name / Abbreviation	Primary Measured Parameter	Main Applications in Groundwater Studies	Typical Depth Range	Advantages	Limitations
1	Electrical Resistivity / Conductivity	Normal / Laterolog / Induction	Formation resistivity / conductivity	Salinity, clay content, aquifer boundaries, saltwater intrusion	10–1000 m	Sensitive to salinity, widely available	Affected by borehole conditions (mud)
2	Natural Gamma Ray	Gamma / GR	Natural radioactivity (mainly K, U, Th)	Lithology identification, clay content, correlation between wells	10–2000 m	Simple, fast, works in any fluid	Does not directly detect water



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## Most Common Borehole geophysics methods for groundwater:

Rank	Method	Common Name / Abbreviation	Primary Measured Parameter	Main Applications in Groundwater Studies	Typical Depth Range	Advantages	Limitations
3	Spontaneous Potential (SP)	SP	Natural electrical potential	Distinguish permeable vs. impermeable layers, fresh vs. saline	10–1000 m	Very simple, cheap	Requires conductive mud, limited in fresh water
4	Caliper	Caliper log	Borehole diameter	Borehole stability, correction for other logs, fracture detection	10–1000 m	Essential for quality control	No direct hydrogeological information
5	Fluid Temperature & Conductivity	Temp / Cond / EC	Borehole fluid temperature & electrical conductivity	Flow zones, inflows/outflows, vertical connectivity, contamination	10–500 m	Directly detects flowing water	Only measures borehole fluid
6	Flowmeter / Spinner	Flowmeter	Vertical flow velocity in borehole	Identify producing / injecting zones, determine flow rates	10–500 m	Quantitative flow distribution	Requires pumping or natural flow



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## Most Common Borehole geophysics methods for groundwater:

Rank	Method	Common Name / Abbreviation	Primary Measured Parameter	Main Applications in Groundwater Studies	Typical Depth Range	Advantages	Limitations
7	Sonic / Acoustic Velocity	Sonic log	Compressional (P-wave) velocity	Porosity estimation, rock strength, lithology	10–1000 m	Good for porosity in clean aquifers	Less effective in unconsolidated formations
8	Nuclear Magnetic Resonance (NMR)	NMR / CMR	Relaxation times (T1, T2), water content	Total & movable porosity, permeability estimation	10–300 m	Direct measurement of water volume & pore size	Expensive, sensitive to magnetic noise
9	Density	Density / Gamma-Gamma	Bulk density	Porosity calculation, lithology	10–1000 m	Accurate porosity in good borehole conditions	Requires radioactive source, hole size issues
10	Neutron	Neutron porosity	Hydrogen index	Porosity estimation (especially in saturated zones)	10–1000 m	Good in cased holes	Affected by clay content, requires calibration



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Example of common logs in groundwater geophysics:

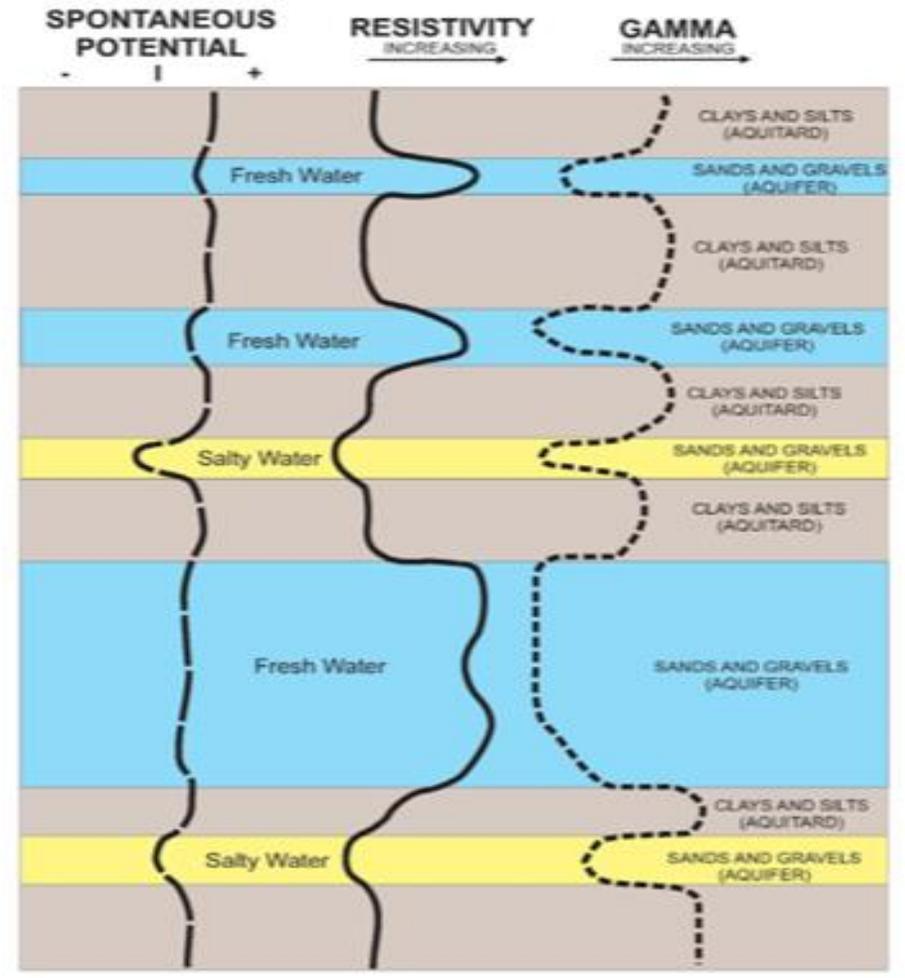


Fig 25: Basic Borehole geophysics

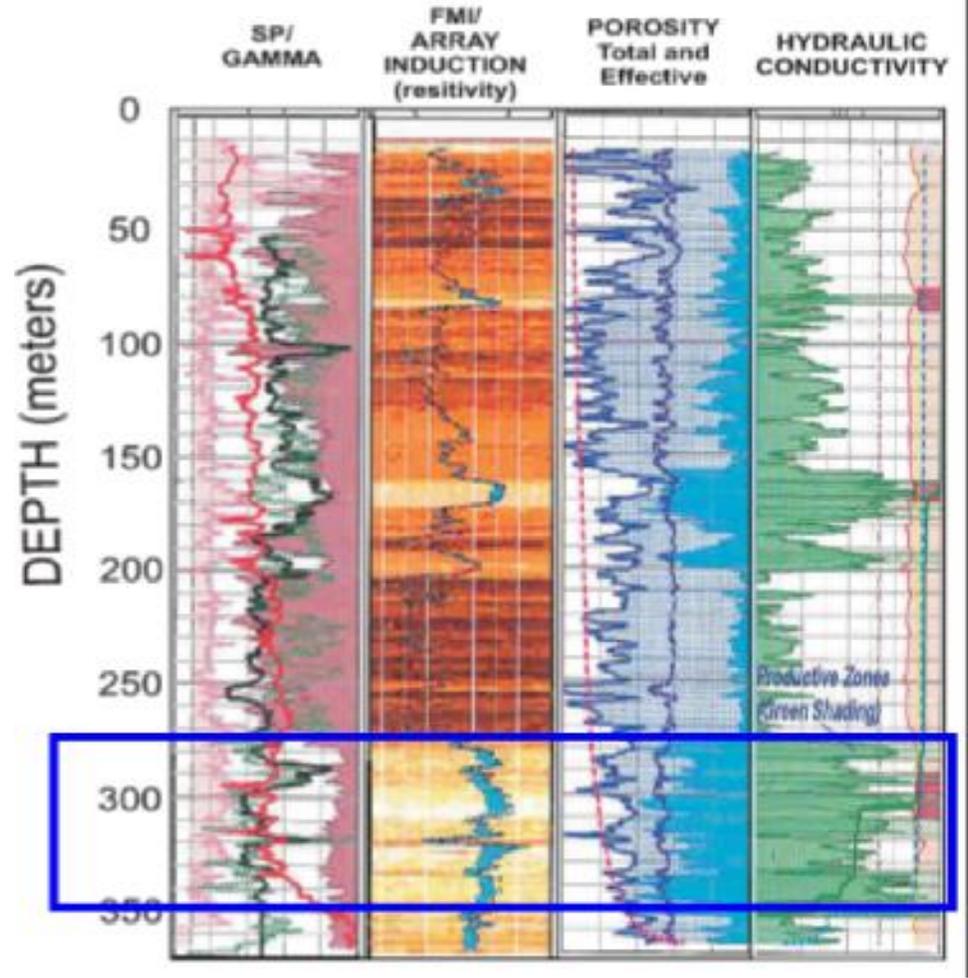


Fig 26: Advanced Borehole geophysics

Source: WRD South California 2009



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**In the field the most common combinations (typical “basic suite” for groundwater wells) are:**

- Gamma + Resistivity + SP → standard low-cost lithological & salinity log
- Gamma + Resistivity + Fluid Temperature + Conductivity + Flowmeter → hydrogeological characterization (flow + quality)
- Gamma + Resistivity + NMR\* → advanced aquifer characterization (porosity & permeability)

**\* NMR: Non Magnetic Resonance**



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## Summary of 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

Source: Tech Bulletin Vol 19 WRD Water Replenishment District of South California 2009

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**Limitations of borehole logging:** Laboratory analysis of core is essential either for direct calibration of logs or for verifying calibration carried out by other means. Calibration of logs for one rock type may not be valid in other rock types, because of how the rock-matrix chemical composition may affect log measurements. For this reason, geophysical logging cannot completely replace sampling. A log analyst cannot evaluate a set of logs properly without information on the local geological and hydrological conditions. To maximize results from logs, at least one core hole should be drilled or core recovered from selected intervals in one borehole at each study site.

Correct interpretation of logs **should be based on a thorough understanding of the operating principles of each logging technique.** Geophysical logs can be analyzed in the field to guide the location and frequency of sampling, and thus may reduce the number of samples needed, along with the cost of sample processing and equipment decontamination. Log data may also be used to identify situations in which potential cross-contamination between aquifer units may occur unless aquifers are immediately isolated from each other by well completion. **Rubin & Hubbard (2005)**