4.7 Surface Nuclear Magnetic Resonance

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4.7.1 Principle of the Method

Surface nuclear magnetic resonance\(^1\) (SNMR) is a novel non-invasive geophysical tool with which the water content of an aquifer and other geohydrological parameters of an aquifer can be determined directly. In contrast to SNMR, other geophysical techniques, e.g., dc resistivity soundings (VES), electromagnetics, seismics, and ground penetrating radar only provide information on the lithological character of aquifers and aquicludes indirectly.

The SNMR method utilizes the nuclear properties of water. Because hydrogen nuclei possess a magnetic moment (spin), they are aligned with the Earth's magnetic field. It is possible to excite them with an external magnetic field and to measure the signal response resulting from precession of the protons after the external magnetic field is switched off. Since the amplitude of the SNMR signal is related to the number of excited hydrogen nuclei (protons), the technique can be used to estimate the water content of soil and rock. Information about other hydraulic properties, such as pore size and hydraulic conductivity can also be derived from this signal.

![Fig. 4.7-1: Principle of the surface nuclear magnetic resonance method](image)

\(^1\) Some authors use the terms magnetic resonance sounding (MRS) or proton magnetic resonance (PMR) for this surface geophysical method.
The first high-precision studies of nuclear magnetic resonance signals from hydrogen nuclei were made by BLOCH and PURCELL in 1946. For this scientific achievement both scientists received the Physics Nobel Prize in 1952. Since then, this technique has found widespread application in chemistry, physics, medicine and borehole geophysics.

In contrast to the NMR methods applied in the laboratory, which use two strong orthogonal magnetic fields generated by the NMR instrument, SNMR uses the Earth's magnetic field and an external magnetic field generated in a large loop on the Earth's surface. In the 1960s, VARIAN and BARRINGER (1968) had the initial idea of SNMR, namely to use the principle of the proton-precession magnetometer (see Section 4.1.4) to develop a tool for prospecting for water. But not until the 1980s were effective instruments developed. They were initially used by Russian scientists (SEMENOV et al., 1988) to search for primary aquifers. Extensive testing of SNMR worldwide under different geological conditions began in the early 1990s.

4.7.2 Applications

- Direct detection of groundwater,
- distinguish between hydrogeological units (aquifers and aquicludes),
- determination of the water content of primary aquifers,
- estimation of hydraulic conductivity,
- determination of the amount of water in the vadose zone,
- estimation of water content and hydraulic properties of karstic and fractured aquifers (research activities).

4.7.3 Fundamentals

Hydrogen nuclei of water molecules have a magnetic moment $\mu$. They can be described in terms of a spinning charged particle. Generally, $\mu$ is aligned parallel to the local magnetic field $B_0$ of the Earth. When another magnetic field – the excitation field – is applied, the axis of the proton is deflected, owing to the torque applied to the spinning protons of the nuclei (Fig. 4.7-1). When the excitation field is removed, the protons generate a magnetic field as they become realigned along $B_0$ (relaxation) while precessing around $B_0$ with the angular frequency

$$\omega_L = \gamma B_0 = 2\pi f_L \tag{4.7.1}$$

where $\gamma = 0.267 \text{ 518 Hz nT}^{-1}$ is the gyromagnetic ratio and $f_L$ is the Larmor frequency for hydrogen protons.