MANAGEMENT OF CONTAMINATED AREAS – WHY NMR?

REDUCE THE COST OF UNCERTAINTY

Contaminated site remediation represents a multi-billion-dollar challenge globally. Yet despite decades of technological advancement, **uncertainty in subsurface characterization remains the single most significant driver of remediation costs, delays, and failures.**

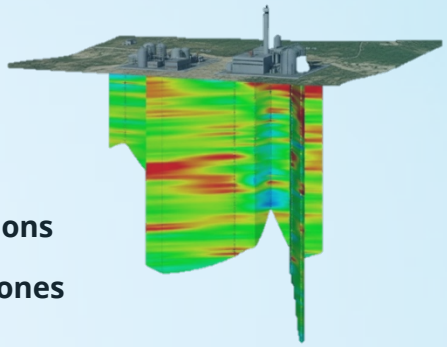
The fundamental problem: **groundwater occurrence and movement controls contaminant fate and transport, yet conventional site characterization provides only indirect estimates of the hydrogeologic parameters that govern how water—and contaminants—actually behave underground.**

Traditional approaches leave critical questions unanswered:

- Where exactly are the mobile contaminant pathways?
- Which zones will drain during remediation versus remain saturated, often as secondary contaminant sources?
- What is the actual hydraulic conductivity distribution controlling plume migration?
- How much mobile versus immobile water is present in each formation?

These uncertainties translate directly into:

- **Remediation systems that miss contaminant pathways**
- **Pump-and-treat operations that fail to achieve closure**
- **Permeable reactive barriers installed in the wrong locations**
- **In-situ treatment amendments that don't reach target zones**
- **Decades of monitoring for plumes that won't stabilize**



Our solution: NMR technology provides the subsurface hydrogeological intelligence you need to address these challenges with confidence and precision.

The NMR Advantage:

Direct Measurement of Critical Parameters

Nuclear Magnetic Resonance directly detects hydrogen in subsurface water molecules, delivering quantitative measurements that traditional geophysical methods cannot match.

Why Current Methods Fall Short

Conventional drilling and sampling provide sparse, point-based measurements at high cost, with disturbed samples that poorly replicate in situ conditions. Hydraulic conductivity estimates can differ from actual conditions by orders of magnitude. The process is slow and expensive, requiring multiple mobilizations, laboratory analysis, and waste disposal—often taking months to years before informing decisions.

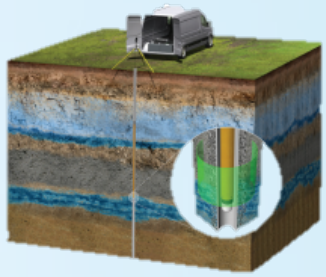
Traditional geophysical methods (electrical resistivity, GPR, seismic) offer broad coverage but rely on fundamentally ambiguous indirect measurements. Signals are influenced by lithology, mineralogy, saturation, and pore fluid chemistry, making it impossible to distinguish between sources (e.g., clay versus saline groundwater in sand) without extensive calibration.

While these methods define geological structure well, they provide minimal quantitative information about critical hydrogeologic parameters controlling contaminant transport and remediation: porosity, hydraulic conductivity, specific yield, and mobile versus bound water. This highlights the need for more efficient and accurate technology like NMR.

THE NMR DIFFERENCE

Direct Measurement of What Matters

Nuclear Magnetic Resonance directly detects and quantifies **hydrogen atoms in water molecules**—providing unambiguous, lithology-independent measurements of the hydrogeologic parameters that control contaminant storage, transport, and remediation effectiveness.

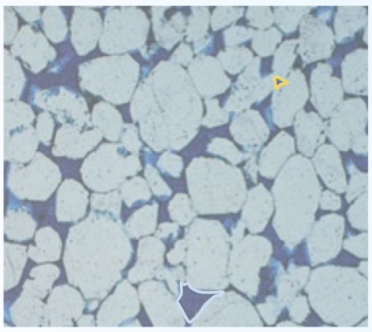


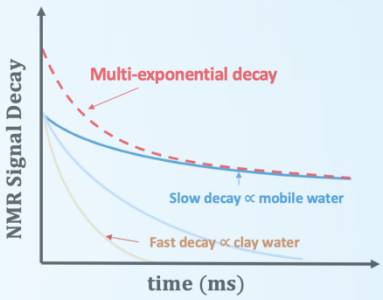
Magnetic Resonance Technology

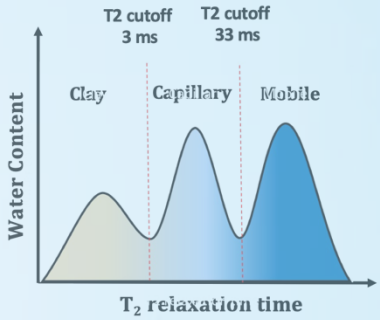
Magnetic Resonance Technology is a non-invasive method that detects and measures hydrogen atoms in materials. Magnetic resonance uses electromagnetic pulses to excite hydrogen protons, which then emit measurable signals when returning to their natural state. This technology—proven in medical imaging as MRI—provides direct, quantitative information about water content, location, and flow characteristics in subsurface environments for groundwater exploration, aquifer assessment, contaminated site characterization, and water resource management.

Geologic materials contain a variety of pore sizes. The NMR signal has a multiexponential decay that reflects the pore size distribution. Water in small pores have a faster relaxation time. Water in large pores have a long relaxation time.

Hydrogeologic Properties from NMR







Directly Measured Properties:
- Volumetric Water Content
- Total Porosity (if fully saturated)
- Relative pore size distribution

Quantitatively Estimated Properties:
- Effective (mobile) porosity
- Bound porosity
- Hydraulic conductivity

COLUMBIA TECHNOLOGIES

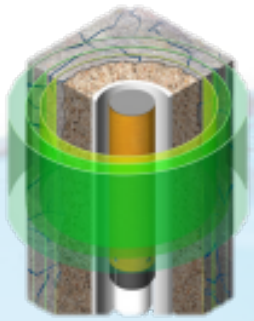
MAGNETIC RESONANCE GEOPHYSICS
Minimize Remediation Cost Uncertainty

MANAGEMENT OF CONTAMINATED AREAS

What NMR Measures

- **Direct water measurement** – No interpretation or guesswork; NMR measures actual water content in situ
- **Total water content** (porosity in saturated zone, moisture content in vadose zone)
- **Mobile versus bound water** (drainage potential and specific yield)
- **NMR provides a continuous estimate of Hydraulic conductivity and permeability** (flow rates and pathway connectivity)
- **Pore size distribution** (defines the dominant flow paths versus zones where flow is minimal or non-existent)

Why This Matters for Remediation



- Target amendments to actual flow paths
- Predict which zones will respond to hydraulic manipulation
- Calculate realistic remediation timeframes based on effective porosity
- Identify confining layers that compartmentalize plumes

NMR Integration with COLUMBIA Technologies' HRSC Platform

COLUMBIA Technologies specializes in high-resolution site characterization (HRSC) using direct sensing technologies and SmartData Solutions®—the company's proprietary decision support platform that enables real-time, collaborative development of accurate 3D conceptual site models (CSMs). This dynamic approach delivers the high-quality data necessary for superior CSMs and more sustainable remediation outcomes.

Traditional HRSC tools (MIP, HPT, LIF, OIP) provide:

- Contaminant distribution with centimeter-scale vertical resolution
- Continuous stratigraphic and lithologic mapping
- Real-time volatile organic contaminant and NAPL source zone detection and mapping.

COLUMBIA TECHNOLOGIES

MAGNETIC RESONANCE GEOPHYSICS
Minimize Remediation Cost Uncertainty

MANAGEMENT OF CONTAMINATED AREAS

NMR fills critical data gaps by quantifying water distribution and permeability—capabilities traditional HRSC tools lack.

Traditional HRSC tools (MIP, HPT, LIF, OIP) provide:

- Contaminant distribution with centimeter-scale vertical resolution
- Continuous stratigraphic and lithologic mapping
- Real-time volatile organic contaminant and NAPL source zone detection and mapping.

NMR complements traditional HRSC by providing the quantitative water distribution and permeability data these tools cannot deliver.

Key NMR Advantages:

- **Accurate, lithology-independent water content and porosity measurements** - Unaffected by clay content or mineralogy
- **Universal application** – From shallow overburden to deep bedrock, exploration through site closure and long-term monitoring.
- **NMR is ideal for surveying existing wells**—collecting stratigraphic and hydrogeologic data to refine your conceptual site model. Acquire critical stratigraphic and hydrogeologic data for CSM reevaluation and remedy optimization.
- **Flexible deployment options** – Surface systems (GMR), Javelin borehole tools (2"–18" wells), and Dart direct push tools
- NMR integration enhances operational excellence and risk reduction across all project scales.

From shallow overburden to deep bedrock aquifers, from exploration through closure, NMR delivers the subsurface data that drives operational excellence and risk reduction.

High-Value NMR Applications for Contaminated Site Remediation

Existing wells with poor or unknown subsurface logs: Countless contaminated sites have undergone multiple investigation phases with minimal remediation progress. NMR provides the perfect solution for logging existing PVC wells to measure the soil and groundwater conditions fundamental to effective site management.

Complex hydrogeology: Where conventional characterization struggles to define 3D flow systems—multiple aquifers, discontinuous confining layers, heterogeneous sediments— NMR resolves the uncertainty.

Large, complex remediation projects: Sites where costs of feasible remedy alternatives are high benefit from improved characterization that delivers ROI through optimized design and reduced performance risk.

Stalled or underperforming systems: When remedies fail to achieve predicted results, NMR reveals the hydraulic conductivity distribution that explains poor performance and guides optimization.

MNA evaluation: NMR provides quantitative, defensible data demonstrating low contaminant mobility to support natural attenuation feasibility.

NAPL recovery optimization: NMR distinguishes permeable zones where NAPL is mobile from low-permeability zones requiring in-situ treatment.

Regulatory challenges: Contentious sites requiring high-confidence characterization data to defend remedy selection and demonstrate protectiveness.

The Bottom Line

Contaminated site remediation fails or underperforms when hydrogeologic uncertainty prevents accurate prediction of how water—and contaminants—actually move through the subsurface.

NMR eliminates this critical uncertainty by directly measuring the hydraulic properties that control flow, providing the quantitative foundation for successful remediation design.

COLUMBIA TECHNOLOGIES

MAGNETIC RESONANCE GEOPHYSICS
Minimize Remediation Cost Uncertainty

MANAGEMENT OF CONTAMINATED AREAS

When integrated with COLUMBIA Technologies' SmartData HRSC platform,

NMR completes the picture by combining contaminant distribution from direct sensing and hydrogeologic properties from NMR, integrated into high-resolution 3D models that enable confident decision-making and superior outcomes.

The question isn't whether your site would benefit from better hydrogeologic characterization.

The question is whether the cost of continued uncertainty exceeds the cost of eliminating the source of the uncertainty.

We deliver:

- **"Water you can measure."-** Unlike resistivity and EM that *infer* water from conductivity, NMR measures it—putting numbers on storage and flow potential.
- **Reliable data** to accurately quantify time frames and costs of remedial alternatives and design more cost effective and sustainable solutions.
- **Better data – Better modeling – More Sustainable Solutions**

Partnership Approach: Integrated Solutions, Proven Results

Vista Clara's NMR technology seamlessly integrates with conventional hydrogeologic and geophysical methods— enhancing project value for clients and meeting the highest regulatory standards.

Our commitment:

⇒ Collaborative project execution

⇒ Transparent data interpretation and reporting

⇒ Solutions aligned with Brazil's evolving water and environmental priorities

Ready to Move Forward?

Whether you're planning a preliminary site characterization, evaluating a known release, hunting for an unknown source, or optimizing an old remedy, Columbia Technologies and Vista Clara provide the subsurface intelligence that transforms uncertainty into opportunity.

Jim Chamness
LATAM Business Manager
jchamness@colombiatechnologies.com
c: +55 (21) 96776-7779
São Paulo, Brasil

John Sohl or Briana McDowell
info@columbiatechnologies.com
P: +1 (888) 344-2704
Columbia Technologies
USA

Mateus Evald
CTO/Senior Project Manager
mateus.evald@columbiatechnologies.com
c: +55 (53) 98437-1010
São Paulo, Brasil