Environmental Remediation

Pacific Northwest
NATIONAL LABORATORY

Committed to restoring the environment for a cleaner future by delivering scientific and technically defensible solutions for global complex environmental challenges

U.S. DEPARTMENT OF
ENERGY

Pacific Northwest National Laboratory (PNNL) provides scientific and technical expertise that supports remedy and monitoring decisions at environmental sites. PNNL enables critical cleanup decisions, leveraging research and knowledge from our government sponsors, including the U.S. Department of Energy (DOE) Offices of Science, Environmental Management, Legacy Management, Nuclear Energy, and Fossil Energy, and the Department of Defense, industry, universities, and other national laboratories. Our strategically focused research and technological contributions provide crucial science-based and risk-informed solutions to global environmental remediation and stewardship challenges that save significant cleanup dollars and reduce both environmental risks and timeframes of cleanup.

We partner with our clients to deploy technical solutions to environmental remediation challenges. Our partnership with the Hanford Site, one of the most complex contaminated soil and groundwater sites in the world, drives science and technology innovations that support regulatory decision-making and cleanup progress at Hanford. At the forefront of environmental remediation advances, PNNL is well positioned to:

- support DOE and site contractors in the current baseline implementation with technology maturation and technical guidance
- develop new technology and approaches to meet future challenges, using applied science and engineering to identify and achieve risk-informed remediation endpoints

We are committed to addressing environmental issues with technically defensible solutions.

STEWARDING CORE COMPETENCIES

PNNL's environmental remediation research and development portfolio stewards a capable and diverse set of staff and capabilities. A multidisciplinary team of scientists, engineers, and professional staff across the laboratory provide innovative solutions for the complex remediation challenges. Technical experts, many of whom are internationally recognized leaders in their respective fields, have earned a reputation for excellence, resulting in leadership roles for PNNL on several government and commercial led partnerships.

PNNL stewards the fundamental scientific and engineering underpinnings necessary to enable four core competencies and foundational, multidisciplinary scientific and technical expertise critical to resolving these challenges not only for DOE EM and other global clients:

- Nature and Extent of Contamination
- Remedial Science
- Remediation Systems
- End States

Nature and Extent

In 1965, PNNL technical leadership and scientific expertise was used to establish an environmental program and conduct environmental surveillance of the Hanford Site, including terrestrial and river ecosystems, groundwater monitoring, and environmental and subsurface characterization. By the 1990s, monitoring indicated that contaminants were deeper in the vadose zone and more widespread in the groundwater than was indicated by the initial conceptual and numerical models. In response, DOE established the Hanford Groundwater/Vadose Zone Integration Project, where PNNL partnered with the DOE Richland Operations (RL) and the site contractor. As part of this effort, PNNL identified key geochemical behaviors of Cs-137, Sr-90, Tc-99, U and Cr in the subsurface environment, and demonstrated the first application of electrical geophysical methods for characterization and monitoring at the Hanford Site.

Although the environmental surveillance program was transferred to the site contractor in 2007, PNNL continues to partner with DOE Richland Operations (RL) and the site contractor to transition the program from one of characterization, to a focus on remediation performance and long-term monitoring. To this end, PNNL has led a collaborative effort to establish a new approach for soil and groundwater monitoring, as documented in Scientific Opportunities for Monitoring at Environmental Remediation Sites (SOMERS). The paradigm establishes quantitative conceptual site models as an enduring basis for monitoring and site decisions, including the use of multiple lines-of-evidence and flux-based approaches as alternatives to point measurements. Monitoring innovations, such as the tight integration of geophysical, remote-sensing, and predictive assessments, contribute to advances that not only quantify the nature and extent of subsurface contamination, but also result in decreasing annual monitoring costs by one-third. Advanced and applied monitoring methods, including in situ sensors and geophysical techniques (e.g., electrical resistivity tomography, spectral induced polarization, electromagnetics, etc.) provide temporal and spatial monitoring data that support systems-based lines of evidence monitoring.

Key capabilities include:

- Characterization of controlling hydrologic, geologic, and biogeochemical processes
- Remote imaging of contaminant distributions and geologic heterogeneities
- Characterization of subsurface geochemical and physical heterogeneities
- Metal and radionuclide speciation and transport behavior
- Microbiological and biological system characterization
- Quantitative conceptual site model translation to numerical models

Remedial Science/Design

For more than 50 years PNNL has developed and maintained a robust capability in subsurface science, with a tight integration in our core strength in systems engineering, PNNL has been designing, developing, and demonstrating novel remediation technologies from bench- to pilot-scale that today are the basis for remedial actions at Hanford.

Our core approach is to understand the natural system and the features, events, and processes that control the behavior, transport, and fate of contaminants and use this understanding to develop effective remediation technologies and approaches, including incorporation of natural attenuation in remedy designs.

Extensive laboratory facilities and expertise enable PNNL researchers to quantify the nature and extent of radionuclide, heavy metal, and organic contamination in sediment samples from the Hanford site and other contaminated locations across the country.

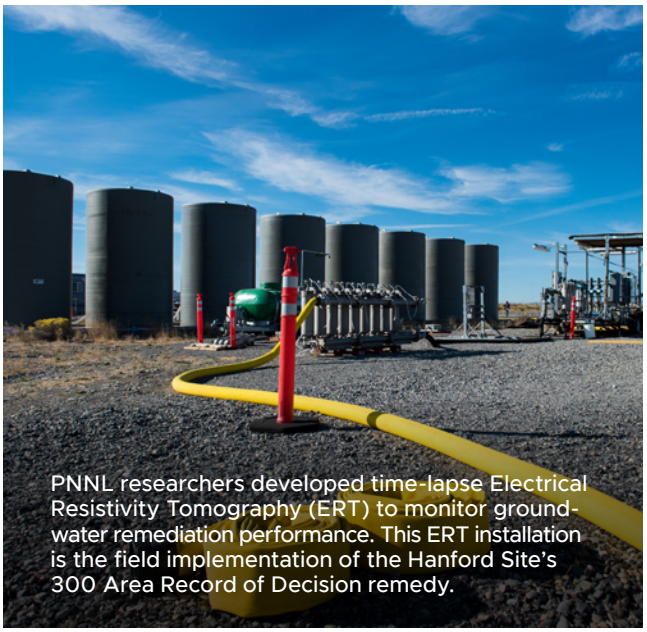
In 1999, this approach led to PNNL establishing the scientific basis for implementing the In Situ Redox Manipulation (ISRM) barrier to reduce chromium flux to the Columbia River and protect critical salmon spawning habitat. PNNL has continued to advance cost-effective remedies that consider in situ natural processes, and evaluate multiple technologies for application to the Hanford deep vadose zone, including soil desiccation, uranium sequestration, in situ grouting, and soil flushing. We have also provided the scientific basis to safely transition from active to passive remedy approaches, resulting in the safe shutdown of a soil vapor extraction (SVE) at Hanford and a cost savings of $6.35M.

Key capabilities include:

- Quantification of attenuation mechanisms
- Quantification of contaminant flux and mass transport processes
- Fate and transport of inorganic and radionuclides
- Moisture and contaminant flux control
- Remediation technology evaluation, maturation, and demonstration, from laboratory- to field-scale

Remediation Systems

The key to successful transition of technologies from concept to implementation is a collaborative relationship between the technology developers and implementers. We are committed to supporting this collaborative effort with DOE site contractors to achieve mission objectives. Since the late 1980s, PNNL has worked closely with the site contractors to translate fundamental principles underpinning remediation technology performance to full-scale operations. With the Hanford Site Permanent Isolation Surface Barrier Development Program, PNNL demonstrated capping as an effective remediation approach, resulting in the construction of the Prototype Hanford Barrier still in operation today. Along the Columbia River, PNNL collaborated with the site contractor to deploy the apatite barrier in the 100-N Area to sequester strontium-90. PNNL also identified sequestration mechanisms for uranium using phosphate amendments, which was applied



PNNL researchers developed time-lapse Electrical Resistivity Tomography (ERT) to monitor groundwater remediation performance. This ERT installation is the field implementation of the Hanford Site's 300 Area Record of Decision remedy.

in the 300 Area. As part of that field treatability test, PNNL provided real-time electrical resistivity tomography (ERT) monitoring as part of remedy performance evaluations using R&D award winning PNNL-developed software, E4D.

PNNL's knowledge of the fundamental scientific and engineering principles allows us to effectively transition remediation technologies to the field scale and is central to our role in technology analysis and maturation. For deep vadose zone applications, we continue to support eSTOMP, the scalable version of the STOMP simulator for regulatory and remedial evaluations of complex sites like Hanford.

Our support enables the site contractor to implement new technologies within the site baseline.

Key capabilities include:

- Systems-based engineering
- Biogeochemical and physical stabilization
- Hydrogeological flux mitigation
- Multi-phase flow and transport
- Surface barrier design
- Predictive analysis, numerical modeling, and high-performance computation
- 4D monitoring of remediation performance

End States

PNNL scientists and engineers are leaders in risk assessment and associated research to evaluate and mitigate potential nuclear and environmental safety issues. We currently perform this work for DOE, the Nuclear Regulatory Commission, industry, and international entities, but our expertise has deep roots in the Hanford mission. As the Hanford Site transitioned from plutonium production, operations, and waste management to cleanup, PNNL led the waste site evaluation in the late 1980s that formed the technical basis for the National Priorities List. In 1998, PNNL conducted the first site-wide composite analysis to support holistic site management, investigating cumulative impacts from existing and future wastes.

Our experience in risk assessments, environmental impact statements, and remediation led to development of a framework for evaluating and adaptively managing risk-based remediation endpoints, ultimately leading to final end states for the Hanford Site. Under continued partnership with DOE and the site contractor, exit strategy approaches were established and transitioned for pump- and-treat systems to facilities along the Columbia River. PNNL also developed and implemented a systems-based approach and guidance to set risk- informed remediation end states for volatile organic contaminants in the vadose zone. To address data access and integration challenges, a geospatial information integration system, PHOENIX (PNNL-Hanford Online ENvironmental Information eXchange), has been developed to facilitate risk-informed decision-making at Hanford by integrating previously isolated datasets into a single-access portal. To support spatial-temporal, big-data analytics at Hanford, the web-based software suite SOCRATES (Suite of Comprehensive Rapid Analysis Tools for Estimation), has been developed to provide decision support for groundwater assessments, remediation activities, and pump-and-treat exit strategies.

Key capabilities include:

- Web-based analysis and risk-informed decision support software
- Exit strategies for active remedies and transition to passive approaches
- Natural hazard characterization (seismic, ashfall, wildfire, flooding, etc)
- Surface barrier and waste form performance assessments
- Systems-based monitoring with advanced geophysical imaging
- System-assessment and predictive and performance simulation

Bordering the Hanford Site's 300 Area near Richland, Washington, this 51-mile free-flowing stretch of the Columbia River is part of the Hanford Reach. From here, it flows south and west toward the Pacific Ocean.

SCIENTIFIC BASIS TO OPERATIONAL SUPPORT

As a DOE Office of Science laboratory, PNNL has delivered and continually developed and enhanced its unique capabilities to provide the scientific and engineering knowledge—from basic science and feasibility research to large-scale demonstrations and operational support—that enables maturation and deployment of advanced technologies to achieve EM mission goals (Figure 1). To support technology maturation, PNNL stewards renowned staff, state-of-the-art equipment, and advanced facilities that support soil and groundwater remediation and enable integrated, cross-disciplinary understanding and development from the atomic scale through bench and pilot scale. This suite of capabilities is unique within the national laboratory complex and allows for the continued development of innovative solutions to support deployment and achieve mission goals.

KEY ACCOMPLISHMENTS

Nature and Extent

- Identified an approach for estimating waste site contaminant inventories for hundreds of waste sites at Hanford, providing subsurface contaminant releases used to form the technical basis for risk, performance, and site-wide assessments
- Quantified conceptual site models describing transport of ^{137}Cs, ^{99}Tc, U, CrO_4^{2-}, and Pu in the vadose zone, accounting for differences in migration behavior under past and current conditions and providing a basis for remedy applications
- Developed a conceptual framework for the influence of fine-scale vadose zone sediments on co-located contaminant lateral transport, providing a technical basis for remedy planning and implementation
- Identified uranium transport behavior dependencies on waste site geochemical conditions at Hanford, advancing site-specific remedies to immobilize contaminants in situ
- Advanced geophysical imaging through high performance computing to cost-effectively obtain high-resolution images of subsurface contaminant distributions

Remedial Science

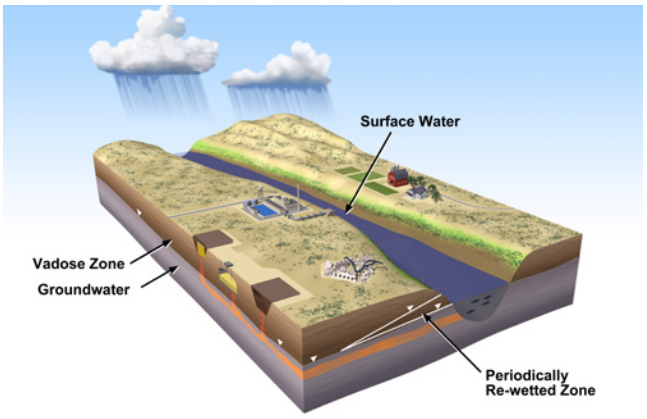
- Evaluated a range of waste disposal chemistries to provide scientific and technical support for remedy approaches and implementation
- Developed a mass-flux performance assessment approach for remediation of organic contaminants in the vadose zone, documenting its scientific and technical basis in a national guidance document for use at DOE, Department of Defense, and other vadose zone sites
- Extended a mass-flux-based remediation and performance assessment framework to inorganic contaminants and radionuclides, providing decision support basis for monitored natural attenuation (MNA)
- Conducted multiple technical investigations to support P&T operations, including the impacts of low pH water injection, hydraulic testing, and resin performance analyses to optimize P&T operational strategies
- Developed a technical approach for immobilizing uranium in the vadose zone with ammonia gas, manipulating the subsurface geochemistry to reduce the downward migration of uranium to groundwater

Remediation Systems

- Quantified mechanisms for chromium sequestration, resulting in implementation of the In Situ Redox Manipulation Barrier to protect critical salmon spawning habitat in the Columbia River.
- Developed phosphate remediation technologies for in situ remediation of contaminants, allowing for contaminants to be sequestered in place.
- Developed conceptual and remedial design basis for soil desiccation to reduce moisture in the vadose zone, thereby reducing the driving force for downward contaminant migration and flux to groundwater.
- Conducted a long-term treatability test for Hanford surface barrier performance, from design to implementation, to verify capping as an effective long-term remedy approach and identify cost-effective monitoring approaches for Hanford conditions
- Provided technical support and modeling for removal of high-uranium concentrations from perched water beneath the B Complex, reducing mass flux and further protecting the underlying groundwater.

End States

- Identified natural attenuation mechanisms and waste release chemistries for risk-driving contaminants at Hanford (e.g., ^{129}I, ^{99}Tc, and U), providing a technical basis for active vadose zone flux reduction approaches and application of long-term monitored natural attenuation
- Developed simulation framework for establishing risk-informed end states that support technical infeasibility waivers for recalcitrant contaminants (e.g., ^{129}I) and facilitate regulatory concurrence and site closure
- Provided the scientific and technical basis for transitioning point-source monitoring approaches to a cost-effective, long-term lines of evidence monitoring approach, integrating spatiotemporal data from autonomous sensors and advanced geophysics with predictive analyses
- Developed PHOENIX to provide single portal access to multiple Hanford Site databases within a geographic information system (GIS) framework



In partnership with DOE and its contractors, PNNL is committed to providing scientific and technical solutions to Hanford Site remediation—working as a team to achieve the desired end state.

- Developed a suite of online tools (SOCRATES) that provide rapid data analytics and visualization of environmental data supporting short- and long-term remedy decisions, optimization, exit strategies and monitoring decisions
- Conducted a Hanford Site probabilistic seismic hazard analysis to confirm the long-term facility seismic safety and establish design requirements for new facilities

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ABOUT PNNL

Pacific Northwest National Laboratory draws on signature capabilities in chemistry, Earth sciences, and data analytics to advance scientific discovery and create solutions to the nation's toughest challenges in sustainable energy and national security. Founded in 1965, PNNL is operated by Battelle for the U.S. Department of Energy's Office of Science.

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