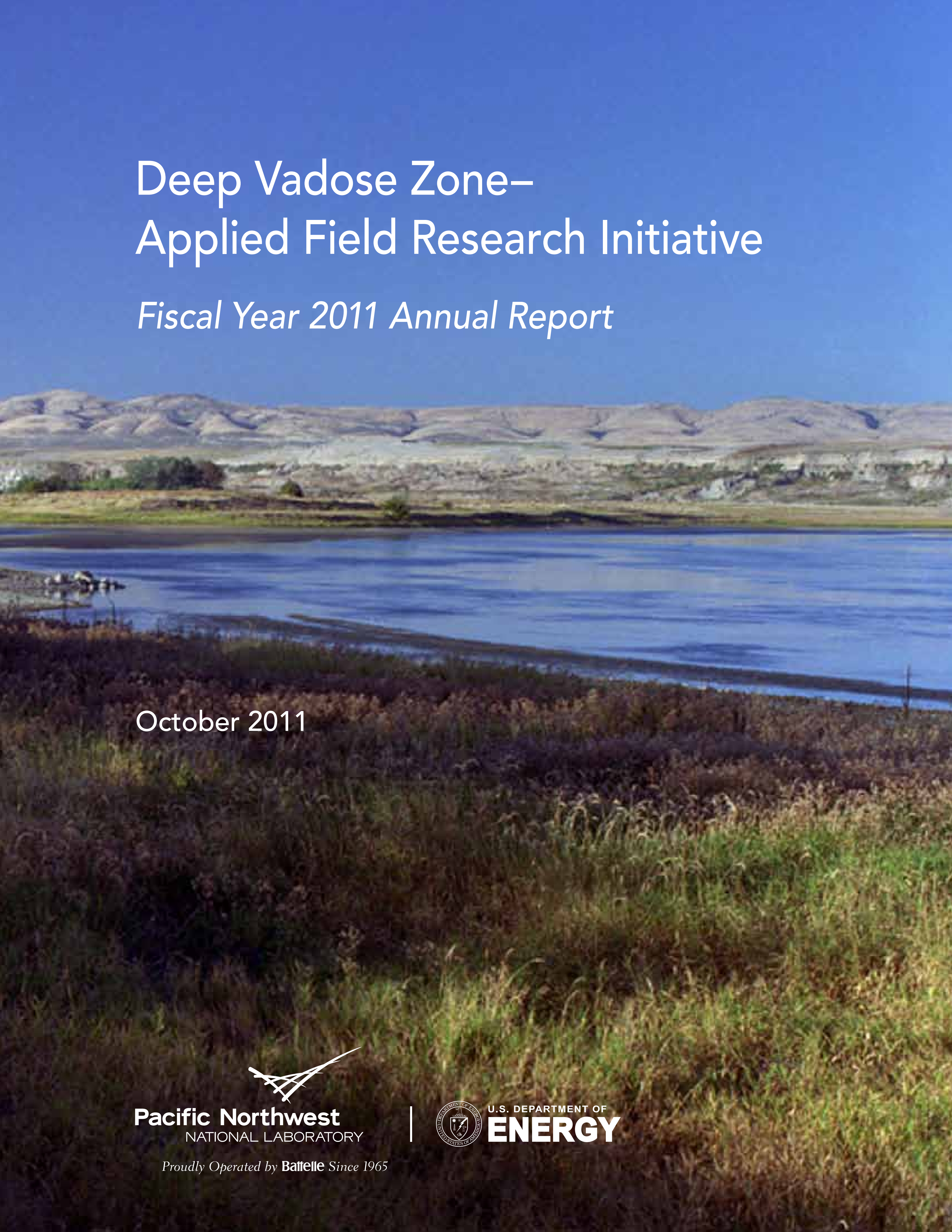
Deep Vadose Zone–Applied Field Research Initiative

Fiscal Year 2011 Annual Report

October 2011



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Deep Vadose Zone-Applied Field Research Initiative

Fiscal Year 2011 Annual Report

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October 2011

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Contents

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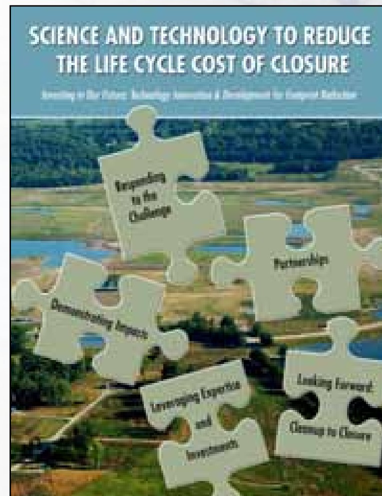
Message from the Deep Vadose Zone-Applied Field Research Initiative Project Manager

The Department of Energy (DOE) Office of Technology Innovation and Development's (OTID) mission is to transform science into viable solutions for environmental cleanup. In 2010, OTID developed the Impact Plan, *Science and Technology to Reduce the Life Cycle Cost of Closure* to outline the benefits of research and development of the life-cycle cost of cleanup across the DOE complex. This plan outlines OTID's ability to reduce by $50 billion, the $200 billion life-cycle cost in waste processing, groundwater and soil, nuclear materials, and deactivation and decommissioning. The projected life-cycle costs and return on investment are based on actual savings realized from technology innovation, development, and insertion into remedial strategies and schedules at the Fernald, Mound, and Ashtabula sites.



To achieve our goals, OTID developed Applied Field Research Initiatives to facilitate and accelerate collaborative development and implementation of new tools and approaches that reduce risk, cost and time for site closure.

The primary mission of the Deep Vadose Zone-Applied Field Research Initiative (DVZ-AFRI) is to protect our nation's water resources, keeping them clean and safe for future generations. The DVZ-AFRI was established for the DOE to develop effective, science-based solutions for remediating, characterizing, monitoring, and predicting the behavior and fate of deep vadose zone contamination. Subsurface contaminants include radionuclides, metals, organics, and liquid waste that originated from various sources, including legacy waste from the nation's nuclear weapons complexes.

The DVZ-AFRI project team is translating strategy into action by working to solve these complex challenges in a collaborative environment that leverages technology and scientific expertise from DOE, Pacific Northwest National Laboratory, CH2M HILL Plateau Remediation Company, and the broad scientific research community. As project manager for the DVZ-AFRI, I have had the privilege this past year to team with creative, talented members of the scientific community nationwide to develop effective long-term solutions to address deep vadose zone contamination.

This report highlights how the DVZ-AFRI project team is delivering results by achieving significant programmatic accomplishments, and developing and field-testing transformational technologies to address the nation's most pressing groundwater and vadose zone contamination problems.

Dawn Wellman
Deep Vadose Zone-Applied Field Research Initiative Project Manager

Our mission is to protect our nation's water resources for our generation and generations to come. Through the Deep Vadose Zone Applied Field Research Initiative, we are working to deliver transformational science and technology-based solutions to clean up contamination in deep vadose zones across the DOE complex. To meet these challenges, DOE is bringing experienced scientists and engineers from the government, academic and commercial sectors to work together in a collaborative framework to develop solutions that are cost-effective, sustainable, and protective of human health and the environment.

—John Morse, U.S. Department of Energy, Richland Operations Office

Key contaminants of concern in the deep vadose zone at the Hanford Site include technectium-99, uranium, chromium, and iodine-129.

Introduction

Remediation of vadose zone contamination is a significant challenge in the United States, particularly in arid and semiarid regions where the vadose zone can be hundreds of feet thick. At U.S. Department of Energy Environmental Management (DOE-EM) sites, subsurface contaminants include radionuclides, metals, organics, and liquid waste that originated from various sources, including legacy waste from the nation's nuclear weapons complexes. Past-practice waste disposal operations allowed waste to be discharged to retention basins, trenches, or cribs where the waste percolated into the soil, and eventually to the vadose zone and groundwater. Contaminated deep vadose zones are a potential source of contamination to the groundwater and other environmental receptors.

Through the Deep Vadose Zone-Applied Field Research Initiative (DVZ-AFRI), DOE is using a collaborative approach to develop effective long-term solutions to address one of the nation's most difficult cleanup challenges and protect our water resources. That approach involves leveraging investments and scientific expertise from DOE; Pacific Northwest National Laboratory (PNNL); CH2M HILL Plateau Remediation Company (CHPRC); federal agencies; national laboratories, including Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory, and Savannah River National laboratory; universities, including Oregon State University and Washington State University; and industrial partners, including ARCADIS, MSE Technology Applications, Inc., and AMEC Geomatrix Consultants, Inc. Collaboration with DOE Office of Science Integrated Field Research Challenges, Science Focus Areas, and other EM-32 centers will also be fostered.

This annual report describes the background of the DVZ-AFRI, and some of the programmatic approaches and transformational technologies in groundwater and deep vadose zone remediation developed during fiscal year (FY) 2011.

Background

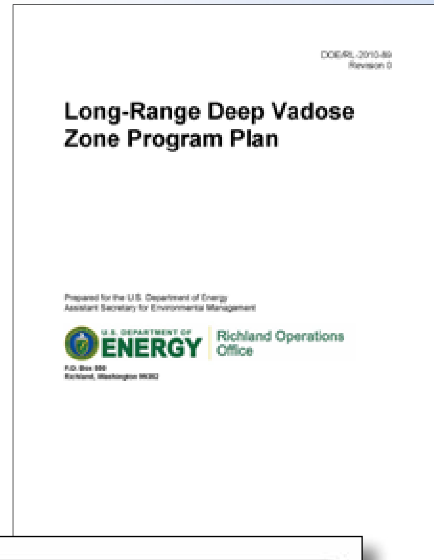
Scientists have been aware for decades that hazardous and radioactive contaminants are present in sediments and groundwater at the Hanford Site in southeastern Washington State. Remediation of contaminants in the shallow vadose zone and groundwater has been underway at the Hanford Site for decades; however, contaminants in the deep vadose zone (DVZ)—beyond the reach of near-surface treatment technologies—are far more challenging to address. Although contaminants in the DVZ pose no direct exposure hazard to humans, these contaminants do serve as possible sources of contamination to the underlying groundwater system with resultant exposure through the groundwater pathway.

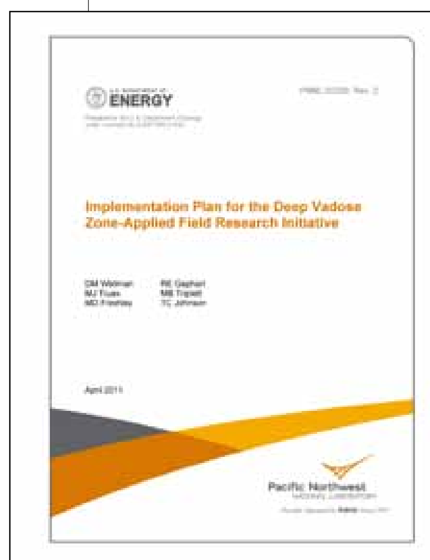
Characterization and remediation of DVZ contamination are complicated by the following factors:

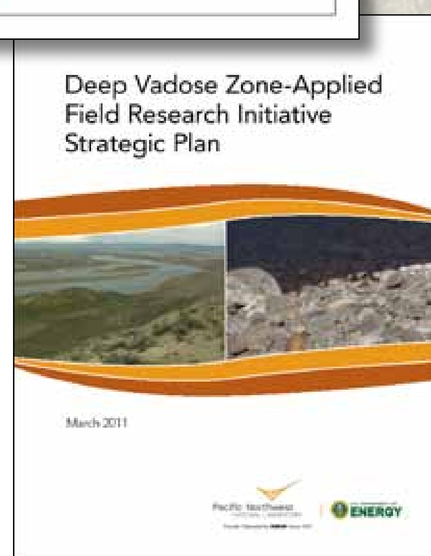
- low moisture content of the sediments

- difficult to access because of depth
- complex hydrogeologic, geochemical, and microbial environments with considerable lateral spreading of contaminants
- limited availability and effectiveness of traditional characterization tools and remediation technologies.

To address these problems, a DVZ Technical Forum was held July 20–21, 2010, in Richland, Washington, to discuss the technical challenges to characterize, monitor, model, access, and remediate the DVZ. Approximately 80 participants in the meeting included representatives from the public, Hanford Site interest groups, the Hanford Advisory Board, state agencies, DOE, Tribal Nations, Hanford Site contractors, national laboratories, universities, and regulatory agencies. The outcome of that meeting served as the basis for development of the *Long-Range Deep Vadose Zone Program Plan* (DOE/RL 2010a). The plan summarized the state-of-knowledge about contaminant cleanup challenges for the DVZ beneath the Central Plateau of the Hanford Site and DOE's approach to solving these challenges.







DOE's DVZ Program Plan (DOE/RL 2010a) was implemented through creation of the Deep Vadose Zone-Applied Field Research Center, managed by PNNL. This program has since been renamed the Deep Vadose Zone-Applied Field Research Initiative. Formal authorization and funding was granted to PNNL from DOE in 2010 to develop management plans for the program and to begin or continue ongoing technical work. The primary objective of the DVZ-AFRI is to provide long-term protection of water resources across the DOE-EM complex by developing and applying effective solutions to solve DVZ challenges in characterization, prediction, remediation, and monitoring of hazardous and radioactive contaminants. At the Hanford Site, these water resources refer to the unconfined aquifer underlying the DVZ and the Columbia River into which the aquifer discharges groundwater.

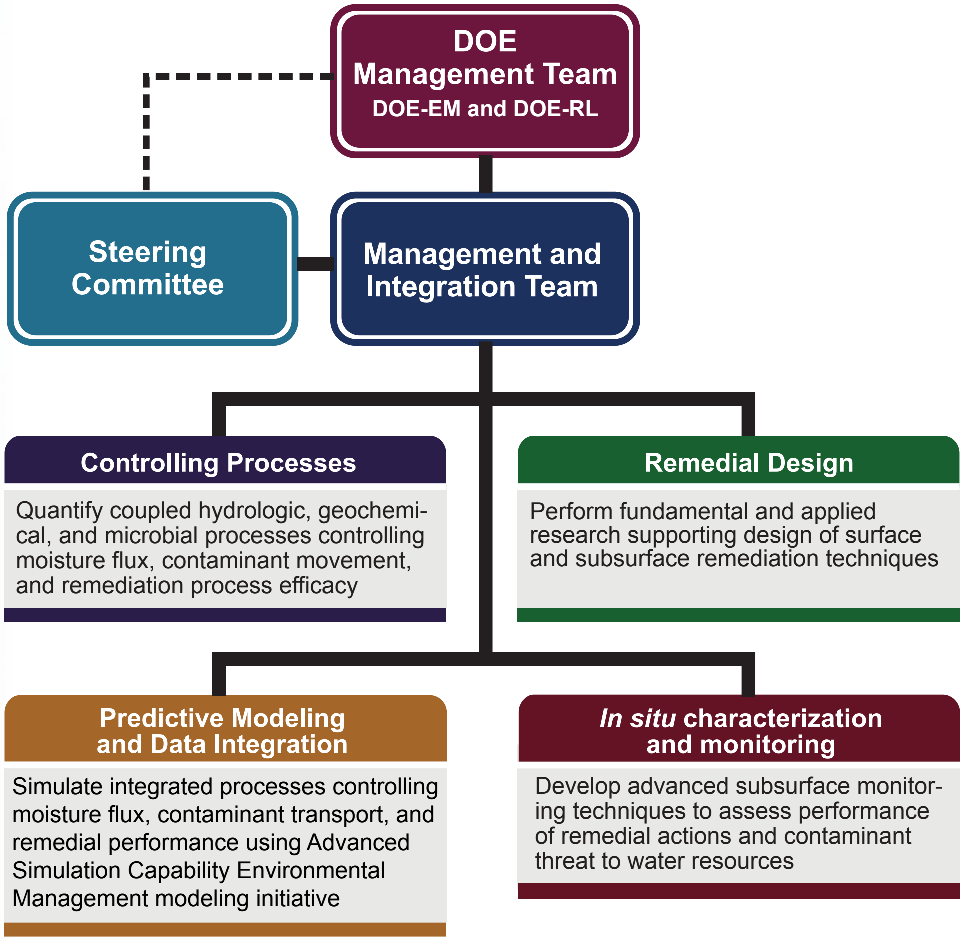
The overall vision is to provide a technical basis to quantify, predict, and monitor natural and post-remediation contaminant discharge from the vadose zone to the groundwater and to facilitate developing in situ solutions that limit this discharge and protect water resources.

Work is conducted collaboratively between technology developers and Hanford Site contractors charged with remediation of the site. DOE is using this approach to develop science-based solutions at the Hanford Site and other DOE sites that build on available knowledge and capabilities, leverage investments from various DOE organizations, and integrate basic and applied science and site engineering activities. Major thrusts of the DVZ-AFRI are to enhance scientific understanding of processes that drive successful vadose zone remediation, and to develop and test promising field-scale solutions to remediation challenges, particularly for contamination in the Hanford Site DVZ.

Yvette Collazo, Director of DOE's Office of Technology Innovation and Development, speaks at the Deep Vadose Zone–Applied Field Research Initiative kick-off meeting in April 2011

Kurt Gerdes, Director of the Office of Groundwater and Soil Remediation, discusses ideas at the Deep Vadose Zone-Applied Field Research Initiative kick-off meeting in April 2011

For the first 6 months, DVZ-AFRI project team members focused on developing the management systems used in the program and organizing the technical work that was already in progress through predecessor initiatives or recently authorized. The project is organized as shown in the diagram. The *Implementation Plan for the Deep Vadose Zone-Applied Field Research Center* and the *Deep Vadose Zone-Applied Field Research Initiative Strategic Plan* were initially published in February and March 2011, respectively (Wellman et al. 2011a; PNNL 2011). Revisions to the implementation plan and strategic plan were published in April and June 2011, respectively (Wellman et al. 2011b; PNNL 2011).



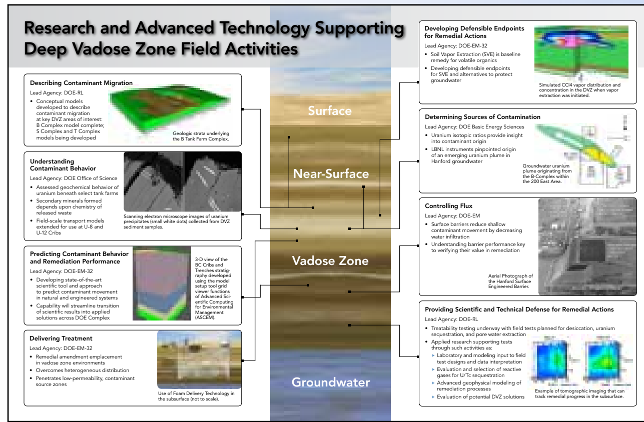
Deep Vadose Zone-Applied Field Research Initiative leadership team and its four major science and research objectives: controlling processes; remedial design; predictive modeling and data integration; and in situ characterization and modeling

The official start of the DVZ-AFRI was celebrated with a formal DOE kick-off that included a poster session and briefing on April 29, 2011, at PNNL. Several dignitaries from DOE-EM attended and spoke at the event, including Mary Neu, the EM Chief Scientist; Yvette Collazo, the Director of the Office of Technology Innovation and Development; and Kurt Gerdes, the Director of the Office of Groundwater and Soil Remediation. Also speaking were representatives from the U.S. Environmental Protection Agency (EPA), the Washington State Department of Ecology (Ecology), Tribal Nations, DOE Richland Operations Office, PNNL, and Hanford Site contractors. The meeting served as an opportunity for DOE, Ecology, and EPA to voice their support of the initiative.

Key Accomplishments

Programmatic Accomplishments

- Major organizational documents were completed during this first annual reporting period. These controlling documents include the *Implementation Plan for the Deep Vadose Zone-Applied Field Research Center* (Wellman et al. 2011a,b); the *Deep Vadose Zone – Applied Field Research Initiative Strategic Plan* (PNNL 2011); the DVZ-AFRI Fact Sheet, and a FY 2011 through FY 2020 schedule integrated with Hanford Site activities.
- The DOE Memorandum of Understanding (DOE 2011) was completed and approved in summer 2011. Signatories included the Manager of DOE Office of River Protection; Director of DOE's Office of Technology Innovation and Development, Office of Environmental Management; and the Manager of DOE Richland Operations Office.
- The DVZ-AFRI was funded and public approval was acknowledged with the DVZ-AFRI kick-off meeting in April 2011. The program received support from the DOE Office of Technology Innovation and Development, DOE Richland Operations Office, Ecology, and EPA.
- The DVZ-AFRI Steering Committee was organized, representatives from contributing entities were identified, and an initial meeting was convened to begin reviewing and prioritizing proposed FY 2012 work scope.



Fact sheet: Research and Advanced Technology Supporting Deep Vadose Zone Field Activities


MEMORANDUM OF UNDERSTANDING
AMONG
DEPARTMENT OF ENERGY, RICHLAND OPERATIONS OFFICE,
DEPARTMENT OF ENERGY, OFFICE OF RIVER PROTECTION
AND
DEPARTMENT OF ENERGY, OFFICE OF ENVIRONMENTAL
MANAGEMENT, OFFICE OF TECHNOLOGY INNOVATION AND
DEVELOPMENT
FOR THE
DEEP VADOSE ZONE APPLIED FIELD RESEARCH INITIATIVE

Concurred By:

Office of River Protection
U.S. Department of Energy

Office of Technology Innovation and Development
Office of Environmental Management
U.S. Department of Energy

Approved:

Richland Operations Office
U.S. Department of Energy

Technical Accomplishments

- The Deep Vadose Zone SharePoint website was completed and access was granted to authorized personnel. This website—the first of its kind at DOE-EM—provides a tool for program users to access program documents, status reports, technical and progress reports, and share technical information in a collaborative online framework. The DVZ Sediment Library, which is part of the DVZ SharePoint site, was also established and will be populated with samples from various DVZ-AFRI activities.
- Field work was conducted in support of the desiccation field treatability test.
- Field work was conducted in support of the vadose zone soil vapor extraction of organics.

We will continue to use emerging technologies and adapt existing technologies to our special needs… and integrate all available tools to get a more complete picture of the problem and the solution.

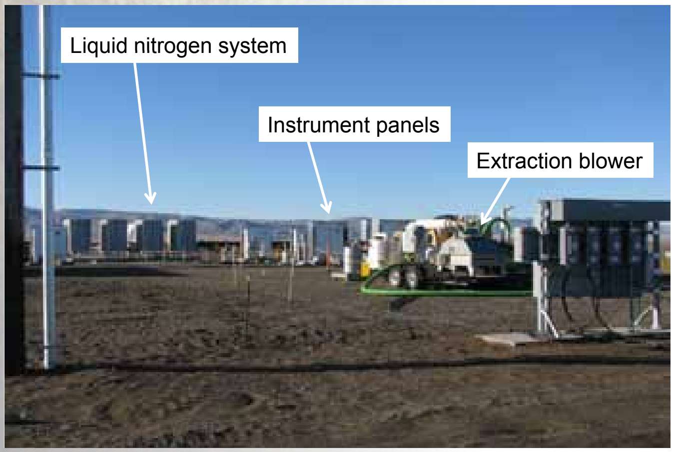
—Susan Eberlein, Washington River Protection Solutions

- Work was conducted to develop advanced geophysical imaging technology to characterize contaminants in the vadose zone.
- Project team developed technical basis for vadose zone foam amendment delivery:
  - optimized foam formulation and generation methods
  - experimental design and testing for scale-up and monitoring
  - physical, hydrological, and geochemical and biological understanding of foam behavior in vadose zone environments
  - numerical simulation of vadose zone foam delivery.
- Research was conducted to quantify the role of geochemical and hydrogeologic heterogeneities on the mass discharge of technetium in the vadose zone.
- Laboratory work was conducted to test and validate geophysical methods for monitoring ammonia gas uranium remediation.
- An extensive scientific and technical publications list attributable to the DVZ-AFRI is provided in the Appendix.

Technical Projects

Support to Vadose Zone Desiccation Field Tests

Concept: Currently, few remediation options are available for inorganic contaminants in the DVZ. Desiccation, if developed and demonstrated, has the potential to be a viable, cost-effective vadose zone remediation approach. The target of desiccation is to reduce contaminant flux to the groundwater by drying the vadose zone. The vadose zone is dried by injecting dry gas into the subsurface where it evaporates pore water until the gas reaches a relative humidity of 100%. The evaporation of pore water significantly decreases the moisture content of the dried zone. The decreased moisture content and associated significant decreases in the aqueous-phase hydraulic conductivity of the dried zone act to reduce the rate of future water movement. The field testing element of this work at the Hanford Site is led by CHPRC with PNNL support for system design and data collection (funded by CHPRC).



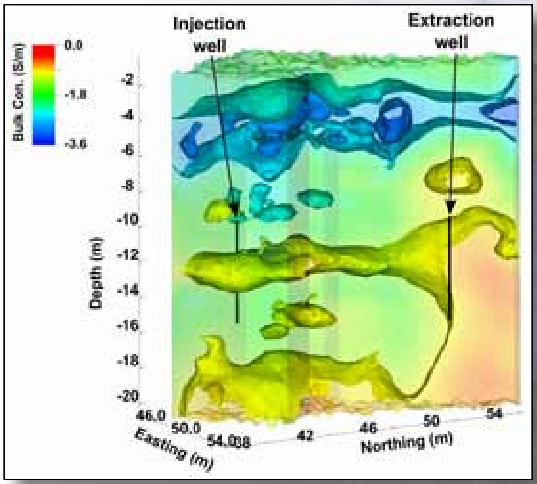
Desiccation test site activities underway at the Hanford Site

Challenges: Moisture removal can be monitored at individual boreholes with in situ sensors and borehole geophysical measurements. However, an understanding is needed of how the desiccation process propagates between monitoring borehole locations and how stratigraphic heterogeneities influence the desiccation process. This type of temporal three-dimensional data to describe the progress of desiccation is needed to develop scale-up information for the technology in support of future feasibility studies to consider effectiveness, implementability, and cost of the technology.

Progress: Methods were developed to apply and interpret cross-hole geophysical measurements to monitor the desiccation process over time at the field scale. In particular, specialized techniques were applied for processing of data provided by CHPRC from cross-hole electrical resistivity tomography (ERT) and ground penetrating radar (GPR) measurements in collaboration with scientists from LBNL. These results are being integrated with the overall assessment of the field treatability test results and provide the primary data to quantify progress over time and the volumetric extent of the desiccation process in the field.

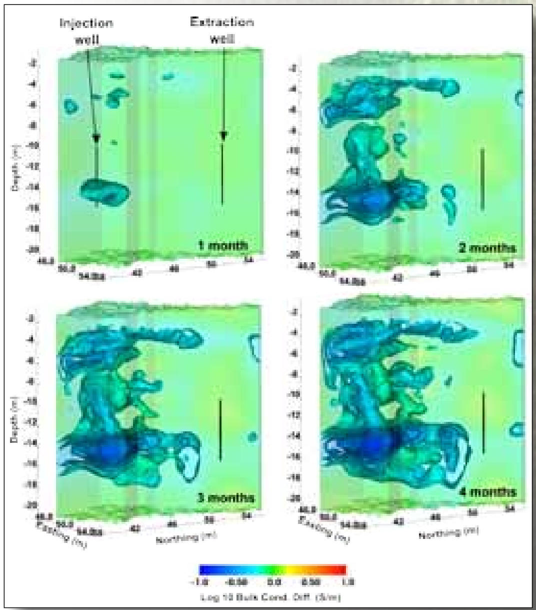
ERT was used to both characterize predesiccation conditions and monitor changes in water content during desiccation. The subsurface electrical conductivity at the desiccation site increases with porosity, water content, and pore fluid ionic strength. The three-dimensional distribution of bulk conductivity is "imaged" with ERT, and provides information concerning each of these three properties.

The image to the right (both generated with the Advanced Simulation Capability for Environmental Management [ASCEM] visualization tool) shows the three-dimensional predesiccation bulk conductivity at the desiccation treatability test site as determined via ERT data collected in vertical boreholes surrounding the injection well. Two conductivity isosurfaces are superimposed within a transparent conductivity color map. Elevated conductivities (warmer colors) are associated with finer-grained material, elevated ionic strength, and/or elevated water content. The anomalously high conductivity is consistent with the ionic strength arising from high nitrate concentration. Lower bulk conductivity regions (cooler colors) are associated with coarser-grained, more permeable units that govern air flow. This baseline ERT image provides valuable three-dimensional information concerning contaminant distribution and soil texture necessary for interpreting desiccation results.



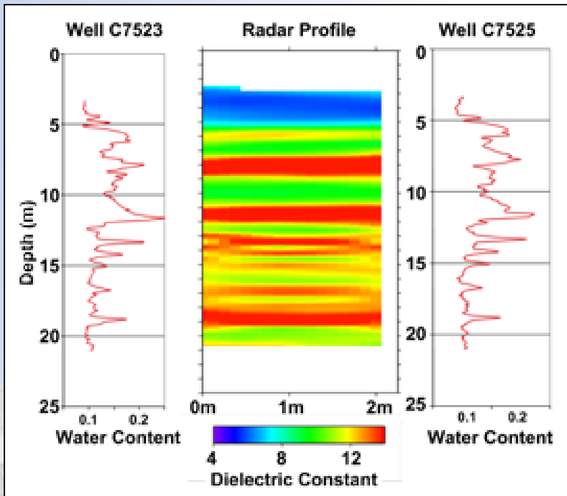
Electrical resistivity tomography showing three-dimensional predesiccation bulk conductivity at the Hanford Site 200 Area desiccation treatability test site

By collecting repeated ERT surveys, desiccation-induced changes in electrical conductivity can be monitored over time. In time-lapse monitoring, the predesiccation baseline conductivity is subtracted from the image so that only changes from baseline conditions are shown. As desiccation progresses, the electrical conductivity of the desiccated region decreases, and is manifest in the corresponding three-dimensional, time-lapsed ERT image. During the desiccation test activity, two such images were collected per day. Time-lapse changes in water content were also estimated along two-dimensional planes using GPR and working in collaboration with LBNL. GPR tomography is used to measure subsurface dielectric constant, which increases with increasing water content. GPR monitoring during desiccation identifies zones of decreasing dielectric constant with respect to predesiccation conditions, which is a proxy for decreasing water content. Geophysical imaging results are now being compared to point sensor information within monitoring wells to provide a comprehensive description of the desiccation test results.



Three-dimensional time-lapse electrical resistivity tomography results showing the growth of the desiccated region with time

The four images (bottom right) show representative sections of the relative change in bulk conductivity from ERT imaging results at 1, 2, 3 and 4 months after starting the desiccation fans (January 17, 2011). Decreases in bulk conductivity are caused by decreases in saturation and the corresponding decrease in current flow pathways during desiccation. Relative changes are dominant in the coarser-grained zones identified in baseline images, suggesting gas flow occurs primarily in the same zones.



Ground penetrating radar tomography data results

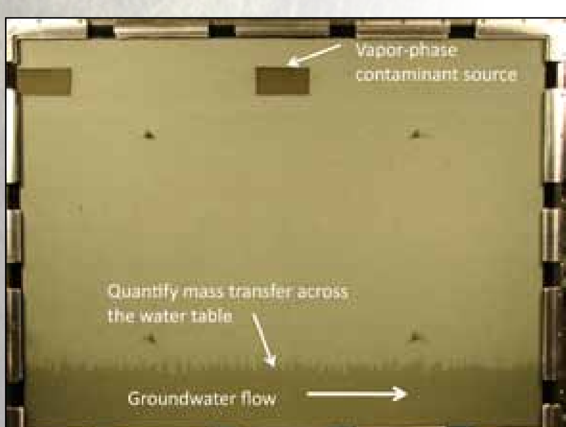
The GPR image (left) shows the correlation between dielectric constant and water content at two of the desiccation monitoring wells. Changes in dielectric constant during desiccation are monitored with GPR tomography to identify corresponding changes in water content.

Vadose Zone Soil Vapor Extraction of Organics

Concept: A scientifically defensible endstate for soil vapor extraction (SVE) will assist sites in managing cost-effective remediation that is protective of groundwater and associated potential receptors. Removal of volatile organic compounds (VOCs) in the DVZ has been successfully accomplished at the Hanford Site using SVE. The basic operation uses a vacuum blower to extract soil gas containing volatile organics from the vadose zone. Considerable carbon tetrachloride has been successfully removed from Hanford Site vadose zone sediments and only low levels of contamination remain—however, it is yet to be determined as to when SVE activities can be terminated. This answer is contingent on determining when the vadose zone contamination is at a low enough level that it no longer poses a risk to groundwater.

A site characterization approach was developed to quantify the nature of the vadose zone contaminant source that persists even with the long-duration operation of the SVE system. The characterization approach uses computer models to apply a mass-flux based analysis for predicting the groundwater contaminant concentrations that would result from the existing vadose zone contamination if the SVE was shut off. This predicted concentration can then be compared to remediation goals to determine if the SVE can be discontinued, thereby providing the technical framework to defensibly transition active SVE remediation to passive remediation.

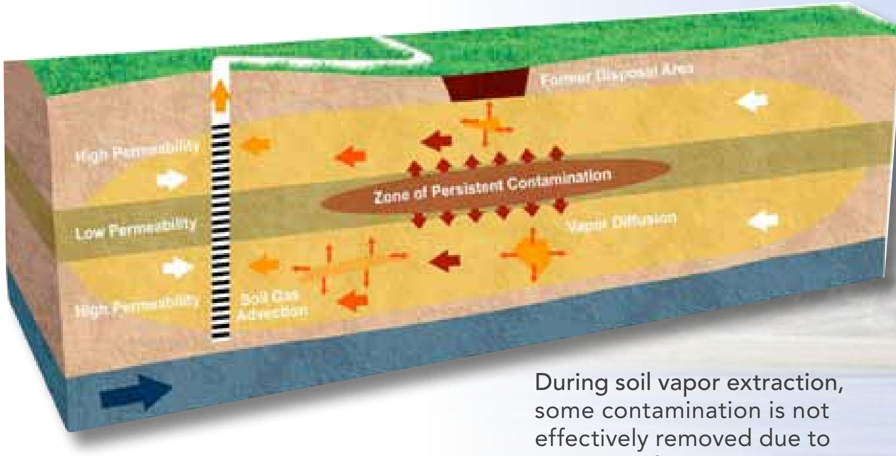
Challenges: While SVE is effective in removing volatile organics from permeable strata in the vadose zone, lower permeability regions reduce extraction progress and complicate interpretation of monitoring data. The effect of these persistent volatile organic sources on estimates of extraction progress and decisions to terminate active SVE or transition to other remediation treatments must be quantified.



Groundwater flow cell tests in laboratory setting

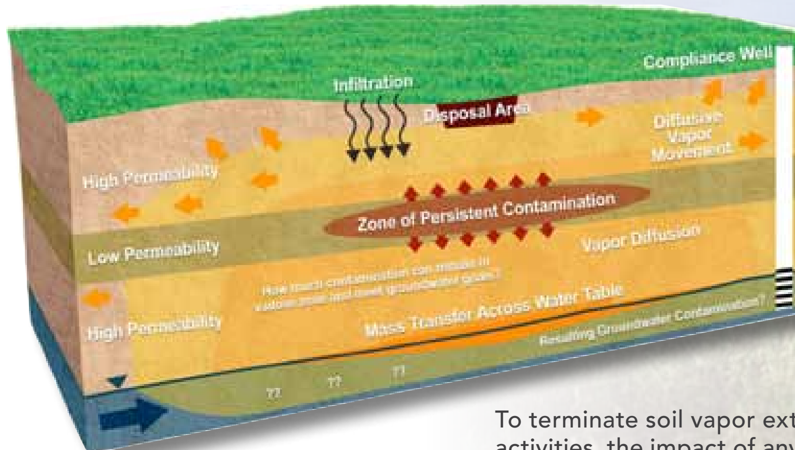
Progress: While the SVE system may struggle to remove all of the contamination effectively, the remediation goal is associated with groundwater protection. Thus, a key question for the site contractors and DOE is determining how much contamination must be removed to be protective of groundwater and is SVE or another passive remedy most effective for meeting this goal? The answer to this question is based on understanding the nature of VOC movement from the residual sources to the water table and the impact on groundwater concentrations.

Building from laboratory work that helps scientists understand the phenomena that control movement of volatile contaminants from the vadose zone to the groundwater (see flow cell image at left), a field treatability test was designed (DOE/ RL 2010b) and conducted at the 216-Z-9 site at the Hanford Site during FY 2011. The field test operating the SVE system was conducted in a prescribed manner and data were collected that quantified the contaminant mass flux from different locations within the vadose zone. This key effort focused on obtaining information about the remaining persistent sources in the vadose zone. This information feeds into the analysis techniques developed by scientists as part of the DOE-EM-32 project that enables site contractors to calculate the groundwater concentration that will result from the existing vadose zone contamination.



During soil vapor extraction, some contamination is not effectively removed due to mass transfer constraints

At the 216-Z-9 site over the past 20 years, CHPRC and its predecessor Hanford Site contractors operated an SVE system to treat carbon tetrachloride contamination in the vadose zone. During SVE, extraction blowers create a vacuum over a network of screened boreholes from which volatile contamination is removed from the porous sediment column. Contaminant gases are separated from the air stream and captured for disposal. The variable permeability of sediment layers results in zones of persistent contamination that serve as reservoirs for the longer-term presence of the volatile contamination and the "rebound" of soil gas concentrations to higher levels when the blowers are turned off.



To terminate soil vapor extraction activities, the impact of any remaining persistent contamination on groundwater needs to be assessed

The technical basis for a mass-flux based method to quantify SVE performance and characterize the nature of persistent vadose zone contaminant sources was published in a recent journal article (Brusseau et al. 2010). Two journal articles have been published to establish the technical basis for applying a mass-flux based analysis to predict the groundwater contaminant concentrations that result from vadose zone sources (Truex et al. 2009; Oostrom et al. 2010). Another journal article demonstrating application of the mass-flux-based approach to assess SVE performance and determine closure decisions is currently in press (Carroll et al. In Press). Laboratory tests have been conducted to examine mass transfer processes as a function of the water table capillary fringe characteristics with presentation of this effort at the summer American Chemical Society meeting and inclusion of a paper in a special edition of a journal from that meeting. Laboratory tests have also been conducted to examine use of vapor phase tomographic methods for refining characterization of vadose zone sources. This vapor-phase tomography is also being applied in a field treatability test, initiated in July 2011, at the Hanford Site. These concepts and other information are being compiled into a multiagency guidance document for SVE closure and transition decisions. The guidance document is being jointly developed by DOE, EPA, and the U.S. Army Corps of Engineers.

Extraction wells setup at Hanford Site test location

Wellhead data logger equipment set up at Hanford Site test location

Flow, temperature, and pressure data logger equipment at Hanford Site test location

Sampling activities at Hanford Site test location

The SVE approach has been incorporated into the Record of Decision for the 200-PW-1 Operable Unit (DOE/RL et al. 2011) at the Hanford Site, where the process defined appropriate remediation goals for an SVE system treating carbon tetrachloride. At Los Alamos National Laboratory, the approach is being applied to determine whether or not active remediation is needed for identified vadose zone contamination, to set remediation goals, and to negotiate with the New Mexico Environment Department on appropriate monitoring strategies. National impact of the effort is being further realized through collaboration with DOE, EPA and U.S. Army Corps of Engineers scientists to adapt the approach and provide guidance for defining the end states for other sites with volatile organic contaminants in the vadose zone.

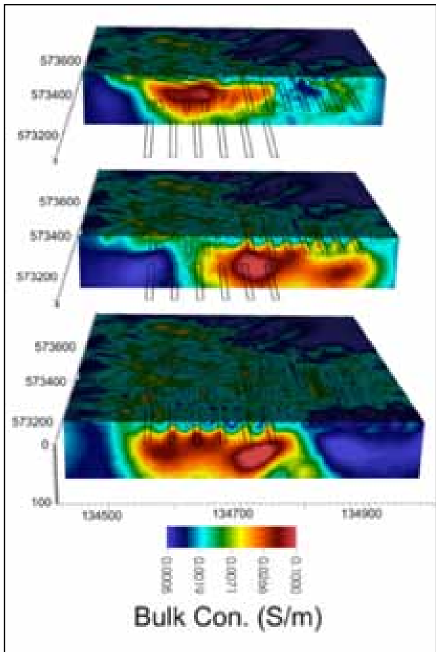
Advanced Geophysical Imaging Technology Characterizes Contaminants in the Deep Vadose Zone

Scientists are tackling subsurface remediation challenges by using advanced geophysical technologies to locate subsurface contamination and focus remediation on areas of greatest hazard. In collaboration with the DOE Office of Science, the DVZ-AFRI developed an advanced electrical resistivity and induced polarization geophysical inversion code that enables scientists to create three-dimensional images to characterize and monitor subsurface environments in situ. This technology is being deployed at the Hanford Site to assist site contractors in locating the spatial extent of vadose zone contamination.

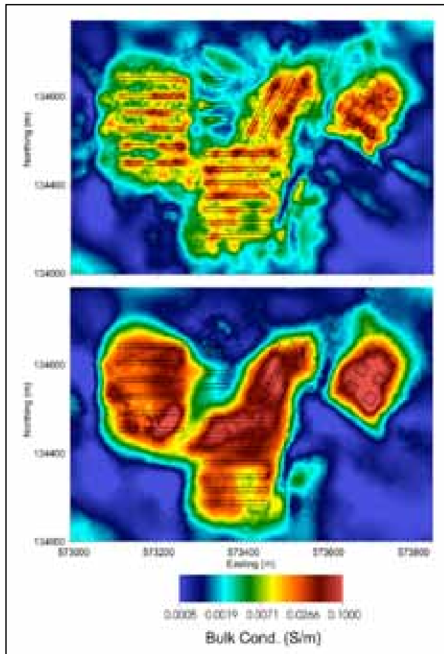
In an unprecedented collaboration between PNNL, hydroGEOPHYSICS, Inc., CHPRC, Washington River Protection Solutions, and the ASCEM Initiative, the geophysical inversion code was demonstrated in the field at the BC cribs and trenches in the 200 Area at the Hanford Site. This geophysical imaging technology enables scientists to locate, view (using the ASCEM visualization software), characterize, and monitor subsurface contaminant plumes; reduce uncertainty in estimating the three-dimensional distribution of parameters that govern groundwater flow and transport; monitor and validate remediation activities in real-time phases; and monitor post-remedial performance, including contaminant mobilization or demobilization.

The top-left images (opposite page) depicts vertical slices of the BC Cribs (6 square features in the upper-left side) and trench areas (long rectangular features). Colors represent electrical conductivity of the sediments in the imaged area ranging from lower conductivity of the undisturbed sediments (blue) to higher conductivity in areas (reds) beneath the disposal facilities where liquid wastes percolated into the sediment column.

Data can be shown as horizontal planes at various depths below ground surface. The top-right images (opposite page) indicate the contamination has migrated well below the ground surface with the result that the higher contaminant levels are deeper in the sediment column.



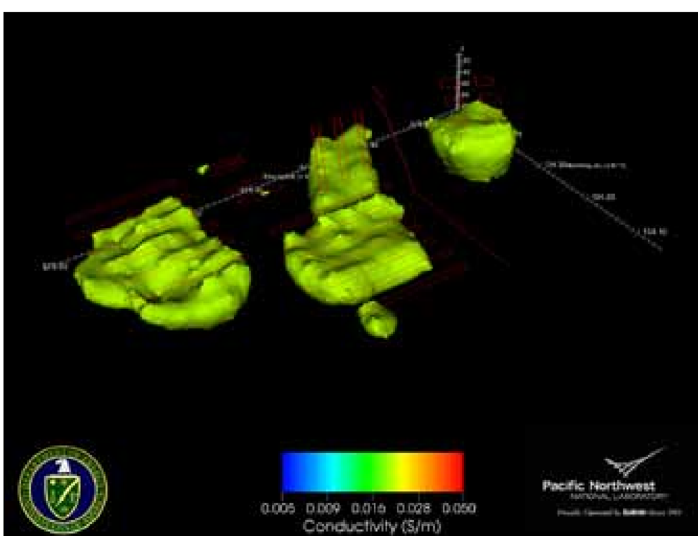
Hanford Site BC Cribs three-dimensional tomography charcaterization



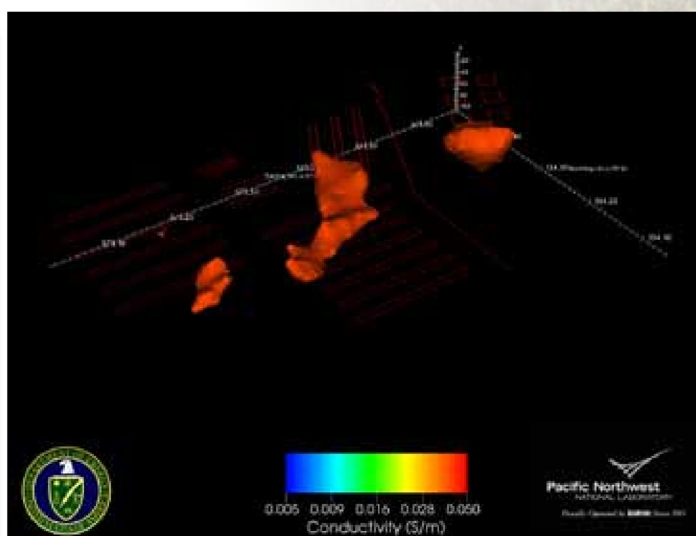
Hanford Site BC Cribs tomography data showing horizontal planes at 20 m (top) and 40 m (bottom) below ground surface

The inverted geophysical results can also be depicted as three-dimensional images of surfaces that represent levels of electrical conductivity. The bottom-left shows the mid-level conductivity surfaces reflecting sediment volumes that have been impacted by waste liquids disposed in the cribs and trenches.

The bottom-right image shows a higher conductivity surface (indicated by the red color). These images are much smaller in volume, indicating areas of high conductivity and correspondingly higher waste concentration.



Hanford Site BC Cribs tomography data showing three-dimensional images of mid-level conductivity



Hanford Site BC Cribs tomography data showing a higher conductivity surface

Looking Forward: Fiscal Year 2012 Tasks

Field Lysimeter Test Facility—The Field Lysimeter Test Facility, located at the Hanford Site, will continue to be used by researchers to further the 20-plus year scientific investigation to understand and define recharge rates for vadose zone environments. The scientific and technical knowledge obtained from this investigation provides critical scientific understanding on defining recharge rates for soil-plant-precipitation combinations relevant to Hanford Site environmental remediation, and testing the ability of surface barrier designs to minimize deep drainage rates.

Systems-Based Monitoring—Systems-based monitoring provides the scientific foundation to advance monitoring approaches beyond traditional sampling of wells and point-source based compliance monitoring to whole system (e.g., watershed, disposal facility, and ecosystem) approaches necessary for monitoring complex sites. This monitoring approach includes using multiple lines of evidence, inclusive of a responsive characterization process, based on conditional rules (i.e., no need to measure reduced gases at sites with measurable dissolved oxygen), and integration with the site conceptual model through the use of robust high-performance computing tools that provide a scientifically defensible approach to characterization and prediction. After site models are calibrated with performance monitoring data, the models can be used to predict system behavior in support of long-term monitoring. Relative to conventional compliance monitoring approaches, a monitoring framework that provides insight to the important remedial and transport processes; encompasses the remediation phases of design, implementation, and performance assessment; and integrates with conceptual site models and predictive analyses will improve the effectiveness, and reduce risk and costs associated with long-term environmental management. Researchers will complete the *Scientific Opportunities for Monitoring Environmental Remediation Sites* document and work with site regulators and the Interstate Technology and Regulatory Council to develop guidance for implementation of systems-based monitoring across the DOE complex.

Geophysical Monitoring for Desiccation—Researchers will complete time-lapsed electrical resistivity tomography and cross-hole radar monitoring to evaluate the spatio-temporal changes in moisture and rewetting induced through soil desiccation at the Hanford Site BC cribs area. The scientific and technical knowledge obtained from this study provides the necessary scientific understanding for the efficacy of desiccation as a remediation option for vadose zone environments.

Systems-based Monitoring of Desiccation Remediation—The extensive temporal, spatial, and integrated monitoring system and dataset afforded by the desiccation treatability test provides an ideal dataset to exemplify the advanced approach of systems-based monitoring for complex sites. This dataset will demonstrate and quantify the utility of systems-based monitoring approaches to advance monitoring approaches beyond traditional sampling of wells and point-source based compliance monitoring to a whole system (e.g., watershed, disposal facility, and ecosystem). This includes using multiple lines of evidence, inclusive of a responsive characterization process, based on conditional rules (e.g., unnecessary to measure reduced gases at sites with measurable dissolved oxygen), and integration with the site conceptual model through the use of robust high-performance computing tools developed by ASCEM that provide a scientifically defensible approach to characterizing and predicting contaminant behavior, the effect of desiccation on vadose zone properties, and the efficacy of desiccation on vadose zone remediation.

End States for Active Remediation of Chlorinated Solvents—Researchers will complete development and publication of technical approaches for establishing appropriate end states for vadose zone remediation of chlorinated solvents. This effort also completes the reporting of the Hanford Site field treatability test conducted in FY 2011 and provide site managers with the technical basis to refine the vapor phase remediation goal for volatile contaminants at the 200-PW-1 Operable Unit as specified in the recent Record of Decision (DOE/RL et al. 2011). Researchers will also complete efforts to develop the mass-flux-based analysis tools and procedures associated with defining end states for transitioning from active (e.g., SVE) to passive (e.g., natural attenuation) remedies for volatile contaminants in the vadose zone. A guidance document authored by EPA, U.S. Army Corps of Engineers, and PNNL researchers, along with journal articles, will be published to provide the technical and regulatory context for sites to pursue effective end states for active vadose zone remediation of volatile contaminants.

Flux-Based Remediation Assessment Framework Development for Inorganic and Radionuclide Contaminants in the Deep Vadose Zone—Researchers will develop and test the remediation assessment framework for the vadose zone with an emphasis on using perturbation and response characterization and monitoring methods to collect data that can be interpreted in terms of flux or processes controlling contaminant flux. The framework is focused on integration of flux-related measurements with predictive analyses to support remediation assessments targeted at mitigating long-term impacts to groundwater, the key concern for deep vadose zone contaminants. This scientific understanding is critical to defining achievable end states and the technological means required to achieve them.

Impact of Waste Disposal Processes on Contaminant Behavior and Defining Achievable Cleanup End States—Although monitored natural attenuation (MNA) of inorganic and radionuclide contaminants in vadose zone environments is a recognized remedial remedy, the technical basis and specific guidance for its application in DVZs does not exist. Waste disposal chemistry has significantly impacted the contaminant chemistry and/or sediment and pore water chemistry in the vadose zone. Researchers will evaluate and document the range of important waste disposal chemistries at the Hanford Site and their impact on attenuation mechanisms for technetium and uranium. This study will assist researchers in developing technical guidance for MNA in vadose zone environments necessary for MNA to be an acceptable technology; this is critical to defining achievable end states and the technological means required to meet them.

Time-lapse, Geophysical Monitoring of Gas Tracers for Vadose Zone Characterization—Surface and subsurface infrastructure interfere with use of electrical geophysical methods to characterize lithology, moisture distribution, and contaminant distribution, and also degrade the ability to monitor for leak detection. In some cases, even in the absence of interferences, enhancement of geophysical responses is needed to enable more effective characterization of vadose zone properties. Injecting gas-phase partitioning tracers to the vadose zone can provide a change in subsurface properties that can be

The 10 square miles of the Inner Area at the Hanford Site is the area of interest for deep vadose zone contamination. The area contains 177 single-shell and double-shell tanks containing 53 million gallons of highly radioactive waste. It also contains five fuel reprocessing facilities; several associated liquid discharge facilities; historic solid waste burial grounds; and active treatment, storage and disposal facilities. The Inner Area contains all of the tank farms, most of the historic liquid discharge areas, and all of the areas that scientists believe pose a threat to groundwater quality from contaminants in the deep vadose zone.

detected by geophysical techniques. Because the tracers provide temporal changes, geophysical data can be analyzed in terms of differences over time. In this type of analysis, static effects, including those from interfering structures, can be subtracted out of the tomographic image, leaving only what has changed with time. The scientific and technical knowledge provided by a coupled tracer-geophysics technique will afford a detectable contrast in geophysical properties allowing characterization of infrastructure, contaminant leaks, and subsurface properties including stratigraphy and moisture content.

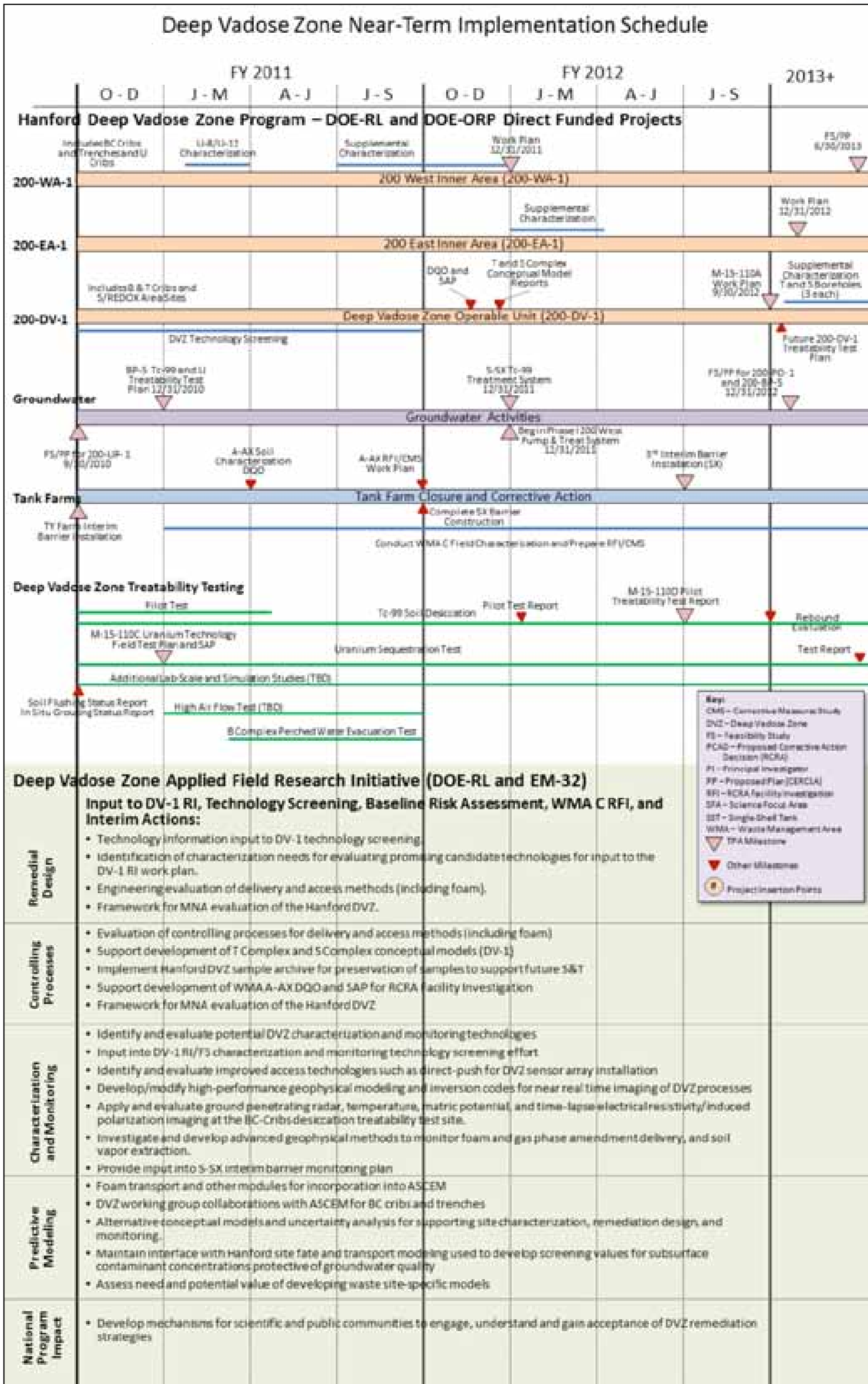
Foam Delivery Technology—Researchers will conduct large-scale demonstration testing for foam delivery technology. This task will 1) quantify the necessary variable to effectively transition foam delivery technology for field-scale deployment, and 2) help researchers understand and correlate remediation-induced end products—including precipitates, moisture fronts, and other elements—with geophysical signature responses to track pore structure and flow path evolution resulting from remediation activities. The scientific and technical information obtained from this task will complete the transformation of foam technology, developed in the oil and gas industry, into a viable method for delivering remedial amendments to vadose zone environments.

Vadose Zone Sediment Library—The Vadose Zone Sediment Library is a collective repository located at PNNL used to categorize and archive sediment samples from DVZ field work. Researchers will continue sample collection activities in collaboration with CHPRC, DOE Office of River Protection and Washington River Protection Solutions, and borehole drilling efforts to archive and store samples for future research by qualified EM-32 and DOE Office of Science researchers. Collecting and archiving samples is critical to maximize resources available to researchers, minimize redundant and costly borehole drilling efforts, and improve scientific understanding of controlling processes and development of viable end states and remediation options.

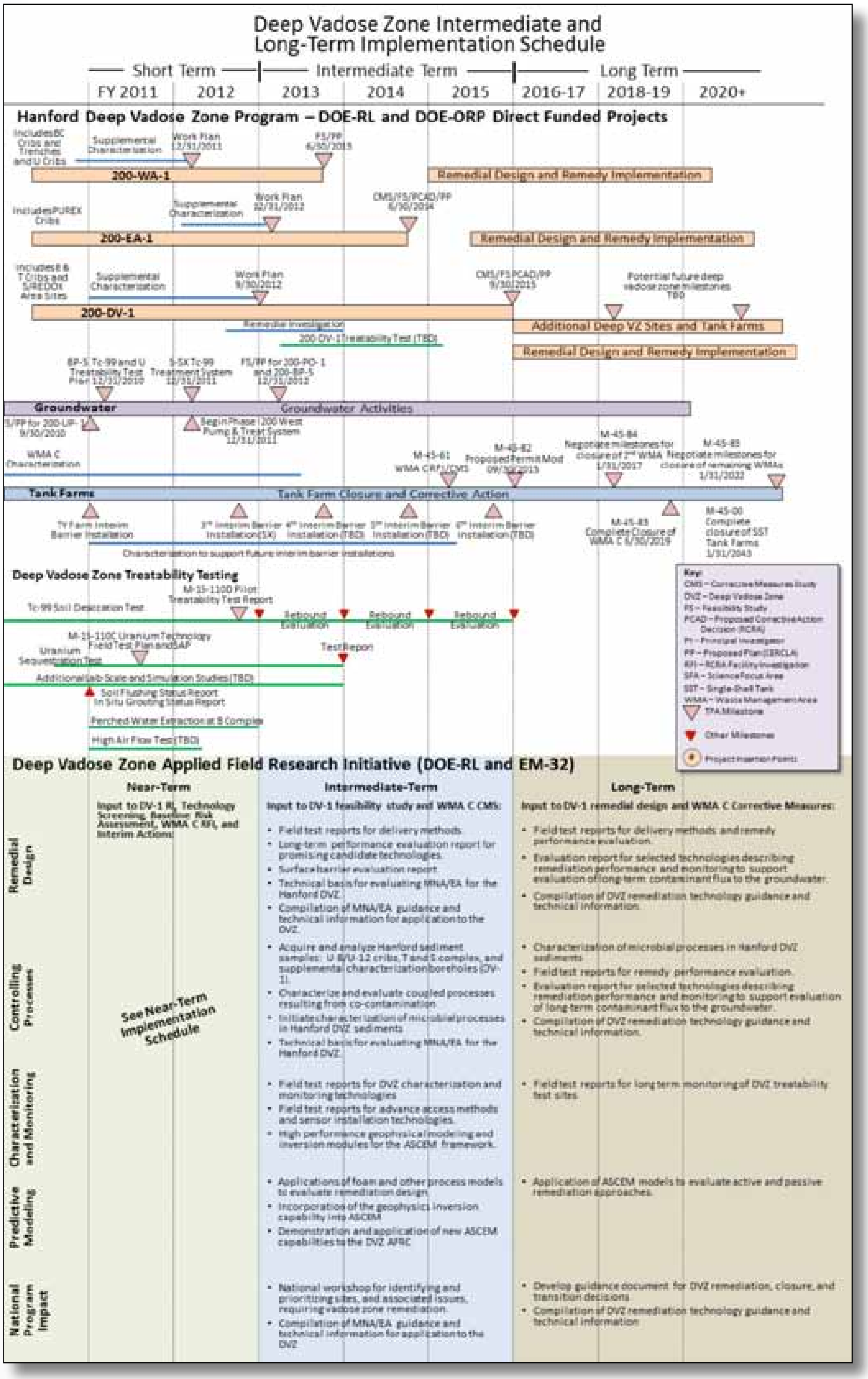
Carbon Tetrachloride Degradation—Researchers will complete the study of abiotic degradation of carbon tetrachloride to better understand its degradation rates and associated subsurface processes. This study will provide necessary scientific and technical understanding to define achievable end states for carbon tetrachloride remediation in vadose zone environments.

Hanford Site Barrier Monitoring—Researchers will continue to evaluate the performance of the 200-BP-1 Prototype Hanford Barrier. Continued research efforts are critical for thorough evaluation and understanding of Hanford Site barrier performance. This monitoring effort, which has been ongoing for 20-plus years, has provided the largest and most extensive monitoring data set that exists for this type of activity at the Hanford Site. The scientific and technical knowledge obtained from this study provides critical understanding and technical validation for the use of engineered, natural barriers for vadose zone cleanup and closure activities.

Efforts in FY 2011 and those planned for FY 2012 and beyond provide researchers from CHPRC, Washington River Protection Solutions, DOE Richland Operations Office, and DOE Office of River Protection with the necessary science and technology to assist in meeting site milestones highlighted in the following two implementation schedules.



Near-Term Deep Vadose Zone Implementation Schedule



Intermediate-to Long-Term Deep Vadose Zone Implementation Schedule

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Appendix

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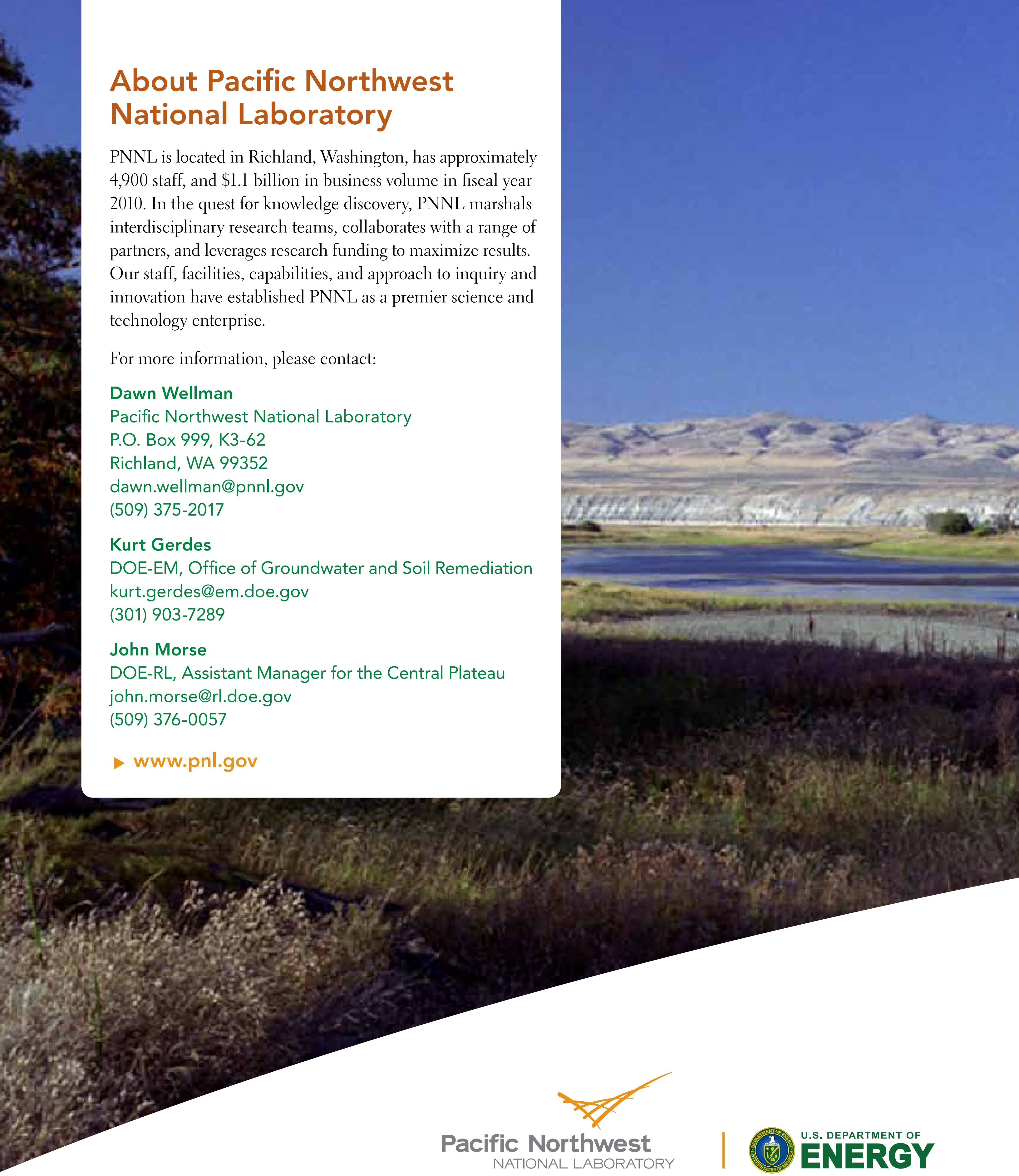

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