ENVIRONMENTAL REMEDIATION PROGRAM

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The key driver for the Environmental Remediation Program (ERP) program within ESD is to provide the scientific foundation needed for environmental remediation and water resources management. Over the last decade, it has become increasingly clear that if we are to face the environmental and water challenges of the future, we must view the system as a complex entity that includes the hydrosphere, geosphere, and biosphere. It has also become clear that these components are coupled and highly dynamic over various spatial and temporal scales. Since the U.S. Department of Energy (DOE) is responsible for the environmental health of over 140 contaminated waste sites across the United States, understanding the complexity of such natural systems is a prerequisite to successful stewardship of the DOE waste sites. As such, the majority of the enviromental research projects within the ERP focus on problems that are critical to the DOE waste sites. However, since many of the contaminants or closely related compounds found at these sites are also dominant at industrial waste sites, much of this research is also applicable to problems faced by the private sector and other government agencies. Deficiencies in our ability to assess basic hydrological processes at the watershed scale also handicap our efforts to sustainably manage our water resources. Because water resources and quality are particularly important for the vitality of water-stressed regions such as California, much of the water resources research performed in the ERP focuses on development of tools and techniques that will lead to better management of California water resources. A brief description of the environmental remediation and water resources programmatic areas of the ERP is given below.

ENVIRONMENTAL REMEDIATION

ESD scientists participating in the ERP conduct multidisciplinary environmental research using theoretical, characterization, modeling, and experimental approaches that range from the molecular to the field scale. The synergy offered by the ensemble of competencies within the ESD facilitates investigation of complex natural systems. Many of the projects within the ERP are associated with one of the following four themes:

- Development of advanced tools and approaches for characterizing biological, hydrological, and geochemical properties and processes at the molecular to field scale
- Development of tools to detect unexploded ordnance (UXOs)
- Improved understanding of complex natural systems and the impact of system complexity on contaminant distribution and remediation efficacy
- Improved ability to predict reactive contaminant transport in the subsurface
- Development of biological or chemical techniques capable of removing or sequestering contaminants.

ESD scientists within the ERP program have developed many novel tools and techniques over the past few years that can be used to characterize properties and processes, and to monitor how they change in response to environmental perturbations. The newly developed Virtual Institute of Microbial Stress and Survival (VIMSS), based at Berkeley Lab, seeks to identify stress-response pathways of microbes important for environmental remediation. ERP scientists associated with VIMSS have determined the signature genes for sulfate-reducing bacteria, developed techniques for large-scale biomass production needed for cell analysis, and have developed a community resource for comparative microbial genomics. ERP scientists associated with VIMSS have also successfully used microarray techniques to characterize the phenotype of bacterial strains important for environmental remediation and have used PLFA techniques to determine the phenotypic response of cells to environmental stressors. High-density DNA microarray technologies were used by ERP researchers to accurately monitor changes in the composition of microbial populations during laboratory- and field-scale studies of uranium (U) bioremediation. Collectively, these studies improve our understanding of microbiological properties and processes, which is critical for designing sustainable contaminant bioremediation treatments.

ERP scientists are involved in the Center for Environmental Kinetics Analysis, a collaborative effort exploring what molecular approaches and insights can be developed to extrapolate rates of environmentally important reactions across a variety of scales. In particular, ERP scientists are investigating the rates of formation and the topology of oxyhydroxide and silicate precipitates from the molecular to the nanoscale using synchrotron techniques, with the goal of understanding precipitate formation and reactivity. Scientists involved in this Center are also investigating mineral dissolution and precipitation rates under biotic and abiotic conditions via synchrotron-based experiments, using microfluidic reactive flow devices and x-ray spectroscopy methods.

Many advances have recently been achieved by ERP scientists in the use of high-resolution geophysical data for characterizing and monitoring subsurface systems. Stochastic joint inversion techniques were developed to combine geophysical and hydrological data for the estimation of hydrological properties at the Hanford Site in Washington, and to estimate fracture zonation at the Oak Ridge National Laboratory in Tennessee. During the past two years, ERP scientists have discovered that noninvasive geophysical techniques could be used at the laboratory scale to monitor biomineralization and gas production associated with bioremediation processes. In related studies, surface geophysical data were used to indicate the change in clay mineralogy caused by bioremediation at the field scale, and tomographic geophysical data were used to monitor amendment distribution associated with a Cr(VI) bioreduction study at the Hanford Site. These studies reveal the potential of high-resolution geophysical data sets for providing the hydrogeological characterization information that is important for predicting contaminant transport, or for noninvasively monitoring system transformations during remedial processes.

Significant advances have also recently been made by ERP scientists in the development of geophysical tools that can detect and extract essential information about buried metallic objects—information that is essential for identification and discrimination of unexploded ordnance (UXO). Through research that received the Strategic Environmental Research and Development Program (SERDP) Project of the Year Award, ERP scientists have developed an active electromagnetic (AEM) field prototype system that can obtain estimates of the location, size, shape, and metal content of a buried metallic object in the presence of other metallic clutter.

Novel isotopic approaches were successfully developed and applied by ERP scientists to identify the source of contaminants at DOE waste sites. Precise U isotopic approaches were used to analyze the pore water of subsurface sediment samples at the T-Waste Management Area (WMA) of the Hanford Site in Washington, and to unravel the history of U contamination there. Isotopic analysis of U and strontium isotopes were used to trace the source of U from the site to the Hanford Reach of the Columbia River, and to monitor how the flux varies with seasons. ERP scientists have streamlined a nitrate isotopic analysis technique and used the technique to study the nitrate distribution and origin at several Hanford vadose zone and groundwater sites. Such novel isotopic approaches are critical to establishing both an understanding of complex transport in natural systems and for establishing remediation strategies and responsibilities.

Laboratory studies conducted by ERP scientists have revealed phenomena that have significant implications for designing and sustaining environmental remediation approaches at the Hanford site. Column studies, designed to mimic the leakage of highly saline and alkaline radioactive waste solutions from Hanford storage tanks into sediments, revealed a significant pH reduction and colloid formation at the plume front. These observations suggest the importance of considering plume-front phenomena for predicting the behavior of contaminants in the Hanford subsurface. Column studies were also used to investigate the conditions that control long-term stability of bioreduced U. These studies indicated that at 100 to500 days after U reduction, U was reoxidized and solublilized even in the presence of a microbial community capable of reducing U(VI). This study suggests that *in situ* U remediation using organic carbon-based reductive precipitation can be problematic in sediments when uranyl carbonates are stable.

ERP scientists have recently assessed the potential for immobilizing and detoxifying chromium (Cr)-contaminated groundwater at the Hanford 100H site using lactate-stimulated bioreduction. Microbial, geophysical, and geochemical analysis of groundwater, coupled with stable isotope monitoring, permitted accurate tracking of microbial processes during this field treatabilty study and confirmed that Cr(VI) was successfully removed from groundwater at the Hanford 100H Site. Such studies reveal the benefits of interdisciplinary approaches for investigating and manipulating complex earth systems.

WATER RESOURCES AND QUALITY

To optimally manage our water resources, ERP scientists are developing tools and approaches that can be used to measure, understand, and predict the flow, transport, and residence times of water, nutrients, and contaminants through natural water systems. With a population of over 30 million people, an agricultural economy based on intensive irrigation, and large urban industrial areas, California is highly dependent on water for its vitality and productivity. Consequently, much of the water research within the ERP is focused on problems important to this state.

ERP scientists have developed a variety of tools to characterize hydrological, geochemical, and biological properties and processes needed for managing water resources. Motivated by the concern about endocrine-disrupting compounds in recycled water, ERP scientists have developed a prototype biosensor capable of assessing estrogenic compounds. These scientists have successfully used the biosensor to assess water from various wastewater treatment and natural systems. Several logging tools have also been developed by the ERP this year and applied to watershed studies, including the electrical conductivity sensors used to identify high-salinity zones in agricultural areas, and heat-based sensors used to indicate flow velocities.

System-level studies are being carried out to understand complex hydrological and ecological phenomena. ERP scientists are investigating the San Joaquin River in the Central Valley of California to examine how non-point-source pollution discharge associated with agricultural activities impacts water quality. Their investigations involve field measurements to determine mass balance of algae and nutrients within the system. Understanding the conditions that give rise to unsaturated flow below a streambed in Sonoma County, California, and the impact that this may have on well operations in the area, is being investigated by ERP scientists using advanced measurement and modeling techniques. ERP scientists are also actively investigating water-balance and water-quality issues within several California counties, including Merced County. Remediation approaches have also been recently developed by ERP scientists working on water resources projects. Our scientists developed an algal-bacterial selenium removal process deployed within the agricultural drainage area of the western San Joaquin Valley to remove nitrate and selenium from irrigation drainage. An important component of many of the water resource projects is the development computer-based decision support systems to enhance environmental monitoring and management of water systems.

ERP PROGRAM MANAGEMENT AND TECHNICAL ASSISTANCE

ERP continues to be the Natural and Accelerated Bioremediation Research (NABIR) Program Office for the Office of Science. The NABIR Program Office maintains the dynamic NABIR Web home page (www.lbl.gov/NABIR/) with links to investigators, program element managers, science team leaders, recent publications, annual meeting registration, calls for proposals, review documents, and other Web sites. In addition, the NABIR Program Office also organizes the NABIR annual investigators meeting, with more than 150 participants and sessions for posters, presentations, and breakout sessions.

ERP scientists also manage the Environmental Program at the Advanced Light Source (ALS), as described by http://esd.lbl.gov/ALS_environmental/index.html. This program is designed to assist environmental researchers in gaining familiarity with and access to the ALS, and in assisting with environmental investigations at the ALS. Many of the environmental investigations in this program focus on understanding how and what microbiological and geochemical species are distributed relative to contaminants and within natural geological materials, which processes occur, and the rates at which they occur. The program provides support across four beamlines, providing a range of measurement support scales from nanometers to centimeters.

ERP scientists provide technical assistance to DOE Environmental Management International projects. The overall objectives of this program are to use foreign sites as analogues to improve the capability of DOE's conceptual and numerical models for predicting radionuclide transport and impact, and to improve DOE remediation technologies. Recent projects have focused on helping in the design of site characterization, radionuclide transport modeling, and remediation technologies at the Kurchatov Institute in Russia, the Chernobyl Exclusion Zone in Ukraine, and the Ezeiza Atomic Center in Argentina.

PARTNERS AND FUNDING

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