Hazardous Substance Research Centers Program: An Incubator for Remediation Research

Mitch Lasat

The Hazardous Substance Research Center (HSRC) was established by the U.S. Environmental Protection Agency (EPA) to assist in the implementation of Superfund and to address major hazardous substance environmental problems at a regional level. Over the past 12 years, the HSRC program has produced more than 1,200 peer-reviewed technical articles, 27 patents and licenses, 21 new technologies for the remediation marketplace, and provided technical assistance to more than 300 communities. Research, technology transfer, and training are conducted by five regional multi-university centers, which focus on different aspects of hazardous substance management. Areas of focus include urban environments, contaminated sediments, natural remediation and restoration technologies, abandoned mine lands, and chlorinated solvents in groundwater. This article provides an overview of the five HSRC programs including current areas of research, field studies, and technology transfer Internet links to access research results and remediation technology information. © 2003 Wiley Periodicals, Inc.

INTRODUCTION

The Hazardous Substance Research Centers program (HSRC) was established by the U.S. Environmental Protection Agency (EPA) to assist in the implementation of the federal Superfund statute. In 1989, the EPA competitively selected five centers to develop multi-university partnerships that brought together researchers from diverse technical disciplines in programs of basic and applied research, technology transfer, and training related to environmental concerns posed by the manufacture, use, transportation, and disposal of hazardous substances. The HSRC program is managed by the EPA's National Center for Environmental Research through the Science To Achieve Results (STAR) grants program. Funding for the program has been jointly provided by the EPA's Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER). In mid-1994, the HSRCs assumed a new role in community outreach, taking on the EPA's newly funded Technical Outreach Services to Communities (TOSC) and the Technical Assistance to Brownfields (TAB) programs.

In the first 12 years, the HSRC program produced more than 1,200 peer-reviewed technical articles, 27 patents and licenses, and 21 new technologies. In addition, the five centers conducted 162 field demonstrations and provided technical outreach assistance to 300 communities. In 2000, funding for these centers was completed and the EPA issued a competitive solicitation to fund new centers for a five-year second phase. In November 2001, the EPA Administrator, Governor Christine Whitman, awarded center designations to five regionally distributed university consortia (Exhibit 1).

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Exhibit 1. EPA Administrator Christie Whitman (center) announces university consortia that will operate the new HSRCs. With her at the award presentation (from left) are Dr. Edward Bouwer, director of the Center for Hazardous Substances in Urban Environments; Dr. Katherine Banks, director of the Midwest HSRC; Dr. Charles Shackelford, director of the Rocky Mountain HSRC; Dr. Mitch Lasat, HSRC program manager in the EPA; Dr. Danny Reible, director of the South & Southwest HSRC; and Dr. Lewis Semprini, director of the Western HSRC

Two of the original centers won follow-on grants to operate HSRCs: the Western Region Center with Oregon State University (lead institution) and Stanford University; and the South and Southwest Center composed of Louisiana State University (lead institution), Georgia Institute of Technology, Rice University, and Texas A&M University. The three new centers are:

- The Center for Hazardous Substances in Urban Environments led by Johns Hopkins University with the University of Maryland, Morgan State University, University of Connecticut, and New Jersey Institute of Technology;
- The Midwest Center led by Purdue University with Virginia Polytechnic and State University, Kansas State University, Michigan State University, University of Cincinnati, University of Missouri, Howard University, Central State University, and Haskell Indian Nations University; and
- The Rocky Mountain Regional Center led by Colorado State University with Colorado School of Mines, and Montana Tech of the University of Montana.

Program Mission

The HSRC program was designed to address major hazardous substance environmental problems at a regional level. For example, the highly urbanized Northeast faces a number of pressing environmental problems including potential exposure to toxic chemicals from contaminated sites, landfills, incinerators, abandoned industrial sites (brownfields), industrial releases, lead, and pesticide use. In this context, the Center headquartered at Johns Hopkins University has identified "Urban Livability" as a strategic research priority for the EPA Regions 1, 2, and 3. In the EPA Regions 4 and 6, the South and Southwest HSRC Center focuses on in situ treatment methods for contaminated sediments and dredged materials. The Midwest HSRC covers the EPA Regions 5 and 7 and focuses on the application of managed natural systems to remediate contaminated soil and water. Examples of natural systems include bioremediation (the use of microorganisms for environmental clean up), phytoremediation (using plants to remediate environmental contamination), and natural attenuation (allowing the natural environment to cleanse itself over time). The Rocky Mountain Regional HSRC focuses on environmental problems associated with mining and mine wastes, a frequent and challenging environmental problem in Region 8. Finally, the Western Region HSRC was selected to develop in situ treatment methods for groundwater contaminated with volatile organic compounds, particularly chlorinated solvents, a recalcitrant problem of significant concern in Regions 9 and 10. The pairings of HSRCs and the EPA regions, designed to provide equitable distribution of technical resources across the nation, are shown in Exhibit 2. The pairings are based on contiguity and, to the extent possible, on similarities of regional profiles and technical issues.

To identify and respond in a timely fashion to regional environmental problems, each center is assisted by a science and technology transfer advisory board. These boards advise center directors on research directions and decision priorities for funding. To maintain a broad perspective, these boards are composed of representatives from the EPA, other federal and state environmental organizations, academia, industry, and private consulting firms.

The HSRC program requires that 30 percent of its funds be used for public outreach and technology transfer. This important stipulation highlights EPA's growing awareness of the need and resolve to provide technical assistance to environmentally troubled communities and help them become more actively involved in site-cleanup decision making. The primary vehicles to achieve these goals are the TOSC and TAB programs.

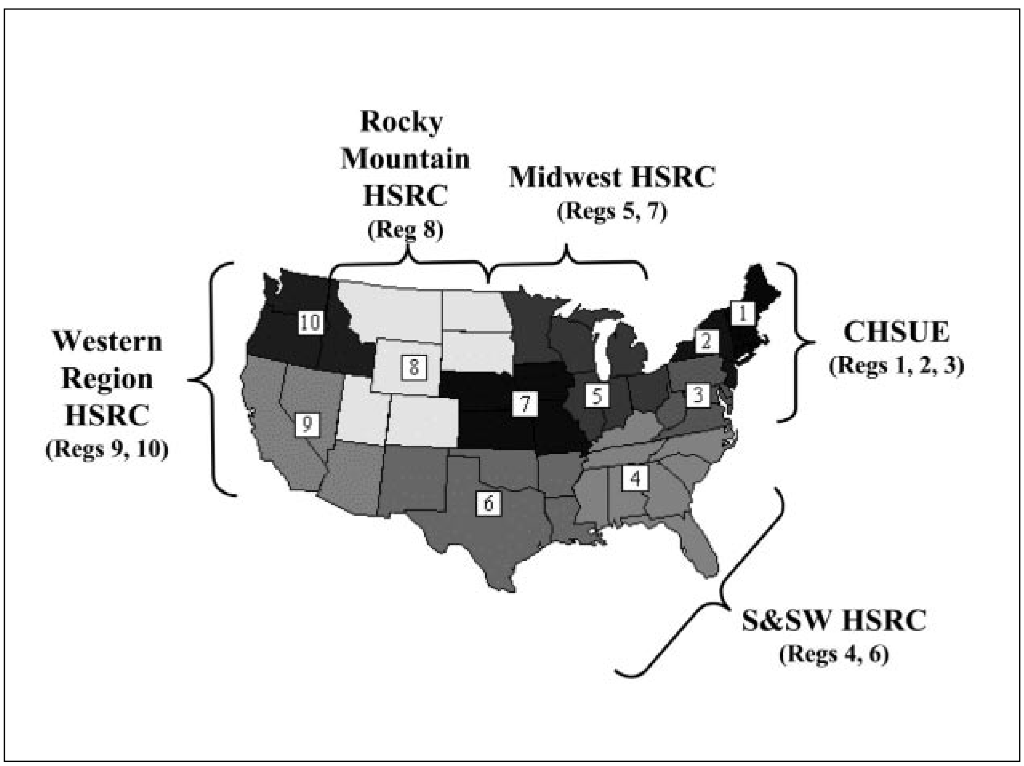

Exhibit 2. Pairing of HSRCs and the EPA federal regions

HSRC Research Challenges

Seventy percent of the funding for the HSRC program is directed to support research efforts. The overall research focus of the HSRC program is to develop and evaluate innovative, cost-effective approaches for detecting, assessing, and reducing environmental risk posed by hazardous substances. EPA hopes that HSRC research will achieve significant results in the following areas:

1. Advancing the science of risk assessment by elucidating the processes leading to exposure, developing innovative and cost-effective methods to predict and measure exposure, and developing a better understanding of the effects of hazardous substances on human health and ecological systems.
2. Demonstrating and evaluating cost-effective, innovative technologies for pollution prevention, control of toxic wastes and emissions, site characterization and monitoring, remediation, and restoration.
3. Developing methods to evaluate the social and economic consequences of pollution and cleanup efforts.
4. Developing more effective approaches for risk characterization and communication.

CENTER FOR HAZARDOUS SUBSTANCES IN URBAN ENVIRONMENTS

Intense industrial and commercial activities in urban settings have contaminated many sites with complex mixtures of contaminants.

In the Northeast, the population is heavily concentrated in urban areas with a rich tradition of manufacturing and handling hazardous substances. Urban residents face potential risks caused by exposure to a number of environmental stressors including toxic chemicals from Superfund sites, landfills, incinerators, and brownfields. In this context, the HSRC headquartered at Johns Hopkins University has identified "Urban Livability" as a strategic research priority for EPA Regions 1, 2, and 3. To address environmental problems prevalent in urban environments, the Center for Hazardous Substances in Urban Environments (CHSUE) has developed a research program composed of seven projects to promote a better understanding of physical, chemical, and biological processes for detecting, assessing, and managing risks posed by contaminated soil, water, sediments, and airborne particles.

Intense industrial and commercial activities in urban settings have contaminated many sites with complex mixtures of contaminants. Predicting the mobility, fate, and bioavailability of these mixtures is essential for realistic risk assessment and effective management strategies. This is particularly challenging for sediment- and soil-bound contaminants, which are not readily bioavailable. Such conditions require a full consideration of the sorptive processes of the chemicals including potentially important interactive effects caused by the complexity of the mixture. In addition, predicting the fate and transport of organic contaminants may be complicated by biotransformation processes. A group of researchers led by William Ball and Edward Bower is evaluating the need and means to achieve improved predictive tools with a focus on models that include sorption, mass transfer, and biodegradation effects. This work will provide better tools for assessment and management of risks posed by sediments and soils contaminated with complex mixtures of organic chemicals.

Organohalide vapors are common landfill gas constituents that can pose a potential health hazard to nearby residents. In addition, highly corrosive hydrogen chloride can be released on gas combustion and can preclude the use of landfill gas as fuel. The utility of metallic iron "permeable barriers" for in situ treatment of organohalides has been recently demonstrated. Despite this, the potential of zero-valent metals for treating vapor phase organohalides in landfill gas is practically unexplored. Lynn Roberts and Howard Fairbrother have initiated a study to elucidate the molecular-scale chemical reactions that influence the success of this treatment technology. Development of an effective treatment for chlorinated constituents in landfill gas will significantly reduce the risk posed by these contaminants to human and ecosystem health. An additional advantage of this approach is that treated landfill gas can be more feasibly used as a source of energy.

In urban areas, industrial sites have historically been placed in close proximity to waterways. Off-site discharge of contaminated groundwater from a waterfront site can pose an additional risk to the ecosystem. At these waterfront sites, the hydrology is typically dominated by interchanges between groundwater and surface water. Despite the importance of this mixing zone for the health of both marine and freshwater ecosystems, this ecotone has been poorly described with respect to contaminant fate and transport. Researchers at CHSUE led by Allison MacKay are investigating the importance of biogeochemical processes at this interface including: (1) partitioning to sediment organic matter, (2) retention to colloid-associated species on sediment grains, and (3) biodegradation in the overall process of polycyclic aromatic hydrocarbon retention at an urban waterfront site. Results of this work will help characterize the transfer of toxic compounds from source to sediments and enable the development of models for assessing the ecological risks of exposure from discharged groundwater contaminants. An additional concern is posed by the migration of metal contaminants to adjacent surface water bodies. The hyporheic zone, or the groundwater/surface water interface, can have a major impact in metal transport. Placed at the interface of two distinct geochemical environments, the hyporheic zone is a primer for unique chemical reactions and ecological niches. Microbial activity can also have a major effect on metal mobility. Despite this significant influence, little information is available about the impact of terminal electron acceptors and carbon flux on metal retardation at the groundwater/surface water interface. Researchers at CHSUE seek to elucidate the processes that govern the fate and transport of heavy metals at waterfront sites. A team of scientists led by Barth Smets is investigating the effect of organic matter and bioavailability of sulfate and iron (II) on the microbial activity and subsequent impact on processes that immobilize metals in the hyporheic zone. The findings will be incorporated in a conceptual model that will be used as a tool to assess and remediate waterfront sites contaminated with heavy metals.

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Waste incinerators are a major source of toxic metals released into the atmosphere. Despite the potential for adverse impact, the contribution of incinerators to the atmospheric burden is not well understood. Robert Mason and Joel Baker are evaluating innovative analytical tools to enhance the understanding of the fate and deposition of airborne contaminants generated by incinerators. The investigators propose to create profiles for these incinerators via downwind sampling at strategic locations. Highly sensitive time measurements will allow resolution of the plumes, facilitate receptor modeling, and provide much needed information to manage the risk posed by these emissions.

The dispersion of aerosols from incinerators has long been a concern. This phenomenon is particularly complex in urban settings because of a variety of factors such as spatial variability of surface heat fluxes and topography, land-water contrasts, and weather patterns. Marc Parlange at the CHSUE leads a research team seeking to use a high-resolution elastic lidar (Light Detection and Ranging) to measure the aerosol plume from the Baltimore waste incinerator. New models will be evaluated to capture unresolved turbulence physics in these complex environments. This investigation will help identify the role of urban heterogeneity on local atmospheric dynamics and plume dispersion. The experiment has the potential to improve urban air quality management by providing an accurate description of plume dispersion under complex conditions associated with urban settings.

SOUTH AND SOUTHWEST HAZARDOUS SUBSTANCE RESEARCH CENTER

Contaminated sediments are emerging as a major environmental concern. The toxic contaminants in sediments can affect aquatic life through direct contact, ingestion, and food chain effects. Humans can also be at risk through direct exposure to pollutants and through consumption of fish and wildlife. At any time, there are over 2,800 fish advisories in the United States, many of which can be traced to contaminated sediments. The risk posed by contaminated sediments is particularly significant in EPA Regions 4 and 6, which encompass approximately 54 percent of the nation's wetlands and 45 percent of the nation's inland waters.

At any time, there are over 2,800 fish advisories in the United States, many of which can be traced to contaminated sediments.

The assessment of risk posed by contaminated sediments is hampered by a lack of methods that accurately quantify a receptor's exposure, which, in turn, is controlled by the release of contaminants from the sorbed state. Significant evidence suggests that soil and sediment toxicity is related to the aging process of the contaminant. In addition, several studies have indicated that a fraction of sediment-bound contaminants desorbs slowly and is difficult to remove by conventional extraction methods. Despite the apparent sequestration, these contaminants may be biologically available to benthic organisms. Through predation, they might also be biomagnified into higher trophic levels. For example, tubificid oligochaetes feed and burrow in sediments. As they pass through the guts of these worms, the irreversibly sorbed contaminants are exposed to a variety of digestive enzymes, bacteria, and chemical conditions (e.g., pH, biosurfactants). It is conceivable that chemical dynamics could be altered by animal processing and lead to changes in desorption, bioavailability, and toxicity of contaminants. A research team lead by Danny Reible has initiated a project to evaluate the dynamics of uptake and availability of desorption-resistant polynuclear aromatic hydrocarbons (PAHs) to tubificid oligochaetes and the feasibility of using the results for prediction, control, and regulation.

Evaluation of methods for managing contaminated sediments, including dredging, is compounded by contaminant release during resuspension. Because of pronounced changes in the redox environment during dredging, the behavior of metals is particularly complex. Risk assessment has primarily focused on sorption and equilibrium processes because the toxicity of heavy metals is associated with dissolved metal species. However, several researchers have shown that desorption is often not the reverse of sorption and, to a large extent, it exhibits hysteresis. Mason Tomson and Louis Thibodeaux have proposed to investigate the processes responsible for heavy metal release during resuspension events based on the physical and chemical variability in the sediment and water column. Results will be used to predict the transport and potential exposure of biota to a variety of metal, sediment, and solution/conditions combinations.

A research team led by John Pardue is investigating the potential for biodegradation of chlorobenzenes in the rhizosphere of selected plant species. This study is based on the observation that high concentrations of organic acids are formed in marshes with *Phragmites* vegetation. The investigators will test the hypothesis that specific detrital decomposition products (i.e., propionate) can stimulate the activity of reducing dechlorinating microorganisms in selected wetland plant species. This information may spur the development of new approaches for sediment remediation, such as constructed wetlands.

Over the years, the South and Southwest HSRC have researched the usefulness of sediment caps to stabilize and isolate contaminated materials. Currently, the Center is working on the construction of second-generation "reactive" caps. This construction requires a more sophisticated understanding and control of the depositional processes during cap placement. A multi-university, interdisciplinary research team led by Danny Reible is testing the hypothesis that the surface chemistry of conventional capping materials can be altered to achieve a desired cap structure and reactivity. Changes in the surface chemistry of the capping materials including adhesion and adsorptive capacity will be quantified. Computer models will also be developed to investigate particle deposition as a function of fundamental physicochemical parameters for a given cap-forming technique. The outcome should be a better design of micro- and nano-scale properties of the cap that will allow a greater control of long-term containment and remediation of hazardous materials in sediments.

MIDWEST HAZARDOUS SUBSTANCE RESEARCH CENTER

The Midwest HSRC was selected to address environmental problems posed by hazardous substances in EPA Regions 5 and 7. The Center will focus on developing and evaluating remediation and restoration technologies based on managed natural systems. Innovative environmental cleanup technologies such as natural attenuation, phytoremediation, and bioremediation are cost effective, less intrusive, and provide an environmentally acceptable alternative to energy-intensive conventional approaches. Although the main focus of the Center is to integrate natural remediation technologies into large-scale remediation plans, the research program will also provide important insights about fundamental scientific issues.

> The National Research Council estimates that between 14 and 28 million cubic yards of contaminated sediments from maintenance dredging must be handled annually in the United States.

Large quantities of sediments are dredged from rivers and lakes to keep these waters navigable. The National Research Council estimates that between 14 and 28 million cubic yards of contaminated sediments from maintenance dredging must be handled annually in the United States. Some of these sediments cannot be disposed on land because the concentration of regulated contaminants exceeds allowable levels. These contaminated sediments are stored in confined placement facilities, but these facilities are nearing their capacity and new sites are becoming difficult to obtain. Thus, a need exists to remediate these sediments and make them suitable for beneficial uses such as industrial fill or construction. A team of scientists led by Paul Schwab is investigating the potential of phytoremediation to accelerate the removal of water from the sediments and to degrade associated contaminants. The effectiveness of this approach will be tested on sediments currently stored near Milwaukee and Green Bay, Wisconsin.

The potential of using natural revegetation to stabilize and remediate sites contaminated with polycyclic aromatic hydrocarbons and heavy metals is being investigated by a research team led by Jodi Shann. The use of natural revegetation would eliminate costs associated with agronomic practices required to maintain foreign plant species. In addition to site cleanup benefits, if successful, this approach will also help restore and maintain the ecosystem.

Monitored natural attenuation (MNA) has been proposed as a cost-effective site remediation approach providing it can achieve a significant level of risk reduction. A potential use of MNA is to restore contaminated aquifers either as a stand-alone technology or in combination with other removal/remediation methods. At contaminated sites, source removal must occur first followed by MNA to further reduce the downgradient risk. Phytoremediation, for example, can be incorporated into complex treatment schemes if the degradation and evapotranspiration rates can reduce the risk to acceptable levels at a given site. It is not clear, however, how clean the source area needs to be to use MNA. Therefore, an effective coupling of source removal/remediation strategies with MNA must be addressed by modeling. John Novak leads efforts to assess the efficacy of MNA at three well-characterized sites contaminated by three classes of compounds including chlorinated solvents, gasoline, and creosote. These sites will serve as locations for field-testing decision/modeling protocols, verifying model results, and documenting the rate of natural processes. This study will directly benefit regulators and environmental professionals by providing improved decision tools to assess the integration of managed natural systems in risk management.

The releases of heavy metals in mine drainage, mine tailings leachate, and industrial wastewater are a major environmental problem. Constructed wetlands have been documented to remove metals from contaminated waters, although occasionally wetlands have failed for unknown reasons. Understanding the process of metal removal is important for optimizing the design of constructed wetlands but the removal mechanisms are not well understood. Mark Fitch and Joel Burken have initiated field and laboratory work to achieve the following objectives: (1) determine the chemistry of metals removed in constructed wetlands, (2) determine the failure mode of constructed wetlands, (3) determine the bioavailability of sequestered metals in constructed wetlands, and (4) determine the effect of operational disturbances on constructed wetlands. It is anticipated this research will develop design and operating guidelines to optimize the efficiency, stability, and efficacy of constructed wetlands. Because of the widespread concern for toxic metals in the environment, and the low expense associated with this treatment approach, these guidelines should facilitate a wider use of constructed wetlands.

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Contaminant biodegradation is inherently complex and involves numerous biotic and abiotic processes. In the subsurface, microorganisms exist predominantly as heterogeneous biofilms which facilitate access to nutrients and stimulate adaptation to frequently changing environmental conditions. Thus, biofilms can play a crucial role in a contaminant's fate in the subsurface. Despite this influence, the structural forms and chemical composition of biofilms in porous media exposed to chemical contaminants are currently not well understood. Particularly, the response of a microbial community to environmental stress upon exposure to hazardous chemical stressors needs much more study. If bioremediation is to become a reliable approach to restore ecosystems to a natural state, we must develop a better understanding of how microbial communities are structured and function, both during and after the completion of the remediation process. Paul Bishop leads a group of researchers seeking to elucidate the adaptive response of an aerobic subsurface microbial biofilm community exposed to several chemical stressors including pentachlorophenols, cadmium, and benzene.

Polychlorinated biphenyls (PCBs) are synthetic organic chemicals with low reactivity and high chemical stability. In general, they are known to be recalcitrant to degradation when released into the environment. However, there is evidence indicating that selected anaerobic bacteria have the potential to attack highly chlorinated congeners and enhance their solubilization via enzyme-catalyzed reactions. Subsequently, there is an increase in microorganism and plant uptake and contaminant metabolism. Research has indicated that some plants exude organic compounds that support and stimulate microbial remediating processes. Furthermore, pollutant breakdown in the rhizosphere by microbes stimulates plant uptake and degradation. The beneficial effects of plant/microbe symbiosis have been demonstrated for a number of processes including the fixation of atmospheric nitrogen. However, the effect of this symbiosis in the rhizosphere contaminated with xenobiotic compound is less understood. Clayton Rugh and Sisitar Dutta are investigating the synergistic mechanism that allows PCB biodegradation in the rhizosphere. This study will identify and characterize effective plant/microbial interactions in support of PCB degradation.

ROCKY MOUNTAIN REGIONAL HAZARDOUS SUBSTANCE RESEARCH CENTER

The mining industry continues to play a significant role in the economy of states associated with EPA Region 8. The potential for adverse environmental impacts from mining activities also exists. Of particular environmental concern is the metal mining industry. An additional, and perhaps even more significant, risk to human health and the environment is posed by more than 40,000 inactive or abandoned mine lands (AMLs) that have yet to be reclaimed in Region 8. Most of the environmental concerns associated with AMLs relate to the negative impact on water quality caused by acid drainage; the leaching of toxic metals into the surrounding soil, groundwater, and surface water; erosion and migration of contaminated sediments; and direct groundwater contamination resulting from seeps from ponds and pits. Among these, the environmental impact resulting from acid mine drainage is a major concern. The research focus of the Rocky Mountain Regional Center is to improve our understanding of the geochemical, biological, hydrological/mineralogical, and engineering aspects of the environmental challenges posed by mining and mine waste, and develop and evaluate cost-effective cleanup technologies.

The potential for adverse environmental impacts from mining activities also exists.

Biogeochemical weathering of reduced selenide minerals to selenate (Se) causes selenium to be released in a highly soluble form. A similar transformation of arsenic (As) sulfide minerals releases soluble arsenite. As a result, both As and Se are commonly found in acid mine drainage and solid mine waste. The adverse effects of arsenic on human health resulting from arsenic were recently revealed in Bangladesh where a significant fraction of the population was affected by contaminated groundwater. Selenium with an MCL of 50 μg/l in drinking water, also poses an environmental concern. Adsorption onto metal oxides is widely used to remove As and Se from drinking and wastewaters. However, the effectiveness of this method depends on the redox chemistry of As and Se. Complexation by organic matter and microbial activity has the potential to catalyze the redox transformation of these chemicals. For example, organic matter facilitates these transformations by acting as electron acceptors in anaerobic respiration and shuttling electrons to other acceptors. However, the mechanisms responsible for these potentially important processes are poorly understood. Subsurface permeable reductive barriers (PRBs) have been proposed for in situ remediation of acid mine drainage. Natural organic matter, the active component of the barrier, has been shown not only to remove anionic metals but also to increase the alkalinity of the inflowing mine drainage. Clearly, the interactions of As, Se, and natural organic matter are important considerations in the design of these PRBs but more needs to be known. A research program led by Donald Macalady seeks to elucidate the effect of natural organic matter on the geochemistry of As and Se and to optimize the design of permeable reactive barriers.

The fate and transport of metals are controlled by sorption and sediment settling and resuspension processes. The physical adsorption of metals depends on the very fine sediment fraction or wash load, which is the major fraction of the sediment transported in mountain streams. The degradation of water quality through sedimentation is difficult to evaluate because of difficulties associated with water monitoring. Because of practical constraints, sediment flux is often measured at large time intervals that provide little relevant information related to stream flow episodes. Inadequate monitoring protocols and the lack of effective sediment transport models limit the ability to characterize how sediments and associated metals could chronically degrade mountain aquatic ecosystems over time. Pierre Julien leads a research team working to improve computer modeling that will accurately characterize the fate and transport of metal-contaminated sediments in streams and rivers impacted by mining. Field measurements will be used to calibrate and test these numerical models at several sites where water quality has been altered by contamination from mine waste.

Contaminants in aquatic systems impact receptors at all levels of organization, from unicellular organisms to entire ecosystems.

Remediation of mine drainage waters usually requires correction of acidity, removal of the acid-generating source, and removal of anionic metals. In a passive bioreactor system, these processes can be mitigated by the activity of sulfate-reducing bacteria. For example, acidity is reduced by the production of bicarbonate from the anaerobic reduction of organic carbon, acid-generating potential is mitigated by the removal of ferrous iron from the water, and anionic metals are reduced and precipitated as sulfides, oxides, or elemental form (e.g., Se). Organic matter produced by the degradation of organic substrates such as peat and composted material can be involved in a variety of reactions that may affect the adsorption and formation of metal-organic complexes and chemical speciation of effluent metals. Despite its potential impact on the performance of the system, chemical characteristics of the organic substrate are not routinely specified, which limits the usefulness of this information to the practitioner. Thus, there is a need for systematic physical, chemical, and biological characterization of the organic substrates relative to sulfate-reducing activity and the efficiency of metal removal. Linda Figueroa leads efforts to evaluate the effect of organic matter characteristics on organic products generated by microbial populations and metal speciation. Her team will work to optimize the design of anaerobic passive bioreactors by characterizing the seasonal variability of sulfate-reduction activity and metal removal capabilities of specific bacteria.

Contaminants in aquatic systems impact receptors at all levels of organization, from unicellular organisms to entire ecosystems. In general, our understanding of contaminant effects is greater at lower levels of organization, particularly for molecular and biochemical processes in unicellular microorganisms. However, the ecological significance of contaminant-induced molecular and biochemical responses is not clear. Recently, ecotoxicologists have emphasized the importance of understanding the impacts at complex levels such as population, community, and ecosystem. Unfortunately, responses at these higher levels of organization are complex and, in general, poorly understood. William Clements and James Ranville seek to integrate stream microcosm studies and field experiments to investigate the biochemical responses of population, communities, and ecosystems impacted by toxic metals. The ultimate goal of this research is to establish causal linkages across levels of biological organization, and to identify indicators of recovery from mining pollution.

WESTERN REGION HAZARDOUS SUBSTANCE RESEARCH CENTER

Subsurface contamination by volatile organic chemicals (VOC), including chlorinated solvents, is a major groundwater problem, particularly in EPA Regions 9 and 10 where about 40 percent of the nation's groundwater is withdrawn. Researchers at the Western Region HSRC are investigating the potential for microbial remediation of groundwater plumes contaminated with chlorinated aliphatic hydrocarbons (CAHs). Although many CAHs, including trichloroethylene (TCE), do not appear to support microbial growth under aerobic conditions, researchers at the Western Region HSRC have identified a butane-grown mixed culture, coined BMG1, capable of degrading recalcitrant CAH mixtures. A team of scientists led by Daniel Arp is characterizing the environmental conditions that maximize the potential of BMG1 to degrade CAH. An important goal of this investigation will be to determine the effects of microbial cellular energy status and toxicity of the degradation products on CAH oxidation to optimize long-term sustainability of BMG1-supported transformation of CAH.

Reductive dechlorination of CAHs has been demonstrated in a number of laboratory and field projects. However, in these studies the CAH concentration was significantly lower than the field CAH concentration near nonaqueous phase liquid (NAPL) source. Lewis Semprini and Mark Dolan seek to build capability to remediate high TCE concentrations by developing a microbial consortium near the NAPL source. Successful degradation of TCE depends on the ability of microorganisms to transform the intermediate and toxic product, vinyl-chloride (VC), to ethylene. This transformation is particularly slow at high NAPL concentrations. A major objective of this study is to develop a culture capable of reductively dechlorinating TCE to ethylene at NAPL concentrations above 1,000 μM. The investigators seek to achieve rapid transformation of TCE to ethylene by developing a microbial consortium composed of two cultures: a fast degrader of TCE to VC, and a rapid transformer of VC to ethylene. A second objective is to evaluate the effect of environmental conditions, including redox potential and pH, on reductive dechlorination kinetics and microbial growth to optimize the process.

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Complex subsurface bioreactors are, in general, less characterized and consequently more difficult to control and manipulate. In the field, the effectiveness of the bioremediation process is a direct reflection of the scheme for mixing the contaminants and delivering the additives. However, little information is available regarding chemical delivery and mixing in porous media such as aquifer sediments where mixing is slow and tends to be a limiting factor. In general, engineered remediation mixing can be enhanced in two ways: within the geological medium through hydrodynamic dispersive mixing, kinetic mass transfer, and hydrodynamic instability, and aboveground within recirculation wells. Peter Kitanidis and Craig Criddle seek to develop and evaluate cost-effective methods for in situ remediation by combining and time-sequencing these two methods. An in situ reactor will be created with the goal of regulating the rates of exchange between the reactor and the rest of the formation. Subsequently, models will be developed to evaluate the interaction between fluid mechanics and biogeochemistry, and compare methods of chemical delivery and mixing for technical and cost effectiveness.

Reductive dechlorination and hydrogenation with palladium (Pd) catalysts is a promising technology to remediate groundwater contaminated with chlorinated aliphatic and aromatic hydrocarbons. Optimization of these Pd reactors is limited by a lack of understanding of the processes that control the catalyst activity, particularly on the catalyst's surface properties. Field catalysts consist of Pd metal clusters dispersed on a highly porous support material and characterizing this surface is problematic with traditional techniques such as spectroscopy. Martin Reinhard and John Westall seek to characterize the surface processes that occur during catalysis by using model catalysts that are more amenable to spectroscopic techniques. Investigators will use model catalysts to characterize and evaluate the impact of groundwater on catalyst activity, elucidate the chemical and physical mechanisms responsible for changes in catalyst activity, investigate potential biofouling that may result from biological activity, and develop convenient and economical methods to regenerate catalysts in situ.

Understanding the processes that control contaminant sequestration in the solid matrix of the aquifer is important for risk-based corrective actions. Sequestration is a complex phenomenon that includes several processes such as adsorption onto the surfaces of aquifer solids, partition into natural organic matter present in the aquifer solids, and diffusion into the internal pores of the aquifer sediments. Despite significant progress, the fundamental chemical and physical processes of contaminant sequestration remain poorly understood. Martin Reinhard is conducting research to elucidate the mechanisms of contaminant sequestration with particular emphasis on multicomponent interactions during sequestration and desorption of complex chemical mixtures. He expects to develop techniques for estimating the microporosity of aquifer sediments, quantify the interactions between multiple contaminants during uptake, and predict the time scale for multicomponent release from natural sorbents.

Identifying microbial cultures that can degrade high concentrations of TCE would be a valuable remediation tool.

Identifying microbial cultures that can degrade high concentrations of TCE would be a valuable remediation tool. There is a need for methods to evaluate the effectiveness of contaminant degradation caused by microorganisms at the field scale. Researchers at the Western HSRC have developed a single-well, "push-pull" method. Jennifer Field and Jonathan Istok are leading efforts to optimize this method to detect and quantify changes in the size and activity of microbial population added to the subsurface to stimulate anaerobic dechlorination of TCE. The overall goal of this project is to further develop the "push-pull" method to monitor TCE-transformation potential by selecting and optimizing concentrations and combinations of substrates.

Degradation of organic compounds depends on the ambient redox conditions in the environment. Several sensing methods have been proposed to evaluate the redox status of a system including the use of platinum (Pt) electrodes as redox indicators. There are conflicting reports on the effectiveness of the Pt electrode, however. An alternative approach is to quantify the changes in the concentration of a surrogate species, a redox indicator that is not a natural component of the system. A team of researchers at Oregon State University led by James Ingle is focusing on redox indicators as monitoring tools to assess and optimize redox conditions to treat TCE with dehalogenating cultures. This investigation is expected to provide unique advantages, such as building on-line monitoring capabilities at field sites.

FIELD STUDIES

Because of the need for cost-effective remediation technology, EPA encourages and supports field studies and demonstrations. In this regard, the HSRC program is an incubator for applied research. For example, studies conducted by Western Region HSRC researchers at Edwards AFB have demonstrated that trichloroethylene, a frequent groundwater contaminant in the Western United States, can be effectively biodegraded cometabolically through the introduction into the subsurface of a primary substrate (toluene or phenol), and oxygen to support the growth and energy requirements of a native population of microorganisms. An estimated 60-m width of the TCE-contaminated plume was treated with this system, reducing its upgradient TCE by about 98 percent from 1,200 μg/l to 25 μg/l. More information about this study can be found at http://www.hsrc.org/hsrc/demonstrations/native.html. At abandoned military bases and munitions plants, the presence of undetonated explosives in the soil is a costly and difficult cleanup challenge. Phytoremediation, the use of aquatic plants to assimilate and detoxify hazardous substances, is one of the promising cleanup methods field-tested by the South & Southwest HSRC. Researchers at this center designed, constructed, and operated a pilot-scale plant lagoon system to simulate field conditions, which would occur during remediation of TNT-contaminated soil. Results indicate that the TNT removal in plant cells matched laboratory batch-study predictions. Removal percentages relative to TNT loading ranged from 85.4 percent to 99.7 percent. More information about this study can be found at http://www.hsrc.org/hsrc/demonstrations/tnt.html. For information on other HSRC field studies the reader is directed to http://www.hsrc.org/hsrc/demonstrations/index.html.

TECHNOLOGY TRANSFER

An important function of the HSRC program is to actively participate in the dissemination of research results and to contribute to the transfer of technology. To meet this important responsibility, the HSRC program is maintaining an Internet site at http://www.hsrc.org. This site is updated periodically to include the latest results of basic and applied research. From the site, electronic links are available to connect the reader to the home pages of the five HSRCs. In addition, annual and final HSRC research reports are posted by the EPA at http://es.epa.gov/ncer/centers/#hsrc2001 to monitor research progress and to keep the general public informed of the latest science and technology developments.

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CONCLUSIONS

The cleanup of contaminated sites is a complex, costly, and time-consuming process. Currently, there are more than 1,200 Superfund sites on the National Priorities List, and 40 new sites expected to be added annually through at least 2010. There are also thousands of sites impacted by leaking underground storage tanks that need cleanup corrective action. In addition, there are thousands of brownfields, which represent a major obstacle to national urban redevelopment. Many of these sites are polluted with hazardous substances, which pose a significant risk to humans and the environment. One of EPA's objectives is to remediate these contaminated sites to prevent harm to people and the natural environment, and to restore them to uses appropriate for surrounding communities. Recognizing that scientific knowledge and existing science-based technologies are inadequate to fully address the identification, remediation, and management of hazardous substance problems, EPA through the National Center for Environmental Research is coordinating an extramural research program to address current research needs, and to develop and evaluate innovative cost-effective cleanup technologies. Funding for the HSRC program is EPA's major support for extramural research related to the assessment and management of risk posed by hazardous substances in the environment. We expect the funding for the program to remain unchanged at the current $4.5 million per year level.

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