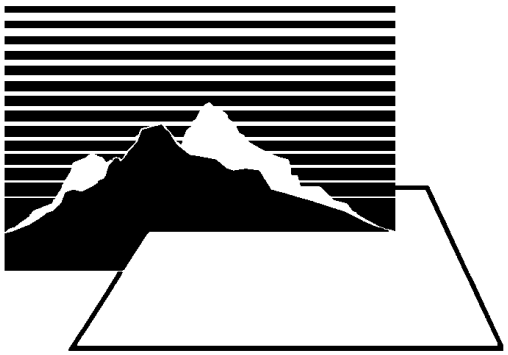
ANNUAL REPORT

of the

Great Plains/Rocky Mountain Hazardous Substance Research Center



December 1999

CONSORTIUM MEMBERS

Colorado State University

Haskell Indian Nations University

Kansas State University

Lincoln University

Montana State University

Montana Tech of the University of Montana

South Dakota State University

University of Iowa

University of Missouri

University of Montana

University of Nebraska

University of Northern Iowa

University of Utah

University of Wyoming

Utah State University

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GREAT PLAINS/ROCKY MOUNTAIN

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Haskell Indian Nations University

Kansas State University

Lincoln University

Montana State University

Montana Tech of the University of Montana

South Dakota State University

University of Iowa

University of Missouri-Columbia, Kansas City, and Rolla

University of Montana

University of Nebraska

University of Northern Iowa

University of Utah

University of Wyoming

Utah State University

Other Participants

Colorado School of Mines

University of Colorado

Iowa State University

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The Center at a Glance

Kansas State University (KSU) leads the consortium comprising the Great Plains/Rocky Mountain Hazardous Substance Research Center, which serves Environmental Protection Agency (EPA) Regions VII and VIII. Other member universities are Colorado State University, Haskell Indian Nations University, Lincoln University, Montana State University, South Dakota State University, Utah State University, and the Universities of Iowa, Missouri, Montana, Nebraska, Northern Iowa, Utah, and Wyoming. All are located in EPA Regions VII and VIII. The center was established in February 1989 to conduct research pertaining to the identification, treatment, and reduction of hazardous substances resulting from agriculture, forestry, mining, mineral processing, and other activities of local interest. In 1994, efforts of center principal investigators were broadened to include programs for minority academic institutions, technical outreach services for communities, and research and re-education for displaced military and Department of Defense personnel.

The center is headed by Dr. Larry E. Erickson, professor of chemical engineering at Kansas State University (KSU). Dr. Erickson is responsible for coordinating all of the center's activities. He is assisted by Dr. Lakshmi N. Reddi, who is the associate director, and by Dr. Richard B. Hayter, associate dean for extension and outreach and director of engineering extension programs, who oversees the conduct of the center's training and technology transfer program. The center benefits from guidance supplied by a 16-person Science Advisory Committee and a 16-person Training and Technology Transfer Advisory Committee. Members of these committees are listed in Tables 1(A) and 1(B).

Table 1(A): Science Advisory Committee

Member	Affiliation	Expertise
Robert Ahlert, Ph.D.	RAMS Env. Consultants	chemical engineering
Terry Baxter***, Ph.D.	Northern Arizona Univ.	environmental engineering
Tim Canfield	U.S. EPA	biology
Ramesh Chawla, Ph.D.	Howard University	chemical engineering
David Constant, Ph.D.	Louisiana State University	hazardous waste engineering; chemical engineering
Carol L. Dona, Ph.D.	U.S. Army Corps of Engineers	environmental engineering
Mitchell Erickson**, Ph.D.	U.S. Department of Energy	chemistry
Felix Flechas	U.S. EPA, Region VIII	environmental engineering
Randy Freeman*, Ph.D.	Solutia, Inc.	chemical engineering
Craig McFarlane, Ph.D.	U.S. EPA	plant physiology
Michael Norland	South Florida Natural Resource Center	plant science
Catherine A. Peters	Princeton University	environmental engineering
Robert Peters, Ph.D.	Argonne National Laboratory	chemical/environmental engineering
Steven Rock	U.S. EPA	phytoremediation
Thomas B. Stauffer	U.S. Air Force	chemistry
Michael Tucker	U.S. EPA, Region VII	biology

*Chair, 1992-1994

**Chair, 1995-1998

***Chair, 1998-Present

Table 1(B): Training and Technology Transfer Advisory Committee

Member	Affiliation	Expertise
Martha Boss	industry	certified industrial hygienist
Abbas Ghassemi	New Mexico State University	environmental engineering
Ronald Hammerschmidt	industry	environmental chemistry
Edward Heyse	govt/USAF	environmental science and engineering
Stephen Hoffman	govt/EPA	environmental management
Michael Kukuk	industry	environmental engineering
Jim Lehr	govt/EPA	environmental management
Jack Lonsinger*	industry	industrial processes
Dale Manty (ex officio)	govt/EPA	federal program management
Edward Mead	govt/Corps of Engineers	industrial processes
Robert Mournighan	govt/EPA	environmental engineering
Ella Mulford	industry	industrial processes
Dennis Murphey	govt/state	professional training
Tanell Roberts	govt/state	state regulation management
Richard Schlenker	govt/state	state regulation management

*Chair

Researchers and extension faculty from various academic programs interact through the center, bringing a diversity of perspectives to address complex problems associated with hazardous substances. Table 2 lists key personnel from each participating consortium institution and related non-consortium universities.

Key investigators at non-consortium institutions include Tissa H. Illangasekare, Colorado School of Mines; Joseph B. Hughes, Rice University; Carl G. Johnston, Mycotech Corporation; and Joel R. Coats, Iowa State University.

Table 2: Key Personnel in the Center

Haskell Indian Nations University

Jamison O. Bear

Brenda Brandon

George L. Godfrey

Daniel R. Wildcat

Lincoln University

Frieda Eivazi

Mary Wyatt

University of Northern Iowa

Barbara A. Hetrick

Catherine Zeman

Kansas State University

Philip L. Barnes

Bertram R. Biles

Terrie K. Boguski

University of Missouri

John Atkinson

Stephen H. Anderson Daniel W. Armstrong

Rakesh K. Bajpai

Shankha K. Banerji

V.M. Boddu

Joel G. Burken

P.C.-H. Chan

Thomas E. Clevenger

T.L. Feldbush

Daniel Forciniti

Syed E. Hasan

Allen W. Hatheway

Shubhender Kapila

S.K. Loyalka

Stanley E. Manahan

University of Nebraska

Istvan Bogardi

Stephen D. Comfort

Mohamed F. Dahab

Bruce Dvorak

Robert D. Grisso

Larry Hammer

Herb Hoover

D. Lewis

Dennis L. McCallister

Shirley M. Niemeyer

William L. Powers

Patrick J. Shea

David P. Shelton

Bob Volk

Wayne E. Woldt

Tian C. Zhang

South Dakota State University

Suzette Burckhard

Susan A. Gibson

James A. Rice

Vernon P. Schaefer

John C. Tracy

University of Iowa

Pedro J.J. Alvarez

David T. Gibson

Craig Just

Burt C. Kross

Gene F. Parkin

Barbara Pies

Jerry L. Schnoor

M.I. Selim

Richard L. Valentine

University of Montana

Lawrence C. Davis
Vernon Deines
Larry E. Erickson
L.T. Fan
William G. Fateley
Richard E. Faw
Steven J. Galitzer
Larry A. Glasgow
Wendy M. Griswold
William J. Hankley
Richard B. Hayter
Prasanta K. Kalita
Kenneth J. Klabunde
Peter Kulakow
Michael W. Lambert
Blase A. Leven
Alexander P. Matthews
Gene M. Meyer
Frederick W. Oehme
Gary M. Pierzynski
Lakshmi N. Reddi
Charles W. Rice
John R. Schlup
James C. Shanteau
J. Kenneth Shultis
James M. Steichen
Daniel W. Sweeney
Walter P. Walawender
LaBarbara Wigfall

Deborah J. Mossman
Thomas J. O'Keefe
R. Lee Peyton
Richard Potter
George Preckshot
Ravi K. Puri
Robert L. Segar
Dabir S. Viswanath
John L. Watson

Montana State University

Anne Camper
J. William Costerton
Al B. Cunningham
Douglas J. Dollhopf
John Goering
William P. Inskeep
Stuart R. Jennings
Warren L. Jones
Zbigniew Lewandowski
Frank F. Munshower
Dennis R. Neuman
Paul J. Sturman
Robert V. Thurston
Bryan K. Warwood
Jon M. Wraith
Nick Zelver

University of Utah

Sam Ghosh
Andrew P. Hong
Jan D. Miller
Robert W. Okey
Russ Price
H.Y. Sohn

Colorado State University

Harry W. Edwards
Kenneth F. Reardon

Utah State University

Carolyn Abbot
Bruce Bugbee
William J. Doucette
R. Ryan Dupont
Conly L. Hansen
Joan E. McLean
Russ Price
Judith L. Sims
Ronald C. Sims
Darwin L. Sorenson
Daniel Smith
David K. Stevens
Stephen B. Turcotte

Jerry J. Bromenshenk
Chris Heyer
D.G. Klarup

Montana Tech

Karl Burgher
Kevin Mellott

University of Wyoming

Lee A. Bulla
Benito M. Chen
P.S. Colberg
Jerry J. Cupal
William P. Iverson
Robert F. Kubichek
K.J. Reddy
Quentin D. Skinner
John P. Turner
George F. Vance
Roger Wilmot

EPA Regions VII and VIII have a curious diversity of interests resulting from the grouping of mineral-rich states such as Colorado, Montana, and Utah, with the states of the Great Plains whose economic foundations rest on agriculture and animal husbandry. The center defined its original mission in terms of these wide-ranging activities and has undertaken research in the following areas:

- Studies of soil and water contamination by heavy metals and mining wastes.

- Research on soil and groundwater contamination from a variety of sources.
- Development of incineration, biodegradation, and immobilization technology.
- Development of simplified and inexpensive methods for analyzing contaminated soil.
- Hazardous waste minimization.
- Determination of safe concentration levels of hazardous substances in soils and in water.

A decision was made in May 1990 to assign the highest priority to risk reduction research on soil and processes to clean up contaminated soil. Research proposals were requested based on the following needs and problems, listed here in order of their priority based on the center's current mission:

- Soil and water contamination by heavy metals such as cadmium, chromium, copper, lead, and zinc associated with mining wastes and other industrial activities. Mine tailings from past mining operations have resulted in contaminated surface and groundwater. The heavy metals listed are very similar to the heavy metals that contaminate DOE sites, except that DOE must also deal with some heavier metals.
- Soil and groundwater contamination by organic chemicals from a variety of sources. Wood preservatives, including pentachlorophenol and creosote, polynuclear aromatic hydrocarbons, carbon tetrachloride, trichloroethylene, vinyl chloride, and other chlorinated aliphatic hydrocarbons, polychlorinated biphenyls (PCBs), and dioxin have been identified as priority substances contaminating groundwater. Numerous pesticides have been identified to be hazardous substances; the fate and transport of pesticides are of particular interest because of the agricultural orientation of Regions VII and VIII. A general need exists for research to develop treatment technologies to clean up contaminated soil.
- Development of improved technologies and methods for characterization and analysis of contaminated soil. Simple inexpensive methods are desired. DOE is interested in developing improved and innovative technologies, including real-time and non-intrusive evaluation and characterization of sites.
- Development of innovative treatment technologies for remediation of contaminated soil and groundwater and for rendering wastes nonhazardous. Technologies that will lead to an *in situ* resolution of the problem are emphasized.
- Development of waste minimization and pollution prevention methods and technologies. The highest priority in this category is assigned to application of these methods to site characterization and remediation processes.

The center has supported research projects at non-consortium institutions through contracts. Less than 10% of the center's funds are allocated for projects at non-consortium institutions.

Diversity of interests in Regions VII and VIII and the large geographic area represented are further reflected in the training and technology transfer program the center currently supports. Much of the center's efforts are dedicated to support of activities that can reach large audiences with a minimum of resources. For example, issues of the center newsletter *HazTech Transfer* have been widely disseminated across the nation; an information clearinghouse at the Kansas State University Hale Library has been established and contains over 1,000 publications, including center-funded theses, dissertations, reports, and videos; the center has held annual conferences on hazardous waste research since 1986 with more than 70 papers presented at each conference; and general public environmental information activities are ongoing. Proceedings of the 1995, 1996, 1997, and 1998 conferences have been published on the Internet and in print form. Many center publications are now available on the World Wide Web at http://www.engg.ksu.edu/HSRC/home.html. These activities, augmented by some carefully selected special audience functions, appear to provide the most effective means of disseminating necessary technical information across this large and varied area.

The center's base support comes from EPA. Participating schools have all made substantial contributions as well. The U.S. Departments of Defense and Energy have partially supported several research projects. Contributions in support of the center have been received from individuals. Additional funding is also being sought through private industry and other public sector organizations; Boeing Commercial Airplane Group, Chevron Inc., Conoco Inc., Dupont, and Phytotech have contributed to the center through the Kansas State University Center for Hazardous Substance Research Industrial Partnership Program. Montana State University also has an industrial partnership program. The center's funding is summarized in Table 3.

Table 3: Great Plains/Rocky Mountain Hazardous Substance Research Center Funding

FUNDING SOURCES	CURRENT FUNDING PERIOD (May 18, 1997-	SECOND AWARD PERIOD (May 17, 1992-	FUNDS TO DATE (Since Feb. 22, 1989)

	Sept. 30, 1999)	Sept. 30, 1997)	
EPA: Five Centers Progs.	$2,801,189	$5,353,515	$12,639,194
EPA: Other	1,544,783	1,974,470	3,990,998
Other Govt: Federal			
U.S. Dept. of Defense	391,091	3,423,358	3,814,449
U.S. Dept. of Energy	0	365,000	915,000
Other Govt: State			
Consortium Universities	1,325,767	4,618,552	10,155,981
Nonconsort. Universities	55,947	279,013	533,403
Private Sector	30,000	42,000	104,000
TOTAL	$6,148,777	$16,055,908	$32,153,025

STUDENT SUPPORT	NUMBER	FUNDING*
Undergraduate	10	$59,900
Graduate	24	547,152
Post Doctoral	5	182,695
TOTAL	39	$789,747

*Includes Tuition and Travel (Rounded Annual Values)

Center Director's Report

The center provides a focal point for hazardous substance research and training and technology transfer in the Great Plains and Rocky Mountain areas comprising EPA Regions VII and VIII. A long-term goal is to serve the needs of the 10-state area using as many available resources within Regions VII and VIII as possible. For instance, training and technology transfer events offered by consortium universities and other institutions are listed in the quarterly newsletter *HazTech Transfer*. Information about the center, the annual report, and proceedings of the annual conference are available on the Internet at http://www.engg.ksu.edu/HSRC. Through personal visits, the newsletter, telephone calls, the Internet, and direct mailings, center staff have emphasized inclusiveness and the idea of "working together for a better environment." Center personnel have made visits to all of the consortium universities, several other universities, EPA regional offices, and other state and federal offices. A variety of professional gatherings and conferences have been sponsored and attended. More than 25,000 individuals have benefited directly through center activities.

A large number of the projects funded by the center include a cooperative element. Many of them involve more than one principal investigator; there is cooperation across academic department boundaries as well as institutional cooperation. In some cases, investigators are cooperating with support through two separate projects. Often publications are co-authored by two or more faculty members. Faculty from several universities have participated in workshops offered by the center. These cooperative activities have helped to strengthen environmental research and technology transfer programs at participating universities. Participating students have benefited from working with a team of investigators.

The advisory committees have been most valuable in guiding the center in selecting research and technology transfer areas to pursue and projects to support. On the advice of the Science Advisory Committee in May 1990, the director assigned the highest priority to research involving soil and processes to clean up contaminated soil, thus pursuing a focal area. Many of the new projects reflect the priority on soil-related research. Members of the committee have encouraged research on innovative applications of vegetation in bioremediation and stabilization of soil. Cooperation with other institutions and organizations has been enhanced because of leadership of committee members.

The center's administrative office is in Ward Hall at Kansas State University. Lakshmi Reddi, associate director, and Blase Leven, program manager, manage the office and provide a variety of public services, including responding to many requests for information on the activities of the center and other environmental issues. Wendy Griswold, project manager, provides administrative management for the Native American and Other Minority Academic Institutions (NAOMI) Program at Haskell Indian Nations University. Terrie Boguski, project manager, provides outreach services. Alison Hodges is the project accountant for the center.

Highlights

February 1999 marked the completion of ten years of federally funded center activities. During this time, over 100 projects have been funded, with over 250 principal investigators and students working on these projects.

In March 1997 a peer review panel of environmental professionals reviewed the center's renewal proposal, reports, publications, and other documents. At the conclusion of their site visit they prepared a report which included the following summary conclusions and recommendations:

> "The Peer Review Panel's opinion of the technical quality and management capabilities of the Great Plains/Rocky Mountain Hazardous Substance Research Center's activities over the past eight years was very favorable. The Center's research is considered to have made important contributions to the areas delineated in its proposals; productivity of most of its funded investigators is of high quality; the training and technical transfer program is effective; and the management of the Center is in the hands of a capable and dedicated Director and staff.
>
> "The Panel considers the Center to have been an effective expenditure of EPA funds and the Panel strongly recommends EPA continued funding of the Center. In addition, the timing of such funding should be sensitive to the uninterrupted support of students on the various Center projects."

As a result of this favorable review, the center received a three-year renewal award in 1997.

While it is very difficult to follow all of the positive impacts of the research, training, and technology transfer activities of the center, estimates show that cost savings due to technology innovation are more than ten dollars for each dollar expended through the center. After ten years of research through the center, utilization of vegetation in the remediation and/or stabilization of contaminated soil is becoming a widely used technology. The number of contractors actively incorporating vegetation into remediation processes is growing rapidly and the number of field sites where vegetation is part of the solution is increasing exponentially. Field studies often show cost savings of more than 60% compared to conventional pump-and-treat technology. This savings has caught the attention of those who are responsible for remediation within federal agencies and the private sector.

Research on the beneficial effects of vegetation in metals-contaminated soils and mine tailings has been applied at several field sites. The influence of mycorrhizal symbiosis on plant growth and heavy metal tolerance in mine tailings has been demonstrated and communicated. Laboratory and field research has demonstrated which soil amendments are essential to revegetate mine tailings because of the need to improve nutrient availability and water-holding capacity. Results have shown that concentrations of arsenic and cadmium in poplar tree leaves are below the level where they would be a health concern for deer and other animals. Vegetation reduces soil erosion and sediment transport to streams and rivers. Center investigators are providing information and advice to those who are revegetating heavy metal-contaminated sites. Vegetative stabilization is often the only cost-effective solution for large acreages of soils and mine tailings containing heavy metals.

Reactive barriers using zero-valent iron and microbial populations to transform contaminants such as chlorinated solvents and nitrate have been investigated and found to provide faster and more complete dechlorination and nitrate removal.

Center investigators have developed new approaches to identify and select chelators for separating heavy metals from soil. Quantitative structure-activity relationships and molecular descriptors can be incorporated into models that allow computers to be used to help identify chelators. These concepts were presented at two workshops.

The comprehensive approach to process synthesis and design developed through the center has been incorporated into spreadsheet software by a commercial firm and is now available for implementation by those who do process synthesis for chemical process industries. This will lead to significant advances in pollution prevention, save design costs, and increase profitability.

Center investigators have demonstrated that Fenton reagent is effective for oxidation of a variety of contaminants, including munitions compounds such as TNT. The work provides new information on the mechanisms of the oxidation process.

Several field projects conducted through the center have demonstrated that bioremediation occurs in the field as predicted by laboratory studies. Availability of oxygen has been shown to be an important consideration for contaminants that must be degraded aerobically. Further research is being conducted to develop cost-effective oxygen transfer technologies. Several companies have provided partial support for these field studies.

With greater emphasis being placed on risk-based hazardous substance management, the center has supported projects designed to understand the fate of environmental contaminants that are bound strongly to soil organic matter. Analytical methods have been developed and applied to investigate contaminant fate. The new knowledge and methods are important to risk-based decision making.

The Research and Re-education for Displaced Defense Personnel (R2D2) program was in place from 1995 to 1998. The R2D2 program was national in scope, with all five centers receiving funding to involve former defense personnel in research programs working on center-funded research projects at center consortium universities. This program enrolled more than 70 displaced Department of Defense employees at HSRC consortium universities. These students worked on center projects to improve remediation technologies at defense sites. New technologies are now available for field application and graduates of the program have advanced to professional positions.

The Technical Outreach Services for Communities program continues to provide assistance to communities impacted by hazardous waste in EPA Regions VII and VIII. Blase Leven and Terrie Boguski provide leadership for this program and the Technical Assistance to Brownfields program. Recent projects include presentations and workshops for citizens in affected communities, and assistance to community groups in South Dakota, Montana, Iowa, Wyoming, Kansas, Colorado, and Missouri. This program matches expertise of center professionals with needs of communities to provide customized education and assistance to community groups dealing with hazardous waste cleanups, permitting, and risk assessment issues.

The Native American and Other Minority Institutions (NAOMI) program has benefited over 60 minority academic institutions (MAIs). Faculty members and students from several MAIs—historically black universities, Native American universities, and predominantly Hispanic universities—have participated in the annual conference and/or the NAOMI Summer Cooperation Program. The NAOMI program has also produced or co-produced several video seminars and satellite-uplinked seminars.

The Technical Outreach Services for Native American Communities (TOSNAC) program has been expanded and a full-time professional, Brenda Brandon, has been hired to provide services to tribal communities. The Oglala Lakota Nation in South Dakota, which has concerns because of the Badlands Bombing Range, is one of many tribal groups being helped through this program.

A very important event this year was the 1999 Conference on Hazardous Waste Research, held in St. Louis, Missouri, May 25-27, 1999. The conference, workshops, and tours attracted approximately 250 participants and 120 papers. Conference topics included sediments, phytoremediation, metals-contaminated soil, remediation processes, biofilms, and barriers. The proceedings are being made available in print form and on the Internet at http://www.engg.ksu.edu/HSRC. The South/Southwest HSRC was one of several cosponsors of the conference.

Amy Ryser, a high school student from Wamego, Kansas, was honored for her poster "Phytoremediation of Crude Oil-Contaminated Soil" at the 12th Annual Conference. Peter Kulakow, one of the center’s investigators, advised Amy in her research.

Louis Licht, University of Iowa bioremediation researcher and CEO of Ecolotree, Inc., was honored in 1996 for utilizing a poplar tree technology developed by Licht and Jerald Schnoor. The American Council of Engineering Consultants selected Ecolotree, Inc., for an Honor Award in the 1996 Engineering Excellence Awards competition for its role in the design, installation, and management of an innovative engineered plant system project for the Woodburn, Oregon, wastewater treatment plant. Poplar trees have been installed at over 40 sites in 11 states and Europe.

Kenneth Klabunde, distinguished professor of chemistry at Kansas State University and a center researcher since 1990, is behind a Manhattan, Kansas, business, Nantek, Inc., which will commercialize the destructive adsorbent technology which has been developed at the laboratory scale. Nantek was selected to receive one of the six 1997 Silicon Prairie Technology of the Year Awards.

A team of chemical engineering seniors under the direction of HSRC faculty designed a plant-based landfill leachate treatment process for Riley County, Kansas. Alfalfa and cottonwood trees have been planted at the site. Use of this innovative technology is expected to save Riley County several million dollars.

Joel Burken and Jerry Schnoor won the 1998 Rudolph Hering Medal from the American Society of Civil Engineers for their paper "Phytoremediation: Plant Uptake of Atrazine and the Role of Exudates" in the *Journal of Environmental Engineering* (ASCE).

Since 1997, the center has become more involved in assisting with brownfield projects and remediation activities at contaminated field sites. Center investigators have responded to requests for assistance from consultants, responsible parties, EPA professionals, state regulators, and community leaders. Funding in support of brownfield activities has enabled the center to provide considerable assistance to community leaders. Educational workshops have been offered in several locations.

HazTech Transfer, the center's quarterly newsletter, continues to be published and distributed to more than 4,000 individuals. *Centerpoint* and *Newspoint*, joint publications of the five centers, have continued to be published with responsibility for managing and editing of each issue revolving among the HSRCs. *Earth Medicine*, the newsletter of the NAOMI program, is published and distributed to minority academic institutions, center consortium universities, tribal offices, government agencies, and other interested individuals.

This year the center has added many pages on the World Wide Web. Center pages include a wealth of information about the center and its programs. Individuals all over the world can access the center's Web pages and find copies of center publications, conference proceedings, journal papers, funded project descriptions, information about center personnel, and general information about the center. The center's home page can be accessed at http://www.engg.ksu.edu/HSRC. There is also a home page for the national HSRC program and information on the four other centers at http://www.hsrc.org. The Magellan Internet Guide recently gave the HSRC Web site a rating of three out of a possible four stars. The center's Internet site has approximately 10,000 hits per month; about 15% of these are from outside the United States.

The popular workshop on "Beneficial Effects of Vegetation in Contaminated Soil" was presented in January 1998 for the sixth time. The center, in cooperation with Kansas Department of Health and Environment, Interstate Technology and Regulatory Cooperation Working Group, and the Remediation Technologies Development Forum, conducted a workshop on "Natural Attenuation of Chlorinated Solvents in Groundwater," in Kansas City. A workshop on environmental analysis of surface and groundwater contaminants was conducted for members of several Native American tribes by faculty from Sinte Gleska University and the University of Nebraska.

As shown by the listing of theses and dissertations in the bibliography, many students have helped with center projects while conducting research required for their advanced degrees. Many of these graduates now have important positions with contractors, industry, government, and universities. Their movement from the university to their places of employment has resulted in technology transfer that has enhanced innovation.

The center repository continues to be a resource for researchers nationwide. Publications that result from funded center projects are placed in the repository at Kansas State University's Hale Library and are available through interlibrary loan.

The Great Plains/Rocky Mountain Hazardous Substance Research Center, the National Mine Land Reclamation Center, and the Waste-management Education and Research Consortium have initiated a cooperative effort to address the following environmental research and technology transfer needs associated with mining and mine lands: 1) national environmental leadership in research and technology transfer; 2) research to develop innovative technologies to reclaim and restore mine lands and recover minerals from mine spoil; 3) professional support on scientific issues to bring good science into decision making; 4) advanced degree graduates with environmental expertise in mine land reclamation and resource recovery; and 5) environmental expertise to support mining and mineral processing industries with special consideration for small-scale operators.

ten-year review of research and technology transfer activities

Progress in Remediation of Contaminated Soil and Groundwater

Since February 1989, when the Hazardous Substance Research Centers were created, innovative technologies have been developed for remediation of contaminated soil and groundwater.

Alternatives to conventional pump-and-treat technologies have been developed. The center has supported biobarrier technologies that can be used for plume management and containment. This technology has shown promise in the laboratory and field testing is now in progress. Plant systems are being used for plume control either alone or in combination with conventional pump-and-treat technologies. Vegetation brings contaminated water to the root zone of the plants. Biodegradation occurs when the contaminants can be biodegraded aerobically. Root-zone biodegradation has been observed for compounds such as toluene, phenol, and polynuclear aromatic hydrocarbons. Some volatile compounds such as chlorinated aliphatic hydrocarbons diffuse into the atmosphere. These compounds move through the soil and the

vegetation. The plants enhance the transport to the atmosphere by removing water from the soil, by transporting contaminated water upward through the roots and stem, and by lowering the water table to expose volatile compounds to an unsaturated environment where gas-phase transport occurs. In the atmosphere, these compounds are degraded by sunlight and chemical processes.

Another technology that has been developed for plumes is to allow the contaminated water to flow through a treatment zone where degradation occurs. Zero-valent metal processes and biodegradation processes have been investigated for use in this and other applications. Microbial degradation processes when combined with zero-valent metal abiotic processes have been demonstrated to be more effective than either process alone.

Management of groundwater flow in the subsurface is complex. Center faculty have contributed to a better understanding of contaminant transport at sites where nonaqueous-phase contaminants are present. This includes progress in understanding groundwater flow, dissolution of contaminants which are present in a nonaqueous phase, and entrapment of nonaqueous-phase liquids.

Research has advanced our knowledge of the fate of organic compounds when bioremediation and phytoremediation are applied. Some organic contaminants bind to organic matter associated with the soil. By using radio labeling and fractionating, center investigators have shown that most bound organic contaminants are associated with humic acid and the lipid components of humin in soil. In both bioremediation and phytoremediation, some compounds are transformed to other chemical forms. Some contaminants react to form dimers and other higher molecular weight compounds. Others are incorporated into microbial and/or plant biomass. Toxicity tests provide one method of evaluating the reduction of risk associated with a remediation process.

Results of center research have been applied by consultants, regulators, and many others. New companies such as Ecolotree, Phytokinetics, and Phytotech have been established to provide professional remediation services. Established companies such as CH2MHill have hired center graduates and employed them in positions where the innovative technologies are applied. Other companies such as Nantek have been formed to commercialize products that can be used in a variety of environmental applications.

From the Flask to the Field: Vegetative Remediation of Mine Tailings

Since the mid-1980s, the Reclamation Research Unit (RRU) at Montana State University-Bozeman has performed treatability studies and designed land reclamation/restoration techniques for a complex of Superfund sites in the Butte and Anaconda, Montana, areas. Beginning in 1993, the GP/RM HSRC and the state of Montana funded benchtop, greenhouse, and field-scale development of a mine tailings re-processing and vegetation method. This technique was successfully demonstrated in bench and greenhouse work and is now being field tested at an operating mine. Work to stabilize and prevent the spread of contamination using vegetation has also been funded by the HSRC in other mining areas.

The method involves use of conventional ore-processing techniques (gravimetric or flotation separation) to remove sulfide minerals from mine tailings. This is an alternative or supplementary method to the use of chemical amendments to reduce acids and metals resulting from weathering of sulfide minerals in tailings over time. The goal is to produce soil-like material that can support vegetation for caps placed over large areas of tailings. Suitable topsoil for vegetated caps is usually not available close to tailings.

Reprocessing of sulfide tailings to decrease plant-inhibitory metal and arsenic levels was successfully completed at the bench scale (~200 kg, three different samples) and at the field pilot scale (~200 tons, one site). Analytical results indicate metal levels were typically decreased in cleaned tailings and were concentrated into approximately 10% of the pretreatment mass. Revegetation of the cleaned tailings (approximately 90% of the pretreatment mass) is analogous to revegetation of silicate-dominated sand. Requirements for addition of lime to prevent future acidity in reprocessed tailings are typically reduced by approximately 95%. None of the high-grade concentrates resulting from treatment failed TCLP analysis, and therefore they can be either disposed as non-hazardous waste or further processed to recover metals (when feasible).

Vegetation establishment was successfully demonstrated during greenhouse evaluation of bench-cleaned tailing material. Basin wildrye (*Leymus cinereus*) and Kentucky Bluegrass (*Poa pratensis*) grew adequately in reprocessed tailings and in tailings amended with lime and compost, compared to plants grown in greenhouse potting soil. However, when the common sunflower (*Helianthus annus*) was planted in both reprocessed and amended tailings from one site, only the reprocessed tailing supported plant growth. Revegetation and monitoring of field test plots will occur during the spring and summer of 2000.

Treatment effectiveness and cost appear to vary from site to site, but the prevalence and technological maturity of mineral separation equipment in use in the mining industry suggest a strong potential for low-cost adaptation of mining technology to remedial treatment. At the Anaconda, Montana, Superfund site, use of chemical amendments to create vegetated caps alone will save more than $150 million over the use of topsoil. Stabilization of contaminated materials with vegetated caps, instead of removal and disposal of all tailings, will save over $1.0 billion.

Work has also been underway at Superfund sites along Whitewood Creek in South Dakota and in southeast Kansas to stabilize and prevent the spread of contamination from streamside tailings and smelter wastes, respectively, using poplar trees, grasses, and other forms of vegetation. In the Galena, Kansas, area, researchers are evaluating effectiveness of vegetation treatments on chat tailings to prevent erosion and ground / surface water quality impacts. Much work remains to understand how to establish self-sustaining vegetative ecosystems and their effects on preventing the spread or transport of contaminants, and to evaluate the permanence of this approach.

Technology Transfer in Indian Country

To improve the ability of tribal nations to address their environmental issues, the Great Plains/Rocky Mountain Hazardous Substance Research Center (GP/RM HSRC) provides environmental training, technology transfer services, and public education to tribal communities. The main thrust of the HSRC's Native American programs has been provided by Haskell Indian Nations University through the Haskell Environmental Research Studies Center (HERS). Haskell, a GP/RM HSRC consortium member, is a keystone institution for education, research, and extension in environmental science for American Indian tribal nations and Alaska Native communities.

Currently, there are over 771 federally recognized American Indian tribes and Alaska Native villages. This number represents a broad range of diversity with respect to cultural, economic, and environmental issues. Examples of these issues include several related to hazardous wastes. Wastes from gold mining (Fort Belknap Reservation, Montana; Cheyenne River, South Dakota) and coal mining (Northern Cheyenne Tribes, Montana) have possibly led to contamination of drinking water supplies. Closure of uranium mines and stored tailings are only some of the environmental challenges facing the Navajo Nation in Arizona and New Mexico. Unexploded ordnance and unknown contaminants on gunnery ranges in the Oglala Lakota Nation (Pine Ridge, South Dakota) and Cheyenne River Reservation (South Dakota) threaten soil and water contamination. In addition to hazardous waste issues, many tribes have brownfield properties within their borders. Issues of concern for these tribes are varied, ranging from remediation of abandoned rail yards to contamination from coal-burning residue and asbestos releases.

While many tribes in the U.S. are faced with serious environmental challenges, their ability to address them is hindered by several issues. Many tribal governments lack the funds and, consequently, the infrastructure to adequately protect their natural resources. HERS assessments of several tribes revealed that some of the reservations had environmental professionals who could quickly pinpoint the environmental degradation on their lands and its causes, while in other cases, responsibility for environmental activities fell to those with little training in this area– the tribal real estate agent or the tribal treasurer. Staff in tribal environmental programs play many roles. Environmental issues can lose focus due to political and financial situations. There is also a high turnover rate for environmental professionals in many tribal programs due to tribal political structure. In addition, there are a limited number of Native American environmental professionals from which tribes can draw qualified environmental staff.

With funding provided from the Native American and Other Minority Institutions (NAOMI) program, the HSRC was able to support a collaborative training effort between Sinte Gleska University (a tribally controlled college) and the University of Nebraska-Lincoln (a GP/RM HSRC consortium member) in 1996. A workshop was developed that focused on water quality parameters, basic environmental analysis techniques, data, and use of field sampling and environmental analysis equipment. This type of training benefits tribes in many ways. With proper training in water quality monitoring, tribal water resources offices can become more self-sufficient. Although the GP/RM HSRC provided funding for SGU and UNL to offer one workshop, Ben Whiting (SGU) and Bruce Dvorak (UNL) were able to obtain subsequent funding from EPA to offer the workshop for additional tribes. A modified version of the workshop was also presented at the Kickapoo Nation of Kansas in summer 1997 with support from Haskell's natural resources program. Throughout successive years, HERS has coordinated the delivery of other technical training to tribal environmental professionals. Topics include air quality management, environmental cleanup and compliance issues, and field-based site characterization and analytical and sampling technologies.

In addition to providing training opportunities for tribal environmental professionals, the GP/RM HSRC has established programs to provide personalized, on-site assistance to tribal environmental programs and communities dealing with hazardous waste and brownfield issues. The Technical Outreach Services for Native American Communities (TOSNAC)

program was officially established in March 1998. The goal of this program is to provide educational resources concerning hazardous substance contamination to individuals, community groups, and environmental programs in affected tribal communities. TOSNAC draws upon the expertise of several HSRC consortium members to provide assistance to tribal communities throughout the U.S.

In its two years of existence, the TOSNAC program has provided assistance to 45 tribal nations and pueblos. One of the tribal nations assisted is the Passamoquody Nation in Maine. The tribe is dealing with PCB contamination of rivers and lakes on tribal land from a nearby Army surplus salvage yard. TOSNAC has provided education to the tribe on the impacts of PCB contamination, conducted ecological and cultural risk assessments, and helped the tribe to compile its comments to the Environmental Protection Agency on this issue. At this particular site, TOSNAC worked with the Technical Outreach Services for Communities (TOSC) staff from the Northeast HSRC to provide the Passamoquody with technical assistance.

In order to provide resources for future and current tribal environmental professionals, the GP/RM HSRC funds the Haskell Environmental Seminar Series (HESS). The purpose of HESS is to provide resources on environmental issues relevant to Indian Country, tribal colleges, environmental offices, and community programs. There are currently 129 participants in the seminar program. Of these, approximately 50 members are based at a tribal college or environmental program. Throughout its six-year history, HERS has produced 22 video and satellite uplink programs in support of the seminar series. The seminar programs are used in classrooms at tribal colleges as teaching aids and are also used by tribal environmental offices as continuing educational materials. Only limited resources are available that feature Native American environmental professionals presenting information relevant to tribal environmental issues.

While tribal nations have great needs with respect to environmental challenges, the GP/RM HSRC framework has provided a mechanism for beginning to address them. Combining the cultural knowledge of a Native American educational institution with the technical knowledge of HSRC consortium institutions has opened a door to providing technical assistance to Indian Country.

Future Directions

The 2000 Annual Conference on Hazardous Waste Research has been set for May 23-25 in Denver, Colorado. This year's conference theme is "Environmental Challenges and Solutions to Resource Development, Production, and Use." Conference co-sponsors are U.S. Environmental Protection Agency, National Institute for Environmental Health Sciences, National Mine Land Reclamation Center, Air Force Office of Scientific Research, U.S. Army Research Office, U.S. Army Corps of Engineers Waterways Experiment Station, Mine Waste Technology Program, the Waste-management Education and Research Consortium, and several other organizations.

With the ever-increasing number of users of the Internet and, more specifically, the World Wide Web, center personnel plan to increase availability of center resources through this medium. Many center publications have already been put on the Web, including electronic publishing of the center's conference proceedings. Efforts to publish peer-reviewed papers in the electronic *Journal of Hazardous Substance Research* are underway. Several papers were published in 1998 and 1999. Plans are to publish 20 to 40 manuscripts each year in electronic format. Hypertext Markup Language (HTML) and Adobe Acrobat will be utilized to publish the journal. Through use of electronic media, this document can be published quickly and inexpensively and has the capability to provide hyperlinks to references as well as graphics, video, and sound. These features can be used to allow users to run simulation models.

During the past ten years, significant progress has been made in developing the capability of the consortium faculty to conduct research in support of Superfund and problems associated with contaminated soil. As a result, many more consortium faculty are actively conducting hazardous substance research now than before the center was established. These faculty are supported with center funds and/or funds from other sources. Because of technological developments associated with the research and growth in faculty expertise, there are more opportunities for site-specific projects. Some of these are funded through the center while others are funded directly.

Professionals at Montana State University are providing leadership for the 8th Billings Symposium on Disturbed Land Rehabilitation, which is scheduled for March 20-24, 2000. This symposium has focused on land reclamation and rehabilitation issues relevant to the Great Plains and Intermountain West.

Program Summary

February 22, 1989 - September 30, 1999

HEAVY METAL CONTAMINATION OF SOIL/WATER

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Keefer	$54k/$0k	3 1990	Metal Recovery and Reuse Using an Integrated Vermiculite Ion Exchange-Acid Recovery System
Hansen, Stevens	$167k/$0k	89-09 1991	Optimal Bioreactor Design for Biological Removal of Mercury
O'Keefe, Watson	$129k/$0k	17 1991	Characterization and Treatment of Hazardous Materials from Metal Mineral Processing Wastes
Walton	$150k/$0k	89-19 1992	An Electrochemical Method for Acid Mine Drainage Remediation and Metals Recovery
Lewandowski	$96k/$0k	89-22 1992	Heavy Metals Removal from Dilute Aqueous Solutions Using Biopolymers
Faw	$78k/$0k	89-29 1992	Neutron Activation Analysis for Heavy Metal Contaminants in the Environment
Clevenger, Hinderberger	$224k/$0k	2 1992	Reclamation of Metal- and Mining-Contaminated Superfund Sites Using Sewage Sludge/Fly Ash Amendments
Pierzynski, Schwab	$94k/$0k	89-30 1992	Reducing Heavy Metal Availability to Perennial Grasses and Row Crops Grown on Contaminated Soils and Mine Spoils
Ghosh	$140k/$0k	4 1992	Removal of Heavy Metals from Hazardous Wastes by Protein Complexation for Their Ultimate Recovery and Reuse
Dollhopf	$132k/$0k	89-21 1992	Sulfide Size and Morphology Identification for Remediation of Acid-Producing Mine Wastes
O'Keefe, Cole, Watson	$206k/$0k	90-16 1994	Development of Electrochemical Processes for Improved Treatment of Lead Wastes
Banks, Hetrick, Schwab	$306k/$0k	90-11 1994	Impact of Soil Microflora on Revegetation Efforts in Southeast Kansas
Schnoor, Licht	$213k/$0k	90-05	Innovative Treatment and Bank Stabilization of Metals-Contaminated Soils and Tailings Along Whitewood Creek,

		1994	South Dakota
Pierzynski, Davis, Reddi, Erickson, Schnoor	$247k/$0k	92-05 1997	Use of Poplar Trees in Remediating Heavy Metal-Contaminated Sites
Lewandowski, Geesey, Roe	$283k/$0k	92-08 1997	Heavy Metals Removal from Contaminated Water Solutions
Schnoor, Licht, St. Clair, Just, Erickson	$214k/$0k	92-11 1996	Metals Soil Pollution and Vegetative Remediation

HEAVY METAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Munshower, Jennings	$270k/$0k	93-12 1999	Acid-Producing Metalliferous Waste Reclamation by Material Reprocessing and Vegetative Stabilization
Hong, Okey, Banerji	$239k/$0k	93-22 1997	Chelating Extraction of Heavy Metals from Contaminated Soils
Schwab, Banks, Erickson, Tracy	$401k/$0k	93-06 1998	Fate and Transport of Heavy Metals and Radionuclides in Soil: The Impacts of Vegetation
Hetrick, Pierzynski, Erickson, Govindaraju, Sweeney	$419k/$21k	93-07 2000	Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants
O'Keefe	$336k/$23k	94-05 2000	Design and Development of an Innovative Industrial-Scale Process to Economically Treat Waste Zinc Residues

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Hunter, Culver	$28k/$0k	15 1990	Computer Method to Estimate Safe Level Water Quality Concentrations for Organic Chemicals

Schlup	$60k/$0k	18 1991	Adsorption of Hazardous Substances onto Soil Constituents
Kross	$160k/$0k	16 1991	Removal of Nitrogenous Pesticides from Rural Well Water Supplies by Enzymatic Ozonation Process
Dickey, Shelton, Steichen, Barnes	$338k/$0k	89-31 1993	Alachlor and Atrazine Losses from Runoff and Erosion in the Blue River Basin
Ghosh	$218k/$0k	89-06 1992	Biodetoxification of Hazardous Solid Wastes by Staged Anaerobic Fermentation Conducted at Separate Redox and pH Environments
Parkin	$84k/$0k	90-04 1992	Biotransformation of Alachlor and Atrazine Under Denitrifying Conditions in Soil-Water Systems
Erickson, Fan	$224k/$0k	6 1992	Development of *In Situ* Biodegradation Technology
Illangasekare	$196k/$0k	89-01 1992	Distribution and Recovery of Refinery Waste Products in Groundwater Aquifers: Experimental Study and Model Evaluation

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Parkin, Gibson	$259k/$0k	5 1992	Feasibility of *In Situ* Anaerobic Bioreclamation of Mixtures of Toxic Chemicals: Feasibility of Using Genetically Engineered Bacteria to Degrade Trichloroethylene in Activated-Sludge Systems
Characklis, Jones, Cunningham, Lewandowski	$394k/$0k	89-23 1992	*In Situ* Bioremediation of Organic Groundwater Contaminants
Banerji, Bajpai	$323k/$0k	7 1992	Migration and Biodegradation of Pentachlorophenol in Soil Environment
Schnoor, Parkin	$349k/$0k	10 1992	Modeling Dissolved Oxygen, Nitrate, and Pesticide Contamination in the Subsurface Environment
Yanders,	$327k/$0k	9	Time-Dependent Movement of Dioxin and Related

Kapila		1992	Compounds in Soil
Glasgow	$141k/$0k	11 1992	Vadose Zone Decontamination by Air Injection
Schnoor, Licht	$246k/$0k	89-10 1994	Deep-Rooted Poplar Trees as an Innovative Treatment Technology for Pesticide and Toxic Organics Removal from Groundwater
Schnoor, Licht	$39k/$0k	R-1 1993	The Role of Deep-Rooted Poplar Trees in Adding Organic Carbon to the Soil for Pesticides and Toxic Organics Removal
Parkin	$135k/$0k	91-08 1994	The Effect of Redox Conditions on Transformations of Carbon Tetrachloride
Kapila, Armstrong, Puri	$282k/$0k	91-04 1994	Laboratory and Field Evaluation of Upward Mobilization and Photodegradation of Polychlorinated Dibenzo-P-Dioxins
Cunningham, Costerton	$306k/$0k	91-25 1994	Microbial Transport in Porous Media
Tracy, Davis, Erickson, Schnoor	$367k/$0k	90-13 1995	Modeling the Use of Plants in the Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances
Licht, Schnoor	$349k/$0k	91-03 1995	Riparian Poplar Tree Buffer Impact on Non-Point Source Surface Water Contamination
Parkin	$214k/$0k	91-07 1995	Formation and Transformation of Pesticide Degradation Products Under Various Electron Acceptor Conditions
Illangasekare	$477k/$0k	91-10 1997	Modeling for Design and Testing of Treatment and Remediation Technologies for Aquifer Soils Contaminated with Organic Waste Chemicals
Erickson, Fan	$269k/$0k	91-29 1996	Remediation of Soil Contaminated with an Organic Phase

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion	Project Title

		Date	
Coats, Anderson	$152k/$0k	93-05 1997	Use of Vegetation to Enhance Bioremediation of Surface Soils Contaminated with Pesticide Wastes
Kapila, Forciniti, Armstrong	$142k/$0k	93-16 1996	Laboratory and Field Evaluation of Upward Mobilization and Photodegradation of Polychlorinated Aromatics in Soil
Bajpai, Banerji, Puri, Zappi	$281k/$0k	94-08 1998	Remediation of Soils Contaminated with Wood-Treatment Chemicals (PCP and Creosote)
Gibson, Tracy, Kennedy	*	NCIBRD 1 1997	Use of C_2 to C_{18} Organic Acids and Selected Surfactants to Enhance Bioremediation of DNAPL-Contaminated Aquifers
Parkin,Schnoor, Alvarez	$416k/$21k	93-02 2000	The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics
Parkin	$198k/$13k	93-24 2000	Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination
Segar	$204k/$11k	94-07 2000	Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors
Schnoor, Burken	$475k/$21k	94-25 2000	Uptake of BETX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation
Davis, Erickson	$345k/$16k	94-27 2000	Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies
Illangasekare	$521k/$26k	94-29 2000	Extension of Laboratory-Validated Treatment and Remediation Technologies to Field Problems in Aquifer Soil and Water Contamination by Organic Waste Chemicals
Miller	$158k/$0k	94-15 1998	Removal of Chlorinated Hydrocarbons from Contaminated Water Using Air-Sparged Hydrocyclone Technology
Doucette, Bugbee, Stevens	$504k/$124k	95-10 2000	Fate of Trichloroethylene (TCE) in Plant/Soil Systems: Evaluating Phytoremediation
Zhang, Comfort, Shea	$361k/$120k	95-32 2000	Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes
Schnoor	$299k/$87k	95-29	Plant Enzyme Systems for the Phytoremediation of Chlorinated Aliphatics in Contaminated Soils

		2000	
O'Connor, Brazos	$61k/$0k	89-17 1991	The Response of Natural Groundwater Bacteria to Groundwater Contamination by Gasoline in a Karst Region

* Funded through the Great Lakes/Mid-Atlantic Hazardous Substance Research Center

ORGANIC CHEMICAL CONTAMINATION OF SOIL/WATER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Schwab, Banks, Leven	$84k/$84	SP96-Riley 2000	Field Validation of an Optimal Design Methodology for Vegetative Remediation of Sediments from the Central Vehicle Wash Facility, Custer Hill, Fort Riley, Kansas
Erickson	$100K/$100K	RTDF 2000	Data Management and Horticultural Evaluation of Field Sites for the RTDF Phytoremediation Field Test of Petroleum Hydrocarbon-Contaminated Soils

ANALYSIS/TREATMENT OF CONTAMINATED SOIL

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Walawender, Fan	$149k/$0k	12 1991	Thermochemical Treatment of Hazardous Wastes
Viswanath, Kapila, Clevenger	$462k/$0k	13 1992	Development, Characterization, and Evaluation of Adsorbent Materials for Waste Streams
Fan	$153k/$0k	1 1992	Experimental Study of Stabilization/Solidification of Hazardous Substances
Peyton, Anderson	$154k/$0k	89-14 1992	Simulation of Three-Dimensional Transport of Hazardous Chemicals in Heterogeneous Porous Media Using X-Ray Computer Tomography
Valentine	$172k/$0k	89-11 1994	*In Situ* Soil and Aquifer Decontamination Using Hydrogen Peroxide and Fenton's Reagent
Klabunde	$394k/$0k	92-03 89-26 1996	Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances
Comfort, Shea	$294k/$0k	92-24	Fate and Transport of Munitions Residues in

Comfort, Shea, McCallister, Powers	$294k/$0k	92-24 1997	Fate and Transport of Munitions Residues in Contaminated Soils
Dupont, Sorensen, Doucette	$439k/$0k	93-20 1998	Evaluation of Biosparging Performance and Process Fundamentals for Site Remediation
Faw, Shultis	$134k/$0k	94-02 1997	Application of PGNAA Remote Sensing Methods to Real-Time, Non-Intrusive Determination of Contaminant Profiles in Soil
Dupont, Sorensen, Kemblowski, Smith	$62k/$0k	SP95-TCE 1996	TCE Attenuation in Groundwater in Severe Northern Climates

ANALYSIS/TREATMENT OF CONTAMINATED SOIL (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
R.C. Sims	$430k/$13k	93-21 2000	Field-Scale Bioremediation: Relationship of Parent Compound Disappearance to Humification, Mineralization, Leaching, and Volatilization of Transformation Intermediates
Inskeep, Johnston, Wraith	$264k/$0k	94-09 1999	Effects of Surfactants on the Bioavailability and Biodegradation of Contaminants in Soils
Rice	$242k/$0k	94-11 1999	Contaminant Binding to the Humin Fraction of Soil Organic Matter
Tracy, Van Lent, Schaefer	$196k/$18k	94-12 2000	Development of a Systematic Methodology for Optimally Designing Vegetative Systems for Remediating Contaminated Soil and Groundwater
Kubichek, Iverson, Cupal	$329k/$0k	94-24 1999	Identifying Groundwater Threats from Improperly Abandoned Boreholes
Turner, Bulla, Skinner	$229k/$0k	94-26 1998	Biofilm Barriers for Waste Containment
Cunningham, Chen	$399k/$20k	93-11 94-28 2000	Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence
Klabunde	$237k/$108k	95-04a	

		2000	Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances in Air, Water, and/or as an Alternative to Incineration

WASTE MINIMIZATION

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Fan	$194k/$0k	14 1992	Computer-Aided Design and Control of Systems for Treatment of Hazardous Waste and Minimization of Waste Production
Fan	$179k/$0k	91-36 1996	Intelligent Process Design and Control for the Minimization of Waste Production and Treatment of Hazardous Waste

TRAINING AND TECHNOLOGY TRANSFER

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Gilliland, Kelly	$128k/$0k	1991	Hazardous Waste Management in Rural Communities in EPA Regions VII and VIII
Harbourt	$265k/$0k	1992	Introduction to Hazardous Waste Management

TRAINING AND TECHNOLOGY TRANSFER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Hiskey	$68k/$0k	1992	Introduction to Waste Minimization Technology and Applications
Kross	$31k/$0k	1992	Remediation of Pesticide Spills: Technology Transfer to Volunteer Firefighters
Biles	$45k/$0k	1992	Technology Database
Edwards	$20k/$0k	1992	Transfer of Manufacturing Pollution Prevention Technology
Hayter	$52k/$0k	1992	Video Conference
Hayter	$35k/$0k	1993	Five-Center HSRC Training and Technology Transfer Conference

Grant	$65k/$0k	PRP 1993	Superfund PRP Conference
Kelly, Keefer, Rohde, Woldt	$77k/$0k	TR92-03a 1995	A Short Course on Remediation of Contaminated Soils and Sediments
Dahab, Woldt	$78k/$0k	TR92-03b 1995	Development of Pollution Prevention Programs for Small Quantity Generators in EPA Regions VII and VIII
Niemeyer, Woldt, Dahab, Grisso	$38k/$0k	TR92-04 1995	Waste Management: Development of Pollution Prevention Educational Materials for Farms and Small Acreages
Grant	$141k/$0k	TR92-PI 1995	HSRC Technology Transfer Public Information Services
R.C. Sims	$212k/$0k	TR-LIBBY 1997	Libby, Montana, Superfund Site: Prepared-Bed Bioremediation in Buried Lifts as Affected by Oxygen Concentration in Soil Gas
Thurston	$54k/$0k	TR94-02 1995	Training to Advance Environmental Research in Lithuania
Cunningham, Warwood, Zelver	$53k/$0k	TR93-02 1996	Engineering Scaleup of *In Situ* Bioremediation Processes: A Workshop on Biotreatability
Grant, Griswold	$804k/$0k	NAOMI 1998	Native American and Other Minority Institutions Program
Wolfe, Erickson,Leven	$396k/$19k	TR-01 2000	Conferences and Workshops
Hayter, Leven	$131k/$3k	TR-01 2000	HSRC Contribution Repository and Information Clearinghouse
Reddi, Leven	$356k/$10k	TR-01 2000	HSRC Newsletter, *HazTech Transfer*
J.L. Sims, R.C. Sims	$182k/$0k	TR93-07 1997	Guidance for the Use of Prepared-Bed Land Treatment as a Bioremedial Technology
Banks, Schwab, Govindaraju	$301k/$0k	D93-01 1997	Bioremediation of Petroleum-Contaminated Soil Using Vegetation
McDonald, Leven,	$1,830k/$365k	SP93-01	Technical Outreach Services to Communities Program, Technical Support to Brownfields

Deines, Wigfall		2000	

TRAINING AND TECHNOLOGY TRANSFER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Leven, Grant	$638k/$0k	R2D2 1998	Research and Re-education for Displaced Defense Personnel Program
Erickson	$37k/$0k	TR95-10 1998	Virtual Library
Reddi	$18k/$0k	TR95-11 1997	Environmental Data Technology Transfer Project
Leven, Godfrey Griswold	$142k/$10k	TR96-05 2000	Collaborative Environmental Seminar Series
Griswold, Brandon	$259k/$75k	TOSNAC 2000	Technical Outreach Services to Native American Communities
J.L. Sims	$81k/35k	TR97-07 2000	Development of a "State-of-the-Science and Technology" Report on Site-Characterization Technologies

Research Project Descriptions

May 18, 1995 - September 30, 1999

Fate and Transport of Heavy Metals and Radionuclides in Soil: The Impacts of Vegetation

A.P. Schwab, M.K. Banks, and L.E. Erickson, Kansas State University;

and J.C. Tracy, South Dakota State University

Project no.: 93-06

Goals: The overall objective of this research was to determine whether establishment of vegetation in heavy metal- and radionuclide-contaminated soil will significantly affect retention of metals in soils and to develop mathematical models to predict the movement of metals in vegetated versus unvegetated soil.

Rationale: Vegetation is often the primary method of reclamation in mining areas to stabilize waste with respect to wind and water erosion and to minimize downward translocation of contaminants. Plants may reduce the possibility of metal leaching through decreased water infiltration, adsorption of metals to root surfaces, plant uptake of metals, and stimulated microbial immobilization in the rhizosphere. However, plants may also increase metal leaching through reactions with rhizosphere organic acids exuded by roots, produced by microbial activity, or generated by decomposition of soil organic matter. Field and laboratory determinations are needed to quantify the effects of vegetation on the leaching of metals. Models that attempt to predict the fate of heavy metals in soils have focused primarily on the geochemical aspects of the problem and have not considered the effect of a plant’s geochemistry. The difficulty associated with using models to

simulate the fate of a heavy metal in the root-soil environment is properly accounting for all interactions among water movement, contaminant transport, and uptake of water and metals by plant roots and geochemistry.

Approach: Impact of vegetation and revegetation schemes on the mobility of metals (lead, cadmium, zinc, barium, etc.) was investigated on contaminated soil and/or mine waste from zinc and lead mining regions of southeast Kansas, lead mines of Montana, and a paint-producing industry in southern Kansas. A series of experiments was employed to pursue the following objectives: a sequential extraction procedure for determination of various fractions and mineral associations of the metals; batch (laboratory-scale equilibrations) and column experiments to directly assess impact of organic acids on heavy metal mobility; large soil columns to determine effects of vegetation overlying soil depth on mobility of metals and metal uptake by plants; sorption/desorption and determination of potential or existing solid phases of the metals to quantify the soil chemical aspects of metal retention; and integration of geochemical and solute transport modeling to predict and analyze the fate of metals as influenced by the presence of vegetation.

Status: In the first year of this project, soil columns were constructed and leaching studies begun. Transport models for metals were developed and studied. Results from experimental equilibrium studies were incorporated into mathematical models. Plant/column studies also were begun, and estimation of root characteristics was incorporated into transport models. Column studies with organic acid were completed. Investigators also identified metal uptake and adsorption characteristics and estimated related parameters for incorporation into a numerical model. Metal uptake and metal adsorption to the soil have been quantified for Pb, Zn, and Cr under several sets of circumstances. A series of batch experiments was performed for solutions containing strong chelating acids and cadmium, lead, and zinc. The investigators did plant/column studies on the effect of vegetation on metal leaching from mine tailings, and the effect of tall fescue on the fate of Cr(VI) in soil. A mathematical model has been developed for understanding the fate of lead in a metal-contaminated soil. In the final phase of the project, hypothetical field-site simulations tested the model. This project has been completed.

Technology Transfer and Outreach: Results from this project have been published in peer-reviewed journals. Results have been presented to consultants, regulators, and other researchers in seven different presentations at various technical conferences in 1995, 1996, 1997, and 1998.

Keywords: vegetation, heavy metals, radionuclides, soil, fate and transport.

Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants

B.A.D. Hetrick, University of Northern Iowa; and G.M. Pierzynski, L.E. Erickson, R.S. Govindaraju, P. Kalita, and D. Sweeney, Kansas State University

Project no.: 93-07

Goals: The following are objectives of this project:

- to assess optimum plant species for survival, growth, and containment of heavy metals
- to quantify the ability of mycorrhizal fungi to facilitate revegetation and plant tolerance to heavy metals
- to evaluate vegetative zones for dissipation and containment of heavy metal runoff and erosion
- to evaluate chemical changes in mine spoil material induced by the vegetation and soil amendments
- to develop a physically based model for the movement of heavy metals in the presence of vegetation

Rationale: In southeastern Kansas, heavy metals were mined until the middle of this century. The result of this mining activity is the presence of large piles of gravel tailings with extremely high levels of cadmium, lead, and zinc. The presence of these metals poses a serious environmental and health risk which led the U.S. Environmental Protection Agency to designate this area as a Region VII Superfund Site in 1985. In areas not designated as Superfund sites, a need also exists for development of economic strategies for containment of heavy metal contamination. Vegetation interceptor strips have been used extensively in agricultural settings to reduce surface water contamination by agricultural herbicides and pesticides. However, the ability of vegetation buffer strips to limit spread of heavy metal contamination in surface water has not been studied. The use of vegetation interceptor strips could represent an economical alternative with broad application to mine spoils and areas of acid mine drainage as well.

Approach: Revegetation of Superfund and non-Superfund areas will be undertaken to stabilize the sites and reduce wind and water erosion from the tailings. Previous research by these investigators and that of the Bureau of Mines has suggested that certain soil microorganisms, the mycorrhizal fungi, contribute significantly to and may be mandatory for survival and establishment of vegetation on mine spoils. Both the ability of various vegetation regimes to limit surface water erosion and spread of heavy metal contamination, and the ability of these vegetation regimes to act as interceptor strips for contamination uphill from the vegetation strips will be studied in this project.

Status: Although investigators experienced significant difficulties collecting water samples due to flooding of the collection basins, they were able to obtain 21 samples, which were analyzed for sediment concentrations and total and soluble metal concentrations. A rainfall simulator was constructed for collecting water samples with accurate volume estimations from field plots. It was installed at a test site in Kansas and yielded useful data. Soil samples collected during Fall 1995, at the initiation of the experiment, were analyzed for total metal concentrations. These concentrations were higher than expected for chat material. Fall 1995 soil samples were also analyzed for KC1-extractable ammonium and nitrate concentrations and for soil pH. Soil samples were again collected in the spring of 1996 and analyzed for extractable ammonium, nitrate, phosphorus, potassium, and soil pH. Soil samples gathered at this time were analyzed with the sequential extractable scheme of Tessier et al. (1979). Plant tissue samples were collected in May 1997 and analyzed for cadmium, lead, and zinc. There were no treatment effects on tissue composition. Root samples were also collected in April 1997 to assess the extent of mycorrhizal colonization, and mycorrhizae have been characterized. Soil samples were again collected in September 1997 and analyzed with the sequential extractable scheme of Tessier et al. (1979). In general, the presence of vegetation has not influenced Pb fractionation. However, the addition of manure seems to significantly reduce the exchangeable and carbonate-bound Pb fraction while significantly increasing the organic-bound fraction. Evaluation of vegetation as a means of slowing the migration of contaminated sediments has been completed. Work on modeling has included a review manuscript, which was completed and submitted for publication. Work is also in progress to develop models applicable to the experimental sites, as well as larger field sites. A new treatment scheme was begun in March 1999. The new treatments are intended to test the effects of leaving the test plots unchanged; reseeding with tall fescue and fertilizing with urea, triple super phosphate, and potash; reapplying manure without reseeding; reapplying manure and reseeding. Preliminary findings show that the presence of tall fescue grass does not appear to reduce heavy metal content in the soil. However, vegetative buffers do reduce the spread of the contamination by wind and water. This project is in its fifth and final year. Analysis of soil and plant samples will continue, and additional information on the new treatment scheme will be conducted.

Technology Transfer and Outreach: Results of this research have been presented at numerous professional meetings and articles have been prepared for publications. The investigators have communicated with members of affected communities and Remedial Project Managers who have expressed interest in understanding the beneficial effects of vegetation in metals-contaminated soil.

Keywords: heavy metals, interceptor zones, mycorrhizal fungi, Superfund, vegetation.

Design and Development of an Innovative Industrial-Scale Process to Economically Treat Waste Zinc Residues

T.J. O'Keefe, University of Missouri - Rolla

Project no.: 94-05

Goal: The primary goal of this project is to design and develop a hydrometallurgical flow sheet to treat waste zinc residues containing iron and other heavy metal impurities such as lead and cadmium. The resulting flow sheet will be used at Big River Zinc Co., or any other industry desiring to treat similar wastes.

Rationale: A major problem faces the minerals industry in the form of huge tonnages of environmentally unacceptable zinc residues. Previously these oxidized dusts, which contain high iron and zinc contents with lead, cadmium, and other heavy metals, were precipitated in chemical forms acceptable for standard landfills. Under current laws, this practice will not be allowed and costs of compliance are expected to increase dramatically. In fact, it may even be necessary to reprocess all the wastes that have been stored and accumulated over the years. The technical challenge is to develop metallurgical and chemical processes to treat these hazardous wastes in an economically viable manner. The most serious technical impediment preventing treatment of these wastes is the inability to separate the iron from the zinc. The investigator on this project has developed a process, galvanic stripping, to separate the iron from the zinc. As the next step, it is important to develop unique in-line processes specifically for handling diversity in feedstock, particularly when certain categories of impurities are present in low concentrations. Many existing processes are basically sound, but supplementary unit

processes must be developed to make them more amenable to treat impure metal wastes and residues in an economic fashion.

Approach: This project is being conducted in conjunction with Big River Zinc Co., where the commercial plant to treat 50 tons per day of residue will be located. Ultimately, this technology will be transferred to others in the industrial sector for use in treating a variety of similar wastes generated in the mining and mineral community. Research is being conducted in three areas. Process parameters needed to optimize the reduction of Fe^{+3} to Fe^{+2} in the D2EHPA organic phase are being evaluated. The type of aqueous stripping solution and design procedure alternative to be used to separate and recover the Fe^{+2} and produce the best, salable iron product are being determined. The influence of the various heavy metal impurities in the solutions are being identified and their distribution (aqueous vs. organic) and effect on subsequent iron and zinc recovery are being evaluated.

Status: First-year milestones were met. Specifically, evaluations of the feed, organic, and metal systems using qualitative feasibility tests were completed. The parameters defined were then studied for both zinc and iron reductants in statistically designed experiments to give the first rough process model. Impurity studies have continued using the procedures developed during the first year. The major process variables of H_2O and O_2 content, alloy type, A/O ratio, final strip solution pH, and time have been evaluated with respect to impurity distribution. Morphology examinations of the reducing agent powders have started and will continue. Two publications providing an overview of the progress on the galvanic stripping process have been completed and accepted for publication. Batch tests were completed and used to produce a materials balance and model flow sheet for a 15-ton per day plant. These results were presented to the Big River Zinc Company. Subsequently, a new completely integrated flow bench scale system was built. Simultaneous galvanic stripping runs using this system will be made during this research period. The actual Big River Zinc leach solutions will be used for the stripping runs. Data provided by this testing program are expected to provide all of the process information needed for design of an industrial-scale system. Also, these data should allow a preliminary economic evaluation of the galvanic stripping process for treating Big River Zinc Company leach zinc residue. Work with another company, Brush Wellman, has shown that iron and uranium removal from a D2EHPA process stream is technically feasible. However, the stripping solution, phosphoric acid, is not an economical alternative. Efforts are being made to find a more suitable stripping solution. Commercial application of the galvanic stripping process looks very favorable. Future plans for this project include finalizing the flow sheet, analyzing the data generated, and preparing a report describing the final process. This project is in its fifth and final year.

Technology Transfer and Outreach: Results from this research have been published in various technical publications. This project involves industrial participants from three different companies.

Keywords: heavy metals, extraction, flow sheet, galvanic stripping, zinc.

The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics

G.F. Parkin, J.L. Schnoor, and P.J.J. Alvarez, University of Iowa

Project no.: 93-02

Goal: This research investigates the hypothesis that both microbial and abiotic processes contribute to reductive dechlorination of xenobiotics in methanogenic incubations with elemental metals, such as iron, serving as an ultimate electron donor.

Rationale: Polychlorinated compounds such as carbon tetrachloride (CT) are known to be transformed via sequential reductive dechlorination by both abiotic and microbial mechanisms under anaerobic conditions. However, existing treatment processes that utilize reductive dechlorination suffer from several drawbacks including inefficient transfer of electrons from the ultimate electron donor to the chlorinated compound and slow rates of reaction, thereby resulting in possible accumulation of transformation products of equal or even greater toxicity. Elemental metals in aqueous solution can act as an energy source for methanogens via production of hydrogen. Using elemental metals as an energy source, reductive dechlorination of chlorinated compounds may proceed by three mechanisms:

1. abiotic processes whereby electrons are transferred directly from the elemental metal to the chlorinated compound,
2. microbial processes whereby electrons from H_2 that are involved in biosynthetic processes are diverted to the chlorinated compound, and

3. microbial-catalyzed abiotic processes whereby electrons from the elemental metal are transferred to the chlorinated compound via biological electron carriers.

Approach: Experiments are being conducted in batch and column-reactor systems. Initial studies investigate iron and carbon tetrachloride (CT). Various chlorinated organics are also being assayed. A hydrogen-utilizing, mixed, methanogenic culture was developed as an inoculum source for all experiments. Initial batch studies were performed to determine the general time-course that the reactions would follow. Inhibition studies using 2-bromoethanesulfonate (BES), a specific methanogenic inhibitor, addressed the role of methanogens. Analytes measured in headspace gas samples include CT, chloroform (CF), dichloromethane (DCM), chloromethane (CM), hydrogen, and methane. Subsequent, detailed, batch kinetic studies were performed and, where appropriate, analytes included ferrous iron, total soluble iron, CT, CF, DCM, CM, hydrogen, methane, and oxidation-reduction potential. The stoichiometry and kinetics of all pertinent reactions were determined. Electron balances were conducted to provide insight into important abiotic and biotic processes. Flow-through column experiments using adjustable-bed-length, glass chromatographic columns packed with steel wool are being conducted to simulate long-term *in situ* treatment and to validate the kinetics determined in batch studies. A one-dimensional, finite-difference, numerical model will be developed to simulate the performance of the column reactors. The model will include advection, dispersion, and sorption, and the appropriate degradation kinetics as determined from batch experiments.

Status: Investigators have established stock-mixed-culture reactors and two pure cultures of methanogens, and conducted a variety of batch, serum-bottle experiments with iron alone, and with iron in combination with pure and mixed cultures. Experiments suggest it is possible to control the rate and direct the products of contaminant degradation. Four column reactors were constructed and have been operating for more than two years. Two pilot-scale steel wool columns were installed at Dover Air Force Base in Delaware to field test the technology. Studies with PCE and 1,1,1 TCE have been conducted to assess the usefulness of methanogen-iron systems. A bacteria-free steel wool column fed a mixture of CT, perchloroethylene (PCE), 1,1,1 trichloroethane, and a biocide has been operated to study the abiotic removal of a mixture of these compounds. Steel wool column studies involving the abiotic conversion of PCE to ethene, and studies with nitrates have been completed and a manuscript of the work will be prepared. This project is in its fifth and final year.

Technology Transfer and Outreach: A patent application has been filed for Fe(0)-based remediation. Investigators have made numerous presentations of this research at technical conferences. Results have been published in peer-reviewed journals.

Keywords: dechlorination, xenobiotics, heavy metals, iron.

Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination

G.F. Parkin, University of Iowa

Project no.: 93-24

Goal: The goal of this project is to advance understanding of anaerobic and mixed-electron-acceptor bioremediation of chlorinated aliphatics to a level that full-scale evaluation of these processes is possible. If successful, field-scale evaluation of technologies developed in this research will be pursued.

Rationale: The U.S. EPA Hazardous Substance Research Centers and national agencies such as the Department of Defense and Department of Energy have identified research on remediation processes for chlorinated aliphatic-contaminated subsurfaces as a high priority. A promising technique is use of *in situ* bioremediation, and full-scale evaluations of this process are ongoing at trichloroethene-contaminated sites. All of these efforts have focused on use of aerobic bacteria, particularly methanotrophs. However, aerobic bacteria do not degrade several of the chlorinated aliphatics of greatest concern. Unlike aerobic biological processes, anaerobic biotransformations of all chlorinated aliphatics occur. This lack of specificity, coupled with the fact that most contaminated aquifers are anaerobic, may make anaerobic bioremediation an alternative or supplement to aerobic processes.

Approach: This research focuses on three chlorinated aliphatics that are not degraded by aerobic bacteria: perchloroethene (PCE), 1,1,1-trichloroethane (1,1,1 TCA), and carbon tetrachloride (CT). If successful, field-scale evaluation of technologies developed in this research will be pursued. In order to accurately assess potential for anaerobic or combined electron acceptor bioremediation technology, all experimental systems are operated under conditions similar to those observed in contaminated aquifers. Additionally, soil cores are obtained from contaminated sites as a source of organisms

that are indigenous to contaminated areas. These cultures may be considerably different than those obtained from anaerobic digesters and may contain organisms particularly suited for chlorinated aliphatic degradation.

Status: All the necessary equipment has been updated and all experimental systems are functioning properly. Preliminary kinetic experiments have been completed and detailed experiments are continuing. Preliminary studies using only anaerobic biofilm columns have essentially been completed. Aerobic columns have been linked to anaerobic columns and studies of the sequential system are complete. A thesis paper based on the results has been submitted to KSU. Batch transformation studies with PCE are continuing. Results from selective inhibitor experiments suggest that more than one group of dechlorinating organisms are present in the microbial enrichment culture. Batch transformation experiments on mixtures of PCE, 1,1,1 TCA, and CT are proceeding using lactate-enrichment cultures acclimated to PCE. Future research plans include added emphasis on the PCE-CT-TCA acclimated lactate-enrichment culture. This project is in its fifth year.

Technology Transfer and Outreach: This project has been the subject of a poster presented at a technical conference and two articles have been submitted for publication in a peer-reviewed scientific journal.

Keywords: anaerobic, bioremediation, chlorinated aliphatics, mixed-electron acceptor.

Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors

R.L. Segar Jr., University of Missouri

Project no.: 94-07

Goal: The goal of this project is to develop a bench-scale, fluidized-bed bioreactor (FBBR) to degrade TCE in extracted groundwater. This study of FBBRs is expected to yield the high performance necessary for pilot or field testing.

Rationale: Our knowledge of organic contaminant biodegradation has advanced from fundamental biochemical/microbiological studies to a stage of active treatment process development. Trichloroethene (TCE), once considered to be nonbiodegradable, can be cometabolized by microorganisms with oxygenase enzymes. The phenol-degrading organisms selected for this work readily form cohesive biofilms, which is a prerequisite for their use in biofilm reactors such as the fluidized-bed bioreactor (FBBR). Development of FBBRs for cometabolizing trace contaminants in extracted groundwater is attractive because they are compact, relatively simple to operate, and their use is widespread in several industries. Biological oxidation of TCE should be less costly than advanced chemical oxidation techniques that use combinations of ultraviolet light, ozone, and hydrogen peroxide. Ongoing research with bioreactors continues to yield improvements in performance as better operating strategies and configurations are tested. Studies with FBBRs, which will be conducted under this project, are expected to yield the high performance necessary for pilot or field testing.

Approach: A mixed culture of phenol-utilizing microorganisms enriched from domestic wastewater will be grown on sand to form bioparticles in a bench-scale FBBR. Reactor inlet conditions will be varied and TCE removal will be measured. Concentrations of phenol, oxygen, and trichloroethylene (TCE) will be determined at various points in the reactor to select inlet conditions or design variations that improve TCE removal. Several sizes and types of sand will be evaluated to increase biomass holdup and control biomass thickness. Facilitating spatial sequencing of bioparticles between growth and degradation zones will be an important factor in designing high performance FBBRs. High- and low-dispersion conditions in the reactor will be obtained by modifying the reactor inlet distributor. Periodic pulsing of phenol will be used in some experiments to increase TCE removal by temporal sequencing of substrates. A draft tube reactor will allow greater control over internal sequencing (via circulation) of bioparticles between phenol and TCE degradation. Performance of this innovative reactor type will be characterized in the same manner as the conventional type of FBBR.

Status: All controllable operational problems related to the bioreactor have been solved. Investigators have completed and evaluated abiotic TCE loss rates, oxygen delivery, and dechlorination effectiveness of the new reactor configuration and feed system. Work has also included characterization of the phenol growth period for fresh and reused 30/35 garnet sand to determine the duration of the start-up and regrowth period, start-up procedures and substrate requirements, and the resulting biomass. Conductivity tracer test data has also been obtained, completed, and evaluated for the 1995 FBBR experiments, including the effect of effluent recirculation on TCE removal and quantification of detention times and dispersion numbers for representative experiments. Investigators have completed and tested a numerical biofilm reactor simulation model for cometabolism. Time-course TCE feeding experiments have been completed for evaluating TCE removal with 30/35 garnet and for verification of variable phenol loading effects observed in prior experiments. Work has also included development of a technique for in-bed sampling of bioparticles and water, which resulted in obtaining phenol and biomass profiles within the bed. Dominant microorganisms in the reactor effluent have been identified. In batch studies, the abiotic reaction rate of various reactor sands with TCE and PCE under oxic and anoxic conditions was

assessed. Future plans include design, fabrication, and troubleshooting of a dual-chamber reactor, as well as reactor operation and measurement removal. Currently, the FBBR is shut down due to funding restrictions and the difficulty in maintaining continuity in student researcher expertise. Future plans include beginning FBBR operations and studies again when a graduate student is assigned to the project. The overall objective of additional research is to determine operating conditions that will sustain a high removal rate for TCE for a prolonged period of time. This project is in its fifth year.

Technology Transfer and Outreach: This research has been the subject of a master's thesis at the University of Missouri-Columbia. Results of this research were presented at the May 1999 HSRC conference. Other technology transfer efforts will be made as research progresses.

Keywords: trichloroethene, cometabolism, fluidized-bed bioreactors, chlorinated solvents, water.

Uptake of BTEX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation

J.L. Schnoor and S.C. Lang, University of Iowa

Project no.: 94-25

Goal: The goal of this research is to determine feasibility and efficacy of vegetative bioremediation, specifically poplar trees, at sites contaminated with benzene, toluene, ethylbenzene, and xylene (BTEX) compounds.

Rationale: Vegetative remediation has become a promising, inexpensive, publicly accepted, and innovative technique for cleaning contaminated hazardous waste sites. This technique is best suited for sites of shallow contamination that are in the zone of impact for deep-rooted poplar trees. BTEX contamination is ideally suited for vegetative remediation. Being light, nonaqueous-phase liquid (LNAPL) contaminants, BTEX compounds are often located near the surface at hazardous waste sites. BTEX contamination is also ubiquitous in today’s environment, and many of these sites are located in rural and abandoned areas where little money is available for more expensive traditional remediation.

Approach: This research explores whether vegetative remediation with poplar trees is a fundamental approach for remediation of BTEX-contaminated sites. Poplar uptake of BTEX compounds is being monitored and translocation within plant tissues is studied. Plant tissues and aerial compartments are examined to measure accumulation in plant tissues and volatilization from leaf surfaces, respectively. Poplars are widely adapted to a wide variety of temperate and boreal environments; they are fast growing, hardy, and easily reproduced from parental cuttings; they are easily rooted at variable and great depths; and they have been successfully grown from tissue cultures.

Status: Work first centered on experimental apparatus design, method development, and experiments utilizing various compounds. Investigators have conducted uptake studies with the majority of these compounds in the reactors designed for this project. These reactors have been designed to contain the individual poplar cuttings and can accommodate growth of the cutting either in hydroponic growth solution or in soil media. The reactors are constructed to contain and collect any VOCs released from the above-ground plant components. Reactors have proven to perform as expected in the laboratory setting. Mass balances for VOC experiments utilizing vigorously-growing cuttings in the reactors have consistently been over 85%. Further improvement of mass balances is a point of focus in future research. Studies to determine structure activity relationships for the leaf volatilization of VOCs by poplar trees are also ongoing, and investigators are examining the impact soil processes have on phytoremediation of VOCs. The overall focus has been the quantification of volatilization, storage, and possible metabolization of specific compounds in poplar tree phytoremediation systems. The impact of soil processes on phytoremediation has been studied. This technology is being transferred to a 20-acre former refinery site. The site was planted as a full-scale phytoremediation effort in April 1999. The technology is also being transferred to a 2-acre site. This site is being used for a demonstration and greenhouse study for Unocal and Ashland Chemical Corporation. This project is in its fifth year.

Technology Transfer and Outreach: This research has been the subject of several published articles. There have also been several presentations of this research at technical conferences. Technology transfer to two field sites is in progress.

Keywords: vegetative remediation, poplar trees, BTEX, soil, plants.

Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies

L.C. Davis and L.E. Erickson, Kansas State University

Project no.: 94-27

Goals: There are four main objectives for this project. Experimental systems to improve oxygen availability for enhanced aerobic biodegradation will be developed. Transfer of contaminants through plants will be monitored. A mathematical model to describe fate of water, contaminant, root exudes, plants, microbes, and oxygen in laboratory and field systems will be applied. This technology will be applied to one or more field sites by working with professionals elsewhere. New funding since May 1998 emphasizes issues of concern during aircraft operations and deicing.

Rationale: Much of the population in U.S. EPA Regions VII and VIII relies on groundwater for its potable water, but many groundwater aquifers within this region have been contaminated with hazardous organic chemicals. Such chemicals may be by-products of agricultural and industrial production or may have leaked from fuel storage tanks or ruptured soil liners at disposal sites. Soil contamination involved in these types of problems is often very dispersed so that conventional soil and groundwater remediation techniques would be very expensive or, in some cases, impractical. Plants can play an important role in remediating soil and groundwater contaminated with organic substances. To put this new technology to effective use, we need to better understand and predict effects that plants have on soil and groundwater remediation, so that effective planting and management plans can be developed.

Approach: Previously a prototype system has been built by these researchers and used for study of bioremediation of groundwater assisted by plants. Based on experience with the prototype system, a new system has been constructed with more but shorter path length channels and a depth of 60 cm. It will permit introduction of controlled amounts of air into the soil, either above or below the water table, in two of the channels. By use of evolutionary operation design, performance of the system will be optimized to minimize air input and maximize degradation of target substances. Material balance measures are used to determine the fate of target substances. Potential intermedia transfer will be monitored by FTIR measurements on the gas phase above the growing plants. Changes in contaminant concentration in the groundwater are monitored by headspace gas chromatography or FT-IR of aqueous samples. The groundwater flow and transport model is used to model behavior of contaminants in the new system under several experimental conditions. The model will be further refined to improve the fit of predicted and observed behavior. It will then be applied to field situations where monitoring wells are in place, such as near landfills.

Status: Experiments with alfalfa in growth chambers are yielding much data, with the flow properties characterized and dissolution of TCE from the nonaqueous phase measured. A Gasmet FT-IR instrument is used for highly sensitive analysis of soil gas composition, except for O_2, which is infrared inactive. Investigators have introduced a nonaqueous-phase TCE below the water table and determined the extent to which it is solubilized by the flow of groundwater. Soil surface fluxes are monitored with the Gasmet. PCR-based techniques have been developed for detection of specific bacteria. Good success has been had in modeling the distributions of reactants and products through the prototype plant growth chamber under steady state conditions. Other modeling studies are underway. As originally proposed, investigators are studying the fate and transport of other contaminants. Pilot-scale studies were done to determine the ability of higher plants to degrade TNT and the sensitivity of alfalfa to soluble TNT. The original prototype chamber was switched to a combination of TCE and toluene to examine cometabolism. Results of both experiments and simulations indicate the crucial role of soil aeration in contaminant degradation and flux. Other contaminants with different volatilities and degradabilities are being introduced into the chamber. An experiment with MTBE is currently in progress. The effect of jet fuel on mosses and plants is being evaluated in pilot studies. Chemical components of deicers used on aircraft are being studied. Some of these compounds are quite toxic to plants and will be the focus of future research. Another aspect of the research is the adsorption of contaminants within plants. Experiments are being conducted using stem segments of popular and willow trees. These studies are important in order to accurately describe contaminant fluxes in the plant system. Two papers documenting modeling efforts have been accepted for publication. The researchers have worked with the Riley County engineering staff to develop plans for control of leaching through the use of plants and trees. The researchers are also working with two private corporations to design plant-based remediation for sites in the Kansas City area. The fate of benzotriazole in soil in the vicinity of plants is a high priority and is being pursued. This project is in its fifth year.

Technology Transfer and Outreach: Results have been presented to consultants, regulators, and other researchers at workshops and conferences. The investigators have visited field sites and provided recommendations to responsible parties and regulators regarding applications of vegetation for specific problems. Publications have been prepared for peer-reviewed scientific journals and for regulators and consultants.

Keywords: plants, soil, groundwater, alfalfa, poplar trees.

Extension of Laboratory-Validated Treatment and Remediation Technologies to Field Problems in Aquifer Soil and Water Contamination by Organic Waste Chemicals

T.H. Illangasekare, University of Colorado

Project no.: 94-29

Goal: The primary goal of this research is to develop and implement systematic procedures for applying, in the field, treatment and remediation technologies for jet fuel and deicing compounds that have been developed in the laboratories, taking into consideration the complexities which are encountered in the field.

Rationale: The primary hypothesis is that natural variability of soil characteristics and variability due to nonaqueous-phase liquid (NAPL) entrapment result in preferential flow of water and treating agents. These constraints to flow and delivery of treating agents alter effectiveness of treatment schemes in the field. This research will attempt to identify the basic processes affected by these complexities and determine the parameters that control the behavior at the field scale.

Approach: A systematic procedure to extend to the field the knowledge gained through experimentation at the laboratory scales of pore, cell, column, and soil flumes will be developed. Laboratory research, modeling, and field investigations will focus on issues related to transport; entrapment; recovery; dissolution; fingering; physical, chemical, and thermal mobilization; blob dispersion to increase dissolution; etc., that are of fundamental importance in developing remediation technologies. Laboratory experiments in cells, columns, and large tanks will be continued to identify basic parameters which need to be upscaled to field problems. Some of the parameters that have been identified for study include hydraulic conductivity, capillary pressure versus saturation, relative permeability, entry pressure, pore-size distribution, dispersivity, sorption coefficient, mass transfer coefficients, and dissolution parameters. Investigators will use chemical mixtures to look at multicomponent mass transfer and realistic field soils. Sites in Kansas, Colorado, Wyoming, and Louisiana will be selected for field studies. Once effective parameters are identified, techniques will be developed to obtain these in the field.

Status: Natural and enhanced dissolution of non-aqueous phase liquids (NAPLs) continues to be studied One report on enhanced dissolution using surfactants and another on thermal mobilization were completed. Investigators have found that interphase mass transfer from entrapped NAPLs can be greatly enhanced with the use of surfactants or heat. Research is now focused on developing methods to estimate mass transfer coefficients at the field scale. Research on development of analytical and computer modeling techniques required to interpret solute breakthrough curves in terms of effective parameters continues. The model has been updated to make it more versatile and to allow for realistic simulation of mass transfer processes in the field. Investigators have identified tracers as one of the most promising methods of determining scale-dependent parameters in heterogeneous systems. Three journal articles documenting the tracer experiments and results have been submitted for publication in scientific journals. Additional research on partitioning tracers and model validation is complete. Model documentation and journal articles on natural and surfactant-enhanced dissolution are complete. Two field investigations relating to this work have been funded by other sources. Future work will include thermal delivery of surfactants and upscaling activities, evaluating bio-processes with deicers, and field testing activities. This project is in its fifth year.

Technology Transfer and Outreach: Numerous lectures and workshops have been conducted to share the results of this research with consultants, regulators, and other researchers. The principal investigator has conducted EPA sponsored workshops, prepared chapters for two different books, and given several lectures about this research project. The principal investigator has also engaged in collaborative research with other universities in the U.S. and Europe.

Keywords: aquifers, organic chemicals, nonaqueous-phase liquids, remediation.

Evaluation of Biosparging Performance and Process Fundamentals for Site Remediation

R.R. Dupont, D.L. Sorensen, and W.J. Doucette, Utah State University

Project no.: 93-20

Goal: The goal of this project is to conduct a detailed investigation of air sparging systems operated in a pulsed mode to provide a fundamental framework from which to evaluate the applicability and effectiveness of biosparging technology for a given set of site, soil, and waste constraints.

Rationale: Air sparging represents a highly attractive remediation alternative for contaminants located below the groundwater table. It has been shown through anecdotal evidence that contaminant emission rates increase and groundwater concentrations are greatly reduced at groundwater monitoring well points. Specific mechanisms of air sparging system performance are yet to be investigated, and adequate monitoring of field-scale systems to quantitatively document their performance throughout affected areas of injection well influence are yet to be developed.

Approach: The proposed research project will involve two integrated components, companion field-scale and laboratory-scale studies. The field study will be utilized to provide mass transfer and contaminant biodegradation rates resulting from a field-scale biosparging system, as affected by media property and heterogeneity limitations inherent at field sites. The laboratory component of the proposed research will provide detailed analysis of mass transfer and contaminant degradation rates under controlled conditions. Laboratory investigations will include an evaluation of the effect of bubble size, air-injection rate, air-injection depth, media properties, and contaminant properties on observed mass transfer and contaminant degradation rates. Air injection versus inert gas injection will allow the separate evaluation of mass transfer and degradation, while air injection in clean water systems will allow an evaluation of system mass transfer relationships independent of effects due to contaminant properties and/or contaminant/media interactions.

Status: Significant progress has been made in the design, testing, and construction of a field instrumentation bundle capable of representative sampling of dissolved oxygen, pressure, and contaminant concentrations within the contaminated aquifer below the Layton field site. A spatially dense, three-dimensional sampling grid consisting of driven gravel points at five vertical depths and four horizontal radii from the injection well has also been installed. Instrumentation bundles have been installed at the field site. A data acquisition system has been configured and is operational. Initial air-injection trials have been completed. It was necessary to remove the asphalt and reinstall a new piping system to provide a means of remote data collection. Conduit originally installed in surface trenches did not support the surface activity at the site. Two sets of laboratory studies began in May 1996– one to evaluate oxygen transfer in air sparging versus in-well aeration systems, and the other to evaluate tracer methods for monitoring air-injection remediation systems. Initial "clean water" oxygen transfer/mixing studies are complete. Future plans include air-sparging tests, in-well aeration tests, clean water tests, dirty water tests, media clean water tests, and media dirty water tests. This project was completed in December 1998.

Technology Transfer and Outreach: Results from this project will be of interest to other researchers, the U.S. Department of Defense, private industry, and regulatory personnel.

Keywords: biosparging, biodegradation, mass transfer.

Field-Scale Bioremediation: Relationship of Parent Compound Disappearance to Humification, Mineralization, Leaching, and Volatilization of Transformation Intermediates

R.C. Sims, Utah State University

Project no.: 93-21

Goal: The overall goal of this research effort is to provide new information about the distribution of polycyclic aromatic hydrocarbon (PAH) biotransformation products in the solid and liquid fractions of soil. Another goal is to determine the effect of environmental variables and amendments on biodegradation of PAH and chemical association with solid and liquid phases.

Rationale: There is a lack of information concerning transformation intermediates regarding their reactions, measurement, and management in soil bioremediation systems. Specifically, the role of the humification process is currently unknown in prepared -bed systems. Disappearance of compounds within soil treatment systems does not necessarily indicate mineralization or detoxification of toxic and hazardous compounds. The formation of intermediates and the fate of those intermediates with regard to association with the soil solid phase in the process of humification is an area where information is needed in order to fully assess the treatment effectiveness of soil bioremediation systems. Development of information addressing behavior of transformation intermediates with an emphasis on characterizing humification of target organic chemicals would increase our understanding of soil bioremediation processes with regard to protection of public health and the environment. Based on information developed in this project, techniques for management of the humification process may be identified and applied to soil bioremediation systems.

Approach: The approach in this project is to use samples of soil taken from field-scale bioremediation systems treating creosote- and creosote/PCP-contaminated soil. Soil samples have been taken from the Champion International Superfund site in Libby, Montana, and the McCormick/Baxter site in Stockton, California. The first activity involves identification of

PAH and PCP transformation products that occur in soil systems and that can be extracted. The second activity involves chemical mass balance and toxicity determinations during treatment and development of instrumental approaches for evaluating humification. The approach is used to generate information concerning (1) chemical bonding of PAHs and PCP/intermediates with the soil solid phase, humic and fulvic acid fractions, and leachate; (2) effects of environmental variables (light, temperature, soil moisture) on the humification process; and (3) effects of amending soil with electron acceptors on humification, mineralization, and volatilization.

Status: Researchers have isolated and characterized four bacterial strains responsible for mineralization in soil from the Libby site. Sequestration/humification studies using the MIBK fraction procedure are complete. A journal article describing these experiments and results has been published. Studies on the effects of alternate electron acceptor addition on mineralization of pyrene are complete and a manuscript has been prepared for publication. Experiments to evaluate the effects of moisture, temperature, and addition of electron acceptors on the fate of target compounds are complete and a manuscript has been prepared for publication. Toxicity assay results for aqueous-phase samples have been performed and indicate that toxicity decreases with time during biological treatment. PAH and PCP intermediates have been characterized. Chemical mass balance experiments have been performed for PCP. The effect of oxygen concentration on pyrene and PCP transformation and biodegradation, and on abiotic transformation, has been studied. Results of these studies have been published in refereed journals. Experiments with electron acceptor addition to McCormick/Baxter site soil were completed. Experiments of PCP reactions with manganese oxides as a function of pH and redox potential have been completed. Fugacity modeling proved to be useful and was used to guide analytical determinations of PAH intermediates. A new test to evaluate the effectiveness of mixing treated soil with untreated soil has been initiated. The project has been expanded to include cooperation with the USEPA Cincinnati NRMRL concerning treatability and technology transfer of "presumptive remedies" for soil contaminated with wood preservative. Plans for future work include studying the application of adapted/acclimated soil to unacclimated soil to evaluate the management option of incorporating untreated soil into treated soil to increase the rate of bioremediation. Field-scale studies on toxicity reduction rates are planned, as well as continued analytical work regarding intermediate characterization. This project is in its fifth year and is scheduled to be completed in May, 2000.

Technology Transfer and Outreach: Results from this project are being used at a site in Libby, Montana. Findings from this site are being applied to the Montana Pole Superfund Site. Techniques developed through this project will be applied to other sites as well. Presentations of this work have been incorporated into the U.S. EPA technology transfer course on natural attenuation. This course has been conducted ten times throughout the United States.

Keywords: bioremediation, humification, mineralization, leaching, volatilization, intermediates.

Effects of Surfactants on Bioavailability and Biodegradation of Contaminants in Soils

W.P. Inskeep and J.M. Wraith, Montana State University; C.G. Johnston, Mycotech Corporation

Project no.: 94-09

Goal: This project is designed to improve understanding of fundamental relationships between surfactant chemistry, contaminant solubilization, and subsequent biodegradation rates in soils, while developing novel methods which may be useful in the bioremediation of nonpolar organic compounds in soils.

Rationale: During the past decade, much discussion has centered on the unavailability of sorbed compounds to soil microorganisms; it is generally now assumed that desorption and diffusion of bound contaminants to the aqueous phase is required for microbial degradation. Furthermore, with aging, many nonpolar contaminants form irreversibly bound residues which are difficult to extract with nonpolar solvents and are essentially unavailable to indigenous microbial communities or to those added as an inoculum to stimulate biodegradation. In a recent workshop convened to discuss major research needs in bioremediation, the bioavailability of soil-bound contaminants was consistently identified as a fundamental limitation in enhancing rates of contaminant biodegradation in soils. One of the strategies for enhancing desorption rates and subsequent biodegradation rates of nonpolar contaminants in soils is the use of surfactants.

Approach: A series of contaminant partitioning studies using a wide range of surfactants with varying structures will be performed. Functional relationships between surfactant concentration, surfactant structure, and extent of contaminant solubilized will be established using batch and column studies. Effects of surfactants on subsequent biodegradation rates of

phenanthrene, PCP, DDT, and PCB will be studied under batch and column conditions using two representative bioremediation strategies: indigenous microbial populations and addition of white-rot fungi. Degradation rates will be determined under batch and flow conditions in previously uncontaminated soils with and without contaminant aging. In addition, contaminant degradation in soil samples from several field sites contaminated with PCP and polyaromatic hydrocarbons will be compared to controlled laboratory experiments.

Status: Experiments in four major areas have been completed over the past four years. Surfactant effects on the solubilization and subsequent transport of nonpolar contaminants through soils have been studied. Surfactant effects on the degradation of contaminants using indigenous microorganisms in both the absence and presence of NAPLs have been studied, and surfactant effects on the degradation of Pentachlorophenol (PCP) using white-rot fungi have been evaluated. Evaluation of microbial population shifts as a result of surfactant application intended to stimulate bioremediation of organic contaminants has been completed. Results from experiments indicate that changes in microbial community structure are associated with high surfactant applications. Experiments including molecular analyses were completed to further explore these results. This project was completed in May 1999.

Technology Transfer and Outreach: This project pertained directly to the activities of a fungal bioremediation firm located in Butte, Montana (Mycotech Corporation). One article discussing the results of this research has been published and four articles have been submitted for publication.

Keywords: surfactants, bioavailability, biodegradation, nonpolar organic compounds.

Contaminant Binding to the Humin Fraction of Soil Organic Matter

J.A. Rice, South Dakota State University

Project no.: 94-11

Goal: The goal of this research is to understand contaminant binding to soil organic matter, particularly the fraction known as humin.

Rationale: Most previous work on the nature of contaminant binding to soil organic matter has utilized ^{14}C-labeled compounds to reconstruct the fate of contaminants introduced into a soil system. Essentially all of these studies have stopped at the point of assigning a fraction of the bound-radioactivity to one of the humic fractions of soil organic matter; no studies have been able to characterize the actual nature of bound-residues or the nature of their interaction with a humic material. The humin fraction of humic substances is usually the predominant organic material in most soils; humin organic-carbon typically represents more than 50% of the total organic-carbon in a soil, and a significant fraction of most anthropogenic organic compounds bind rapidly and, in many cases, irreversibly to it. Yet, despite these compelling reasons for a detailed understanding of the nature of contaminant binding to humin, very little is known about its environmental chemistry.

Approach: This study will utilize a new technique that not only isolates humin but, for the first time, permits the separation of humin's organic components from its inorganic component and fractionates the organic components into recognized compound classes. Carbon-14 and carbon-13 labeled contaminants; the polynuclear aromatic hydrocarbons naphthalene, phananthrene, and benzo[a]pyrene; and the polychlorinated biphenyls 4,4'-dichlorobiphenyl and 2,2',5,5'-tetrachlorobiphenyl will be incubated with two soils of different composition in separate experiments. Organic components of the soil will be isolated by a combination of traditional and MIBK methods. Humin will be fractionated into its components using the MIBK method. Using ultrafiltration, scintillation counting, and ^{13}C CPMAS NMR, the organic matter will be fractionated and the qualitative and quantitative nature of contaminant binding to humin assessed. The role of lipids in contaminant binding to humin will be investigated utilizing column adsorption studies with humin from which first the lipids and then the humic component have been selectively removed. These results will be evaluated in light of the partitioning model of contaminant sorption to soil organic matter.

Status: Many of the objectives of this research have been met. Experiments have shown that PAHs and PCBs irreversibly bind primarily with the humin fraction of soil organic matter. The bound PAHs and PCBs preferentially associate with the bound-lipid component. PAH binding to soil organic matter and humin is nonlinear which indicates site-specific interactions. This is in contrast to the generally cited partitioning model which describes hydrophobic organic contaminant interaction with soil organic matter as a solute partitioning phenomenon. Removal of lipids decreases the tendency of PAHs and PCBs to form bound residues. The work on this project includes collaboration with R.C. Sims and J.K.C. Nieman, Utah State University, to apply the MIBK method to the fractionate bound-PAH residues in soil from an actual

contaminated soil. A comparison of the MIBK method and the traditional alkaline extraction method for fractionating soil organic matter has been prepared based on the work done in this study. This project was completed in May 1999.

Technology Transfer and Outreach: Several papers covering results of this research have been presented at technical conferences. One article has been published in a peer-reviewed scientific journal and four additional articles have been submitted for publication. This research is included in the written proceedings of three different technical conferences.

Keywords: contaminant binding, humin, soil organic matter, binding mechanisms.

Development of a Systematic Methodology for Optimally Designing Vegetative Systems for Remediating Contaminated Soil and Groundwater

V.R. Schaefer and S.R. Burckhard, South Dakota State University

Project no.: 94-12

Goal: The goal of this project is to develop a systematic approach to the design and management of vegetative remediation schemes and to implement this approach in a decision support system that can be used by environmental professionals to evaluate the potential use of vegetative systems for remediation.

Rationale: Several research projects have investigated the potential for vegetation to aid in remediation of soils and groundwater that are contaminated near the soil surface. One of these projects produced models that can predict the fate of hazardous organic substances in the root zone of a soil. Preliminary comparisons between developed models and laboratory experiments were favorable, yet two significant modeling limitations were observed. First, the models could only simulate a limited number of contaminant degradation processes. Second, the models require a large amount of information about a site where vegetation is being considered as a remediation option. These limitations could prevent use of the models in predicting potential benefits of a vegetative remediation system designed by environmental professionals involved in soil and groundwater remediation projects. Overcoming these limitations requires development of a methodology that can synthesize the required modeling data from information that is available about a remediation site and use the model to systematically arrive at an efficient remediation design.

Approach: Objectives of this project related to the efficient design of vegetative remediation systems will be achieved by developing a general methodology based on systems theory. This involves forming a systems statement that includes the quantitative definition of goals of the remediation project, design variables that can be manipulated to attain these goals, and practical and legal constraints that limit attainment of these goals. Several conventional and heuristic solution procedures will be used to solve the systems statement. The most robust and computationally efficient procedures will be selected for continued use in this project. Once developed, the design procedure will be applied to a field site within U.S. EPA Regions VII and VIII that has near-surface soils and groundwater contaminated with hazardous organic substances. Then a graphically based decision support system will be developed from this design experience for future use by environmental professionals.

Status: Development and analysis of conventional gradient programming solutions to solve the design systems statement, and development and analysis of heuristic solution methods to solve the design systems statement are completed. Existing vegetative remediation models have been modified to incorporate a wider range of field conditions and these models have been validated. The use of modified models and design methodology to develop a pump-and-treat style vegetative remediation system is complete. A Windows-based interface for the design and operation support system has been developed and has been applied to two field sites contaminated with hazardous organic contaminants. Preliminary results are very promising and potential applications of the program are being vigorously pursued. Plans to complete this project include completion of a manuscript on the simulated annealing algorithm, completion of a user-friendly interface for the model, use of BIOROOT for ET cover evaluation, field case histories of phytoremediation of contaminated sites, completion of model documentation, and preparation of progress and final reports. This project is in its fifth year. HSRC funding was completed in May 1999. The project is continuing with other sources of funding.

Technology Transfer and Outreach: Results have been presented to consultants, regulators, and other researchers at workshops and conferences. Plans are being made to develop a Web site devoted to the dissemination of information from this research.

Keywords: modeling, vegetation, phytoremediation, plant remediation.

Identifying Groundwater Threats from Improperly Abandoned Boreholes

R.F. Kubichek, W.P. Iverson, and J.J. Cupal, University of Wyoming

Project no.: 94-24

Goal: This research explores the possibility of using sonic pulse propagation, combined with advanced signal processing techniques, to determine the depth of coherent cement plugs in abandoned wells.

Rationale: Each year many wells are plugged and abandoned throughout the United States. These include water wells, mineral exploration wells, and oil and gas production wells. Many wells penetrate one or more aquifers. The wells also pierce formations containing oil and gas reservoirs, mineral deposits such as uranium and lead, and water contaminated with salt, iron, selenium, sulfates, and radon. The well borehole provides a mechanism for communication of fluids and gasses between formations. When aquifers are involved, this poses a severe pollution threat. For example, if the borehole passes through both an aquifer and a brine-bearing formation, the brine can invade the aquifer and compromise the quality and purity of the water. The problem escalates if the brine layer is pressurized with respect to the aquifer, causing continuous flow of brine into the fresh-water formation. Conversely, water will escape from the aquifer if its hydrostatic pressure exceeds the pressure in other porous layers. Improperly plugged wells can compromise the integrity of the aquifer layer since this natural isolation is destroyed, allowing water to come in contact with these potentially toxic materials.

Approach: In this project, investigators will develop, instrument, and test a borehole scale model. Research will be undertaken to understand wave propagation and plug reflections in the model. Investigators will simulate responses for selected borehole scenarios and evaluate various models and receiver configurations. They will develop a sensor system, analog-to-digital conversion, and portable computer-based analysis system for measuring plug reflections; develop signal processing methods to extract plug information from reflection data; and conduct field tests to characterize performance of the prototype system.

Status: Original plans called for equipment and signal analysis techniques to be tested using a water well. However, high ambient noise levels from nearby car traffic and underground steam tunnels made the site unsuitable. The tests were shifted to an artificial borehole test bed developed over the past year. Tests using the artificial borehole have shown standard commercial geophones to have adequate bandwidth and sensitivity for use in this project. Additional advantages include ruggedness and low cost. The structure of received geophone signals is very complex, comprising both primary reflections from plug surfaces and secondary reverberations from energy reflecting back and forth between plugs. To help understand the nature of various reflection events, two computer modeling programs have been developed. Limited site testing was performed but efforts were shifted to troubleshoot and improve performance of the transducer system. New data acquisition software was written for recording data from the modified transducers and this has yielded excellent signal-to-noise ratios. During the summer of 1998, the performance and reliability of the data acquisition system was improved. A number of field tests at the artificial borehole and at two plugged borehole sites were conducted. Problems with actual wells were encountered. These problems include reflections from unexpected sources such as subsurface rock layers, collar joints, and water or air pockets within the borehole. These problems cannot be easily resolved. It is unlikely that an acoustic detection system can be developed for unambiguous resolution of the length or location of plugs lying below a long surface plug. However, it does appear that a system could reliably determine when a well has been improperly abandoned with a short surface plug. This project is complete.

Technology Transfer and Outreach: Two technical papers on this research have been prepared for publication. The results of the project were presented at the Wyoming Water Conference in 1997.

Keywords: boreholes, aquifers, oil wells, gas wells, cement plugs.

Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence

A.B. Cunningham, Montana State University, and B.M. Chen, University of Wyoming

Project no.: 94-28, 93-11

Goal: The overall goal of this project is to understand factors which promote or retard biomass accumulation in porous media with an intent to apply such understanding toward prediction and beneficial manipulation of permeability and mass transport properties.

Rationale: A concept which appears promising in the manipulation of biological and chemical processes for remediation of subsurface hazardous waste sites is the creation of biobarriers for containment and remediation of soil and groundwater contaminated with organics and heavy metals. Biobarriers are formed by stimulating the growth of microbial biomass. The free-pore space-flow paths through porous media are plugged by the microbial biomass, thereby reducing permeability and mass transport. Selective plugging of permeable strata is currently being explored as a means of preventing contaminant migration of groundwater contaminants from hazardous waste sites. Penetration of bacteria through porous media varies between extensive penetration of ultramicrobacteria and formation of plugging biofilms on the proximal formations by well-fed cells of the same organisms. Investigators will attempt to use simple nutritional differences to deliver bacteria to any location in the subsurface environment to resuscitate and either plug the formation or carry out specific biodegradation.

Approach: Test organisms will include a *Klebsiella pneumoniae,* as well as these same bacteria starved for ultramicrobacteria size. Experimental objectives will be carried out using a series of flowing packed- bed reactors, including flat-plate flow cells and packed columns. Procedures will be developed for applying bacterial inoculum, along with subsequent resuscitation with nutrients, so as to produce controlled reduction of porous media permeability and dissolved oxygen transport. Researchers will quantify and model temporal and spatial variability in the biofilm accumulation (and mass transport) using bioluminescence. Finally, a mathematical model for biofilm accumulation and corresponding permeability and dissolved oxygen gradients in porous media will be developed and evaluated.

Status: Investigators have determined quantitative relationships that describe biomass accumulation and corresponding mass transport properties in saturated porous media. Methods for controlling biobarrier thickness, longevity, and degree of permeability reduction have been established. The efficacy of using biobarriers to create and maintain anaerobic conditions has been assessed. Funding from a major oil company has been obtained for a pilot project that will test the feasibility of installing a biobarrier at a field site to control hydrocarbons leaching from the groundwater system into a nearby river. This project is underway. Methods for injecting starved bacteria into the subsurface and recovering them *in situ* have been developed. Up to 80 percent recovery has been realized These methods will substantially reduce the cost of inoculum preparation in the field. Experiments with the lysimeters constructed for this project indicate that barriers built under normal field hydraulic gradient conditions can be maintained indefinitely without incurring significant costs for injecting additional nutrients. Experiments simulating radial flow conditions in the field have been completed and indicate that biobarrier formation methods are effective under radial flow conditions. A second set of radial flow reactor experiments has been run to develop protocol for extending and maintaining the biobarrier above the ambient water table. A mathematical model has been developed and improved so that the effects of thick biofilms on the plugging of the pores can be simulated. Multispecies biofilm experiments have been completed. The project team is now working with MSE Technologies to construct a field demonstration lysimeter facility in Butte, Montana. This project is in its fifth and final year.

Technology Transfer and Outreach: This research has been published in the chapters of two different books and in various conference proceedings and journals. A patent disclosure was filed in 1996.

Keywords: biofilms, hydraulic conductivity, ultramicrobacteria, waste containment, barriers.

Fate of Trichloroethylene (TCE) in Plant/Soil Systems

W.J. Doucette, B. Bugbee, and D.K. Stevens, Utah State University

Project no.: 95-10

Goal: The goal of this research is to 1) investigate the fate of TCE and other chlorinated ethenes in plant/soil systems through a combination of laboratory experiments and mathematical modeling, and 2) to evaluate the applicability of a plant-based bioreactor for the remediation of groundwater contaminated with TCE.

Rationale: Chlorinated solvents, such as TCE, are among the most frequently found groundwater contaminants at military installations, due to their widespread use in degreasing operations. Understanding the fate of these contaminants is critical in performing risk assessments and evaluating remediation options. Development of less costly remediation alternatives for contaminated groundwater is also of considerable importance. The uptake into plants is a potentially important fate process that has not been adequately evaluated for TCE and other chlorinated solvents. Determination of uptake rates, plant/water and plant/air distribution coefficients, and degradation rates would greatly improve fate modeling and risk assessment efforts. In addition, the literature indicates that conditions in the rhizosphere may favor co-metabolic transformation of TCE. Phytoremediation has shown promise, but its implementation has been limited, in part due to the difficulties associated with non-engineered systems. The plant-based bioreactor proposed in this study may provide a cost-effective

approach for remediating groundwater that is contaminated with TCE and other hazardous organic chemicals. The bioreactor approach enables the control of key environmental variables, such as moisture, nutrients, pH, and oxygen in order to maximize plant growth and remediation efficiency.

Approach: Laboratory studies have been designed to evaluate the fate of chlorinated ethenes in hydroponic systems. Specifically, these studies determine plant/water/air distribution coefficients and plant uptake rates. This approach has been extended to laboratory and field plant/soil systems. Based on the results, a plant-based bioreactor for the remediation of contaminated groundwater has been constructed. Environmental conditions are managed to optimize plant growth and microbial activity.

Status: Four plant growth chamber systems have been constructed. These systems have been used to study the rate and extent of TCE uptake, transformation, and transpiration in hydroponic systems The systems provide high mass recovery and reproducibility for TCE while maintaining a realistic plant environment. Experimental results are indicating that uptake of TCE is very low. Volatilization of TCE or carbon dioxide from transpiration of TCE has not been observed. However, the TCE degradation product 2,2,2 trichloroethanol has been identified in the system. Other hydroponic experiments using hybrid poplars were done to study the uptake and metabolism of metabolites of TCE. The compounds studied were trichloroethanol (TCEt) and trichloroacetic acid (TCAA). It was found that both TCEt and TCAA are taken up by plants, but the transpiration stream concentration factors were orders of magnitude smaller than expected based on log Kow values. Plant uptake chamber studies were performed to study the effect of exposure concentration and duration on the plant uptake of TCE. Results indicate that microbial degradation independent of the plants is occurring in the hydroponic solution. Significant decreases in mineralization have been observed with higher TCI concentrations. This suggests that higher concentrations of TCE are toxic to the microorganisms. Two additional studies were performed to quantify the uptake of TCEt and TCAA by hybrid poplars. These studies were performed in open, aerated, hydroponic systems using unlabeled compounds. A detailed report of these studies can be found in the master's thesis of J.K. Chard at Utah State University. This project is in its fourth year.

Technology Transfer and Outreach: Platform and poster presentations of this research have been made at technical conferences. Several presentations have been made to the staff members of the Environmental Restoration group at Hill Air Force Base in Ogden, Utah. Two articles have been published in peer-reviewed scientific journals.

Keywords: chlorinated solvents, trichloroethylene, TCE, contaminated groundwater, remediation, soil systems, plant systems.

Plant Enzyme Systems for the Phytoremediation of Chlorinated Aliphatics in Contaminated Soils

J.L. Schnoor and C. Just, University of Iowa

Project no.: 95-29

Goal: The goal of this project is to determine the feasibility of using plants to remediate soils contaminated with chlorinated aliphatic compounds by studying their uptake, translocation, and resulting metabolites, and by investigating plant enzyme capabilities to degrade these compounds.

Rationale: Based on previous research, there are several potential mechanisms for the uptake and transformation of TCE in a plant-soil system. Understanding these mechanisms will lead to improved remediation techniques.

Approach: Investigators will research potential mechanisms and the feasibility of phytoremediation to enhance the cleanup of TCE-contaminated sites. Studies will examine the uptake of TCE or its metabolites into the roots, the xylem transfer of the compounds to the leaves, volatilization from the leaves, foliar uptake of TCE from air, phloem transfer, and bound-residue formation throughout the plant.

Status: Progress has been made on determining uptake, translocation, and accumulation of TCE in plants. Volatilization rates of TCE through poplar cuttings compared to soil volatilization were determined. Potential metabolites contained in soil, poplar tissues, and transpired air are being investigated. Investigation of plant enzyme activity continues. Toxicity tests with suspended cell cultures have been problematic due to contamination of agar plates and liquid culture with bacteria colonies. Toxicity experiments will continue with hybrid poplar cuttings and chlorinated aliphatics. The effect on toxicity of number of chlorine atoms, redox potential, isomeric effects, and varying log Kow will be investigated. This project is in its fourth year.

Technology Transfer and Outreach: The investigators are encouraging the application of this research through a field demonstration at a site owned by a private company. NASA is using the findings of this research at Cape Canaveral, Florida. A U.S. patent application has been made. Presentations of the results of this research have been made to consultants, government staff, and other researchers at several different technical conferences. Research results have been published in two peer-reviewed journals.

Keywords: plant enzyme systems, chlorinated aliphatic compounds, TCE, phytoremediation.

Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes

T.C. Zhang, P.J. Shea, and S.D. Comfort, University of Nebraska

Project no.: 95-32

Goal: The objectives of this project are to 1) develop and test zero-valent iron-promoted processes for simultaneous remediation of atrazine and nitrate in contaminated ground and surface water, sediment, and soil; 2) investigate the technical and economic feasibility of the iron-promoted systems for above-ground and *in situ* remediation of ground and surface water, sediment, and soil contaminated with atrazine and nitrate; and 3) elucidate mechanisms of transformation and determine kinetics associated with the proposed processes.

Rationale: Preliminary studies demonstrate the potential use of iron-promoted processes to remediate ground and surface waters contaminated with atrazine and nitrate.

Approach: Investigators are using zero-valent iron-promoted processes, employing fine-grained iron metal as a reducing agent, to simultaneously transform atrazine and nitrate found in contaminated water, sediment, and soil.

Status: Initial batch tests are complete and the column reactors have been fabricated. Experiments were conducted to determine the feasibility of using the iron-promoted process to remediate waters containing 20 μg atrazine L^{-1} and 20 mg atrazine L^{-1}. The distribution of atrazine and its transformation products has been determined using ^{14}C-ring labeled atrazine. The mechanisms of nitrate removal in the iron-water system were investigated and results were verified. The abiotic transformation of nitrate using iron and electrokinetics was explored also. Experiments to evaluate the iron process coupled with biofilms have been completed. Results indicate that the iron-promoted treatment wall coupled with biofilm processes is efficient for *in situ* remediation of nitrate- and-atrazine contaminated groundwater for quite a long period of time. Experiments investigating nitrate and atrazine removal under different pH/redox conditions have been performed. The results indicate that the formation of magnetite may be a critical step in the nitrate reduction process. A series of adsorption/desorption studies with atrazine and iron has been conducted. Experiments to determine atrazine removal from solution and transformation after prolonged exposure to zero-valent iron are continuing. An on-site field demonstration of the technology was initiated in April 1999. Two articles regarding this research have been published in peer-reviewed journals. Papers have been presented and published in conference proceedings. The researchers have collaborated with two environmental consulting companies at a demonstration site. This project is in its fourth year.

Technology Transfer and Outreach: Investigators have published articles in peer-reviewed scientific journals, presented results at numerous technical conferences, and incorporated the technology into university classroom instruction. In addition, the investigators are disseminating the project findings within EPA Regions VII and VIII. The technology is currently being evaluated at a demonstration site in collaboration with two consulting companies.

Keywords: atrazine, nitrate, groundwater, surface water, contamination, zero-valent iron-promoted processes.

Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances in Air, Water, and/or as an Alternative to Incineration

K.J. Klabunde, Kansas State University

Project no.: 95-04a

Goal: The goal of this project is to develop a one-step process that uses ultra-high-surface-area metal and metal oxide particles for destroying hazardous substances, including chlorocarbons, chlorofluorocarbons, organophosphorus, nitrogen, and sulfur compounds.

Rationale: Zinc is an effective metal in the dehalogenation of chlorocarbons that contaminate groundwater. This reagent can help efficiently remove chlorinated hydrocarbons with high capacity. Trichloroethylene (TCE), one of the most common pollutants, was found to be degraded by zero-valent zinc in aqueous solutions under neutral pH conditions.

Approach: To gain more insight into the dominant pathway and general mechanism involved, important intermediates of different systems were investigated. A variety of techniques were used to analyze the gaseous, aqueous, and solid phases. Ethylene, ethane, and monchlorinated hydrocarbons were identified as the hydrogenation or elimination products. Dehydrochlorination or beta-elimination was also evident by acetylene appearance. Other related C_1 or C_2 compounds were produced in much smaller yields. Under similar conditions, experiments were also performed to assess the mass balance and carbon distribution. Both kinetic and mechanistic aspects were explored. In anaerobic environments, zinc generally provides electrons to organic molecules and further promotes the hydrocarbon formation. In a separate study, pH changes in Zn and Sn reductive systems were measured and compared. The catalytic effects of Ag^0 and Pd^0 promoters were studied, also.

Status: At the beginning of this project, high-surface-area zinc metal particles were used to destroy chlorocarbon contaminants in water. The understanding about the reactions of aluminum (Al), zinc (Zn), and tin (Sn) zero-valent particles with chlorocarbons in water improved a great deal, but these reactions must be cataloged for all reactive metals in order to extend the technology to field applications. Tests on a variety of core/shell nanoparticles with shells of transition metal oxides and cores of magnesium oxide (MgO) and calcium oxide (CaO) have been performed. The purpose of these tests is to help determine which combinations of metal oxides are most effective overall for treating contaminated water, and whether larger and less expensive microparticles can substitute for nanoparticles. Studies of doping zinc with silver, palladium, and gold indicate that reactivity towards carbon tetrachloride in water is increased significantly. A fixed-bed reactor for destructive adsorption of air pollutants has been constructed and experiments continue. Three patents have been obtained and work continues to transfer this technology to the private sector via a partnership with a small business. This project is in its fourth year.

Technology Transfer and Outreach: The investigators are working in partnership with a small start-up company to transfer the technology to the private sector. Investigators continue to present papers at meetings and technical conferences, publish papers, and answer many inquiries regarding this technology.

Keywords: nanoscale, nanoparticle, DAT, destructive adsorption technology, metal oxide.

Data Management and Horticultural Evaluation of Field Sites for the RTDF Phytoremediation Field Test of Petroleum Hydrocarbon Contaminated Soils (RTDF)

L.E. Erickson and P. Kulakow, Kansas State University

Project no.: Research Technology Development Forum (RTDF)

Goals: The goal of this project is to test phytoremediation of contaminated soils at six to twelve locations to gather data in support of the use of phytoremediation and its acceptance by the regulatory community. The trials will compare petroleum hydrocarbon dissipation in vegetated soils and unvegetated soils for a three-year period.

Rationale: The EPA-sponsored Research Technology Development Forum (RTDF) for Phyto-remediation, Total Petroleum Hydrocarbon (TPH) Subgroup has developed a protocol for a nationwide field test of phytoremediation of petroleum hydrocarbon-contaminated soils. This project will enter appropriate field sites into a testing program and develop a database of the field test results. Results of this project will provide valuable scientific information about the use of phytoremediation to clean up soils contaminated with petroleum hydrocarbons.

Approach: Data will be collected from the field sites and laboratories and sent to Kansas State University (KSU). The data will be cataloged, stored, and distributed in accordance with the data sharing and site confidentiality agreements arranged for this program. KSU will format all of the data into a common format to support data summary, statistical analysis, and reporting. Annual visits by KSU researchers will be made to several locations for the purpose of evaluating plant growth and development. Plant growth parameters will include vegetation coverage, species composition, aboveground biomass production, and plant rooting characteristics such as root length and diameter. Soil analyses will be performed at each field site as needed. Analyses will include pH, nitrogen, potassium, and phosphorus. Initial sampling will also include soil texture, organic matter, available zinc, available iron, cation exchange capacity, and salt alkali. An annual report of research progress will be prepared for internal use by the RTDF. A separate public report will be prepared following recommendations from the RTDF.

Status: As of September 1999, ten sites are expected to be entered into the RTDF trial. Seven of the sites have received regulatory approval to proceed with the trial. Six sites have been planted. The RTDF committee has been meeting by conference call on a monthly basis. One of the field trials is at Fort Riley, Kansas. This site was planted on September 15, 1999. Site visits have been made to three other locations and root samples have been collected at two sites to document plant growth after one growing season. Future work on this project will include site visits and analysis of root growth at sites completing the first growing season, continued development of the database, participation in the RTDF conference calls, and providing assistance to the RTDF participants depending on need.

Technology Transfer and Outreach: Technology transfer for this project has included regular interaction with all project participants including representatives from EPA, DOD, industry, and universities. A poster abstract has been submitted for the Partners in Environmental Technology Technical Symposium and Workshop sponsored by SERDP and ESTCP. An annual report for use by RTDF participants will be prepared on data received by November 30, 1999. A summary of this report will be prepared for the public.

Keywords: phytoremediation, vegetation, soil, fate and transport.

Training and Technology Transfer Project Descriptions

May 18, 1994 - September 30, 1999

HSRC Technology Transfer Program

L.N. Reddi, R.B. Hayter, and B.A. Leven, Kansas State University

Project no.: TR-01

Goal: Core training and technology transfer activities integrate new information and technology, primarily from HSRC research activities, into use by public and private organizations. The center accomplishes this by hosting annual conferences and workshops; publishing newsletters, proceedings, and other documents; developing and maintaining an HSRC information repository; responding to requests for information and educational services; and administering competitively selected training and technology transfer projects. Center staff provide support to several special HSRC programs with important technology transfer components to ensure integration of results from concurrent HSRC activities and to learn of technology needs for future HSRC research efforts.

Rationale: Many barriers to rapid, cost-effective implementation of environmental research results and new technologies exist due to unique regulations, liabilities, and specific issues associated with environmental cleanup sites. A variety of technology transfer and training activities are necessary to adequately address the full spectrum of issues and audiences involved in cleanup situations.

Approach: The center maintains communication with its consortium members, more than 90 principal investigators, non-consortium institutions, government offices, and interested businesses and individuals through newsletters, press releases, the Internet, workshops, and conferences. To keep pace with changing issues, resources, and needs for technology transfer, greater emphasis is being placed on information exchange systems that will allow centers to address specific on-the-ground needs for this broad audience.

Status: Principal investigators on essentially all HSRC research and technology transfer projects continue to publish papers in technical journals, books, and conference proceedings. The center publishes this information in a less technical format for quick review by consultants, industry, and regulators in newsletters such as *HazTech Transfer* and *Centerpoint*, as well as in guidebooks and video productions. *HazTech Transfer* has been published quarterly for ten years and is currently distributed in hard copy to more than 5,000 addressees, with readership estimated at 20,000 per issue. Many of these center and other non-center publications are maintained in the HSRC Information Repository at KSU, and can be accessed through the GP/RM HSRC World Wide Web site (http://www.engg.ksu.edu/HSRC).

Every week the center receives many requests for information from individuals and groups of stakeholders. Responses to these requests range from simple verbal and e-mail messages to oral presentations on the collective thoughts of several HSRC researchers on specific technical issues. Center staff frequently make informational presentations to program managers in state and EPA regional offices. In conjunction with the Technical Outreach Services for Communities (TOSC) and Native American and Other Minority Institutions (NAOMI) programs, several new collaborative research and field demonstration projects have begun.

Technology Transfer and Outreach: The entire purpose of this program is to transfer technology developed by the HSRC to practicing environmental professionals in government agencies, businesses, interested individuals, and other researchers. This is accomplished through the various communication methods discussed above.

Keywords: collaborative problem solving, partnerships, technology transfer, newsletter, repository, communication, training, World Wide Web.

Conference on Hazardous Waste Research

L.N. Reddi, C.A. Wolfe, L.E. Erickson, and B.A. Leven, Kansas State University

Goal: The goal of this project is to hold an annual research conference on hazardous substance research and to provide opportunities for individuals from public and private sectors to share technical information regarding the management of hazardous substances.

Rationale: Conferences provide good opportunities for the exchange of information. The conference serves as a mechanism of technology transfer by bringing together researchers, regulators, and industry to discuss relevant and timely research impacting everyday government and business decisions.

Approach: Kansas State University's approach has been to expand the Conference on Hazardous Waste Research to include issues of technology transfer and training. Other universities host the conference in alternate years.

Status: The 14th Annual Conference on Hazardous Waste Research was held in St. Louis, Missouri, May 25-27, 1999, with more than 200 people participating. Researchers from around the country and abroad attended the conference to present and hear papers, participate in panel discussions, and view posters and exhibits. The 1999 conference involved several co-sponsors and cooperating supporters, including the U.S. EPA, American Society of Civil Engineers, National Institute of Environmental Health Sciences, Mine Waste Technology Program, Colorado School of Mines, Integrated Petroleum Environmental Consortium, and the Waste-management, Education and Research Consortium. The 2000 Conference on Hazardous Waste Research will be held in Denver, Colorado, May 23-25, 2000. It will be co-sponsored by other co-funding organizations. The 1999 conference proceedings are being prepared for publication on the Internet and in print form.

Technology Transfer and Outreach: This annual conference brings together researchers, regulators, and industry for the express purpose of exchanging information and transferring technology.

Keywords: conference, information exchange, research.

Virtual Library: Transferring HSRC Research Results Through the Internet

L. E. Erickson, Kansas State University

Goal: The goal of this project is to publish the *Journal of Hazardous Substance Research*, an electronic, peer-reviewed journal distributed via the Internet.

Rationale: Investigators believe distributing this journal via the Internet will improve the delivery time of HSRC findings and information about related research. It should also provide an inexpensive alternative to library subscriptions and offer a means for evaluating the Internet as a vehicle for the delivery of refereed research results.

Approach: The journal will publish selected papers on hazardous substance research. Manuscripts will be selected for publication by a team of editors following peer review by members of the editorial board, HSRC advisory committees, and other qualified individuals. The journal will be freely accessible via the Internet to industry as well as the public at large. Anyone interested will be able to easily follow up with researchers by electronic mail or any other means of communication.

Status: An editorial team and advisory board have been established and a Web site is in place at http://www.engg.ksu.edu/HSRC/JHSR. Information concerning manuscript submission is on-line, and a call for papers has been created and distributed. A number of manuscripts have been submitted and peer reviewed, and ten articles are posted on the Web site. The articles are posted in portable document format (pdf) with searchable abstracts also available in HTML. Future plans include marketing research and studies to identify reliable methods for indexing, cataloging, and archiving the journal. Efforts to identify funding sources continue. This project is in its third year.

Technology Transfer and Outreach: This form of virtual publishing offers tremendous cost/benefit potential to industry, academia, and the general public by providing more fluid access and distribution of scientific and technological information.

Keywords: *Journal of Hazardous Substance Research*, publishing, Internet, World Wide Web, Web site, manuscripts, editorial.

Technical Outreach Services to Communities (TOSC) Program

B.A. Leven, T. Boguski, V. Deines, and L. Wigfall, Kansas State University

Goals: Technical Outreach Services for Communities (TOSC) provides technical assistance to communities, groups, and individuals affected by hazardous substances at EPA Superfund/RCRA, brownfield, former defense, and tribal sites. This includes providing information on the underlying issues related to the cleanup and reuse of sites with real or perceived environmental impacts.

Rationale: EPA and Congress have shown increasing interest in the level of community involvement in the decision-making process at hazardous waste sites in general, and specifically under the Superfund process. In 1986, Congress strengthened requirements for community participation in Superfund when it passed the Superfund Amendments and Re-authorization Act. These requirements were further strengthened when the revised National Oil and Hazardous Substances Contingency Plan (NCP) was released in 1990. One effort in support of furthering community involvement is EPA's Technical Assistance Grants program, where EPA provides community groups up to $50,000 per site for the purpose of obtaining outside technical assistance. This program has had success, but has been hampered by administrative burdens placed on community groups to obtain the grants and is limited to sites designated on the NPL.

Approach: The program provides a variety of services to interested citizens in the 10-state region:

- Toll-free telephone access to the TOSC Program Office.
- In-community presentations, workshops, and handouts on health risk and remediation issues. A listing of workshops appears in the final section of this report.
- In-community technical assistance at a basic level and from researchers in a variety of technical areas ranging from toxicology to engineering.
- Assistance with review of technical documents including site characterization reports, risk assessments, feasibility studies, and remedial designs.
- Attendance at public hearings and assistance in preparing written comments.
- Public education on hazardous substance issues.

Status: The TOSC program continues to provide education and outreach services to communities impacted by hazardous waste cleanup projects. Last year the TOSC program supported 20 communities. This support has grown to include 26 communities. The TOSC base program is currently supporting communities at nine sites, as well as providing most of the technical and administrative resources for all technical outreach programs including Technical Assistance to Brownfields (TAB) and the national Technology Outreach Services to Native American Communities (TOSNAC) program. In addition to base TOSC funding, the TOSNAC program at Haskell Indian Nations University is providing support to nine communities. TOSNAC also works to coordinate support to develop the capacity of tribal governments to address environmental concerns. These activities will help tribal communities affected by hazardous substance contamination issues overcome significant cultural and legal barriers in dealing with these issues. In addition to providing tribal communities with workshops, hands-on assistance, and personal expert assistance, TOSNAC activities will include needs assessment and communications techniques targeted specifically for Native Americans. TOSC is also receiving funds to support redevelopment of abandoned or underutilized sites through the EPA Brownfields program. Support is being provided to eight pilot projects in EPA Regions VII and VIII. This project is in its sixth year.

Technology Transfer and Outreach: This program assists in technology transfer from university research projects by providing information and technical assistance to communities in a format that is more easily understood. A greater level of understanding sometimes increases the remediation options that can be considered.

Keywords: communities, outreach services, Technical Assistance Grants, National Priority List.

Collaborative Environmental Seminar Series

G.L. Godfrey, Haskell Indian Nations University; and W.M. Griswold and B.A. Leven,

Kansas State University

Project no.: TR96-05

Goals: The goal of this project is to produce a series of seminars primarily for audiences at Haskell Indian Nations University (HINU) and other American Indian Higher Education Consortium (AIHEC) colleges and universities. The seminars will provide technical information to students, faculty, and tribal environmental professionals throughout the U.S. through quality videotaped seminars, and to students and faculty at HINU through traditional seminars on campus.

Rationale: Although NAOMI program funds expired in December 1997, the most successful elements of this program receive continued support through center funds awarded in open competition. Seminars produced under the NAOMI program are distributed to approximately 130 participants at AIHEC colleges and universities, tribal environmental offices, other minority academic institutions, Kansas colleges, and HSRC consortium institutions. In a survey, these participants indicated that the videos are the most effective delivery method and that they are used primarily as classroom tools and staff development tools.

Approach: The HINU Environmental Seminar Series consists of four high-quality video programs per year, companion on-campus seminar presentations at HINU, and semi-annual production of *Earth Medicine* newsletter. Video topics include a panel discussion of tribal environmental planning and management and pollution prevention opportunity assessments. A peer review of the program scripts has been recently implemented.

Status: The videos will be completed by March 2000.

Technology Transfer and Outreach: This program is similar to the TOSC program in that it assists in technology transfer by providing information and technical assistance to Native communities in an easily understood format.

Keywords: Native American, minority colleges, seminar, training.

Development of a "State-of-the-Science and Technology" Report on Site Characterization Technologies

J.L. Sims and R.C. Sims, Utah State University

Project no.: TR 97-07

Goals: The goal of this project is to prepare a "State-of-the-Science and Technology" report for site characterization technologies.

Rationale: Effective site characterization technologies are essential to the effective implementation of remedial action programs. The Office of Research and Development (ORD) of the U.S. Environmental Protection Agency (U.S. EPA) identified a need to have a "State-of-the-Science and Technology" report developed for site characterization technologies, with an emphasis on defining required improvements that will enhance understanding of subsurface conditions in soils, groundwater, and bedrock that affect the fate and transport of contaminants. The Utah Water Research Laboratory is preparing this report.

Approach: The report will be based on recently published research, research presently being conducted, and innovative activities being implemented and tested in field applications. Gaps in knowledge and technology and future areas of research will also be identified. The report will be prepared in hard copy and in interactive CD-ROM form, with Internet delivery capability.

Status: Library and Internet database searches have been conducted and major sources of published information on site characterization technologies have been identified. Site characterization technologies and technology categories have been identified and reviewed. The current development and application of identified technologies have been reviewed and

evaluated. Information has been collected from published resources and from known researchers in the given fields. An open request for information was sent to e-mail news groups dealing with environmental characterization in an effort to collect current information on the selected technologies. The draft final report will be completed in November 1999.

Technology Transfer and Outreach: This "State-of-the-Science and Technology" report will be a valuable resource for other technology transfer activities.

Keywords: technology, site characterizations, remediation.

Field Validation of an Optimal Design Methodology for Vegetative Remediation of Sediments from the Central Vehicle Wash Facility, Custer Hill, Fort Riley, Kansas—A Technology Transfer Project

A.P. Schwab , P. Kulakow, B.A. Leven, Kansas State University; M.K. Banks, Purdue University; and S.R. Burckhard, South Dakota State University

Project no.: SP96-Riley

Goals: The goals of this project are to develop an optimal remediation design using vegetative systems, to obtain regulatory approval for use of this technique to treat sediments on an ongoing basis, and to transfer this technology through computer software, demonstrations, and involvement of environmental professionals.

Rationale: The Central Vehicle Wash Facility concrete sedimentation basin at Fort Riley produces petroleum hydrocarbon-contaminated sediments on an ongoing basis. Vegetative remediation is potentially an inexpensive and acceptable innovative technique for treating these contaminated sediments. Results from this study could lead to feasibility evaluations and design of vegetative treatment systems for contaminated materials from other locations such as wastewater lagoons and UST sites, or for on-site treatment of miscellaneous petroleum spills.

Approach: This research involves establishing several vegetative treatment plots at the site, monitoring and comparing results, and calibrating evolving computer models and design tools. Additional field tests of this technology are being conducted at other unique cleanup sites, or for other waste types as funds become available. Technology transfer is an ongoing part of this project.

Status: Field experiments with three vegetation treatments are ongoing. Sediments contaminated with petroleum hydrocarbon were spread on plots with no vegetation; a grass mixture of tall fescue and western wheatgrass; and a grass/legume mixture of tall fescue with red clover, birdsfoot trefoil, and yellow sweetclover. Progress has been made towards completing a model and Graphical User Interface (GUI) to facilitate phytoremediation at Fort Riley. The model includes historic climate data and different planting/management schemes. Primary model parameters are the level of total petroleum hydrocarbons, soil texture, field density of the sediments, length of the growing season, climate of the site, and biomass production of the vegetation. Formulation of the cost/benefit analysis component of the model has begun. The evaluation for using the graphical results from the model to predict results of plant-based remediation on a growing season basis continues. Future work will compare the model results with experimental data and make the model available to users to make rapid decisions regarding contaminant transport. This project is beginning its third year.

Technology Transfer and Outreach: Technology transfer activities include simultaneous involvement of environmental professionals at Fort Riley, the Army Environmental Center, and state regulatory and private contractors throughout this project. A written guide and Internet-based software product are being developed to assess the feasibility and help implement phytoremediation of washrack sediments. Broad dissemination of project protocols and results is planned through workshops and platform presentations at various conferences.

Keywords: vegetation, phytoremediation, petroleum hydrocarbons.

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Orchard, B.J., "Evaluation of the Uptake and Fate of Trichloroethylene by Hybrid Poplar Trees Using a Sealed Plant-Growth Chamber System," M.S. Thesis, Utah State University, Logan, 1998. Project no. 95-10.

Patel, B.B., "Simulation of Waste-Generating Characteristics of a Chemical Reactor Network During Start-Up," M.S. Thesis, Kansas State University, 1996. Project no. 91-36.

Paterson, K.G., "Fate of Alachlor and Atrazine in Small Plot Field Studies," M.S. Thesis, University of Iowa, Iowa City, 1990.

Petrie, R.A., "Oxidation of Pentchlorophenol Affected by Manganese Oxide under Various Redox Environments," Ph.D. Dissertation, Utah State University, Logan, Utah, 1997. Project no. 93-21.

Picken, H.D., "Sequential Anaerobic-Aerobic Treatment of Chlorinated Aliphatic Hydrocarbons," M.S. Thesis, University of Iowa, Iowa City, 1998. Project no. 93-24.

Pirkl, D.R., "Petroleum Hydrocarbon Residual Product Effects on Soil-Water Retention Curves," M.S. Thesis, South Dakota State University, Brookings, 1999. Project no. 94-12.

Pytte, K., "Dimensionality and Heterogeneous Effects on Enhanced LNAPL Recovery Using Hot Water Flooding," M.S. Thesis, University of Colorado, Boulder, 1996. Project no. 94-29.

Ranf, T., "Assessing the Potential for *In Situ* Bioremediation of Contaminated Aquifers," M.S. Thesis, Montana State University, Bozeman, 1990.

Rao, D., "Mobility of Lead in Mining Wastes Due to Landfill Leachate," M.S. Thesis, University of Missouri, Columbia, 1991.

Rayavarapu, R. "Biodegradation of Pentachlorophenol by *Pseudomonas cepacia* AC 1100," M.S. Thesis, University of Missouri, Columbia, 1991.

Redy, B., "Validation of a Sequential Extraction Method for Lead, Cadmium, and Zinc," M.S. Thesis, University of Missouri, Columbia, 1992.

Regmi, T.P., "Biodegradaton of Chelating Agents Used for Removal of Metals from Contaminated Soils," M.S. Thesis, University of Missouri, Columbia, 1996. Project no. 93-22.

Saba, T.A., "Upscaling of Natural and Enhanced Dissolution of Nonaqueous-Phase Waste Chemicals," PhD. Dissertation, University of Colorado, 1998.

Santharam, S., "The Role of Vegetation and Surfactants in Remediating Soil Contaminated with Polycyclic Aromatic Hydrocarbons," M.S. Thesis, Kansas State University, Madras, India, 1992.

Schwarz, P.G., "Effect of Poplar Trees on Fate of Atrazine in a Model Tree System through Metabolism, Degradation, and Accumulations," M.S. Thesis, University of Iowa, Iowa City, 1991.

Seybert, R.A., "Design and Preliminary Evaluation of a Chlorinated Hydrocarbon Incinerator," M.S. Thesis, Kansas State University, Manhattan, 1990.

Shetty, K.G., "Relationship Between Mycorrhizal Symbiosis and Zinc Tolerance in Plants," Ph.D. Dissertation, Kansas State University, Manhattan, 1994.

Shurtliff, M.M., "Aerobic Biotransformation of Trichloroethylene by a Phenol-Induced, Mixed Culture," M.S. Thesis, University of Iowa, Iowa City, 1992.

Singh, J., "Natural and Accelerated Detoxification of Atrazine and RDX in Contaminated Soil and Water," Ph.D. Dissertation, University of Nebraska, Lincoln, 1997. Project no. 92-24.

Sturman, P. "Effectiveness and Interspecies Competition in Colonized Porous Pellets," M.S. Thesis, Montana State University, Bozeman, 1991.

Syverson, A.E., "Biotransformation of Volatile Chlorinated Organics in Anaerobic Filters with Acetate Enrichment Cultures," M.S. Thesis, University of Iowa, Iowa City, 1989.

Thies, G.T., "Metal Removal and Recovery Using a Vermiculite Ion Exchange System and Acid Extraction," M.S. Thesis, University of Nebraska, Lincoln, 1990.

Till, B.A., "Treatment of Nitrate-Contaminated Waters Using Autotrophic Denitrifiers and Zero-Valent Iron," M.S. Thesis, University of Iowa, Iowa City, 1997. Project no. 93-02.

Utamapanya, S., "Investigations of Molecular and Surface Properties of Magnesium Oxide," Ph.D. Dissertation, Kansas State University, Manhattan, 1990.

Vivek, S., "Treatment of Trichloroethene with a Fluidized-Bed Bioreactor," M.S. Thesis, University of Missouri, Columbia, 1996.

Walser, G.S., "Vadose Zone Infiltration, Mobilization, and Retention of Nonaqueous-Phase Liquid," Ph.D. Dissertation, University of Colorado, Boulder, 1995.

Wang, J.C., "Migration of PCP in Soil Columns in Presence of Nonaqueous Phase," M.S. Thesis, University of Missouri, Columbia, 1992.

Wang, J.M., "Migration of Sodium Pentachlorophenol in Unsaturated Soil Columns," M.S. Thesis, University of Missouri, Columbia, 1992.

Wang, Y., "Biodegradation of Chelating Agents Used for Removal of Metals from Contaminated Soils," M.S. Thesis, University of Missouri, Columbia, 1997. Project no. 93-22.

Wang, S.-P., "Application of Supercritical Fluid Extraction and Supercritical Fluid Chromatography for Determination of Steroidal Compounds," M.S. Thesis, University of Missouri, Columbia, 1992.

Watanabe, H., "Alachlor and Atrazine Losses from Runoff and Erosion in the Blue River Basin," M.S. Thesis, Kansas State University, Manhattan, 1993. Project no. 89-31.

Watermeier, N.L., "Impacts of Tillage System and Chemical Incorporation on Surface Losses of Water, Soil, Atrazine, and Alachlor," M.S. Thesis, University of Nebraska, Lincoln, 1993.

Waters, Y., "The Influence of Organic Acids on Leaching of Heavy Metals from Contaminated Mine Tailings," M.S. Thesis, Kansas State University, Manhattan, 1992.

Weathers, L.J., "Biological and Metallic Iron-Promoted Transformation of Carbon Tetrachloride and Chloroform under Methanogenic Conditions," Ph.D. Dissertation, University of Iowa, Iowa City, 1995.

Wei, S.M., "Interactions of Pentachlorophenol on Soils," M.S. Thesis, University of Missouri, Columbia, 1991.

Wetzel, S., "Biodegradation and Analysis of Pyrene in Rhizosphere Soils," M.S. Thesis, Kansas State University, Manhattan, 1995.

Wichman, M.D., "Fate and Toxicity of Volatile Organic Chemicals in a Poplar Plot," M.S. Thesis, University of Iowa, Iowa City, 1991.

Wigger, J.W., "Breakthrough Analysis Using X-Ray Computed Tomography," M.S. Thesis, University of Missouri, Columbia, 1991.

Wilber, G.G., "Kinetics of Alachlor, Atrazine, and Chloroform Transformation under Various Electron-Acceptor Conditions," Ph.D. Dissertation, University of Iowa, Iowa City, 1991.

Wildman, M.J., "Treatment of RDX-Contaminated Soil Using a Combined Microbial Fe(0) Approach," M.S. Thesis, University of Iowa, Iowa City, 1998.

Wu, J.C., "Modeling of *In Situ* Neutralization and Biodegradation Processes and Numerical Simulation with the Three-Point Backward Finite Difference Method," M.S. Thesis, Kansas State University, Manhattan, 1989.

Wu, X., "Examining the Fate of Released Pseudomonas Putida Fl through a Microcosm Study," M.S. Thesis, Kansas State University, Manhattan, 1998. Project no. 94-27.

Yang, X., "Characterizing *In Situ* Bioremediation of Organic-Contaminated Soils," Ph.D. Dissertation, Kansas State University, 1995.

Yates, D.N., "The Transport and Distribution of Nonaqueous Organics in Groundwater Aquifers: Experimental Investigation and Numerical Development," M.S. Thesis, University of Colorado, Boulder, 1989.

Ye, Q., "Studies on Uptake and Metabolism of PCBs by Terrestrial Plants," M.S. Thesis, University of Missouri, Columbia, 1991.

Zawaideh, L.L., "Remediation of Nitrate-Contaminated Water by Fe^0-Promoted Processes," M.S. Thesis, University of Nebraska, Lincoln, 1997. Project no. 95-32.

Zhang, S., "Biological Detoxification of Mercury-Contaminated Soil," M.S. Thesis, Utah State University, Logan, 1991.

Zhu, D., "The Fate and Transport of Heavy Metals in Soil as Affected by Vegetation and Organic Complexing Agents," Ph.D. Dissertation, Kansas State Univversity, Manhattan, 1998. Project no. 93-06.

G. CONFERENCES AND WORKSHOPS

Three-day workshop — Introduction to Hazardous Waste Management, Sioux Falls, South Dakota, November 9-11, 1989 — University of Missouri, Columbia, Missouri.

Three-day workshop — Introduction to Hazardous Waste Management, Denver, Colorado, January 18-20, 1990 — University of Missouri, Columbia, Missouri.

One-day conference — Hazardous Waste Minimization, Omaha, Nebraska, January 23, 1990 — Iowa Department of Natural Resources, Des Moines, Iowa; and Nebraska Department of Environmental Control, Lincoln, Nebraska.

Three-day workshop — Introduction to Hazardous Waste Management, Overland Park, Kansas, February 15-17, 1990 — University of Missouri, Columbia, Missouri.

Two-day cluster of conferences — Agricultural Impacts on Groundwater Quality; Groundwater Geochemistry; Groundwater Management and Wellhead Protection; Environmental Site Assessments: Case Studies and Strategies, Kansas City, Missouri, February 20-21, 1990 — National Water Well Association and Association of Groundwater Scientists and Engineers, Columbus, Ohio.

Two-day conference — Controlling Water Contamination, Manhattan, Kansas, March 7-8, 1990 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Helena, Montana, March 15-17, 1990 — University of Missouri, Columbia, Missouri.

Five-day conference — 1990 Billings Reclamation Symposium, Billings, Montana, March 25-30, 1990 — Montana State University, Bozeman, Montana.

Three-day workshop — Introduction to Hazardous Waste Management, Kansas City, Missouri, April 18-20, 1990 — University of Missouri, Columbia, Missouri.

One-day teleconference — Ask the Experts: Third Annual Hazardous Materials and Waste Management Update, Manhattan, Kansas, May 11, 1990 — Oklahoma State University, Stillwater, Oklahoma.

Two-day conference — Conference on Hazardous Waste Research, Manhattan, Kansas, May 21-22, 1990 — Kansas State University, Manhattan, Kansas.

One-day workshop — Minimizing Hazardous Waste: A Workshop for Metal Finishers, Manhattan, Kansas, May 23, 1990 — Kansas State University, Manhattan, Kansas.

Three-day conference — Interfacial Microbial Process Engineering, Bozeman, Montana, July 18-20, 1990 — Montana State University, Bozeman, Montana.

Five-day workshop — Summer Institute on Hazardous Waste Management, Columbia, Missouri, August 6-10, 1990 — University of Missouri, Columbia, Missouri.

Five-day symposium — Mineral and Hazardous Waste Processing Symposium, Butte, Montana, September 30-October 5, 1990 — Montana College of Mineral Science and Technology, Butte, Montana; and the Northern Rocky Mountain Water Congress.

Three-day workshop — Introduction to Hazardous Waste Management, Des Moines, Iowa, October 18-20, 1990 — University of Missouri, Columbia, Missouri.

Three-day conference — 25th Midwest Regional Meeting of the American Chemical Society, Manhattan, Kansas, November 7-9, 1990 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Salt Lake City, Utah, November 29-December 1, 1990 — University of Missouri, Columbia, Missouri.

Two-day video conference — The Environment: Corporate Stewardship and Business Opportunity in the Decade of Global Awakening, Manhattan, Kansas, December 5-6, 1990 — Business Week and World Resources Institute.

Three-day workshop — Introduction to Hazardous Waste Management, Lincoln, Nebraska, December 14-16, 1990 — University of Missouri, Columbia, Missouri.

Three-day workshop — Introduction to Hazardous Waste Management, St. Louis, Missouri, February 6-8, 1991 — University of Missouri, Columbia, Missouri.

Two-hour video conference — Pollution Prevention in Business: How Small Rural Businesses Can Minimize Their Pollution, Manhattan, Kansas, February 21, 1991 — Kansas State University, Manhattan, Kansas.

Two-day conference — Water and the Future of Kansas, Manhattan, Kansas, March 4-5, 1991 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Kansas City, Missouri, March 6-8, 1991 — University of Missouri, Columbia, Missouri.

Four-day conference — Hydrology Days, Fort Collins, Colorado, April 2-5, 1991 — Colorado State University, Fort Collins, Colorado.

One-day workshop — Underground Storage Tanks, St. Louis, Missouri, April 11, 1991 —University of Missouri, Columbia, Missouri.

One-day workshop — Sampling and Identification of Hazardous Waste, St. Louis, Missouri, April 12, 1991 — University of Missouri, Columbia, Missouri.

One-day conference — Hazardous Waste Management Conference: Remediation Alternatives and Case Studies, Kansas City, Missouri, April 23, 1991 — University of Missouri, Columbia, Missouri.

One-day workshop — Underground Storage Tanks, Kansas City, Missouri, April 25, 1991 —University of Missouri, Columbia, Missouri.

One-day workshop — Sampling and Identification of Hazardous Waste, Kansas City, Missouri, April 26, 1991 — University of Missouri, Columbia, Missouri.

Four-day conference — On-Site Bioremediation Conference, Hickory Corners, Michigan, May 19-22, 1991 — University of Michigan, Ann Arbor, Michigan.

Two-day conference — Conference on Hazardous Waste Research, Manhattan, Kansas, May 29-30, 1991 — Kansas State University, Manhattan, Kansas.

Two-day workshop — Primer in Environmental Initiatives, St. Louis, Missouri, May 30-31, 1991 — University of Missouri, Columbia, Missouri.

Two-day workshop — Primer in Environmental Initiatives, Kansas City, Missouri, June 13-14, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Cape Girardeau, Missouri, July 9, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Sikestone, Missouri, July 10, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Kirksville, Missouri, July 30, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Hannibal, Missouri, July 31, 1991 — University of Missouri, Columbia, Missouri.

Five-day workshop — Hazardous Waste Management Summer Institute, Columbia, Missouri, August 5-9, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, Kansas City, Missouri, August 20, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, St. Joseph, Missouri, August 21, 1991 — University of Missouri, Columbia, Missouri.

One-day course — Small Business Hazardous Chemical and Waste Management Course, St. Louis, Missouri, September 10, 1991 — University of Missouri, Columbia, Missouri.

Three-day workshop — Beneficial Effects of Vegetation in Contaminated Soils, Manhattan, Kansas, January 7-9, 1992 — Kansas State University, Manhattan, Kansas.

One-day workshop — Bioremediation: The State of Practice in Hazardous Waste Remediation Operations, A Satellite Seminar, held at eight sites in EPA Regions VII and VIII, January 9, 1992 — Air and Waste Management Association, Pittsburgh, Pennsylvania.

Three-day workshop — Hazardous Waste Management, Casper, Wyoming, January 16-18, 1992 — University of Missouri, Columbia, Missouri.

Two-day workshop — Primer in Environmental Initiatives, Columbia, Missouri, January 23-24, 1992 — University of Missouri, Columbia, Missouri.

One-day conference — 42nd Environmental Engineering Conference, Lawrence, Kansas, February 5, 1992 — University of Kansas, Lawrence, Kansas.

Two-day workshop — Our Changing Environment, AGU 1992 Front Range Meeting, Boulder, Colorado, February 10-11, 1992 — Rush Services Technical Communications.

Three-day workshop — Hazardous Waste Management, Columbia, Missouri, February 13-15, 1992 — University of Missouri, Columbia, Missouri.

Four-day workshop — Project Management for the Hazardous Waste Professional, Columbia, Missouri, February 19-22, 1992 — University of Missouri, Columbia, Missouri.

Two-day conference — Waste Management Conference, Logan, Utah, March 4-5, 1992 — Utah State University, Logan, Utah.

Three-day workshop — Hazardous Waste Management, Wichita, Kansas, March 26-28, 1992 — University of Missouri, Columbia, Missouri.

Two-day workshop — Waste Minimization Technology and Applications, Salt Lake City, Utah, April 29-30, 1992 — University of Missouri, Columbia, Missouri.

Two-day seminar — Technical Seminar on Groundwater, Topeka, Kansas, May 12-13, 1992 — Kansas Water Well Association.

Two-day workshop — Waste Minimization Technology and Applications, Wichita, Kansas, May 13-14, 1992 — University of Missouri, Columbia, Missouri.

Two-day conference — Alternate Fuels Conference, Manhattan, Kansas, May 14-15, 1992 — Kansas State University, Manhattan, Kansas.

Two-day conference — 7th Annual Conference on Hazardous Waste Research, Boulder, Colorado, June 1-2, 1992 — Kansas State University, Manhattan, Kansas.

One-day workshop — Impact of Heavy Metals on Mine Land Restoration Workshop, Boulder, Colorado, June 3, 1992 — Kansas State University, Manhattan, Kansas.

Five-day workshop — Hazardous Waste Site Operations Training, Kansas City, Kansas, June 15-19, 1992 — University of Kansas, Lawrence, Kansas.

Four-day conference — Subsurface Restoration Conference, Dallas, Texas, June 21-24, 1992 — Rice University, Houston, Texas.

Six-day workshop — Shaping Our Environmental Heritage, Kansas City, Missouri, June 21-26, 1992 — Air & Waste Management Association, Pittsburgh, Pennsylvania.

Two-day conference — Annual Conference and Exhibition Application of Geostatistics and Kriging to Spatial Estimation Problems in Groundwater, Golden, Colorado, July 16-17, 1992 — Colorado School of Mines, Golden, Colorado.

Five-day workshop — 11th Annual Hazardous Waste Management Summer Institute, Columbia, Missouri, August 10-14, 1992 — University of Missouri, Columbia, Missouri.

Five-day workshop — Principles and Applications of Modeling Chemical Reactions in Groundwater, Golden, Colorado, August 10-14, 1992 — Colorado School of Mines, Golden, Colorado.

Four-day workshop — Transport and Fate of Organic Chemicals in Multimedia Environmental Systems, Golden, Colorado, August 17-20, 1992 — Colorado School of Mines, Golden, Colorado.

Five-day workshop — Fundamentals of Bioremediation of Hazardous Waste-Contaminated Soils, Logan, Utah, August 24-28, 1992 — Utah State University, Logan, Utah.

Five-day workshop — Introduction in Groundwater Modeling, Golden, Colorado, September 14-18, 1992 — Colorado School of Mines, Golden, Colorado.

Four-day workshop — Primer in Environmental Initiatives, Columbia, Missouri, September 20-23, 1992 — University of Missouri, Columbia, Missouri.

One-day workshop — Sampling and Laboratory Analysis of Hazardous Substances, Columbia, Missouri, September 25, 1992 — University of Missouri, Columbia, Missouri.

Two-day workshop — Pollution Prevention Technology and Applications, Columbia, Missouri, October 14-15, 1992 — University of Missouri, Columbia, Missouri.

Three-day workshop — Five-Center Technology Transfer and Training Meeting and Workshop, Excelsior Springs, Missouri, October 14-16, 1992 — Kansas State University, Manhattan, Kansas.

Two-day conference — Total Quality Environmental Management, 6th Annual Colorado Hazardous Waste Management Society Conference and Exhibit, Denver, Colorado, October 22-23, 1992 — Hazardous Waste Management Society, Denver, Colorado.

Two-day workshop — Pollution Prevention Technology and Applications, St. Louis, Missouri, February 17-18, 1993 — University of Missouri, Columbia, Missouri.

Four-day workshop — Project Management for the Hazardous Waste Professional, Kansas City, Missouri, February 23-26, 1993 — University of Missouri, Columbia, Missouri.

Three-day workshop — Introduction to Hazardous Waste Management, Helena, Montana, March 17-19, 1993 — University of Missouri, Columbia, Missouri.

One-day workshop — Remedial Design Issues...Keeping Your Projects on Schedule and Within Budget, Kansas City, Missouri, March 25, 1993 — University of Missouri, Columbia, Missouri.

Two-day conference — Potentially Responsible Parties Superfund Settlement Incentives, Denver, Colorado, April 15-16, 1993 — Kansas State University, Manhattan, Kansas.

One-day workshop — Pollution Prevention Workshop for the Electroplating Industry, Manhattan, Kansas, May 24, 1993 — Kansas State University, Manhattan, Kansas.

Two-day conference — 8th Annual Conference on Hazardous Waste Research, Manhattan, Kansas, May 25-26, 1993 — Kansas State University, Manhattan, Kansas.

One-day workshop — Underground Storage Tank Site Characterization and Remediation Technologies, Manhattan, Kansas, May 27, 1993 — Kansas State University, Manhattan, Kansas.

Two-month workshop — Environmental Biotechnology Workshop for Thai Professors, Manhattan, Kansas, June 7-July 30, 1993 — Kansas State University, Manhattan, Kansas.

Four-day convention — National Groundwater Association's 45th Annual Convention and Exposition, Kansas City, Missouri, October 17-20, 1993 — National Groundwater Association, Dublin, Ohio.

One-day course — The Annual HAZMAT Update, St. Louis, Missouri, November 3, 1993 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT Employee Training, Testing and Certification, St. Louis, Missouri, November 4, 1993 — University of Missouri, Columbia, Missouri.

One-day course — Hazardous Waste Sampling, St. Louis, Missouri, November 5, 1993 — University of Missouri, Columbia, Missouri.

Four-day course — CHMM Review Course and Exam, St. Louis, Missouri, November 17-20, 1993 — University of Missouri, Columbia, Missouri.

One-day course — Hazardous Waste Sampling, Kansas City, Missouri, November 18, 1993 — University of Missouri, Columbia, Missouri.

One-day course — Advanced Hazardous Waste Management, Columbia, Missouri, November 30, 1993 — University of Missouri, Columbia, Missouri.

Three-day course — Introduction to Hazardous Waste Management, Kansas City, Missouri, December 1-3, 1993 — University of Missouri, Columbia, Missouri.

Three-day course — Three-Day Short Course on Soil Contamination, Kansas City, Missouri, December 2-3, 1993 — University of Nebraska, Lincoln, Nebraska.

Three-day workshop — Beneficial Effects of Vegetation in Contaminated Soils, Manhattan, Kansas, January 5-7, 1994 — Kansas State University, Manhattan, Kansas.

Three-day course — Introduction to Hazardous Waste Management, St. Louis, Missouri, January 5-7, 1994 — University of Missouri, Columbia, Missouri.

One-day course — CHMM Examination, St. Louis, Missouri, January 8, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Air Quality Management Update, Kansas City, Missouri, January 25, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT 8-Hour Refresher Course, Kansas City, Missouri, February 3, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, Springfield, Missouri, February 3-4, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT Transportation Safety, Kansas City, Missouri, February 4, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Project Management for the Hazardous Waste Professional: Phase I, St. Louis, Missouri, February 8-19, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Air Quality Management Update, St. Louis, Missouri, February 23, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, St. Louis, Missouri, February 24-25, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Working Trees—Farming in the 1990s: Ecolotree™ Buffers for Riparian Edge Management, Owatonna, Minnesota, March 3, 1994 — Minnesota Soil & Water Conservation Association, Owatonna, Minnesota.

Two-day course — Project Management for the Hazardous Waste Professional: Phase II, Kansas City, Missouri, March 10-11, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, Kansas City, Missouri, March 18-19, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Advanced Water Treatment, Columbia, Missouri, March 24-25, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Pollution Prevention Course, Springfield, Missouri, April 7-8, 1994 — University of Missouri, Columbia, Missouri.

Four-day course — CHMM Review and Examination, St. Louis, Missouri, April 20-23, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT 8-Hour Refresher Course, Cape Girardeau, Missouri, May 5, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HAZMAT Transportation Safety, Cape Girardeau, Missouri, May 6, 1994 — University of Missouri, Columbia, Missouri.

Five-day course — Forty-Hour HAZWOPER, Columbia, Missouri, May 16-20, 1994 — University of Missouri, Columbia, Missouri.

Two-day workshop — Beneficial Effects of Vegetation in Soils Contaminated with Heavy Metals, Denver, Colorado, May 23-24, 1994 — EPA Region VIII, Denver, Colorado; and Kansas State University, Manhattan, Kansas.

Two-day course — Primer in Environmental Initiatives, Columbia, Missouri, May 24-25, 1994 — University of Missouri, Columbia, Missouri.

One-day field trip — Mine Lands Revegetation Field Trip, Butte, Montana, June 7, 1994 — Montana State University, Bozeman, Montana.

One-day workshop — Synergistic Solutions: A Conversation Among Industry, Government and Academia, Bozeman, Montana, June 7, 1994 — Montana State University, Bozeman, Montana.

Three-day conference — 9th Annual Conference on Hazardous Waste Remediation, Bozeman, Montana, June 8-10, 1994 — Kansas State University, Manhattan, Kansas; and Montana State University, Bozeman, Montana.

One-day field trip — Mine Waste Field Trip, Butte, Montana, June 11, 1994 — Montana State University, Bozeman, Montana.

Five-day course — Hazardous Waste Management Summer Institute, Columbia, Missouri, August 8-12, 1994 — University of Missouri, Columbia, Missouri.

Two-day course — Primer in Environmental Laws and Multimedia Auditing, Columbia, Missouri, September 22-23, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Introduction to Sampling, Columbia, Missouri, September 28, 1994 — University of Missouri, Columbia, Missouri.

One-day course — HazMat Refresher, Springfield, Missouri, October 6, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Introduction to Sampling, Columbia, Missouri, October 12, 1994 — University of Missouri, Columbia, Missouri.

One-day course — ASTM—Risk-Based Corrective Action for Petroleum Sites, Columbia, Missouri, October 19, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Hazardous Waste Sampling, Columbia, Missouri, November 3, 1994 — University of Missouri, Columbia, Missouri.

Seminar — The NAOMI Program and HERS: New Opportunities in Environmental Research, Lawrence, Kansas, November 2, 1994 — Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Comparison of Native American and European Worldviews: A Native American Viewpoint, Lawrence, Kansas, November 4, 1994 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — Advanced Hazardous Waste Management, St. Louis, Missouri, November 16, 1994 — University of Missouri, Columbia, Missouri.

Three-day course — Introduction to Hazardous Waste Management, Denver, Colorado, December 1-3, 1994 — University of Missouri, Columbia, Missouri.

One-day course — Advanced Hazardous Waste Management, Kansas City, Missouri, January 25, 1995 — University of Missouri, Columbia, Missouri.

Seminar — Environmental Impacts of Gold Mining Operations Near the Fort Belknap Reservation, Lawrence, Kansas, January 26, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — Environmental Risk Management, Kansas City, Missouri, January 26, 1995 — University of Missouri, Columbia, Missouri.

One-day course — 8-Hour HazMat Refresher, St. Louis, Missouri, February 9, 1995 — University of Missouri, Columbia, Missouri.

One-day course — HazMat HM-126/181, St. Louis, Missouri, February 10, 1995 — University of Missouri, Columbia, Missouri.

One-day course — Air Quality Management Update, St. Louis, Missouri, February 22, 1995 — University of Missouri, Columbia, Missouri.

Seminar — Comparison of Native American and European Worldviews: A European Viewpoint, Lawrence, Kansas, March 3, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — Air Quality Management Update, Kansas City, Missouri, March 8, 1995 — University of Missouri, Columbia, Missouri.

Three-day course — Introduction to Hazardous Waste Management, St. Louis, Missouri, March 16-18, 1995 — University of Missouri, Columbia, Missouri.

Two-day course — Advanced Water Treatment, Columbia, Missouri, March 23-24, 1995 — University of Missouri, Columbia, Missouri.

Seminar — Basin Creek Mine Closure Reclamation Techniques, Butte, Montana, April 13, 1995 — Mine Waste Technology Program, Butte, Montana; and Haskell Indian Nations University, Lawrence, Kansas.

Seminar — PCBs in Our Environment—The Legacy Continues, Flagstaff, Arizona, April 21, 1995 — Northern Arizona University, Flagstaff, Arizona; and Haskell Indian Nations University, Lawrence, Kansas.

Four-day seminar — A Gathering for the Earth, Washington, DC, April 21-23, 1995 — U.S. Department of Agriculture, Washington, DC; and Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Topics in Pollution Prevention, Lawrence, Kansas, May 2, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

One-day course — 8-Hour HAZWOPER Refresher Course, Manhattan, Kansas, May 22, 1995 — Kansas State University, Manhattan, Kansas.

One-day workshop — Bioremediation of Munitions-Contaminated Soil, Manhattan, Kansas, May 22, 1995 — Kansas State University, Manhattan, Kansas; and Western Governors' Association Military Munitions Waste Working Group.

Two-day conference — 10th Annual Conference on Hazardous Waste Research, Manhattan, Kansas, May 23-24, 1995 — Kansas State University, Manhattan, Kansas.

Two-day workshop — Chelating Agents Design and Application in Heavy Metals Extraction from Contaminated Soils, Manhattan, Kansas, May 23-24, 1995 — University of Utah, Logan. Project no. 93-22.

One-day workshop — Beneficial Effects of Vegetation in Contaminated Soils, Manhattan, Kansas, May 25, 1995 — Kansas State University, Manhattan, Kansas.

One-day workshop — Designer Chelators: Study of Structure-Activity Relationships to Obtain the Ideal Chelator, Manhattan, Kansas, May 25, 1995 — University of Utah, Salt Lake City, Utah; and Kansas State University, Manhattan, Kansas.

One-day workshop — Environmentally Conscious Printing, Manhattan, Kansas, May 25, 1995 — Kansas State University, Manhattan, Kansas.

Five-day seminar — Freight Pipeline Seminar, Columbia, Missouri, July 10-14, 1995 — University of Missouri, Columbia, Missouri.

Two-week workshop — Technologies in Cleanup and Compliance, Lawrence, Kansas, July 16-29, 1995 — Haskell Indian Nations University, Lawrence, Kansas; Kansas State University, Manhattan, Kansas; and Kansas State University, Salina, Kansas.

Five-day course — Hazardous Waste Summer Institute, Columbia, Missouri, August 7-11, 1995 — University of Missouri, Columbia, Missouri.

Two-day seminar — Phytoremediation of Soil and Water Contaminants, Orlando, Florida, August 25-30, 1996 — 212th National Meeting of the American Chemical Society.

Seminar — Comparison of Native American and European Worldviews: A Roundtable Discussion, Lawrence, Kansas, September 20, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

Five-day workshop — 40-Hour HAZWOPER Training, Missoula, Montana, October 9-13, 1995 —University of Montana, Missoula, Montana.

Seminar — The Badlands Bombing Range Project, Lawrence, Kansas, October 11, 1995 — Haskell Indian Nations University, Lawrence, Kansas.

Five-day workshop — 40-Hour HAZWOPER Training, Missoula, Montana, November 13-17, 1995 — University of Montana, Missoula, Montana.

One-day workshop — Advanced Hazardous Waste Management, St. Louis, Missouri, Nov 29, 1995 — University of Missouri, Columbia, Missouri.

One-day workshop — Annual Hazardous Materials Update (8-Hour Refresher), television simulcast from Kansas City, St. Louis, and Columbia, Missouri, Oct 25, 1995 — University of Missouri, Columbia, Missouri.

One-day workshop — Bioremediation Alternatives, Helena, Montana, December 7, 1995 — Montana State University, Bozeman, Montana.

Five-day workshop — 40-Hour HAZWOPER Training, Missoula, Montana, December 11-15, 1995 — University of Montana, Missoula, Montana.

Five-day workshop — 40-Hour HAZWOPER Training, Manhattan, Kansas, January 15-19, 1996 — Kansas State University, Manhattan, Kansas.

Seminar — Comparison of Native American and European Worldviews: A Roundtable Discussion, Part II, Lawrence, Kansas, January 23, 1996 — Haskell Indian Nations University, Lawrence, Kansas.

One-day workshop — Advanced Hazardous Waste Management Course, Kansas City, Missouri, February 8, 1996 — University of Missouri, Columbia, Missouri.

Two-day workshop — Real Estate Site Assessment, Phase I, Kansas City, Missouri, March 5-6, 1996 — University of Missouri, Columbia, Missouri.

Three-day workshop — Bioremediation Alternatives, Annual UST/LUST National Conference, Chicago, Illinois, March 11-13, 1996 — Montana State University, Bozeman, Montana.

One-week symposium — Billings Reclamation Symposium, Billings, Montana, March 17-23, 1996 — Montana State University, Billings, Montana.

Two-day workshop — Real Estate Site Assessment, Phase I, Omaha, Nebraska, March 19-20, 1996 — University of Missouri, Columbia, Missouri.

Two-hour video conference — An Environmental Legacy for Our Grandchildren, Lawrence, Kansas, April 11, 1996 — Haskell Indian Nations University.

Seminar — Geoscience Education in Native American Communities, Rapid City, South Dakota, April 19, 1996 — South Dakota School of Mining and Technology, Rapid City, South Dakota and Haskell Indian Nations University, Lawrence, Kansas.

One-day exposition — Solvent Alternative Expo, Salina, Kansas, April 25, 1996 — Kansas State University, Manhattan, Kansas.

One-day workshop — Beneficial Effects of Vegetation in Metals-Contaminated Soils, Albuquerque, New Mexico, May 20, 1996.

One-day workshop — HAZWOPER Refresher, Columbia, Missouri, May 21, 1996 — University of Missouri, Columbia, Missouri.

Two-day workshop — Real Estate Site Assessment, Phase I, Salt Lake City, Utah, May 21-22, 1996 — University of Missouri, Columbia, Missouri/ASTM.

One-day workshop — Bioremediation Alternatives, HSRC/WERC Joint Conference on the Environment, Albuquerque, New Mexico, May 21-23, 1996 — Montana State University, Bozeman, Montana.

Three-day conference — HSRC/WERC Joint Conference on the Environment, Albuquerque, New Mexico, May 21-23, 1996 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Five-day workshop — HAZWOPER 40-Hour Course, Columbia, Missouri, May 20-24, 1996 — University of Missouri, Columbia, Missouri.

One-day workshop — Remediation of Munitions-Contaminated Soil and Water, Albuquerque, New Mexico, May 23, 1996.

Two-day workshop — HAZWOPER 8-Hour Refresher Short Course, Albuquerque, New Mexico, May 23-24, 1996.

Two-day workshop — Selection of Remediation Technologies Short Course, Albuquerque, New Mexico, May 23-24, 1996.

Two-day workshop — Risk-Based Corrective Action, Wichita, Kansas, June 25-26, 1996 — University of Missouri, Columbia, Missouri/ASTM.

Five-day workshop — Hazardous Waste Summer Institute, Columbia, Missouri, July 29-August 2, 1996 — University of Missouri, Columbia, Missouri.

Two-day training — Environmental Analysis Training, Rosebud, South Dakota, November 20-22, 1996 — Sinte Gleska University and University of Nebraska-Lincoln.

Seminar — Biology of the Earth: All Things Are Connected, Lawrence, Kansas, January 28, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Two-day workshop — Risk-Based Corrective Action (ASTM Standards), Kansas City, Missouri, January 28-29, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Air Quality Management Update, St. Louis, Missouri, February 13, 1997 — University of Missouri-Columbia, Missouri.

Two-day workshop — Real Estate Phase I Assessment (ASTM Standards), Memphis, Tennessee, February 25-26, 1997 — University of Missouri-Columbia, Missouri.

Seminar — Biology of the Earth: Our Connection to the Land, Lawrence, Kansas, February 28, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

One-day training — 8-Hour HAZWOPER Refresher, Columbia, Missouri, March 4, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Advanced Hazardous Waste Management, Columbia, Missouri, March 5, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Air Quality Management Update, Kansas City, Missouri, March 6, 1997 — University of Missouri-Columbia, Missouri.

Two-day workshop — Department of Transportation Requirements for Hazardous Materials Handling, Columbia, Missouri, March 6-7, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — Advanced Water Treatment, Columbia, Missouri, March 20, 1997 — University of Missouri-Columbia, Missouri.

Seminar — Biology of the Earth: Water – Going Beneath the Surface of the Issue, Lawrence, Kansas, March 20, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Two-day workshop — ISO 14000 Auditing for Managers, Kansas City, Missouri, April 8-9, 1997 — University of Missouri-Columbia, Missouri.

Two-day conference— WERC/HSRC Joint Conference on the Environment, Albuquerque, New Mexico, April 22-24, 1997 — Waste-management Education and Research Consortium and the South/Southwest Hazardous Substance Research Center.

Seminar — Biology of the Earth: Air-Ensuring Quality for the Future, Lawrence, Kansas, April 22, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Six-week video course — Certified Hazardous Materials Manager Review, various locations throughout Missouri, April 24-May 29, 1997 — University of Missouri-Columbia, Missouri.

Test — Certified Hazardous Materials Manager Examination, Columbia, Missouri, April 26, 1997 — University of Missouri-Columbia, Missouri.

Two-day course — Risk-Based Corrective Action: The Standard for Petroleum Release Sites ASTM Standard E 1739, St. Louis, Missouri, April 29-30, 1997 — University of Missouri-Columbia, Missouri.

Two-day course — ISO 14000 for Auditors, Kansas City, Missouri, May 13-14, 1997 — University of Missouri-Columbia, Missouri.

One-day workshop — 8-Hour HAZWOPER Refresher, Kansas City, Missouri, May 19, 1997 — Kansas State University, Manhattan, Kansas.

One-day workshop — Acid Mine Drainage Short Course, Kansas City, Missouri, May 19, 1997 — West Virginia University.

One-day course — 8-Hour HAZWOPER Refresher, Columbia, Missouri, May 20, 1997 — University of Missouri-Columbia, Missouri.

Three-day conference — 12th Annual Conference on Hazardous Waste Research, Kansas City, Missouri, May 20-22, 1997 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop — Application of Chelating Agents for Removal of Heavy Metals from Soils, Kansas City, Missouri, May 22, 1997 — Utah State University, Logan, Utah. Project no. 93-22.

One-day workshop — Prepared-Bed Bioremediation of Contaminated Soils, Kansas City, Missouri, May 22, 1997 — Utah State University, Logan, Utah.

One-day workshop — Water Quality Workshop, June 3, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Three-day conference — EPA Region 7 Pollution Prevention Conference, Kansas City, Missouri, June 3-5, 1997 — Kansas State University, Manhattan, Kansas.

Five-day seminar — 16th Annual Hazardous Waste Summer Institute, Columbia, Missouri, August 4-8, 1997 — University of Missouri-Columbia, Missouri.

Two-day workshop — Environmental Site Assessment Practices for Commercial Real Estate ASTM Standard E 1527 and 1528, St. Louis, Missouri, August 12-13, 1997 — University of Missouri-Columbia, Missouri.

Three-day workshop — Symposium on Science in the Tallgrass, 53rd Southwest Regional Meeting, Tulsa, Oklahoma, October 1-3, 1997 — American Chemical Society, Washington, DC.

Three-day workshop — Certified Hazardous Materials Manager Review, St. Louis, Missouri, October 15-17, 1997 — University of Missouri-Columbia, Missouri.

Seminar — Native American Environmentalism at the Cusp of the Millennium, Lawrence, Kansas, November 5, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Effects of the 1997 Nuclear Waste Policy Act, Lawrence, Kansas, November 10, 1997 — Haskell Indian Nations University, Lawrence, Kansas.

Three-day workshop — Compacted Clay Liners, Columbia, Missouri, November 11-13, 1997 — University of Missouri-Columbia, Missouri.

Five-day workshop — HAZWOPER 40-hour Course, Manhattan, Kansas, January 5-9, 1998 — Kansas State University, Manhattan, Kansas.

One-day workshop — HAZWOPER Refresher, Manhattan, Kansas, January 7, 1998 — Kansas State University, Manhattan, Kansas.

Three-day workshop — Workshop on Beneficial Effects of Vegetation in Contaminated Soil, Manhattan, Kansas, January 7-9, 1998 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day workshop — Introduction to Hazardous Waste Management, Columbia, Missouri, January 12-14, 1998 — University of Missouri-Columbia, Missouri.

Two-day workshop — Compliance with DOT Regulations Training, Testing, and Certification, Columbia, Missouri, January 15-16 — University of Missouri-Columbia, Missouri.

Seminar — Environmental Justice in Indian Country, Lawrence, Kansas, March 20, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Nine-day conference — Wetlands Engineering and River Restoration Conference, Denver, Colorado, March 20-29, 1998 — American Society of Civil Engineers, Reston, Virginia; and Society of Wetland Scientists, Lawrence, Kansas.

Three-day conference — Joint Conference on the Environment, Albuquerque, New Mexico, March 31-April 2, 1998 — Waste-management Education and Research Consortium, Las Cruces, New Mexico; Western Region HSRC, Stanford, California; and New Mexico Hazardous Waste Management Society.

Seminar — Microscale Chemistry in the Classroom, Lawrence, Kansas, April 11, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Three-day workshop — Certified Hazardous Materials Manager Review Course, Columbia, Missouri, April 15-17, 1998 — University of Missouri-Columbia, Missouri.

One-day workshop — On-Site Insights: Innovative Technologies for Site Assessment and Monitoring, Snowbird, Utah, May 18, 1998 — Northeast HSRC, Newark, New Jersey.

One-day workshop — Predictive Modeling of Pitlake Chemistry: Theory, Methods, Application, and Regulatory Issues, Snowbird, Utah, May 18, 1998 — Montana Tech of the University of Montana, Butte, Montana.

One-day workshop — Quantitative Assessment of Natural Attenuation Processes for Site Remediation, Snowbird, Utah, May 18, 1998 — Utah State University, Logan, Utah; and Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day conference — 13th Annual Conference on Hazardous Waste Research, Snowbird, Utah, May 19-21, 1998 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Two-day workshop — Natural Attenuation of Chlorinated Solvents in Groundwater, Salt Lake City, Utah, July 15-16, 1998 — Utah Department of Environmental Quality, Salt Lake City, Utah; Hill Air Force Base, Utah; Utah State University, Logan, Utah.

Four-day conference — Animal Production Systems and the Environment: An International Conference on Odor, Water Quality, Nutrient Management, and Socioeconomic Issues, Des Moines, Iowa, July 19-22, 1998 — Iowa State University, Ames, Iowa.

Seminar — Wetland Ecology and Indian Culture, Lawrence, Kansas, September 10, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Seminar — Water Resource Protection Programs — A Tribal Perspective, Lawrence, Kansas, September 11, 1998 — Haskell Indian Nations University, Lawrence, Kansas.

Two-day workshop — Natural Attenuation of Chlorinated Solvents in Groundwater, Kansas City, Kansas, September 16-17, 1998 — Kansas Department of Health and Environment, Topeka, Kansas and Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day workshop — Fate, Transport, and Remediation of Non-Aqueous Phase Liquids (NAPLs), Helena, Montana, September 22-24, 1998 — Colorado School of Mines, Golden, Colorado; Colorado State University, Fort Collins, Colorado; and University of Nevada, Las Vegas, Nevada.

Four-day conference – 5th International Petroleum Environmental Conference, Albuquerque, New Mexico, October 20-23, 1999 – Integrated Petroleum Environmental Consortium and Waste-management Education and Research Consortium.

Five-day workshop — HAZWOPER 40-hour Course, Manhattan, Kansas, January 4-8, 1999 — Kansas State University, Manhattan, Kansas.

One-day workshop — HAZWOPER Refresher, Manhattan, Kansas, January 6, 1999 — Kansas State University, Manhattan, Kansas.

Three day conference – Tailings and Mine Waste ’99 Conference, Ft. Collins, Colorado, January 24-27, 1999 – Colorado State University.

Two day course – Introduction to Hazardous Waste Management, Columbia, Missouri, January 25-27, 1999 – University of Missouri-Columbia.

Two day course – Compliance with DOT Regulations: Training, Testing and Certification, Columbia, Missouri, January 27-29, 1999 – University of Missouri-Columbia.

Four-day conference – Ninth Annual Waste-management Education and Research Consortium Conference on the Environment, Las Cruces, New Mexico, April 26-29, 1999 – WERC.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, Sioux Falls, South Dakota, May 4, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, Des Moines, Iowa May 6, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, St. Louis, Missouri, May 24,1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Three-day conference — 14th Annual Conference on Hazardous Waste Research, St. Louis, Missouri, May 25-27, 1999 — Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Community Involvement Strategies, Wellston, Missouri, May 27, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Permeable Reactive Barriers, St. Louis, Missouri, May 27, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

One-day workshop – Assessment and Cleanup Strategies for Site Redevelopment Based on Intended Land Use and Risk Analysis, Salt Lake City, Utah, June 3, 1999 – Great Plains/Rocky Mountain HSRC, Manhattan, Kansas.

Five-day workshop — HAZWOPER 40-hour Course, Manhattan, Kansas, June 14-18, 1999 — Kansas State University, Manhattan, Kansas.

Five-day workshop – Field-Based Site Characterization Technologies Course, Haskell National Training Center, Lawrence, Kansas, June 21-25, 1999, Haskell Environmental Resources Study Center, Lawrence, Kansas.

One-day workshop — HAZWOPER Refresher, Manhattan, Kansas, June 21, 1999 — Kansas State University, Manhattan, Kansas.

One day workshop – Assessment and Cleanup Strategies Workshop, Denver, Colorado, July 8, 1999 – GP/RM HSRC and EPA Brownfields and Community Involvement Offices.

Three day tour – Nebraska Summer Water Tour "Opportunities and Alternatives in Water and Agriculture," July 19-21, 1999 – University of Nebraska-Lincoln and other sponsors; Kearney Area Chamber of Commerce.

Three day course – Introduction to Hazardous Waste Management (Course 2), August 2-4, 1999, Columbia, Missouri – University of Missouri-Columbia.

One day course – Advanced Hazardous Waste Management, August 5, 1999, Columbia, Missouri – University of Missouri-Columbia.

One day course – Hazardous Waste Management Update, August 6, 1999, Columbia, Missouri – University of Missouri.

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