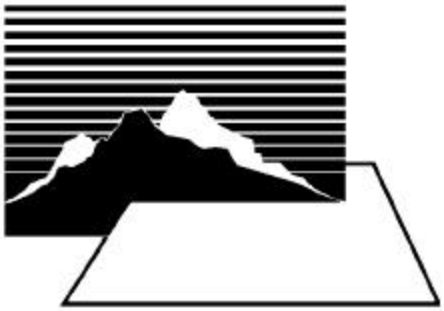
ANNUAL REPORT

of the

Great Plains/Rocky Mountain Hazardous Substance Research Center



December 1998

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

Edited by
Wendy M. Griswold, Terrie K. Boguski, Larry E. Erickson, and Lakshmi N. Reddi
Great Plains/Rocky Mountain Hazardous Substance Research Center
Kansas State University
101 Ward Hall
Manhattan, KS 66506-2502

Published by
Great Plains/Rocky Mountain
Hazardous Substance Research Center

Available electronically at
http://www.engg.ksu.edu/HSRC/

Printed on recycled paper.

GREAT PLAINS/ROCKY MOUNTAIN HAZARDOUS SUBSTANCE RESEARCH CENTER

Director
Dr. Larry E. Erickson
Great Plains/Rocky Mountain Hazardous Substance Research Center
101 Ward Hall
Kansas State University
Manhattan, KS 66506-2502
Phone: (785) 532-4313/2380
Fax: (785) 532-5985
E-mail: lerick@ksu.edu

Associate Director
Dr. Lakshmi N. Reddi
Great Plains/Rocky Mountain Hazardous Substance Research Center
101 Ward Hall
Kansas State University
Manhattan, KS 66506-2502
Phone: (785) 532-1586
Fax: (785) 532-5985
E-mail: reddi@ksu.edu

Technology Transfer Director
Dr. Richard B. Hayter
Engineering Extension
133 Ward Hall
Kansas State University
Manhattan, KS 66506-2508
Phone: (785) 532-6026
Fax: (785) 532-6952
E-mail: rhayter@ksu.edu

Participants

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-Columbia 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

TABLE OF CONTENTS

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 State 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
Robert Puls, Ph.D.	U.S. EPA	soil science
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
Abbas Ghassemi	New Mexico State University	environmental engineering
Gil Greenwood	industry	industrial processes
Ronald Hammerschmidt	govt/state	environmental chemistry
Dave Henney	industry	industrial processes
Edward Heyse	govt/USAF	environmental science and engineering
Stephen Hoffman	govt/EPA	environmental management
William Hotchkiss	govt/USGS	industrial processes
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/city	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
Brenda Brandon

Lincoln University
Frieda Eivazi
Mary Wyatt

Kansas State University
Philip L. Barnes
Bertram R. Biles
Terrie K. Boguski
Lawrence C. Davis
Vernon Deines
Rosalind Dalefield
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
La Barbara Wigfall

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
Allen W. Hatheway
Shubhender Kapila
S.K. Loyalka
Stanley E. Manahan
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 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

University of Utah
Sam Ghosh
Andrew P. Hong
Jan D. Miller
Robert W. Okey
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

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
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

University of Northern Iowa
Barbara A. Hetrick
Catherine Zeman

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 that are 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, and 1997 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, 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-Sept. 30, 1998)	SECOND AWARD PERIOD (May 17, 1992-Sept. 30, 1997)	FUNDS TO DATE (Since Feb. 22, 1989)
EPA: Five Centers Programs	$1,853,189	$5,353,515	$11,691,194
EPA: Other	949,000	1,974,470	3,395,215
Other Govt: Federal			
U.S. Dept. of Defense	224,345	3,423,358	3,647,703
U.S. Dept. of Energy	0	365,000	915,000
Other Govt: State			
Consortium Universities	879,679	4,618,552	9,709,893
Nonconsortium Universities	35,566	279,013	513,022
Private Sector	0	42,000	74,000
TOTAL	$3,941,779	16,055,908	$29,946,027

STUDENT SUPPORT	NUMBER	FUNDING*
Undergraduate	10	$59,900
Graduate	31	706,738
Post Doctoral	5	182,695
TOTAL	46	$949,333

*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 consortia 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; Blase Leven, program manager; and Carla Wolfe, office manager and program associate, 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. Alison Hodges is the project accountant for the center and Rita Shade provides clerical support.

HIGHLIGHTS

February 1998 marked the completion of nine 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 nine 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 that are 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 ground 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 begun in 1995. The R2D2 program is national in scope, with all five centers receiving funding to involve former defense personnel in working on center-funded research projects at center consortium universities. During its first year, this program enrolled more than 70 displaced Department of Defense employees at HSRC consortium universities. These students worked on 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 provides leadership for this 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 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 1998 Conference on Hazardous Waste Research, held in Snowbird, Utah, May 18-21, 1998. The conference, workshops, and tours attracted approximately 250 participants and 120 papers. Conference topics included phytoremediation, metals-contaminated soil, pit

lakes, 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.

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 brownfields 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 brownfields 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.

FUTURE DIRECTIONS

The 1999 Annual Conference on Hazardous Waste Research has been set for May 25-27, 1999, in St. Louis, Missouri. This year's conference theme is "Gateways to Environmental Solutions." Conference co-sponsors are South and Southwest Hazardous Substance Research Center, U.S. Environmental Protection Agency, National Institute for Environmental Health Sciences, National Mine Land Reclamation Center, and the Waste-management Education and Research Consortium.

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. 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 have the capability to provide hyperlinks to references as well as graphics, video, and sound. These features will allow users to run simulation models.

During the past nine 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 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, 1998

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 1994	Innovative Treatment and Bank Stabilization of Metals-Contaminated Soils and Tailings Along Whitewood Creek, 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/$40k	93-06 1998	Fate and Transport of Heavy Metals and Radionuclides in Soil: The Impacts of Vegetation
Hetrick, Pierzynski, Erickson, Govindaraju, Sweeney	$398k/$41k	93-07 1999	Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants
O'Keefe	$313k/$57k	94-05 1999	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, Kapila	$327k/$0k	9 1992	Time-Dependent Movement of Dioxin and Related 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 Date	Project Title
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/$16k	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	$395k/$53k	93-02 1999	The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics
Parkin	$185k/$27k	93-24 1999	Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination
Segar	$193k/$24k	94-07 1999	Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors
Schnoor, Burken	$454k/$47k	94-25 1999	Uptake of BETX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation
Davis, Erickson	$329k/$97k	94-27 2000	Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies
Illangasekare	$495k/$124k	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/$6k	94-15 1998	Removal of Chlorinated Hydrocarbons from Contaminated Water Using Air-Sparged Hydrocyclone Technology
Doucette, Bugbee, Stevens	$380k/$106k	95-10 1999	Fate of Trichloroethylene (TCE) in Plant/Soil Systems: Evaluating Phytoremediation
Zhang, Comfort, Shea	$241k/$51k	95-32 1999	Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes
Schnoor	$212k/$65k	95-29 1999	Plant Enzyme Systems for the Phytoremediation of Chlorinated Aliphatics in Contaminated Soils
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

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, 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
R.C. Sims	$417k/$39k	93-21 1999	Field Scale Bioremediation: Relationship of Parent Compound Disappearance to Humification, Mineralization, Leaching, and Volatilization of Transformation Intermediates
Inskeep, Johnston, Wraith	$264k/$30k	94-09 1999	Effects of Surfactants on the Bioavailability and Biodegradation of Contaminants in Soils

ANALYSIS/TREATMENT OF CONTAMINATED SOIL (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Rice	$242k/$38k	94-11 1999	Contaminant Binding to the Humin Fraction of Soil Organic Matter
Tracy, Van Lent, Schaefer	$178k/$20k	94-12 1999	Development of a Systematic Methodology for Optimally Designing Vegetative Systems for Remediating Contaminated Soil and Groundwater
Kubichek, Iverson, Cupal	$329k/$45k	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	$379k/$39k	93-11 94-28 1999	Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence
Klabunde	$129k/$70k	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
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

TRAINING AND TECHNOLOGY TRANSFER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
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	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	$377k/$24k	TR-01 2000	Conferences and Workshops
Hayter, Leven	$128k/$3k	TR-01 2000	HSRC Contribution Repository and Information Clearinghouse
Reddi, Leven	$346k/$10k	TR-01 2000	HSRC Newsletter, *HazTech Transfer*
J.L. Sims, R.C. Sims	$182k/$0k	TR93-07 1997	Guidance for 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, Deines, Wigfall	$1,465k/$385k	SP93-01 2000	Technical Outreach Services to Communities Program, Technical Support to Brownfields
Leven, Grant	$638k/$0k	R2D2 1998	Research and Re-education for Displaced Defense Personnel Program
Erickson	$37k/$0k	TR95-10 1998	Virtual Library

TRAINING AND TECHNOLOGY TRANSFER (cont.)

Principal Investigator(s)	Budget Total/Current	Project No./ Completion Date	Project Title
Reddi	$18k/$0k	TR95-11 1997	Environmental Data Technology Transfer Project
Leven, Godfrey, Griswold	$132k/$42k	TR96-05 1999	Collaborative Environmental Seminar Series
Griswold, Brandon	$184k/$75k	TOSNAC 2000	Technical Outreach Services to Native American Communities
J.L. Sims	$46k/46k	TR97-07 1999	Development of a "State of the Science and Technology" Report on Site Characterization Technologies

RESEARCH PROJECT DESCRIPTIONS

May 18, 1995 - September 30, 1998

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 is 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.) is being 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 will be 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 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 were performed for solutions containing strong chelating acids and cadmium, lead, and zinc. The investigators have finished 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 is completed.

Technology Transfer and Outreach: Results from this project have been published in one peer-reviewed journal. Four additional articles have been submitted to 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: This research has two purposes. First, the efficacy of different plant and microbial regimes in reducing surface water contamination from revegetated plots will be assessed. To determine the ability of various vegetation/microbial regimes to act as buffer strips, the design of the experiment will be altered after the first year of the project. Half of the plots will remain as non-interceptor strips, while half will receive surface runoff from contaminated tailings uphill from the plots. In this way the ability of the various vegetation strips to limit heavy metal-contaminated runoff can be quantified.

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. This project is in its fourth and final year.

Technology Transfer and Outreach: The results of this research have been presented at 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 will be conducted in conjunction with Big River Zinc Co., where the commercial plant to treat 50 tons per day of residue will be located. In addition, two suppliers of the organic extractant and another zinc producer, Noranda Ltd., will also provide support and assistance. 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 will be conducted in three areas. The process parameters needed to optimize the reduction of Fe^{+3} to Fe^{+2} in the D2EHPA organic phase will be 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 will be determined. The influence of the various heavy metal impurities in the solutions will be identified and their distribution (aqueous vs. organic), and effect on subsequent iron and zinc recovery will be evaluated.

Status: First year milestones were met. Specifically, the 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. The 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. The data provided by this testing program are expected to provide all of the process information needed for the 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 the extended continuous running of the bench scale pilot plant. This project is in its fourth year.

Technology Transfer and Outreach: Results from this research have been published in four different technical publications and two additional articles have been submitted for publication. This project involves industrial participants from three different companies.

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

Remediation of Soils Contaminated with Wood-Treatment Chemicals (PCP and Creosote)

R.K. Bajpai, S.K. Banerji, and R.K. Puri, University of Missouri; and M.E. Zappi, U.S. Army Corps of Engineers

Project no.: 94-08

Goal: The goal of this project is to develop a slurry biotreatment process for soils contaminated with Pentachlorophenol (PCP) and creosote.

Rationale: PCP and creosote polyaromatic hydrocarbons (PAHs) are found in most contaminated soils at wood-treatment sites. Treatment methods currently being used for such soils include soil washing, incineration, and biotreatment. Soil washing involves removal of hazardous chemicals from soils using solvents, but the solvent stream must still be treated for destruction of contaminants. Incineration is an effective tool for destruction of contaminants but is costly and lacks public acceptance. Bioremediation has been considered and used for treatment of soils contaminated with wood-treatment chemicals, but bioremediation may leave regulated chemicals in the soil. Slurry-phase biotreatment of contaminated soils and sediments is an innovative treatment technology. Its advantages include easy manipulation of physicochemical variables and operating conditions to enhance rates of biodegradation and ease of containment of exhaust gases and effluent. Bioslurry technology is currently hampered by some bottlenecks that need to be relieved.

Approach: Engineering and process development aspects of bioslurry treatment of PCP- and creosote-contaminated soils from a Superfund site will be studied in this project in shake flasks and in 14-liter well-instrumented fermentors. Use of surfactants and cosolvents will be explored in order to enhance aqueous solubility of hydrophobic and sparingly soluble contaminants. The effect of cosolvents on microbial activity will be studied. Kinetic studies for biodegradation of PCP and PAHs will be carried out in sealed bioreactors so that accurate material balances can be taken. Experiments are planned to investigate the role of surfactant/cosolvent, temperature, carbon source, and oxygen delivery by sparging of pure oxygen in reduction of concentrations of PAHs and PCP in the contaminated soil slurry. Reactors with power measurement devices will be used to investigate several different types of mechanical agitators in order to keep the solids in suspension. The power requirement under aerated and unaerated conditions will be correlated with geometrical and system parameters such as particle size, nature of soil, solid density, and physical dimensions in the reactor. Oxygen transfer rate and oxygen transfer efficiency in the slurries with sufficient power input for minimal and complete suspension will also be studied in this reactor. All of the information will be used to develop a flow diagram of the bioslurry treatment process for cleanup of contaminated sites and to generate cost data that may be used to determine cost-effectiveness of this process for field-scale treatment.

Status: Areas that have been studied include the surfactant-induced enhancement of solubility of high molecular weight PAHs; surfactant utilization by mixed microbial cultures; the effect of surfactants on microbial growth; and surfactant-soil interactions. A manuscript describing the effect of solubility on microbial growth has been published, and a manuscript related to work on the biodegradation of surfactants has been prepared for publication. A bioslurry reactor has been constructed and has been used to determine the correlation between Power number and Reynold number for a specific impeller under different conditions. An economic analysis of slurry bioreactor operation was performed for three site scenarios. Biodegradation studies for creosote-contaminated soil are complete. The results of these experiments are currently being processed and will form the MS thesis of Mr. Mark Farraro. Future research plans involve

enhancing the biodegradation of high molecular weight hydroscopic organic compounds by management of cometabolism. This project is in its fourth year.

Technology Transfer and Outreach: This project was the subject of two poster presentations at the annual HSRC conference in 1997. Results from the project have been published in one peer-reviewed journal and more articles are planned. Investigators are planning to make presentations at various scientific conferences and to attend conferences to interact with consultants and companies that are interested in bioslurry reactor technology, as funding allows.

Keywords: soil, PCP, creosote, slurry bioreactor, wood treatment.

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 will investigate 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. Reductive dechlorination of chlorinated compounds could then 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 will be conducted in batch and column-reactor systems. Initial studies will investigate iron and carbon tetrachloride (CT). Other metals such as aluminum, tin, and zinc will be used in later studies. Various chlorinated organics will also be assayed. A hydrogen-utilizing, mixed, methanogenic culture will be developed as an inoculum source for all experiments. Initial batch studies will be performed to determine the general time-course that the reactions will follow. Inhibition studies using 2-bromoethanesulfonate (BES), a specific methanogenic inhibitor, will address the role of methanogens. Analytes to be measured in headspace gas samples include CT, chloroform (CF), dichloromethane (DCM), chloromethane (CM), hydrogen, and methane. Subsequent, detailed, batch kinetic studies will be performed and, where appropriate, analytes will include ferrous iron, total soluble iron, CT, CF, DCM, CM, hydrogen, methane, and oxidation-reduction potential. The stoichiometry and kinetics of all pertinent reactions will be determined. Electron balances will be 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 will be 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, 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. Future plans include more batch experiments with iron filings, studies involving the abiotic conversion of PCE to ethene, and studies with nitrates. This project is in its fourth 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, several of the chlorinated aliphatics of greatest concern are not degraded by aerobic bacteria. 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 will focus 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 will be operated under conditions similar to those observed in contaminated aquifers.

Additionally, soil cores will be 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 have not proceeded because the organisms have not been able to survive exposure to all three compounds over a sufficient time period. Future research plans include expanded batch transformation studies, characterization of mixed cultures, growth substrate utilization studies, and development of high-rate PCE-dechlorinating cultures from contaminated soil. This project is in its fourth year.

Technology Transfer and Outreach: This project has been the subject of a poster presented a technical conference and an article has been accepted 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 the 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 shutdown due to funding restrictions and the difficulty in maintaining continuity in student researcher expertise. Future plans include beginning FBBR operations and studies again in December 1998. 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 fourth year.

Technology Transfer and Outreach: The results of this research will be presented at the May 1999 HSRC conference and other technology transfer efforts will be made.

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 at rural and abandoned sites where little money is available for more expensive traditional remediation.

Approach: This research will attempt to determine whether vegetative remediation with poplar trees is a fundamental approach for remediation of BTEX-contaminated sites. Poplar uptake of BTEX compounds will be monitored and translocation within plant tissues will be studied. Plant tissues and aerial compartments will be 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 has 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 in either 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%. The 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 will be planted as a full-scale phytoremediation effort in April 1999. Further research is planned to develop adsorption isotherms for several different compounds. This project is in its fourth year.

Technology Transfer and Outreach: This research has been the subject of five articles published in scientific journals. There have also been several presentations of this research at technical conferences. In 1999, technology transfer will occur via a full-scale phytoremediation effort in Charleston, VA.

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.

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 will be monitored by headspace gas chromatography or FT-IR of aqueous samples. The groundwater flow and transport model will be 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 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 de-icers 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 poplar 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. This project is in its fourth 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 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 that are 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, and 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 nonaqueous-phase liquids (NAPLs) continues to be studied. One report on enhanced dissolution using surfactants and another on thermal mobilization were completed last year. 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. Two journal articles documenting the tracer experiments and results have been submitted for publication in scientific journals. Additional research on partitioning tracers has begun. A proposal was submitted to the Army Research Office to conduct field work at a site in Idaho. Future plans include laboratory investigations on partitioning tracers, development of field characterization techniques, and field testing and applications. This project is in its fourth 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 Principle 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, and 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, construction, and operation 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 spacially 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. Air-sparging tests and in-well aeration tests have been conducted at the field site. The results indicate that the radius of influence of *in situ* air sparging was generally less than 3 feet at this field site. This project has been completed.

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. Several papers have been submitted for publication, and two have been published.

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: The 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 written and accepted for publication. Studies on the effects of alternate electron acceptor addition on mineralization of pyrene are complete. Experiments to evaluate the effects of moisture, temperature, and addition of electron acceptors on the fate of target compounds are complete. 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. The 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 fourth year.

Technology Transfer and Outreach: The results from this project are being used at a site in Libby, Montana. Findings from this site will be applied to the Montana Pole Superfund Site, as well as other sites. Presentations of this work have been incorporated into the U.S. EPA technology transfer course on natural attenuation. This course has been conducted 10 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 three major areas have been completed over the past three years. Surfactant effects on the solubilization and subsequent transport of nonpolar contaminants through soils has been studied. Surfactant effects on the degradation of contaminants using indigenous microorganisms in both the absence and presence of NAPLs has been studied, and surfactant effects on the degradation of pentachlorophenol (PCP) using white-rot fungi has been evaluated. Results from recent experiments indicate that changes in microbial community structure are associated with high surfactant applications. Experiments including molecular analyses have been initiated to further explore these results. This project is in the final stages. Future work will focus on developing and refining the molecular analyses of microbial community dynamics during surfactant application and publication of results. This project is in its fourth year.

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 napthalene, 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. Experiments designed to provide insight into the binding phenomena and the parameters that control it are underway and will be completed in this project year. This project is in its fourth year.

Technology Transfer and Outreach: Several papers covering the 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 graphic-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 being addressed. 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 fourth year.

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 will explore 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. Efforts continue on modeling and on analysis of collected data. This project is in its fourth year.

Technology Transfer and Outreach: Two technical papers on this research are currently being 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. Experiments aimed at developing a multiple-species biofilm barrier will begin soon. In-depth assessment of the technical feasibility for biobarrier construction and maintenance at designated field sites are also planned. The results of the project will be assembled into a final report containing the investigators' assessment of the technical feasibility for biobarrier construction and maintenance in the field. This project is in its fourth year.

Technology Transfer and Outreach: This research has been published in the chapters of two different books and in various conference proceedings. 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 will evaluate the fate of chlorinated ethenes in hydroponic systems. Specifically, these studies will determine plant/water/air distribution coefficients and plant uptake rates.

This approach will be extended to laboratory and field plant/soil systems. Based on the results, a plant-based bioreactor for the remediation of contaminated groundwater will be constructed. Environmental conditions will be 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 were expected, based on log Kow values. Plant uptake chamber studies are now being 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. Experiments using sterile nutrient solution are planned. Future studies will focus on exposure concentration and duration. This project is in its third year.

Technology Transfer and Outreach: Platform and poster presentations of this research have been made at technical conferences. A presentation has been made to the staff members of the environmental restoration group at Hill Air Force Base in Ogden, Utah. Three articles are currently being prepared for publication 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 transformations 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; and 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 is in the early stages. 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 third 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.

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 are being 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. These experiments will continue. A series of adsorption/desorption studies with atrazine and iron have been conducted. Experiments to determine atrazine removal from solution and transformation after prolonged exposure to zero-valent iron are continuing. Three articles related to this project have been written and accepted for publication. This project is in its third year.

Technology Transfer and Outreach: Investigators have prepared articles for publication 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 with a Washington-based company.

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. Later, this fixed-bed unit may be converted into a flow reactor for treating contaminated water. This project is in its third 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.

Acid-Producing Metalliferous Waste Reclamation by Material Reprocessing and Vegetative Stabilization

F.F. Munshower, Montana State University

Project no.: 93-12

Goal: This project will attempt to demonstrate an alternative, cost-effective, permanent mine tailing reclamation methodology through the marriage of mineral processing and land reclamation techniques. The approach to be used, clean tailing reclamation (CTR), utilizes potentially field-deployable mineral separation technologies to remove dense sulfide minerals from tailing material by gravimetric separation, followed by vegetative stabilization of the cleaned tailing material with native plants. CTR will allow for removal of environmental contaminants and acid-forming materials.

Rationale: Mine waste is a widespread and pervasive problem in EPA Regions VII and VIII. Historical mining activity has contaminated many thousands of acres of soil by uncontrolled waste disposal practices resulting in resource degradation that will cost billions of dollars to remediate. One of the principal problems associated with reclamation of hardrock mine sites is tailing reclamation. Tailing materials cover tens of thousands of acres of land in the region pair. This research specifically compliments research being conducted in Anaconda, Montana, on tailing reclamation and will provide comparisons on the relative strength of this technology through plant performance, geochemical distribution of contaminants, and cost of implementation. Upon completion of this research, the findings will be useful to Superfund managers and Potentially Responsible Party decision-makers, and to operational mines and regulators.

Approach: Research will be implemented at Montana State University. Outside expertise will be solicited from other experts in mineral separation in conjunction with the use of experimental equipment housed at Butte, Montana. Contract laboratories will be solicited and appropriate sample analyses will be submitted for analysis. Sample material used in research will be collected from three locations in coordination with regulatory personnel. Representative samples of tailings materials will be collected from each of the three locations and chemically characterized to identify the elemental and mineralogical distribution of the heavy metal and acid-generating contaminants. Subsequent to sample characterization, mineralogical separation of the dense sulfide minerals will be performed using gravimetric techniques. For bench-scale work, mineral separation technologies considered will include technologies developed through the Superfund Innovative Technology Evaluation (SITE) Program. Following tailing material reprocessing activity, subsamples will be chemically characterized to determine the efficacy of the reprocessing/tailing cleaning

technologies. Greenhouse studies will be implemented in the cleaned tailing material to compare performance of the cleaned tailing material with conventional reclamation approaches. The native grass species selected for use are Red top (*Agrostis alba*) and Basin wild rye (*Leymus cinereus*).

Status: During the first phase of this study, significant effort was expended to collect samples and initiate the project. Three tailing materials were collected and transported to the laboratory, and characterization was completed. Bench-scale and subsequent pilot-scale separation of sulfides from silicates in tailings was performed. Soluble chemistry evaluation of various treatments was initiated, as was literature-review activity. Much of the research conducted during the early phase of the project has been completed. Samples were submitted for acid-base account analysis for characterization of the acid-generating potential of all three tailing materials, both before and after reprocessing. Metal analysis of the initial tailing material, high-grade concentrate, and cleaned tailing material has been performed. The greenhouse study began May 31, 1996, and has been completed. The soluble chemistry study is complete and data reduction efforts have been initiated. A technology transfer seminar was hosted with participants from industry and government attending. Further inquiry of mineral separation effectiveness is planned. The potential for metal recovery and reuse will also be evaluated upon receipt of the final metal analyses, which are underway. A four-acre experimental tailing pond location has been sited and a retaining dam constructed. The pond will begin receiving tailings when the proper ore is mined. This is projected to happen in 1999. A no-cost time extension has been requested for this project. Data summary, interpretation, and write-up will follow completion of data collection. This project is in its fifth year.

Technology Transfer and Outreach: This research will be of interest to those in the mining industry and regulatory agencies.

Keywords: vegetation, reclamation, metallic minerals, mining, tailings.

TRAINING AND TECHNOLOGY TRANSFER PROJECT DESCRIPTIONS

May 18, 1994 - September 30, 1998

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 also 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 nine 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.

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. Recently, center staff began making informational presentations to program managers in state and EPA regional offices. In conjunction with the Technical Outreach Services for Communities (TOSC), Research and Re-education for Displaced Defense (R2D2), 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

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. The conference is hosted in alternate years by other universities.

Status: The 13th Annual Conference on Hazardous Waste Research was held in Snowbird, Utah, May 18-21, 1998, 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 1998 conference involved 26 sponsors and cooperating supporters, seven of whom provided substantial funding. The 1999 Conference on Hazardous Waste Research will be held in St. Louis, Missouri, on May 25-27, 1999. It will be co-sponsored by the South/Southwest HSRC and other co-funding organizations. The 1998 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. Information concerning manuscript submission is now on-line, and a call for papers has been created and distributed. Adobe's Acrobat software and its portable document format (PDF) technology have been chosen as the preferred tools for publishing articles on the Internet, rather than HTML, the simple programming language used to create Web pages. Abstracts will still be available in HTML format and searchable with existing search engines. Future plans include marketing research and studies to identify reliable methods for indexing, cataloging, and archiving the journal. A number of manuscripts have been submitted, peer reviewed, and published. They are available at http://www.engg.ksu.edu/HSRC/JHSR.

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, V. Deines, and L. Wigfall, Kansas State University

Goals: Technical Outreach Services for Communities (TOSC) provides technical assistance to communities affected by hazardous substances. The program is designed to supplement EPA's Technical Assistance Grant (TAG) Program that provides grants to community groups for sites on EPA's National Priority List (NPL). The Technical Outreach Services for Communities program exceeds the scope of EPA's TAG program by providing assistance to communities, groups, and individuals, regardless of the site's status in Superfund (i.e., proposed or final NPL), and the regulatory program taking the lead in site cleanup activities. Additional goals of the program include the following:

- Assisting with community involvement at the beginning of the process for non-time-critical removal and other remediation activities.

- Assisting small business, *de minimis* responsible parties, and small municipalities with technical issues.
- Serving as a point of contact for technical assistance and information related to hazardous substances.

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 citizen groups 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.

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 10 communities. This support has grown to include 20 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 TOSNAC and TOSC to brownfields. In addition to base TOSC funding, the national Technology Outreach Services to Native American Communities (TOSNAC) program at Haskell Indian Nations University is providing support to five 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 urban sites through the EPA Brownfields program. Support is being provided to the Bonne Terre, Des Moines, Kansas City, St. Louis, and Wellston pilot projects in EPA Region VII. This project is in its fifth 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. This project also includes continuation of *Earth Medicine* newsletter, which links the seminar producers and the target audience.

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. *Earth Medicine*, the newsletter produced by Haskell Environmental Research Studies Center (HERS), publicizes the seminar series as well as other accomplishments of HERS.

Approach: The HINU Environmental Seminar Series will consist of four high-quality video programs per year, companion on-campus seminar presentations at HINU, and quarterly production of *Earth Medicine*. Selected programs will also be broadcast via satellite uplink to interested program participants. Success of the project will be evaluated by a semiannual survey of all program participants. Video topics include pollution prevention opportunity assessments, environmental enforcement and justice in tribal law, environmental management and planning systems, and microscale chemistry. Formats for these videos will include panel discussions, case studies, and instructional approaches, using subject matter experts from tribal and other arenas. *Earth Medicine* has continued to publicize these and other events to a readership of more than 1,800, including tribal offices and colleges, HSRC consortium members, and EPA regional offices.

Status: Two seminars have been filmed by HERS. These are "Environmental Justice in Indian Country" and "Microscale Chemistry in the Classroom." In addition to these seminars, "Native American Environmentalism at the Cusp of the Millenium" by Winona LaDuke and "The Effects of the Nuclear Policy Act of 1997" by Corbin Harney, have also been filmed. Two campus lectures, "Wetland Ecology and Indian Culture" by Dan Wildcat and "Building Water Resource Protection Program— A Tribal Perspective" by Wes Martel, have also been filmed. The HERS office has implemented a peer review of program scripts whereby members of the Technology Transfer and Training Committee review the scripts.

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 a format that is more easily understood.

Keywords: Native American, minority colleges, seminar, newsletter, 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. EPS) 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 for review. The current development and application of identified technologies will be reviewed and evaluated. Information will continue to be collected from published resources and from known researchers in the given fields. An open request for information will be sent to e-mail news groups dealing with environmental characterization in an effort to collect current information on the selected technologies.

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 and P.Kulakow, and B.A. Leven, Kansas State University; 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 from these sites, and calibrating evolving computer models and design tools. Additional field tests of this technology will be 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. Future plans include a Beta-version of the modeling software and a second field experiment in the spring of 1999. This project is beginning its second 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.

BIBLIOGRAPHY

February 22, 1989 - September 30, 1998

A. REFEREED JOURNAL ARTICLES

Abbas, J.D., B.A.D. Hetrick, and J.E. Jurgenson, "Isolate Specific Detection of Mycorrhizal Fungi Using Genome Specific Primer Pairs," *Mycologia*, Vol. 88, No. 6, pages 939-946, 1996. Project no. 93-07.

Abdel-Saheb, I., A.P. Schwab, M.K. Banks, and B.A.D. Hetrick, "Chemical Characterization of Heavy Metal-Contaminated Soil Transects in Southeast Kansas," *Water, Air, and Soil Pollution*, Vol. 78, No. 1-2, pages 73-82, 1995. Project no. 93-06.

Anderson, S.H., R.L. Peyton, J.W. Wigger, H. Wang, and C.J. Gantzer, "Influence of Aggregate Size on Solute Transport Measured Using Computed Tomography," *Geoderma*, Vol. 53, pages 387-398, 1992.

Anderson, T.A., and J.R. Coats, "Screening Rhizosphere Soil Samples for the Ability to Mineralize Elevated Concentrations of Atrazine and Metolachlor," *Journal of Environmental Science and Health*, Vol. 30, pages 473-484. Project no. 93-05.

Atteya, M., and K.J. Klabunde, "Nanoscale Metal Oxide Particles as Chemical Reagents. Heats of Adsorption of Heteroatom Organics on Heat-Treated Magnesium Oxide," *Chemistry of Materials*, Vol. 3, pages 182-187, 1991.

Bajpai, R.K., and S.K. Banerji, "Bioremediation of Soils Contaminated with Pentachlorophenol," *Biochemical Engineering VII. Annals of the NY Academy of Sciences*, Vol. 665, pages 423-434, 1991.

Banerji, S.K., R.K. Bajpai, and S.M. Wei, "Pentachlorophenol Interactions with Soil," *Water, Air and Soil Pollution*, Vol. 69, pages 149-163, 1993.

Banerji, S.K., and R.K. Bajpai, "Cometabolism of Pentachlorophenol by Microbial Species," *Journal of Hazardous Materials*, Vol. 39, pages 19-31, 1994.

Banks, M.K., G.R. Fleming, A.P. Schwab, and B.A. Hetrick, "Effects of the Rhizosphere Microflora on Heavy Metal Movement in Soil," *Chemosphere*, Vol. 29, No. 8, pages 1691-1699, 1994.

Banks, M.K., C.Y. Waters, and A.P. Schwab, "The Influence of Organic Acids on Leaching of Heavy Metals from Contaminated Mine Tailings," *Journal of Environmental Science and Health*, Vol. A29, No. 5, pages 1045-1056, 1994.

Boronina, T., and K.J. Klabunde, "Destruction of Organohalides in Water Using Metal Particles: Carbon Tetrachloride/Water Reactions with Magnesium, Tin, and Zinc," *Environmental Science and Technology*, Vol. 29, pages 1511-1517, 1995. Project no. 89-26, 92-03.

Boronina, T., K.J. Klabunde, and G. Sergeev, "Rebuttal to Comment on 'Destruction of Organohalides in Water Using Metal Particles: Carbon Tetrachloride/Water Reactions with

Magnesium, Tin, and Zinc'," *Environmental Science and Technology*, Vol. 30, page 3645, 1996. Project no. 95-04a.

Burckhard, S.R., A.P. Schwab, and M.K. Banks, "The Effects of Organic Acids on the Leaching of Heavy Metals from Mine Tailings," *Journal of Hazardous Materials*, Vol. 41, pages 135-145, 1996. Project no. 93-06.

Burken, J.G., and J.L. Schnoor, "Phytoremediation: Plant Uptake of Atrazine and the Role of Root Exudates," *ASCE Journal of Environmental Engineering*, Vol. 122, No. 11, pages 958-963, 1995. Project no. 94-25.

Burken, J.G., and J.L. Schnoor, "Uptake and Metabolism of Atrazine by Poplar Trees," *Environmental Science and Technology*, Vol. 31, No. 5, Pages 1399-1406, 1997. Project no. 94-25.

Cady, J.C., S. Kapila, S.E. Manahan, D.W. Larsen, and A.F. Yanders, "Evaluation of a Novel Carbon Adsorbent for Fractionation and Treatment of Halogenated Organic Wastes," *Chemosphere*, Vol. 20, pages 1959-1966, 1990.

Camper, A., J.T. Hayes, P.J. Sturman, W. Jones, and A.B. Cunningham, "The Effects of Motility and Adsorption Velocity on the Transport of Bacteria through Saturated Porous Media," *Applied and Environmental Microbiology*, Vol. 59, page 3455, 1993.

Chang, D., K. Fukushi, and S. Ghosh, "Stimulation of Activated Sludge Cultures for Enhanced Heavy Metal Removal," *Water Environment Research*, Vol. 67, pages 822-827, 1995.

Chen, B., A. Cunningham, R. Ewing, R. Peralta, and E. Visser, "Two-Dimensional Modeling of Microscale Transport and Biotransformation in Porous Media," *Numerical Methods for Partial Differential Equations*, Vol. 10, pages 65-83, 1994.

Chen, D., Z. Lewandowski, F. Roe, and P. Surapaneni, "Diffusivity of CU^{+2} in Calcium Alginate Gel Beads," *Biotechnology and Bioengineering*, Vol. 41, pages 755-760, 1993.

Chen, T.-C., and A. Hong, "Chelating Extraction of Lead and Copper from an Authentic Contaminated Soil Using N-(2-acetamido)iminodiacetic Acid and S-carboxymethyl-L-cysteine," *Journal of Hazardous Materials*, Vol. 41, pages 147-160, 1995. Project no. 93-22.

Chen, T.-C., E. Macauley, and A. Hong, "Selection and Test of Effective Chelators for Removal of Heavy Metals from Contaminated Soils," *Canadian Journal of Civil Engineering*, Vol. 22, pages 1185-1197, 1995. Project no. 93-22.

Clevenger, T.E., "Use of Sequential Extraction to Evaluate the Heavy Metals in Mining Wastes," *Journal of Air, Water, and Soil Pollution*, Vol. 50, pages 241-254, 1990.

Coffin, D., and L. Glasgow, "Effective Gas Flow Arrangements in Soil Venting," *Water, Air and Soil Pollution*, Vol. 62, pages 303-324, 1992.

Comfort, S.D., P.J. Shea, L. Hundal, Z. Li, B.L. Woodbury, J.M. Martin, and W. Powers, "TNT Transport and Fate in Contaminated Soils," *Journal of Environmental Quality*, Vol. 24, pages 1174-1182, 1995. Project no. 92-24.

Coyle, C.G., G.F. Parkin, and D.T. Gibson, "Aerobic, Phenol-Induced TCE Degradation in Completely Mixed, Continuous Culture Reactors," *Biodegradation*, Vol. 4, pages 59-69, 1993.

Cunningham, A.B., W.G. Characklis, F. Abedeen, and D. Crawford, "Influence of Biofilm Accumulation on Porous Media Hydrodynamics," *Environmental Science and Technology*, Vol. 25, No. 7, pages 1305-1310, 1991.

Cunningham, A.B., "Engineering Scale-Up of *In Situ* Bioremediation Processes: A Review," *Journal of Contaminant Hydrology*, Vol. 19, pages 171-203, 1995.

Davis, L.C., L.E. Erickson, E. Lee, J.F. Shimp, and J.C. Tracy, "Effects of Plants on the Bioremediation of Contaminated Soil and Groundwater," *Environmental Progress*, Vol. 12, No. 1, pages 67-75, 1993.

Davis, L.C., M. Narayanan, V.P. Visser, C. Chaffin, W.G. Fateley, L.E. Erickson, and R.M. Hammaker, "Alfalfa Plants and Associated Microorganisms Promote Biodegradation Rather than Volatilization of Organic Substances from Groundwater," *Bioremediation through Rhizosphere Technology*, T.A. Anderson and J.R. Coats (Eds.), ACS Symposium Series No. 563, Washington, DC, pages 112-122, 1994.

Davis, L.C., S. Vanderhoof, J. Dana, K. Selk, K. Smith, B. Goplen, and L.E. Erickson, "Chlorinated Solvent Movement through Plants Monitored by Fourier Transform Infrared (FT-IR) Spectrometry," *Journal of Hazardous Substance Research*, Vol. 1, No. 4, pages 1-26, 1998. Project no. 94-27.

Decker, S., and K.J. Klabunde, "Enhancing Effect of Fe_2O_3 on the Ability of Nanocrystalline Calcium Oxide to Adsorb SO_2," *Journal of the American Chemical Society*, Vol. 118, pages 12465-12466, 1996. Project no. 95-04a.

Dennis, M.L., and J.P. Turner, "Hydraulic Conductivity of Compacted Soil Treated with Biofilm," *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 124, No. 2, pages 120-127, 1998. Project no. 94-26.

Dhawan, S., L.T. Fan, L.E. Erickson, and P. Tuitemwong, "Modeling, Analysis, and Simulation of Bioremediation of Soil Aggregates," *Environmental Progress*, Vol. 10, pages 251-260, 1991.

Dhawan, S., L.E. Erickson, and L.T. Fan, "Model Development and Simulation of Bioremediation in Soil Beds with Aggregates," *Journal of Groundwater*, Vol. 31, No. 2, pages 271-284, 1993.

Erickson, L.E., "An Overview of Research on the Beneficial Effects of Vegetation in Contaminated Soil," *Annals of the New York Academy of Sciences*, Vol. 829, pages 30-35, 1997. Project no. 94-27.

Erickson, L.E., J.P. McDonald, L.T. Fan, S. Dhawan, and P. Tuitemwong, "Bioremediation: A Challenging Application of Biochemical Engineering Principles," *Biochemical Engineering VII, Annals of the N.Y. Academy of Sciences*, Vol. 665, pages 404-411, 1991.

Erickson, L.E., M.K. Banks, L.C. Davis, A.P. Schwab, M. Narayanan, K. Reilley, and J.C. Tracy, "Using Vegetation to Enhance *In Situ* Bioremediation," *Environmental Progress*, Vol. 13, pages 226-231, 1994.

Erickson, L.E., L.C. Davis, and M. Narayanan, "Bioenergetics and Bioremediation of Contaminated Soil," *Thermochimica Acta*, Vol. 250, pages 353-358, 1995.

Figge, D.H., B.A.D. Hetrick, and G.W.T. Wilson, "Role of Expanded Clay and Porous Ceramic Amendments on Plant Establishment in Mine Spoils," *Environmental Pollution*, Vol. 88, No. 2, pages 161-165, 1995.

Friedler, F., L.T. Fan, and B. Imreh, "Process Network Synthesis: Problem Definition," *Networks*, Vol. 31, pp. 119-124, 1996.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Graph-Theoretic Approach to Process Synthesis: Axioms and Theorems," *Chemical Engineering Science*, Vol. 47, pages 1973-1988, 1991.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Combinatorial Algorithms for Process Synthesis," *Computers and Chemical Engineering*, Vol. 16, suppl. 313-320, 1992.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Graph-Theoretic Approach to Process Synthesis: Polynomial Algorithm Maximal Structure Generation," *Computers and Chemical Engineering*, Vol. 17, pages 929-942, 1993.

Friedler, F., J.B. Varga, and L.T. Fan, "Algorithmic Approach to the Integration of Total Flowsheet Synthesis and Waste Minimization," *Pollution Prevention via Process and Product Modifications*, E.L. Gaden, Jr., M.M. El-Halwagi, and D.P. Petrides (Eds.), AIChE Symposium Series, Vol. 90, No. 303, New York, pages 86-97, 1995. Project no. 91-36.

Friedler, F., J.B. Varga, and L.T. Fan, "Decision-Mapping: A Tool for Consistent and Complete Decisions in Process Synthesis," *Chemical Engineering Science*, Vol. 50, pages 1755-1768, 1995. Project no. 91-36.

Gandhi, P., L.E. Erickson, and L.T. Fan, "A Simple Method to Study the Effectiveness of Bioremediation-Aided, Pump-and-Treat Technology for Aquifers Contaminated by Nonaqueous-Phase Liquids, I. Single Component Systems," *Journal of Hazardous Materials*, Vol. 39, pages 49-68, 1994.

Gandhi, P., L.E. Erickson, and L.T. Fan, "A Simple Method to Study the Effectiveness of Bioremediation-Aided, Pump-and-Treat Technology for Aquifers Contaminated by Nonaqueous-Phase Liquids, II. Multi-Component Systems," *Journal of Hazardous Materials*, Vol. 41, pages 185-204, 1995.

Ghosh, S., and S. Bupp, "Stimulation of Biological Uptake of Heavy Metals," *Water, Science and Technology*, Vol. 26, No. 1-2, pages 227-236, 1992.

Ghoshal, S., R.K. Bajpai, and S.K. Banerji, "Role of Photodegradation in PCP Decontamination in Soils," *Biochemical Engineering VII, Annals of the NY Academy of Sciences*, Vol. 665, pages 412-422, 1991.

Gilliland, M.W., W.E. Kelly, and D. Lokke, "Hazardous Waste Management in Rural Areas," *Journal of Professional Issues in Engineering*, Vol. 117, pages 102-110, 1991.

Ginn, J., R.C. Sims, D.P. Smith, D.L. Sorensen, and W.J. Doucette, "Aerobic Biotransformation of Polycyclic Aromatic Hydrocarbons and Associated Metabolites in Soil," *Journal of Polycyclic Aromatic Compounds*, Vol. 11, pages 43-55, 1996. Project no. 93-21.

Gu, J., G.W. Preckshot, S.K. Banerji, and R.K. Bajpai, "Effect of Some Common Solubility Enhancers on Microbial Growth," *Annals of the New York Academy of Sciences*, Vol. 829, pages 62-73, 1997.

Hangos, K.M., J.B. Varga, F. Friedler, and L.T. Fan, "Integrated Synthesis of a Process and Its Fault-Tolerant Control System," *Computers and Chemical Engineering*, Vol. 19, pages S465-S470, 1995.

Held, R., and T.H. Illangasekare, "Fingering of Dense Nonaqueous Phase Liquids in Porous Media: 1. Experimental Investigation," *Water Resources Research*, Vol. 31, No. 5, pages 1213-1222, 1995.

Held, R., and T.H. Illangasekare, "Fingering of Dense Nonaqueous Phase Liquids in Porous Media: 2. Analysis and Classification," *Water Resources Research*, Vol. 31, No. 5, pages 1223-1231, 1995.

Helland, B.R., P.J.J. Alvarez, and J.L. Schnoor, "Reductive Dechlorination of Carbon Tetrachloride with Elemental Iron," *Journal of Hazardous Materials*, Vol. 41, pages 205-216, 1995.

Hetrick, B.A., G.W.T. Wilson, and D. Hoobler, "The Influence of Mycorrhizal Symbiosis and Fertilizer Amendments on Establishment of Vegetation in Heavy Metal Mine Spoil," *Environmental Pollution*, Vol. 86, pages 171-179, 1994.

Hillier, A.C., and C.W. Walton, "Modeling Electroplating Rinse Systems Using Equation-Solving Software," *Plating and Surface Finishing–Journal of AESF*, Vol. 78, No. 11, pages 72-75, 102, 1991.

Hong, A., T.-C. Chen, and R.W. Okey, "Chelating Extraction of Copper from Soil with S-Carboxymethylcysteine," *Water Environment Research*, Vol. 67, pages 971-978, 1995. Project no. 93-22.

Hong, A., T.-C. Chen, and R.W. Okey, "Chelating Extraction of Zinc from Soil with N-(2-acetamido)iminodiacetic Acid," *ACS Symposium Series*, Vol. 607, pages 210-223, 1995. Project no. 93-22.

Hong, A., and T.-C. Chen, "Extractive Recovery of Cadmium from Soil Using Pyridine-2,6-dicarboxylic Acid," *Water, Air and Soil Pollution*, Vol. 86, pages 335-346, 1996. Project no. 93-22.

Hooker, P.D., and K.J. Klabunde, "Destructive Adsorption of Carbon Tetrachloride on Iron(III) Oxide," *Environmental Science and Technology*, Vol. 28, pages 1243-1247, 1994.

Hsu, S.M., J.L. Schnoor, L.A. Licht, M.A. St. Clair, and S.A. Fannin, "Fate and Transport of Organic Compounds in Municipal Solid Waste Compost," *Compost Science*, Vol. 1, No. 4, pages 36-48, 1993.

Huang, Y.L., and L.T. Fan, "A Distributed Strategy for Integration of Process Design and Control: A Knowledge Engineering Approach to Incorporation of Controllability into Process Synthesis," *Computers and Chemical Engineering*, Vol. 16, pages 497-522, 1992.

Huang, Y.L., and L.T. Fan, "Analysis of a Work Exchanger Network," *Industrial and Engineering Chemistry Research.*, Vol. 35, pages 3528-3538, 1996. Project no. 91-36.

Huang, Y.L., and L.T. Fan, "Artificial Intelligence for Waste Minimization in the Process Industry," *International Journal of Computers in Industry*, Vol. 22, pages 117-128, 1993.

Huang, Y.L., and L.T. Fan, "HIDEN: A Hybrid Intelligent System for Synthesizing Highly Controllable Exchanger Networks: Implementation of Distributed Strategy for Integration of Process Design and Control," *Industrial and Engineering Chemistry Research*, Vol. 33, pages 1174-1187, 1994. Project no. 91-36.

Huang, Y.L., Y.W. Huang, and L.T. Fan, "A Fuzzy-Logic-Based Approach to Building Efficient Fuzzy Rule-Based Expert Systems," *Computers and Chemical Engineering*, Vol. 17, pages 181-192, 1993.

Huang, Y.L., G. Sunder, and L.T. Fan, "MIN-CYANIDE: An Expert System for Cyanide Waste Minimization in Electroplating Plants," *Environmental Progress*, Vol. 10, pages 89-95, 1991.

Hughes, J.B., and G.F. Parkin, "The Effect of Mixtures of Xenobiotics and Primary Electron Donor on the Anaerobic Biotransformation of High Concentrations of Chlorinated Aliphatics," *Water, Science and Technology*, Vol. 26, pages 117-126, 1992.

Hundal, L., J. Singh, E.L. Bier, P.J. Shea, S.D. Comfort, and W.L. Powers, "Removal of TNT and RDX from Water and Soil Using Iron Metal," *Environmental Pollution*, Vol. 97, pages 55-64, 1997. Project no. 92-24.

Hundal, L.S., P.J. Shea, S.D. Comfort, W.L. Powers, and J. Singh, "Long-Term TNT Sorption and Bound-Residue Formation in Soil," *Journal of Environmental Quality*, Vol. 26, pages 896-904, 1996. Project no. 92-24.

Hurst, C.J., R.C. Sims, J.L. Sims, D.L. Sorensen, and J.W. McLean, "Polycyclic Aromatic Hydrocarbon Biodegradation as a Function of Oxygen Tension in Contaminated Soil," *Journal of Hazardous Materials*, Vol. 51, pages 193-208, 1996. Project no. 93-21.

Hurst, C.J., R.C. Sims, J.L. Sims, D.L. Sorensen, J.W. McLean, and S. Huling, "Soil Gas Oxygen Tension and Pentachlorophenol Biodegradation," *Journal of Environmental Engineering*, Vol. 123, No. 4, pages 364-370, 1997. Project no. 93-21.

Illangasekare, T.H., J.L. Ramsey, K.H. Jensen, and M. Butts, "Experimental Study of Movement and Distribution of Dense Organic Contaminants in Heterogeneous Aquifers," *Journal of Contaminant Hydrology*, Vol. 20, pages 1-25, 1995.

Illangasekare, T.H., J.H. Brannon, and B. Amadei, "Three-Dimensional Aquifer Flow and Transport by Integral Transforms," *Journal of Hydrology*, 161, Vol. 1, No. 4, pages 109-132, 1993.

Illangasekare, T.H., D.N. Yates, and E.J. Armbruster, "Effect of Heterogeneity on Transport and Entrapment of Nonaqueous-Phase Waste Products in Aquifers: An Experimental Study," *ASCE Journal of Environmental Engineering*, Vol. 121, No. 8, pages 572-579, 1995.

Illangasekare, T.H., D.N. Yates, E.J. Armbruster, and D.D. Reible, "Effect of Heterogeneity on Transport and Entrapment of Nonaqueous Phase Products in Aquifers: An Experimental Study," *ASCE Journal of Environmental Engineering*, Vol. 121, No. 8, pages 572-579, 1995.

Itoh, H.S., Utamapanya, J.V. Stark, K.J. Klabunde, and J.R., Schlup, "Nanoscale Metal Oxide Particles as Chemical Reagents. Intrinsic Effects of Particle Size on Hydroxyl Content and on Reactivity and Acid/Base Properties of Ultrafine Magnesium Oxide," *Chemistry of Materials*, Vol. 5, pages 71-77, 1993. Project no. 89-26, 92-03.

Jennings, S.R., and D.J. Dollhopf, "Acid-Base Account Effectiveness for Determination of Mine Waste Potential Acidity," *Journal of Hazardous Materials*, Vol. 41, pages 161-175, 1995. Project no. 93-12.

Jennings, S.R., D.J. Dollhopf, and W. Inskeep, "Hydrogen Peroxide Oxidation of Sulfide and Sulfate Minerals for Prediction of Mine Waste Acid Generation," *Geological Society of America*, Vol. 27, No. 4, page 16, 1995. Project no. 93-12.

Jones, W.L., J.D. Dockery, C.R. Vogel, and P.J. Sturman, "Diffusion and Reaction within Porous Packing Media: A Phenomenological Model," *Biotechnology and Bioengineering*, Vol. 41, pages 947-956, 1993.

Jordahl, J.L., L. Foster, J.L. Schnoor, and P.J.J. Alvarez, "Effect of Hybrid Poplar Trees on Microbial Populations Important to Hazardous Waste Bioremediation," *Environmental Toxicology and Chemistry*, Vol. 16, No. 6, pages 1318-1321, 1997. Project no. 94-25.

Kapila, S., R.K. Puri, A.F. Yanders, S. Cerlesi, and A.A. Elseewi, "The Effect of Co-Pollutant Degradation on Partitioning of Polychlorinated Dioxins in Saturated Soils," *Organohalogen Compounds*, Vol. 3, pages 327-330, 1990.

Kapila, S., Y.H. Lo, C.E. Orazio, R.K. Puri, A.F. Yanders, and A.A. Elseewi, "Evaluation of Solvent Flotation Coupled with Photodegradation for Decontamination of Soil," *Organohalogen Compounds*, Vol. 9, pages 111-114, 1992.

Kapila, S., K.S. Nam, M.H. Liu, R.K. Puri, and A.F. Yanders, "Promises and Pitfalls of Supercritical Fluid Extraction in Polychlorinated Compound Analyses," *Chemosphere*, Vol. 25, No. 1-2, pages 11-16, 1992.

Klabunde, K.J., "Nanoscale Particles Destroy Toxic Substances," *Centerpoint*, Vol. 2, No. 1, pages 1-3, 1994. Project no. 89-26, 92-03.

Klabunde, K.J., J. Stark, O. Koper, C. Mohs, D.G. Park, S. Decker, Y. Jiang, I. Lagadic, and D. Zhang, "Nanocrystals as Stoichiometric Reagents with Unique Surface Chemistry," *Journal of Physical Chemistry*, Vol. 100, pages 12142-12153, 1996. Project no. 89-26, 92-03.

Klabunde, K.J., A. Khaleel, and D. Park, "Overlayer of Iron Oxide on Nanoscale Magnesium Oxide Crystallites," *High Temperature Materials Science*, Vol. 33, pages 99-106, 1995. Project no. 89-26, 92-03.

Kohl, S.D., and J.A. Rice, "Binding of PCBs and PAHs to the Humin Fraction of Soil Organic Matter," *Chemosphere*, Vol 36, pages 251-261, 1998. Project no. 94-11.

Koper, O., I. Lagadic, and K.J. Klabunde, "Destructive Adsorption of Chlorinated Hydrocarbons on Ultrafine (Nanoscale) Particles of Calcium Oxide, 2," *Chemistry of Materials*, Vol. 9, pages 838-848, 1997. Project no. 95-04a.

Koper, O.B., and K.J. Klabunde, "Destructive Adsorption of Chlorinated Hydrocarbons on Ultrafine (Nanoscale) Particles of Calcium Oxide, 3 Chloroform, Tricholoethene and Tetracholoethene," *Chemistry of Materials*, Vol. 9, pages 2481-2485, 1997. Project no. 95-04a.

Koper, O.B., I. Lagadic, A. Volodin, and K.J. Klabunde, "Alkaline-Earth Oxide Nanoparticles Obtained by Aerogel Methods: Characterization and Rationale for Unexpectedly High Surface Chemical Reactivities," *Chemistry of Materials*, Vol. 9, pages 2468-2480, 1997. Project no. 95-04a.

Koper, O., Y.-X. Li, and K.J. Klabunde, "Destructive Adsorption of Chlorinated Hydrocarbons on Ultrafine (Nanoscale) Particles of Calcium Oxide," *Chemistry of Materials*, Vol. 5, pages 500-505, 1993. Project no. 89-26, 92-03.

Koper, O., E.A. Wovchko, J.A. Glass Jr., J.T. Yates Jr., and K.J. Klabunde, "Decomposition of CCl_4 on CaO," *Langmuir*, Vol. 11, pages 2054-2059, 1995. Project no. 89-26, 92-03.

Kovács, Z., F. Friedler, and L.T. Fan, "Parametric Study of Separation Network Synthesis: Extreme Properties of Optimal Structures," *Computers and Chemical Engineering*, Vol. 19, S107-S112, 1995. Project no. 91-36.

Kovács, Z., F. Friedler, and L.T. Fan, "Recycling in a Separation Process Structure," *American Institute of Chemical Engineers Journal*, Vol. 39, pages 1087-1089, 1993.

Lambert, M.W., G.M. Pierzynski, L. Erickson, and J. Schnoor, "Remediation of Lead, Zinc, and Cadmium-Contaminated Soils," *Contaminated Land and Its Reclamation, Issues in Environmental Science and Technology*, Royal Society of Chemistry, Cambridge, UK, pages 91-102, 1997. Project no. 93-07.

Langner, H.W., W.P. Inskeep, H.M. Gaber, W.L. Jones, B.S. Das, and J.M. Wraith, "Pore Water Velocity and Residence Time Effects on the Degradation of 2,4-D During Transport," *Environmental Science Technology*, Vol. 32, pages 1308-1315, 1998. Project no. 94-09.

Lewandowski, Z., G. Walser, and W. Characklis, "Reaction Kinetics in Biofilms," *Biotechnology and Bioengineering*, Vol. 38, pages 877-882, 1991.

Lewandowski, Z., S.A. Altobelli, P.D. Majors, and E. Fukushima, "NMR Imaging of Hydrodynamics Near Microbially Colonized Surface," *Water, Science and Technology*, Vol. 26, pages 577-584, 1992.

Li, Y.-X., and K.J. Klabunde, "Nanoscale Metal Oxide Particles as Chemical Reagents. Destructive Adsorption of a Chemical Agent Stimulant Dimethylmethylphosphonate (DMMP) on Heat-Treated Magnesium Oxide," *Langmuir*, Vol. 7, pages 1388-1393, 1991.

Li, Y.-X., J.R. Schlup, and K.J. Klabunde, "A Fourier Transform Infrared Photoacoustic Spectroscopy (FT-IR-PAS) Study of the Adsorption of Organophosphorus Compounds on Heat-Treated Magnesium Oxide," *Langmuir*, Vol. 7, pages 1394-1399, 1991.

Li, Y.-X., and K.J. Klabunde, "Heterophasic Isotope Exchange in Nanoscale Metal Oxide Particles. Lattice Oxygen and Surface OH Groups with Water Vapor (D_20 and $H_2{}^{18}0$)," *Chemistry of Materials*, Vol. 4, pages 611-615, 1992. Project no. 89-26, 92-03.

Li, Y.-X., O. Koper, M. Atteya, and K.J. Klabunde, "Adsorption and Decomposition of Organophosphorus Compounds on Nanoscale Metal Oxide Particles. *In Situ* GC-MS Studies of Pulsed Microreactions over Magnesium Oxide," *Chemistry of Materials*, Vol. 4, pages 323-330, 1992. Project no. 89-26, 92-03.

Li, Y.X., and K.J. Klabunde, "Destructive Adsorption of Chlorinated Hydrocarbons on Ultrafine (Nanoscale) Particles of Magnesium Oxide and Calcium Oxide," *Environmental Science and Technology*, Vol. 28, pages 1248-1253, 1994.

Li, Z.M., P.J. Shea, and S.D. Comfort, "Destruction of 2,4,6- trinitrotoluene (TNT) by Fenton Oxidation," *Journal of Environmental Quality*, Vol. 26, pages 840-847, 1997. Project no. 92-24.

Li, Z.M., P.J. Shea, and S.D. Comfort, "Fenton Oxidation of 2,4,6-trinitrotoluene in Contaminated Soil Slurries," *Environmental Engineering Science*, Vol. 14, pages 55-56, 1997. Project no. 92-24.

Li, Z.M., M.M. Peterson, S.D. Comfort, G.L. Horst, P.J. Shea, and B.T. Oh, "Remediating TNT-Contaminated Soil by Soil Washing and Fenton Oxidation," *Sci. Tot. Environ.*, Vol. 204, pages 107-115, 1997. Project no. 92-24.

Little, B., R. Ray, P. Wagner, Z. Lewandowski, W.H. Lee, W.G. Characklis, and F. Mansfeld, "Impact of Biofouling on the Electrochemical Behavior of 304 Stainless Steel in Natural Seawater," *Biofouling*, Vol. 3, pages 45-59, 1991.

Liu, M.H., S. Kapila, A.F. Yanders, T.E. Clevenger, and A.A. Elseewi, "Role of Entrainers in Supercritical Fluid Extraction of Chlorinated Aromatics from Soils," *Chemosphere*, Vol. 23, pages 1085-1095, 1991.

Liu, M.H., S. Kapila, R.K. Puri, and A.F. Yanders, "Determination of Chlorinated Phenols by Supercritical Fluid Extraction (SFE)-Coupled Liquid Chromatography (LC) System," *Organohalogen Compounds*, Vol. 8, page 91, 1992.

Liu, M.H., S. Kapila, K.S. Nam, and A.A. Elseewi, "A Tandem Supercritical Fluid Extraction (SFE) and Liquid Chromatography (LC) System for Determination of Chlorinated Phenols in Solid Matrices," *Journal of Chromatography*, Vol. 639, pages 151-157, 1993.

Macauley, E., and A. Hong, "Chelation Extraction of Lead from Contaminated Soil," *Journal of Hazardous Materials*, Vol. 40, pages 257-270, 1995. Project no. 93-22.

Madison, M.F., and L.A. Licht, "Agricultural Ecosystems–The World Is Watching," *Agricultural Engineering*, Vol. 71, No. 1, pages 12-15, 1990.

Martin, J.L., S.D. Comfort, P.J. Shea, T.A. Kokjohn, and R.A. Drijber, "Denitration of 2,4,6,-trinitrotoluene (TNT) by *Pseudomonas savastanoi*," *Canadian Journal of Microbiology*, Vol. 43, 447-455, 1996. Project no. 92-24.

Miller, C.M., and R.L. Valentine, "Hydrogen Peroxide Decomposition and Quinoline Degradation in the Presence of Aquifer Material," *Water Research*, Vol. 29, No. 10, pages 2353-2359, 1995.

Miller, C.M., and R.L. Valentine, "Oxidation Behavior of Aqueous Contaminants in the Presence of Hydrogen Peroxide and Filter Media," *Journal of Hazardous Materials*, Vol. 41, pages 105-116, 1995.

Mohs, C., and K.J. Klabunde, "Photocatalytic Oxidation of Chloroform by Titanium Dioxide," *Proceedings of the 9th Annual Conference on Hazardous Waste Research*, Bozeman, Montana, page 103, 1994. Project no. 89-26, 92-03.

Moldan, B., and J.L. Schnoor, "Czechoslovakia's Environmental Problems: A Case Study of Central European Environmental Decline and Plan for Recovery," *Environmental Science and Technology*, Vol. 26, pages 14-21, 1992.

Nachabe, M., and T.H. Illangasekare, "Use of Tension Infiltrometer Data with Unsaturated Hydraulic Conductivity Models," *Groundwater*, Vol. 32, No. 6, pages 1017-1021, 1994.

Nachabe, M., A. Islas, and T.H. Illangasekare, "Analytical Solutions for Water Flow and Solute Transport in the Unsaturated Zone," *Groundwater*, Vol. 33, No. 2, pages 304-310, 1995.

Nair, D.R., and J.L. Schnoor, "Effect of Two Electron Acceptors on Atrazine Mineralization Rates in Soil," *Environmental Science and Technology*, Vol. 26, No. 11, pages 2298-2300, 1992.

Nair, D.R., J.G. Burken, J.L. Schnoor, and L.A. Licht, "Mineralization and Uptake of Triazine Pesticide in Soil-Plant Systems," *Journal of Environmental Engineering*, ASCE, Vol. 119, No. 5, pages 842-854, 1993.

Nair, D.R., and J.L. Schnoor, "Effect of Soil Conditions on Model Parameters and Atrazine Mineralization Rates," *Water Research*, Vol. 28, pages 1199-1205, 1994.

Nam, K.S., S. Kapila, A.F. Yanders, and R.K. Puri, "Supercritical Fluid Extraction and Cleanup Procedures for Determination of Xenobiotics in Biological Samples," *Chemosphere*, Vol. 20, pages 873-880, 1990.

Nam, K.S., S. Kapila, A.F. Yanders, and R.K. Puri, "A Multiple Sample Extraction and Online System for the Analysis of Chlorinated Compounds," *Chemosphere*, Vol. 23, pages 1109-1116, 1991.

Nam, K.S., S. Kapila, R.K. Puri, A.F. Yanders, and B.R. Larsen, "Evaluation of Supercritical Fluid Extraction for Eliminating Interferences During Multiresidue Pesticide Analysis," *Organohalogen Compounds*, Vol. 8, pages 115-120, 1992.

Narayanan, M., L.C. Davis, and L.E. Erickson, "Fate of Volatile Chlorinated Organic Compounds in a Laboratory Chamber with Alfalfa Plants," *Environmental Science and Technology*, Vol. 29, pages 2437-2444, 1995. Project no. 94-27.

Narayanan, M., L.C. Davis, J.C. Tracy, L.E. Erickson, and R.M. Green, "Experimental and Modeling Studies of the Fate of Organic Contaminants in the Presence of Alfalfa Plants," *Journal of Hazardous Materials*, Vol. 41, pages 229-249, 1995.

Narayanan, M., J.C. Tracy, L.C. Davis, and L.E. Erickson, "Modeling the Fate of Toluene in a Chamber with Alfalfa Plants 1. Theory and Modeling Concepts," *Journal of Hazardous Substance Research*, Vol. 1, No. 5, 1998. Project no. 94-27.

Narayanan, M., L.C. Davis, J.C. Tracy, and L.E. Erickson, "Modeling the Fate of Toluene in a Chamber with Alfalfa Plants 2. Numerical Results and Comparison Study," *Journal of Hazardous Substance Research*, Vol. 1, No. 5, 1998. Project no. 94-27.

Neira, M., T.J. O'Keefe, and J.L. Watson, "Solvent Extraction Reagent Entrainment Effects on Zinc Electrowinning from Waste Oxide Leach Solution," *Minerals Engineering*, Vol. 5, No. 3-5, pages 521-534, 1992.

Novak, P.J., L. Daniels, and G.F. Parkin, "Enhanced Dechlorination of Carbon Tetrachloride and Chloroform in the Presence of Elemental Iron and *Methanosarcina barkeri, Methanosarcina thermophila*, or *Methanosaeta concillii*," *Environmental Science and Technology*, Vol. 32, pages 1438-1443, 1998. Project no. 93-02.

Novak, P.J., L. Daniels, and G.F. Parkin, "Rapid Dechlorination of Carbon Tetrachloride and Chloroform by Extracellular Agents in Cultures of *Methanosarcina thermophila*," *Environmental Science and Technology*, Vol. 32, pages 3132-3136, 1998. Project no. 93-02.

Novak, P.J., S.C. Christ, and G.F. Parkin, "Kinetics of Alachlor Transformation and Identification of Metabolites under Anaerobic Conditions," *Water Research*, Vol. 31, pages 3107-3115, 1997. Project no. 93-02.

Orazio, C.E., S. Kapila, R.K. Puri, and A.F. Yanders, "Persistence of Chlorinated Dioxins and Furans in the Soil Environment," *Chemosphere*, Vol. 25, pages 1469-1474, 1992.

Paterson, K.G., and J.L. Schnoor, "Fate of Alachlor and Atrazine in Riparian Zone Field Site," *Research Journal of the Water Pollution Control Federation*, Vol. 64, pages 274-283, 1992.

Paterson, K.G., and J.L. Schnoor, "Vegetative Alteration of Nitrate Fate in Unsaturated Zone," *Journal of Environmental Engineering*, ASCE, Vol. 119, No. 5, pages 986-993, 1993.

Perkovich, B.S., T.A. Anderson, E.L. Kruger, and J.R. Coats, "Enhanced Mineralization of ^{14}C-atrazine in *Kochia scoparia* Rhizospheric Soil from a Pesticide-Contaminated Site," *Pesticide Science*, Vol. 46, pages 391-396, 1996. Project no. 93-05.

Peterson, M.M., G.L. Horst, P.J. Shea, S.D. Comfort, and R.D.K. Peterson, "TNT and 4amino-2,6-dinitrotoluene Influence on Germination and Early Seedling Development of Tall Fescue," *Environmental Pollution*, Vol. 93, pages 57-62, 1996. Project no. 92-24.

Petrie, R.A., P.R. Grossl, and R.C. Sims, "Controlled Environment Potentiostat to Study Solid-Aqueous Systems," *Soil Science Society of America Journal*, Vol. 62, pages 379-382, 1998. Project no. 93-21.

Peyton, R.L., B.A. Haeffner, S.H. Anderson, and C.J. Gantzer, "Applying X-Ray CT to Measure Macropore Diameters in Undisturbed Soil Cores," *Geoderma*, Vol. 53, pages 329-340, 1992.

Pierzynski, G.M., and A.P. Schwab, "Bioavailability of Zinc, Cadmium, and Lead in a Metal-Contaminated Alluvial Soil," *Journal of Environmental Quality*, Vol. 22, pages 247-254, 1993.

Puri, R.K., S. Kapila, Y-H. Lo, C. Orazio, T.E. Clevenger, and A.F. Yanders, "Effect of Co-Contaminants on the Disposition of Polychlorinated Dibenzo-P-Dioxins and Polychlorinated Dibenzofurans in Saturated Soils," *Chemosphere*, Vol. 20, pages 1589-1596, 1990.

Puri, R.K., Y. Quiping, C.E. Orazio, A.F. Yanders, S. Kapila, S. Cerlesi, and S. Facchetti, "Transport and Persistence of Chlorinated Organics in Varied Soil Environments," *Organohalogen Compounds*, Vol. 9, pages 187-190, 1992.

Reilley, K., M.K. Banks, and A.P. Schwab, "Dissipation of Polynuclear Aromatic Hydrocarbons in the Rhizosphere," *Journal of Environmental Quality*, Vol. 25, pages 212-219, 1996.

Ryoo, K., S. Kapila, R.K. Puri, and A.F. Yanders, "Evaluation of Carbon for Removal and Destruction of Polychlorinated Biphenyls (PCBs)," *Chemosphere*, Vol. 25, pages 1569-1573, 1992.

Santharam, S., L.E. Erickson, and L.T. Fan, "Modeling the Role of Surfactant and Biodegradation in the Remediation of Aquifers with Nonaqueous-Phase Contaminants," *Journal of Hazardous Materials*, Vol. 53, pages 115-139, 1997. Project no. 94-27.

Schnabel, W.E., A.C. Dietz, J.G. Burken, J.L. Schnoor, and P.J.J. Alvarez, "Uptake and Transformation of Trichloroethylene by Edible Garden Plants," *Water Research*, Vol. 31, pages 816-824, 1996. Project no. 95-29.

Schnoor, J.L., L.A. Licht, S.C. McCutcheon, N.L. Wolfe, and L.H. Carreira, "Phytoremediation of Organic and Nutrient Contaminants," *Environmental Science and Technology*, Vol. 29, No. 7, pages 318A-323A, 1995. Project no. 94-25.

Schwab, A.P., M.K. Banks, and M. Arunachalam, "Influence of the Rhizosphere on Biodegradation of Phenanthrene and Pyrene," *On-Site Bioreclamation*, Hinchee and Olfenbuttel (Eds.), Butterworth and Heinemann, 1995.

Segar, J.R, R.L., S.-Y. Leung, and S.A Vivek, "Treatment of Trichloroethene (TCE)-Contaminated Water with a Fluidized-Bed Bioreactor," *Annals of the New York Academy of Sciences*, Vol. 829, pages 83-96, 1997. Project no. 94-07.

Shetty, K.G., M.K. Banks, B.A.D. Hetrick, and A.P. Schwab, "Biological Characterization of a Southeast Kansas Mining Site," *Water, Air and Soil Pollution*, Vol. 78, No. 1-2, pages 169-177, 1994.

Shetty, K.G., B.A.D. Hetrick, D. Hoobler, and A.P. Schwab, "Effects of Mycorrhizae and Other Soil Microbes on Revegetation of Heavy Metal-Contaminated Mine Spoil," *Environmental Pollution*, Vol. 86, pages 181-188, 1994.

Shimp, J.F., J.C. Tracy, L.C. Davis, E. Lee, W. Huang, L.E. Erickson, and J.L. Schnoor, "Beneficial Effects of Plants in the Remediation of Soil and Groundwater Contaminated with Organic Materials," *Critical Reviews in Environmental Control*, Vol. 23, No. 1, pages 41-77, 1993.

Shue, S.L., R.E. Faw, and J.K. Shultis, "Thermal Neutron Intensities in Soils Irradiated by Fast Neutrons from Point Sources," *Chemical Geology*, Vol. 144, pages 47-61, 1998. Project 94-02.

Singh, J., S.D. Comfort, and P.J. Shea, "Long-Term RDX Sorption and Fate in Soil," *Journal of Environmental Quality*, Vol. 27, pages 572-577, 1997. Project no. 92-24.

Singh, J., P.J. Shea, L.S. Hunda, S.D. Comfort, T.C. Zhang, and D.S. Hage, "Iron-Enhanced Remediation of Water and Soil Containing Atrazine," *Weed Science*, Vol 46, No. 3, pages 381-388, 1998. Project no. 95-32.

Sivils, L.D., S. Kapila, Q. Yan, and A.A. Elseewi, "Application of a Two-Dimensional Chromatography System for Gas-Phase Photodegradation Studies of Polychlorinated Dibenzo-p-Dioxins," *Journal of Chromatography*, Vol. 688, pages 221-230, 1994.

Sivils, L.D. S. Kapila, and Q. Yan, "Photodegradation of Polychlorinated Dibenzo-p-Dioxins (PCDDs) in Vapors and Aerosols," *Organohalogen Compounds*, Vol. 24, pages 368-373, 1995.

Stark, J.V. and K.J. Klabunde, "Nanoscale Metal Oxide Particles/Clusters as Chemical Reagents: Adsorption of Hydrogen Halides, Nitric Oxide, and Sulfur Trioxide on Magnesium Oxide Nanocrystals and Compared with Microcrystals," *Chemistry of Materials*, Vol. 8, pages 1913-1918, 1996. Project no. 89-26, 92-03.

Stark, J.V., D.G. Park, I. Lagadic, and K.J. Klabunde, "Nanoscale Metal Oxide Particles/Clusters as Chemical Reagents: Unique Surface Chemistry of Magnesium Oxide as Shown by Enhanced Adsorption of Acid Gases (Sulfur Dioxide and Carbon Dioxide) and Pressure Dependence," *Chemistry of Materials*, Vol. 8, pages 1904-1912, 1996. Project no. 89-26, 92-03.

Sturman, P.J., W.L. Jones, and W.G. Characklis, "Interspecies Competition in Colonized Porous Pellets," *Water Research*, Vol. 28, No. 4, page 831, 1994.

Sturman, P.J., P.S. Stewart, A.B. Cunningham, E.J. Bouwer, and J.H. Wolfram, "Engineering Scaleup of *In Situ* Bioremediation Processes: A Review," *Journal of Contaminant Hydrology*, Vol. 19, pages 171-203, 1995.

Tilio, R., S. Kapila, and K.S. Nam. "Reduction/Elimination of Sulfur Interference in Organochlorine Residue Determination by Supercritical Fluid Extraction," *Journal of Chromatography*, Vol. 662, pages 191-197, 1994.

Tilio, R., K. Krishnan, S. Kapila, K.S. Nam, and S. Facchetti, "A Simple Analytical Methodology for Multiresidue Pollutant Determinations," *Chemosphere*, Vol. 20, No. 9-11, pages 1849-1858, 1994.

Till, B.A., L.J. Weathers, and P.J.J. Alvarez, "Fe^0-Supported Autotrophic Denitrification," *Environmental Science and Technology*, Vol. 32, pages 634-639, 1997. Project no. 93-02.

Utamapanya, S., K.J. Klabunde, and J. Schlup, "Nanoscale Metal Oxide Particles/Clusters as Chemical Reagents. Synthesis and Properties of Ultra-High Surface Area Magnesium Oxide," *Chemistry of Materials*, Vol. 3, pages 175-181, 1991.

Vanhoudt, P., Z. Lewandowski, and B. Little, "Iridium Oxide pH Microelectrode," *Biotechnology and Bioengineering*, Vol. 40, pages 601-608, 1992.

Varga, J.B., F. Friedler, and L.T. Fan, "Parallelization of the Accelerated Branch-and-Bound Algorithm of Process Synthesis: Application in Total Flowsheet Synthesis," *Acta Chimica Slovenica*, Vol. 42, pages 15-20, 1995. Project no. 91-36.

Walton, C.W., and K.J. Loos, "Assessment and Options for Waste Minimization in the Metal Finishing Industry," *Plating and Surface Finishing–Journal of the AESF*, Vol. 79, No. 11, pages 8-14, 1992.

Weathers, L.J., G.F. Parkin, and P.J.J. Alvarez, "Utilization of Cathodic Hydrogen as Electron Donor for Chloroform Cometabolism by a Mixed, Methanogenic Culture," *Environmental Science and Technology*, Vol. 31, pages 880-885, 1997. Project 93-02.

Wildenschild, D., K.H. Jensen, K.J. Hollenbeck, T.H. Illangasekare, D. Znidarcic, and T. Sonnenborg, "A Two-Stage Procedure for Determining Hydraulic Characteristics Using a Syringe Pump and Outflow Observations," *Journal of Soil Science Society of America*, Vol. 61, No. 2, pages 347-359, 1996. Project no. 94-29.

Woodbury, B.L., S.D. Comfort, and W.L. Powers, "An Automated Sampling System for Large Column Transport Studies," *Transactions of ASAE*, Vol. 39, No. 6, pages 2163-2166, 1996. Project no. 92-24.

Wu, J.C., L.T. Fan, and L.E. Erickson, "Modeling and Simulation of Bioremediation of Contaminated Soil," *Environmental Progress*, Vol. 9, pages 47-56, 1990.

Wu, J.C., L.T. Fan, and L.E. Erickson, "Modeling and Simulation of *In Situ* Neutralization and Bioremediation Processes," *Groundwater Management*, Vol. I, pages 279-293, 1990.

Wu, J.C., L.T. Fan, and L.E. Erickson, "Three-Point Backward Finite Difference Method for Solving a System of Mixed Hyperbolic-Parabolic Partial Differential Equations," *Computers and Chemical Engineering*, Vol. 14, pages 679-685, 1990.

Yan, Q., S. Kapila, R.K. Puri, and A.A. Elseewi, "Effects of Co-Contaminants on Photodegradation Kinetics of OCDD," *Organohalogen Compounds*, Vol. 12, pages 95-98, 1993.

Yan, Q., S. Kapila, R.K. Puri, and A.A. Elseewi, "Effects of Co-Contaminants on Photodegradation Kinetics of Polychlorinated Dibenzo-p-Dioxins," *Chemosphere*, Vol. 20, No. 9-11, pages 2183-2192, 1994.

Yan, Q., S. Kapila, L.D. Sivils, and A.A. Elseewi, "Effects of Sensitizers and Inhibitors on Phototransformation of Polychlorinated Dibenzo-p-Dioxins (PCDDs)," *Chemosphere*, Vol. 31, No. 7, pages 3627-3634, 1995.

Yanders, A.F., S. Kapila, Y.-H. Lo, R.K. Puri, and S. Cerlesi, "Persistence of Tetrachlorodibenzo-P-Dioxin in Soil: Times Beach Case Study," *Chemosphere*, Vol. 25, pages 1569-1572, 1992.

Yang, X., L.E. Erickson, and L.T. Fan, "Dispersive-Convective Characteristics in the Bioremediation of Contaminated Soil with a Heterogeneous Formation," *Journal of Hazardous Materials*, Vol. 38, pages 163-185, 1994.

Yang, X., L.E. Erickson, and L.T. Fan, "A Discrete Blob Model of Contaminant Transport in Groundwater with Trapped Nonaqueous-Phase Liquids," *Chemical Engineering Communications*, Vol. 154, pages 33-57, 1995.

Yang, X., L.E. Erickson, and L.T. Fan, "A Study of Dissolution Rate-Limited Bioremediation of Soils Contaminated by Residual Hydrocarbons," *Journal of Hazardous Materials*, Vol. 41, pages 299-313, 1995.

Yang, X., L.T. Fan, and L.E. Erickson, "A Conceptual Study on the Biowall Technology: Feasibility and Process Design," *Remediation*, Vol. 6, pages 55-67, 1995.

Yang, X., L.E. Erickson, and L.T. Fan, "A Bench-Scale Study on Biodegradation and Volatilization of Ethylbenzoate in Aquifers," *Journal of Hazardous Materials*, Vol. 50, pages 169-182, 1996.

B. ARTICLES SUBMITTED OR IN PRESS

Adamson, D.T., and G.F. Parkin, "Biotransformation Kinetics of Mixtures of Chlorinated Aliphatic Hydrocarbons by a Mixed Methanogenic Enrichment Culture," *Journal of Water Research*, 1998. Project no. 93-24.

Arthur, E.L., B.S. Perkovich T.A. Anderson, and J.R. Coats, "Degradation of an Atrazine and Metolachlor Herbicide Mixture in Pesticide-Contaminated Soils from Two Agrochemical Dealerships in Iowa," *Water, Air and Soil Pollution*, 1998. Project no. 93-05.

Barrera, J.A., and T.J. O'Keefe, "A Continuous Flow Evaluation of the Galvanic Stripping Process," *Separation Science and Technology*, 1998. Project no. 94-05.

Barth G.R., T.H. Illangasekare, M.H. Hill, and H. Rajaram, "Characterization of NAPL Contaminated Sites Using Tracer Techniques," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-29.

Barth, G., T.H. Illangasekare, M. Hill, and H. Rajaram, "Analysis of Intermediate-Scale Tracer Experiments for the Development of Tracer Density Guidelines," *Water Resources Research*, 1998. Project no. 94-29.

Barth, G., M. Hill, T.H. Illangasekare, and H. Rajaram, "Predictive and Regression Modeling of Heterogeneous Intermediate-Scale Flow and Transport Experiments," *Water Resources Research*, 1998. Project no. 94-29.

Boronina, T.N., I. Lagadic, G. Sergeev, and K.J., Klabunde, “Activated and Non-Activated Forms of Zinc Powder: Reactivity Towards Chlorocarbons in Water and AFM Studies of Surface Morphologies,” *Environmental Science and Technology*, 1998. Project no. 95-04a.

Boronina, T.N., I. Lagadic, and K.J. Klabunde, “Zinc-Silver, Zinc-Palladium, and Zinc-Gold as Active Bimetallic Systems for Carbon Tetrachloride Dechlorination in Water,” *Journal of Hazardous Substance Research*, 1998. Project no. 95-04a.

Bugbee, B., and W.J. Doucette, “Phytoremediation: Physiological Procedure for Scaling from Laboratory to Field,” *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 95-10.

Burckhard, S.R., J.-A. Kim, and V.R. Schaefer, "Design of a Graphic User Interface for a Decision Support System," *Proceedings of the13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-12.

Burken, J.G., and J.L. Schnoor, “Predictive Relationships for Uptake of Organic Contaminants by Hybrid Poplar Trees,” *Environmental Science and Technology*, 1998. Project no. 94-25.

Chard, J.K., B.J. Orchard, C.J. Pajak, B. Bugbee, and W.J. Doucette, "Uptake of Trichloroethanol and Trichloroacetic Acid by Hybrid Poplar," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 95-10.

Chew, C.F., and T.C. Zhang, “In Situ Remediation of Nitrate-Contaminated Groundwater by Electrokinetics/Iron Wall Processes,” *Water Science and Technology*, 1998. Project no. 95-32.

Chew, C.F., and T.C. Zhang, “Simultaneous Transformation of Nitrate and Atrazine by Metal Iron Powder,” *Proceedings of the WEF 71st Annual Conference and Exposition*, Orlando, Florida, 1998. Project no. 95-32.

Chew, C.F., and T.C. Zhang, “Removal of Nitrate/Atrazine Contamination with Zero-Valent Iron Promoted Processes,” *Proceedings of the 13th Annual Conference on Hazardous Waste Research*,” Snowbird, Utah, 1998. Project no. 95-32.

Davis, L.C., S. Vanderhoof, and D. Lupher, “Sorption of Trichloroethylene and Other Halogenated Aliphatics on and in Plant Material,” *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snow Bird, Utah, 1998. Project no. 94-27.

DeJournett, T., and P.J.J. Alvarez, “Feasability of Fe(0) Bioaugmentation with Hydrogenotrophic Denitrifiers for Nitrate Removal from Groundwater,” *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 93-02.

Doughten, R.A., W.P. Inskeep and C.G. Johnson, “Mineralization of Pentachlorophenol in Soil by a White-Rot Fungi in the Presence of Surfactants,” *Biodegradation*, 1998. Project no. 94-09.

Friedrich, M., R.J. Grosser, E.A. Kern, W.P. Inskeep, and D.M. Ward, “Biodegradation of Phenanthrene in Reduced Bioavailability Environments: II Characterization of Microbial Communities by DGGE and Sequence Analysis,”*Applied Environmental Microbiology*, 1998. Project no. 94-09.

Fukushi, K., S. Ghosh, and D. Chang, "Enhanced Heavy Metal Uptake by Activated Sludge Cultures Grown in the Presence of Biopolymer Stimulators," *Water Science and Technology*, 1996.

Gaber, H.M., W.P. Inskeep, and J.M. Wraith, "Surfactant-Enhanced Transport of Organic Solutes: Effects of Method of Surfactant Application," *Journal of Environmental Quality*, 1998. Project no. 94-09.

Ghosh, S., D. Chang, K. Fukushi, and A. Chan, "Biostimulation of Cadmium and Copper Removal in the Presence of Special Nutrients," *Water Research*, 1996.

Ghosh, S., and M.L. Sun, "Anaerobic Biodegradation of Benzene under Acidogenic Fermentation Conditions," *Water Research*, 1996.

Green, R.M., L. E. Erickson, P. Kalita, and G. Pierzynski, "Utilization of the Kinematic Runoff and Erosion Model in Predicting the Effects of Vegetation on Heavy Metal Containment in Southeast Kansas," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 93-07.

Griswold, W.M., G.L. Godfrey, and P.T. Yazzie, "HERS Supports Connection Between Technology and Native American Cultures," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. TR96-05.

Grosser, R.J., M. Friedrich, D.M. Ward, and W.P. Inskeep, "Biodegradation of Phenanthrene in Reduced Bioavailability Environments: I Characterization of Enrichment Strategies," *Applied Environmental Microbiology*, 1998. Project no. 94-09.

Gu, H., C.-M. Chang, J.A. Barrera-Godinez, and T.J. O'Keefe, "Preliminary Design of Solvent Extraction Process for Separating Iron from Zinc by Galvanic Stripping," *Transactions SME*, 1998. Project no. 94-05.

Hall, B., D. V. Sisson, D.K. Stevens, and R.R. Dupont, "Design of Monitoring Grid and Sample Collection Method for Evaluating Air Injection Remediation Technologies." *Environmetrics*, 1998. Project no. 93-20.

Hall, B., C.K. Baldwin, T.E. Lachmar, and R.R. Dupont, "Instrumentation Design and Installation for Monitoring Air Injection Ground Water Remediation Technologies," *Ground Water Monitoring and Remediation*, 1998. Project no. 93-20.

Hall, B., T.E. Lachmar, and R.R. Dupont, "Field Performance Monitoring of *In Situ* Air Sparging," *Ground Water,* 1998. Project no. 93-20.

Hall, B., T.E. Lachmar, and R.R. Dupont, "Field Performance Monitoring of In-Well Aeration," *Ground Water*, 1998. Project no. 93-20.

Hayhurst, S.C., W.J. Doucette, B.J. Orchard, C.J. Pajak, B. Bugbee, and G. Koerner, "Phytoremediation of Trichloroethylene: A Field Evaluation." *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 95-10.

He, Y., A.P. Schwab, and M.K. Banks, “The Influence of Citrate on Adsorption of Zinc in Soils,” *Environmental Science and Technology*, 1998. Project no. 93-06.

Hong, A., “Improved Recovery of Heavy Metals and Chelating Agents Following Extraction from Contaminated Soil,” *Journal of Environmental Engineering*, 1996. Project no. 93-22.

Hong, A., and R. Peters, “Metals Extraction from Soil with Aqueous Chelating Agents,” *The Encyclopedia of Environmental Analysis and Remediation*, John Wiley & Sons, Inc., 1996. Project no. 93-22.

Hong, A., C. Li, W.-M. Jiang, and T.-C. Chen, “Chelating Agents for Extraction of Heavy Metals: Complexing Power, Selectivity, and Recoverability,” *ACS Symposium Series*, 1996. Project no. 93-22.

Hu,. J., M. Narayanan, L.C. Davis, and L.E. Erickson, “Modeling and Simulation of Volatile Organic Compounds in Soil-Root Environments,” *Proceedings of the Conference on Hazardous Waste Research*, Snow Bird, Utah, 1998. Project no. 94-27.

Illangasekare, T.H., and H. Rajaram, "Use of Sparse Data for Characterization of Aquifers to Model Water Flow and Chemical Transport: Intermediate Scale Testing for Theory Validation," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-29.

Jordan, R., and A.B. Cunningham, "Surfactant Effects on Bioavailability of Soil-Sorbed Organics," *Proceedings of the NATO Advanced Study Institute on Bioavailability of Organic Xenobiotics in the Environment*, Jesenik (Ed.), 1997. Project no. 94-28.

Kohl, S.K., and J.A. Rice, "Contribution of Lipids to the Early Sorption of Hydrophobic Contaminants to Soil," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-11.

Kohl, S.K., M. Gabbert, and J.A. Rice, “Comparison of the Traditional Alkaline Extraction of Humic Materials to Methods using Water-Immiscible Solvents,” *Geoderma*, 1998. Project no. 94-11.

Kohl, S.K., and J.A. Rice, “Interaction of PAHs with Soil Organic Matter,” *Organic Geochemistry*, 1998. Project no. 94-11.

Kuiper, L., and T.H. Illangasekare, “A Three-Dimensional Multiphase Flow Model for Immiscible Fluids in Porous Media: Validation for Heterogeneous Conditions,” *Journal of Contaminant Hydrology*, 1998. Project no. 94-29.

Li, W., and K.J. Klabunde, “Ultrafine Zinc and Nickel, Palladium, Silver Coated Zinc Particles Used for Reductive Dehalogenation of Chlorinated Ethylenes in Aqueous Solution,” *Croatica Chemica Acta*, 1998. Project no. 95-04a.

Licht, L.A., “Ecolotree™ Buffers Case Histories,” *American Chemical Society*, 1996.

Macur, R.E., and W.P. Inskeep, "Effects of a Nonionic Surfactant on Biodegradation of Phenanthrene and Hexadecane in Soils," *Environmental Toxicological Chemistry*, 1998. Project no. 94-09.

Mehl, S., M.C. Hill, and T.H. Illangasekare, "Predictability of Hydraulic Conductivity at the Intermediate Scale Using Inverse Modeling Techniques," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-29.

Narayanan, M., N.K. Russell, L.C. Davis, and L.E. Erickson, "Fate and Transport of Trichloroethylene in a Chamber with Alfalfa Plants," *Journal of Environmental Quality*, 1998. Project no. 94-27.

Narayanan, M., L.E. Erickson, and L.C. Davis, "Simple Plant-Based Design Strategies for Volatile Organic Pollutants," *Environmental Progress*, 1998. Project no. 94-27.

Narayanan, M., N.K. Russell, L.C. Davis, and L.E. Erickson, "Fate and Transport of Trichloroethylene in a Chamber with Alfalfa Plants: Experimental and Modeling Studies," *Water Resources Research*, 1996. Project no. 94-27.

Nedunuri, K.V., R.S. Govindaraju, A.P. Schwab, and L.E. Erickson, " Modeling of Heavy Metal Movement in Vegetated, Unsaturated Soils with Emphasis on Geochemistry," *Advances in Environmental Research*, 1998. Project no. 93-06.

Nieman, J.K.C., R.C. Sims, J.L. Sims, D.L. Sorensen, J.E. McLean, and J.A. Rice, "Sequestration of Pyrene in Creosote-Contaminated Soil Evaluated with the MIBK Fractionation Method," *Environmental Science and Technology*, 1998. Project no. 93-21. Project no. 94-11.

Nieman, J.K.C., R.C. Sims, J.L. Sims, D.L. Sorensen, and J.E. Mclean, "Environmental Variables Affecting Mineralization and Sequestration of Pyrene at the Champion International Superfund Site," *Bioremediation Journal*, 1998. Project no. 93-21.

Nieman, J.K.C., R.C. Sims, J.L. Sims, D.L. Sorensen, and J.E. Mclean, "Fate of Pyrene in Contaminated Soil Amended with Alternate Electron Acceptors," *Journal Chemosphere*, 1998. Project no. 93-21.

Okeson, S., D. Szlag, and T.H. Illangasekare, "Dissoloution of Multicomponent Non-Aqueous Phase Liquids in a Two-Dimensional Flow Field: Experimental Investigaton," *Journal of Contaminant Hydrology*, 1998. Project no. 94-29.

Okeson, S., D. Szlag, and T.H. Illangasekare, "Dissoloution of Multicomponent Non-Aqueous Phase Liquids in a Two-Dimensional Flow Field: Modeling Investigation," *Journal of Contaminant Hydrology*, 1998. Project no. 94-29.

Okey, R.W., S.-W. Lin, and A. Hong, "Predicting Stability Constants of Various Chelating Agents Using QSAR Technology," *ACS Symposium Series*, 1996. Project no. 93-22.

Orchard, B.J., J.K. Chard, C.J. Pajak, B. Bugbee, and W.J. Doucette, "Phytoremediation of Trichloroethylene Using Hybrid Poplar: Non-Stressed vs. Stressed Uptake," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 95-10.

Orchard, B.J., J.K. Chard, C.J. Pajak, B. Bugbee, and W.J. Doucette, "Fate of TCE in Hybrid Poplar: Studies on Update, Translocation and Transpiration," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 95-10.

Pajak, C.J., and W.J. Doucette, "Analysis of TCE and Chlorinated Metabolites in Plant Tissue," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 95-10.

Parkin, G.F., "Anaerobic Biotransformation of Chlorinated Aliphatic Hydrocarbons: Ulgy Duckling to Beautiful Swan?" *Water Environment Research*, 1998. Project no. 93-24.

Ruan, H., and T.H. Illangasekare, "A New Model for Relative Permeability in Sandy Soils," *Journal of Hydrology*, 1998. Project no. 94-29.

Ruan, H., and T.H. Illangasekare, "A Model to Couple Overland Flow and Infiltration into Macroporous Vadose Zone," *Journal of Hydrology*, 1998. Project no. 94-29.

Ruan, H., and T.H. Illangasekare, "A Model for Relative Hydraulic Conductivity for Unsaturated Sandy Soils," *Proceedings of the International Workshop on Unsaturated Porous Media*, Rivers Side, California, 1997. Project no. 94-29.

Saba, T., and T.H. Illangasekare, "Effect of Groundwater Flow Dimensionality on Mass Transfer from Entrapped Non-Aqueous Phase Liquids," *Water Resources Research*, 1998. Project no. 94-29.

Schmidt, A.M., S.R. Burckhard, and V.R. Shaefer "Parameters Used in the Modeling of Vegetative Remediative System," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-12.

Shrake, C.E., S.R. Burckhard, and V.R. Shaefer, "Predicting Landfill Leachate Reduction Using Vegetation," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-12.

Stevens, D.K., C.L. Hansen, and G.S. Choudhury, "Growth Kinetics of Mercury-Resistant Bacteria in the Biological Mercury Removal Process," *Biotechnology and Bioengineering*, 1996.

Walser, G.S., T.H. Illangasekare, and A.T. Corey, "Retention of Liquid Contaminants in Layered Soils," *Water Resources Research*, 1998. Project no. 94-29.

Wildman, M.J., and P.J.J. Alvarez, "Feasability of Bioaugmentation of Fe^{O} with Anaerobic Sludge to Remove RDX from Soil and Groundwater," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 93-02.

Wu, X., N. Chou, D. Lupher, and L.C. Davis, "Benzotriazoles: Toxicity and Biodegradation," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-27.

Zawaideh, L.L., and T.C. Zhang, "Effects of pH and Addition of an Organic Buffer (HEPES) on Nitrate Transformation in Fe^{0}-Water System," *Water Science and Technology*, 1998. Project no. 95-32.

Zhang, Q., L.C. Davis, and L.E. Erickson, "Effect of Vegetation on Transport of Groundwater and Nonaqueous Phase Liquid Contaminants," *Journal of Hazardous Substance Research*, 1998. Project no. 94-27.

Zhang, Q., L.C. Davis, and L.E. Erickson, "An Experimental Study of Trichloroethylene Fluxes into the Atmosphere," *Proceedings of the 27th Annual Biochemical Engineering Symposium*, Colorado State University, Fort Collins, Colorado, 1998. Project no. 94-27.

Zhang, Q., L.C. Davis, and L.E. Erickson, "Using Vegetation to Treat Methyl-Tert-Butyl Ether Contaminated Groundwater," *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, 1998. Project no. 94-27.

Zhu, D., A.P. Schwab, and M.K. Banks, "Heavy Metal Leaching from Mine Tailings as Affected by Plants," *Journal of Environmental Quality*, 1998. Project no. 93-06.

Zhu, D., and A.P Schwab, "Redistribution of Heavy Metals in Soil after Extensive Leaching," *Chemosphere*, 1998. Project no. 93-06.

Zwonitzer, J., G. Pierzynski, and G. Hettiarachchi, "Phosphorus Source and Rate Effects on Cadmium, Lead, and Zinc Bioavailability in a Metal-Contaminated Soil," *Journal of Environmental Quality*, 1997. Project no. 93-07.

C. BOOKS AND BOUND PROCEEDINGS

Characklis, W.G., and K.C. Marshall (Eds.) *Biofilms*, Wiley, New York, 1990.

Erickson, L.E. (Ed.), *Proceedings of the Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, May 23-24, 1989.

Erickson, L.E. (Ed.), *Proceedings of the Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, May 21-22, 1990.

Erickson, L.E. (Ed.), *Proceedings of the Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, May 29-30, 1991.

Erickson, L.E., S.C. Grant, and J.P. McDonald (Eds.), *Proceedings of the Conference on Hazardous Waste Research*, University of Colorado, Boulder, Colorado, June 1-2, 1992.

Erickson, L.E., D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, May 25-26, 1993.

Erickson, L.E., D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), *Proceedings of the 9th Annual Conference on Hazardous Waste Remediation*, Montana State University, Bozeman, Montana, June 8-10, 1994.

Erickson, L.E., D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, May 23-24, 1995.

Erickson, L.E., D.L. Tillison, S.C. Grant, and J.P. McDonald, Editors, *Proceedings of the 1996 HSRC/WERC Joint Conference on the Environment*, Albuquerque, New Mexico, May 21-23, 1996. URL: http://www.engg.ksu.edu/HSRC/.

Erickson, L.E., M.M. Rankin, S.C. Grant, and J.P. McDonald, Editors, *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, Kansas City, Missouri, May 19-22, 1997. URL: http://www.engg.ksu.edu/HSRC/.

Erickson, L.E., M.M. Rankin, L.N. Reddi, and C.A. Wolfe, Editors, *Proceedings of the 13th Annual Conference on Hazardous Waste Research*, Snowbird, Utah, May 18-21, 1998.

Jennings, S.R., and D.J. Dollhopf, "Geochemical Characterization of Sulfide Mineral Weathering for Remediation of Acid-Producing Mine Wastes," Reclamation Research Publication #9502, Montana State University, Bozeman, Montana, 1996. Project no. 93-12.

Kruger, E.L., T.A. Anderson, and J.R. Coats, *Phytoremediation of Soil and Water Contaminants*, American Chemical Society Symposium Series, ACS Books, Washington, DC, 1997. Project no. 93-05.

Lehr, J.H. (Ed.), *Groundwater Management: Proceedings of the 1990 Cluster of Conferences*, Water Well Publishing Company, Dublin, Ohio, February 20-21, 1990.

Munshower, F.F., and S.E. Fisher (Eds.), "Planning, Rehabilitation, and Treatment of Disturbed Lands," *Proceedings Seventh Billings Symposium*, Reclamation Research Publication #9603, Montana State University, Bozeman, Montana, March 17-23, 1996.

Schnoor, J.L. (Ed.), *Fate of Pesticides and Chemicals in the Environment*, John Wiley & Sons, New York, 1992.

D. CHAPTERS IN OTHER BOOKS OR BOUND PROCEEDINGS

Adamson, D.T., and G.F. Parkin, "Biotransformation of Mixtures of Carbon Tetrachloride, Perchlorethylene, and 1,1,1 Trichloroethane," *In Situ and On-Site Bioremediation*, B.C. Alleman and A. Leeson (Eds.), Battelle Press, Columbus, Ohio, Vol. 3, pages 15-20, 1997. Project no. 93-24.

Al-Sheriadeh, M., and T.H. Illangasekare, "Modeling of Transport of Nonaqueous-Phase Contaminants in Heterogeneous Aquifers," *Proceedings of 1993 Groundwater Modeling Conference*, International Groundwater Modeling Center, Colorado School of Mines, Golden, Colorado, pages 3.1-3.19, 1993.

Anderson, T.A., and J.R. Coats, "An Overview of Microbial Degradation in the Rhizosphere and Its Implications for Bioremediation," *Bioremediation, Science and Applications*, SSSA, ASA, and CSS, Madison, Wisconsin, pages 135-143, 1995. Project no. 93-05.

Anderson, T.A., E.L. Kruger, and J.R. Coats, "Rhizosphere Microbial Communities of Herbicide-Tolerant Plants as Potential Bioremedients of Soils Contaminated with Agrochemicals," *Bioremediation of Pollutants in Soil and Water*, B.S. Schepart (Ed.), ASTM, Philadelphia, Pennsylvania, pages 149-157, 1995. Project no. 93-05.

Anhalt, J.C., E.L. Arthur, A. Chouhy, T.A. Anderson, and J.R. Coats, "Pesticide-Contaminated Soil Studies: Effects of Aging Herbicide Mixtures on Herbicide Degradation, Soil Respiration, and Plant Survival and Phytoremediation Study with Native Prairie Grasses," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, pp. 542-555, May 19-22, 1997. Project no. 93-05.

Arthur, E.L., and J.R. Coats, "Phytoremediation," *Pesticide Remediation in Soils and Water*, P.C. Kearney and T.R. Roberts (Eds.), John Wiley and Sons, Ltd., UK, pages 251-283, 1998. Project no. 93-05.

Atteya, M., and K.J. Klabunde, "Nanoscale Metal Oxide Particles as Chemical Reagents. Heats of Adsorption of Heteroatom Organics on Heat-Treated Magnesium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 230-256, 1990.

Baldwin, C.A., J.P. McDonald, and L.E. Erickson, "Effect of Hydrocarbon Phase on Kinetic and Transport Limitations for Bioremediation of Microprobes Soil," *Proceedings of the 22nd Annual Biochemical Engineering Symposium*, P.J. Reilly (Ed.), Iowa State University, Ames, Iowa, pages 1-10, 1992.

Baldwin, C.K., B.L. Hall, and R.R. Dupont, "*In Situ* Instrumentation for Evaluating Air Injection Remediation Technologies," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 408-423, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Banks, M.K., B.A.D. Hetrick, A.P. Schwab, K.G. Shetty, I. Abdelsaheb, and G. Fleming, "Characterization of a Heavy Metal-Contaminated Site," *Proceedings of the Environmental Engineering Division*, ASCE Water Forum, Baltimore, Maryland, pages 463-467, 1992.

Barth, G., T.H. Illangasekare, H. Rajaram, and H. Ruan, "Model Calibration and Verification for Entrapped NAPL Using Tracer Tests in a Large, Two-Dimensional Tank with Heterogeneous Packing," *Proceedings of Model CARE 96 (Calibration and Reliability in Groundwater Modeling)*, IAHS Publications, Vol. 237, pages 169-178, 1996.

Barth, G., T.H. Illangasekare, and H. Rajaram, "Use of Tracers for the Characterization of Scale-Dependent Subsurface Properties: Initial Evaluation," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 433-442, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Berry, N., and J. Schlup, "Initial FTIR Studies of the Adsorption of Polycyclic Aromatic Hydrocarbons onto Soil Constituents," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 347-356, 1989.

Bondugula, R., and T.E. Clevenger, "Heavy Metal Contamination in Southwest Missouri," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 46-54, 1991.

Boronina, T., and K.J. Klabunde, "Destruction of Organohalides in Water Using Metal Particles: Carbon Tetrachloride/Water Reactions with Magnesium, Tin, and Zinc," *Proceedings of the 9th Annual Conference on Hazardous Waste Remediation*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Bozeman, Montana, pages 81-98, 1994. Project no. 89-26, 92-03.

Burken, J.G., and J.L. Schnoor, "Atrazine Phytoremediation and Metabolism by Poplar Trees," *Proceedings of the 69th Annual Water Environment Federation Conference*, Dallas, Texas, 1996. Project no. 94-25.

Burken, J.G., and J.L. Schnoor, "Hybrid Poplar Tree Phytoremediation of Volatile Organic Compounds," *Proceedings of the ACS National Meeting*, Orlando, Florida, 1996. Project no. 94-25.

Burken, J.G., and J.L. Schnoor, "Uptake and Fate of Organic Contaminants by Hybrid Poplar Trees," *Proceedings of the 213th American Chemical Society Convention*, San Francisco, California, 1997. Project no. 94-25.

Burken, J.G., A.C. Dietz, J.L. Jordahl, B.E. Schnabel, P.L. Thompson, L.A. Licht, P.J.J. Alvarez, and J.L. Schnoor, "Phytoremediation of Hazardous Waste," *Proceedings of the 69th Annual Water Environment Federation Conference*, Dallas, Texas, 1996. Project no. 94-25.

Butts, M.B., K.H. Jensen, D. Szlag, and T.H. Illangasekare, "Fate of the Miscible and Immiscible Components Following a Light Oil Spill: An Experimental Study," *Proceedings of 1993 Groundwater Modeling Conference*, International Groundwater Modeling Center, Colorado School of Mines, Golden, Colorado, page 3.13.9, 1993.

Cady, J.D., S. Kapila, S.E. Manahan, and D.S. Viswanath, "Evaluation of Counterflow Oxidation for Regeneration of Granular Carbon Adsorbents," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 739-750, 1990.

Campbell, J.A., and T.H. Illangasekare, "Experimental Study and Modeling of Preferential Flow of Immiscible Fluids in Groundwater Aquifers," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 66-85, 1992.

Chang, C.M., H. Gu, T.J. O'Keefe, and S.E. James, "Galvanic Stripping of Iron from Solvent Extraction Solutions from Zinc Residue Leaching," *Second International Symposium on Iron Control in Hydrometallurgy*, J.E. Dutrizac and G.B. Harris (Eds.), Canadian Institute of Mining, Metallurgy,and Petroleum, Iron Control and Disposal, pages 417-430, 1996. Project no. 94-05.

Chang, C.M., and T.J. O'Keefe, "The Electrochemical Behavior of Zn-Pb (1.7%) in Galvanic Stripping," *EPD Congress 1998 Adsorption, Ion Exchange and Solvent Extraction TMS*, pages 393-405, 1998. Project no. 94-05.

Chang, C.M., H. Gu, and T.J. O'Keefe, "Review of Galvanic Stripping Process for Use in Treating Oxidized Metal Wastes," *Proceedings HSRC/WERC Joint Conference on the Environment*, pages 164-175, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Chen, B., and A.B. Cunningham, "Modeling of Subsurface Biobarrier Formation and Persistence," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, pages 159-166, 1997. Project no. 94-28.

Chen, B., A.B. Cunningham, and E. Visser, "Numerical Simulation of Biofilm Growth on Porous Media and the Microscale," *Proceedings of the 11th Internation Conference on the Computational Methods in Water Resources*, Cancun, Mexico, 1996. Project no. 94-28.

Chen, D., Z. Lewandowski, F. Roe, and P. Surapaneni, "Diffusivity of Metal Ions in Biopolymer Gels," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 1-19, 1992.

Chew, C.F., and T.C. Zhang, "*In situ* Remediation of Nitrate-Contaminated Groundwater by Electrokinetics/Iron Wall Processes," *Water Quality International: Proceedings of the IAWQ 19th Biennial International Conference*, Vancouver, Canada, Book 7, pages 133-140, 1998. Project no. 95-32.

Chew, C.F., and T.C. Zhang, "Nitrate Removal Using Electrokinetic/Iron Wall Processes," *Proceedings of the 1998 National Conference on Environmental Engineering*, Chicago, Illinois, pages 639-644, 1998. Project no. 95-32.

Chew, C.F., and T.C. Zhang, "Nitrate Removal Using Electrokinetic/Iron Wall Processes," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kansas City, Missouri, pages 99-111, May 19-22, 1997. Project no. 95-32.

Cho, I.H., V.M. Boddu, D.S. Viswanath, S. Kapila, and R.K. Puri, "Adsorption of Benzene, Phenol and a Mixture on XAD-4 and Coal Char," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 298-309, 1990.

Chou, S.T., and L.T. Fan, "Stabilization/Solidification of Low-Level Radioactive Liquid from a BWR Nuclear Power Plant with Pozzolan-Based Fixation Process," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 452-466, 1989.

Chou, S.T., and L.T. Fan, "Solidification of K061 Waste," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 385-394, 1990.

Chou, S.T., and L.T. Fan, "Influence of the Type and Amount of Binding Agent on the Characteristics of Solidified Arsenic Waste," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 866-876, 1990.

Chou, S.T., and L.T. Fan, "Stabilization/Solidification of Arsenic-Contaminated Soil: Effect of Type and Composition of Soil," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 423-431, 1991.

Chou, S.T., and L.T. Fan, "Characteristics of Solidified Samples of Arsenic-Containing Soil: Influence of Acidity," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 493-501, 1992.

Clevenger, T.E., E. Hinderberger, D.W. Roberts, A. Bush, and P. Phillips, "Lead, Cadmium and Zinc Contamination in Southwest Missouri," *Proceedings of the 25th Annual Conference on Trace Substances in Environmental Health*, Delbert Hemphill (Ed.), pages 85-93, 1991.

Coffin, D., and L.A. Glasgow, "Some Engineering Considerations in the Application of Soil Venting," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 257-297, 1990.

Coffin, D., and L.A. Glasgow, "Effective Gas Flow Arrangements in Soil Venting," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 388-416, 1991.

Cunningham, A.B., "Hydrodynamics and Solute Transport at the Fluid-Biofilm Interface," *Structure and Function of Biofilms*, W.G. Characklis and P.A. Wilderer (Eds.), John Wiley and Sons, Dahlem Workshop Report Series, Life Science Research Report No. 46, pages 19-31, 1989.

Cunningham, A.B., F. Abedeen, W.G. Characklis, and E.M. Bouwer, "Influence of Microbial Transport on the *In Situ* Bioremediation of Organic Groundwater Contaminants," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 1-12, 1989.

Cunningham, A.B., E.J. Bouwer, and W.G. Characklis, "Biofilms in Porous Media," *Biofilms*, W.G. Characklis and K.C. Marshall (Eds.), John Wiley, New York, pages 692-732, 1990.

Cunningham, A.B., and O. Wanner, "Modeling Biofilm Accumulation and Activity in Porous Media," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 71-81, 1991.

Cunningham, A.B., "Effects of Biocolloids on Hydrodynamic Properties of Porous Media," *Proceedings of the Mantaeo III Conference: Concepts in Manipulation of Groundwater Colloids for Environmental Restoration*, John F. McCarthy (Ed.), Lewis Publishers, pages 103-109, 1993.

Cunningham, A.B., and O. Wanner, "Modeling Microbial Processes in Porous Media with Application to Biotransformation," *Hydrological, Chemical, and Biological Processes of Transformation and Transport of Contaminants in Aquatic Environments: Proceedings of the Rostov-on-Don Symposium*, IAHS Publication No. 217, 1993.

Cunningham, A.B., and O. Wanner, "Modeling Microbial Processes in Porous Media with Application to Biotransformation," *Proceedings Hydrochemistry 1993: International Symposium on Hydrological, Chemical, and Biological Processes of Transformation and Transport of Contaminants in Aquatic Environments*, Rostov-on-Don, Russia, IASH Publication No. 21. 1993.

Cunningham, A.B., B.K. Warwood, P.J. Sturman, K. Horrigan, G. James, and J.W. Costerton, "Biofilm Processes in Porous Media—Practical Applications," *Microbiology of the Terrestrial Subsurface*, Amy and Halderman (Eds.), CRC Press, Inc., Chapter 17, 1997. Project no. 94-28.

Cunningham, A.B., and B. Chen, "Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*," L.E. Erickson, M.M. Rankin, S.C. Grant and J.P. McDonald (Eds.), Kansas State University, Kansas City, Kansas, 1997. Project no. 94-28.

Cunningham, A.B., B.K. Warwood and G. James, "Containnment of Heavvy Metal and Chlorinated Organic Solvent Contamination Using Subsurface Barriers," *Proceedings of the Joint Conference on the Environment*, L.E. Erickson (Ed.), Albuquerque, New Mexico, 1996. Project no. 94-28.

Cunningham, A.B. and P.J. Sturman, "*In Situ* Bioremediation Process Engineering Concepts," *Bioremediation: Principles and Practice*, Technomics Publishers, Vol. 1, 1998. Project no. 94-28.

Dave, S., T.E. Clevenger, and E. Hinderberger, "Effect of Cover Material on Leachability of Lead Mine Tailings," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 395-416, 1990.

Davis, L.C., C. Chaffin, M. Narayanan, V.P. Visser, W.G. Fateley, L.E. Erickson, and R.M. Hammaker, "Monitoring the Beneficial Effects of Plants in Bioremediation of Volatile Organic Compounds," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 236-249, 1993.

Davis, L.C., M. Narayanan, V.P. Visser, C. Chaffin, W.G. Fateley, L.E. Erickson, and R.M. Hammaker, "Alfalfa Plants and Associated Microorganisms Promote Biodegradation Rather than Volatilization of Organic Substances from Groundwater," *Microbial Degradation of Organic Bioremediation through Rhizosphere Technology*, T.A. Anderson and J.R. Coats (Eds.), ACS Symposium Series, No. 563, pages 112-122, 1994.

Davis, L.C., M.K. Banks, A.P. Schwab, M. Narayanan, L.E. Erickson, and J.C. Tracy, "Plant-Based Bioremediation," *Bioremediation: Principles and Practice*, R.L. Irvine and S.K. Sikdar (Eds.), Technomic, Lancaster, PA, 1995. Project no. 94-12.

Davis, L.C., and N.C. Chou, "Metabolism of TNT Associated with Roots of Higher Plants," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 569-576, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/. Project no. 94-27.

Dietz, A.C., and J.L. Schnoor, "Phytotoxicity Screening of Chlorinated Aliphatics," *Proceedings of the Battelle Conference on Remediation of Chlorinated and Recalcitrant Compounds*, Monterey, California, 1998. Project no. 95-29.

Dhawan, S., L.E. Erickson, L.T. Fan, P. Tuitemwong, and R. Mahadevaiah, "Microcosm Techniques for Investigating the Biodegradation Potential of Light Nonaqueous-Phase Liquids and Dense Nonaqueous-Phase Liquids," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 578-599, 1989.

Dhawan, S., L.E. Erickson, and L.T. Fan, "Modeling the Bioremediation of Contaminated Soil Aggregates: A Phenomenological Approach," *Proceedings of the Twentieth Annual Biochemical Engineering Symposium*, Kansas State University, Manhattan, Kansas, pages 77-86, 1990.

Dhawan, S., L.E. Erickson, and L.T. Fan, "Modeling and Simulating Bioremediation in Soil Beds with Aggregates," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 432-446, 1991.

Erickson, L.E., "Waste Minimization and Process Safety in Process Development, Design, Construction, and Start-Up," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 525-527, 1989.

Erickson, L.E., L.T. Fan, S. Dhawan, and P. Tuitemwong, "Modeling, Analysis, and Simulation of Bioremediation of Soil and Water," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 17-46, 1990.

Erickson, L.E., and P. Tuitemwong, "Growth Yields, Productivities, and Maintenance Energy of Methylotrophs," *Biology of Methylotrophs*, I. Goldberg and J.S. Rokem (Eds.), Butterworths, Stoneham, Massachusetts, pages 149-172, 1991.

Erickson, L.E., L.C. Davis, S.K. Santharam, S.C. Kim, M. Narayanan, and C.W. Rice, "Biodegradation in the Rhizosphere: Analysis of the Beneficial Effects of Vegetation," *87th Annual Meeting, AWMA*, Cincinnati, Ohio, Paper No. 94-WA86.04, 1994.

Erickson, L.E., and L.C. Davis. "Beneficial Effects of Vegetation in Bioremediation of Contaminated Soil," *Proceedings of the International Symposium on Environmental Biotechnology*, pp. 7-12, Korean Society of Applied Microbiology, Pusan National University, Pusan, South Korea, 1996. Project no. 94-27.

Fan, L.T., and Y.L. Huang, "HIDEN: A Hybrid Intelligent Computer-Aided System Towards Process Design Automation," *Proceedings of the 2nd International Conference on Automation, Robotics and Computer Vision*, Singapore, Vol. 2, pages IA-8.2.1, 1992.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Graph-Theoretic Approach to Process Synthesis: Application to Waste Minimization," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 877-892, 1990.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "An Accelerated Branch-and-Bound Method for Process Synthesis," *Proceedings at the 4th World Congress of Chemical Engineering*, Karlsruhe, Germany, Vol. 4, pages 12.2-5, 1991.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Process Synthesis by Exploiting the Combinatorial Properties of Feasible Process Structures," *Proceedings at the 4th World Congress of Chemical Engineering*, Karlsruhe, Germany, Vol. 4, pages 12.2-3, 1991.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Waste Minimizing Synthesis of a Process for Production of Perchloromethyl Mercaptan: Systematic Approach," *Proceedings of the Conference*

on Hazardous Waste Research, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 248-261, 1991.

Friedler, F., and L.T. Fan, "Process Synthesis Incorporating In-Plant Waste Treatment: Algorithmic Approach," *Book of Abstracts for the Special Symposium on Emerging Technologies for Hazardous Waste Management*, Atlanta, Georgia, Vol. I, pages 325-328, 1992.

Friedler, F., Z. Kovács, and L.T. Fan, "Unique Separation Networks for Improved Waste Elimination," *Book of Abstracts for the Special Symposium on Emerging Technologies for Hazardous Waste Management*, Atlanta, Georgia, Vol. II, pages 457-460, 1992.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Accelerated Branch-and-Bound Method for Process Network Synthesis," *Preprints of the Department of Mathematics*, University of Veszprém, Hungary, Vol. 3/5, pages 1-7, 1992.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "Computer-Aided Waste Minimizing Design of a Chemical Process," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 107-116, 1992.

Friedler, F., K. Tarján, Y.W. Huang, and L.T. Fan, "A Systematic Approach to Waste Minimizing Synthesis of a Chemical Process: Production of Perchloromethyl Mercaptan," *Proceedings of the Conference on Process Technology for Waste Reduction*, AIChE National Meeting, Pittsburgh, Philadelphia, pages 93-98, 1992.

Galitzer, S.J., "Utilization of Waste Exchanges in a Waste Minimization Program," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 528-536, 1989.

Gandhi, P., X. Yang, L.E. Erickson, and L.T. Fan, "In-Well Aeration: An Innovative Subsurface Remediation Technology," *Proceedings of the 24th Annual Biochemical Engineering Symposium*, R.H. Davis (Ed.), University of Colorado, Boulder, pages 1-10, 1994.

Ghosh, S., S. Bupp, and L.M. DeBirk, "Removal of Heavy Metals by Biopolymers," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 449-476, 1990.

Ghosh, S., and S. Bupp, "Uptake of Heavy Metals by Unacclimated Aerobic Cultures," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 30-45, 1991.

Ghosh, S., D. Chang, K. Fukushi, and A. Chan, "Biostimulation of Cadmium and Copper Removal in the Presence of Special Nutrients," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 20-38, 1992.

Ghosh, S., and M.L. Sun, "Anaerobic Biodegradation of Benzene under Acidogenic Fermentation Condition," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 208-218, 1992.

Ghosh, S., K. Fukushi, D. Chang, and S. Bupp, "Enhanced Heavy Metal Uptake by Activated Sludge Cultures Grown in the Presence of Metallothionein Stimulators," *Proceedings of the Symposium I&EC*, Atlanta, Georgia, 1993.

Ghoshal, S., S.K. Banerji, and R.K. Bajpai, "Photodegradation of PCP," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 806-816, 1990.

Ghoshal, S., S.K. Banerji, and R.K. Bajpai, "Photodegradation of Pentachlorophenol," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 197-215, 1991.

Ghoshal, S., S.K. Banerji, and R.K. Bajpai, "A Strategy for Decontamination of Soils Containing Elevated Levels of PCP," *Proceedings of the 21st Annual Biochemical Engineering Symposium*, Colorado State University, Fort Collins, Colorado, pages 104-120, 1991.

Gilliland, M.W., W.E. Kelly, and D. Lokke, "Hazardous Waste Management in Rural Communities in EPA Regions VII and VIII," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 478-481, 1989.

Glasgow, L.A., "Some Engineering Considerations in the Venting of Vadose Zone Soils," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 600-620, 1989.

Govindaraju, R.S., and L.E. Erickson, "Modeling of Overland Flow Contamination Due to Heavy Metals in Shallow Soil Horizons," *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 289-302, 1995. URL: http://www.engg.ksu.edu/HSRC/95Proceed/home.html.

Grant, S.C., "Citizens, Risk, and Hazardous Substances," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 190-199, 1993.

Green, R., L. Roig, R.S. Govindaraju, and L.E. Erickson, "Effects of Vegetation on Contaminant Transport in Surface Flows," *Proceedings of the HSRC-WERC Joint Conference on the Environment, Albuquerque*, New Mexico, pages 126-141, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Green, R.M., L.E. Erickson, R. Govindaraju, and P. Kalita, "Modeling the Effects of Vegetation on Heavy Metals Containment," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, pages 476-496, 1997. Project no. 93-07.

Griswold, W.M., G.L. Godfrey, S.C. Grant, and D.L. Tillison, "The NAOMI Program and HERS: Working to Create Lasting Links," *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 336-340, 1996. URL: http://www.engg.ksu.edu/HSRC/95Proceed/home.html.

Griswold, W.M., G.L. Godfrey, S.C. Grant, and P.T. Yazzie, "HERS: A Center for Research, Education, and Communication," *Proceedings of the HSRC/WERC Joint Conference on the Environment*, pages 683-687, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Griswold, W.M., G.L. Godfrey, S.C. Grant, and J. Yazzie, "HERS: An Expanding Program in a Shrinking World," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds), Kansas State University, pages 536-541, 1997.

Hall, B.L., C.K. Baldwin, R.R. Dupont, "*In Situ* Field Performance Monitoring of Air Injection Groundwater Remediation Technologies." *In* B.C. Alleman and A. Leeson (Eds.), *In Situ and On-Site Bioremediation: Volume 2*. Battelle Press, Columbus, Ohio, page 647, 1997. Project no. 93-20.

Hamdi, S., J.M. Steichen, A.P. Schwab, and P.L. Barnes, "Freundlich Adsorption and Its Impact on Solution of the Non-Linear Chemical Transport Model," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 286-306, 1992.

Hangos, K.M., Friedler, F., J.B. Varga, and L.T. Fan, "Integration of Waste Minimization into Total Flowsheet Synthesis," *Proceedings of the 5th European Symposium on Computer Aided Process Engineering*, Bled, Slovenia, 1995. Project no. 91-36.

Hansen, C.L., D.K. Stevens, S. Zhang, and D.N. Warner, "Biologically Enhanced Removal of Mercury from Contaminated Soil," *Proceedings of the Air & Waste Management Association 1992 Annual Meeting and Exhibition*, Paper # 92-25.03, 1992.

Hanson, R.S., and B.S. Mattox, "Educational Aspects of Hazardous Waste Management Training," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 187-201, 1992.

Hartford, S.A., and T.H. Illangasekare, "Use of a Solute Transport Model as a Computer-Aided Management and Design Tool," *Proceedings of the Colorado Water Management Conference*, Denver, Colorado, 1992.

Helland, B.R., J.L. Schnoor, and P.J.J. Alvarez, "Oxygen-Controlled Product Formation of CCl_4 Dechlorination Using Zero-Valent Iron," *Preprints of Papers, 209th ACS National Meeting*, American Chemical Society, Anaheim, California, page 732-733, 1995.

Hettiarachchi, G., Pierzynski, J. Zwonitzer, and M. Lambert, "Phosphorus Source and Rate Effects on Cadmium, Lead, and Zinc Bioavailability," *Extended Abstracts of the Fourth International Conference on the Biogeochemistry of Trace Elements*, Berkeley, California, pages 463-464, 1997. Project no. 93-07.

Hillier, A.C., and C.W. Walton, "A Demonstration of the Application of an Equation-Solving Program for Modeling Rinse and Recovery Systems," *Proceedings of the 12th Annual AESF/EPA Environmental Control Conference for the Metal Finishing Industry*, T.V. Tran (Ed.), American Electroplaters and Surface Finishers Society, Orlando, Florida, pages 192-219, 1991.

Hoffman, R.M., V.P. Visser, L.C. Davis, L.E. Erickson, M. Narayanan, R.M. Hammaker, and W.G. Fateley, "Monitoring Plant Bioremediation of Volatile Organic Compounds (VOCs) Using Open Path Fourier Transform Infrared (FT-IR) Spectrometry," *Proceedings of the 9th Annual Conference on Hazardous Waste Remediation*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Bozeman, Montana, pages 108-116, 1994.

Holmes, J.L., R.L. Peyton, and T.H. Illangasekare, "Spatial Distribution of Nonaqueous-Phase Liquids in Sand Cores Using X-Ray Computed Tomography," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 35-43, 1993.

Hooker, P.D., and K.J. Klabunde, "The Destructive Adsorption of Carbon Tetrachloride on Iron (III) Oxide," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 151-164, 1993. Project no. 89-26, 92-03.

Hooker, P.D., and K.J. Klabunde, "The Destructive Adsorption of Carbon Tetrachloride on Iron (III) Oxide," *Environmental Science and Technology*, Vol. 28, pages 1243-1247, 1994. Project no. 89-26, 92-03.

Hsieh, M., R.K. Bajpai, and S.K. Banerji, "Degradation of PCP by Ligninase Produced by *Phanerochaete chrysosporium*," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, 797-805, 1990.

Hsieh, M., R.K. Bajpai, and S.K. Banerji, "Biodegradation of Pentachlorophenol by *Phanerochaete chrysosporium* in Soil," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 521-536, 1991.

Hsieh, C.M., R.K. Bajpai, and S.K. Banerji, "Influence of Carbon Source on Pentachlorophenol Degradation by *P. chrysosporium* in Soil," *Proceedings of the 21st Annual Biochemical Engineering Symposium*, Colorado State University, Fort Collins, Colorado, pages 195-205, 1991.

Hu, J., M. Narayanan, L.C. Davis, and L.E. Erickson, "Modeling Root Uptake and Transport of Trichloroethylene," *Proceedings of the 27th Annual Biochemical Engineering Symposium*, Colorado State University, Fort Collins, Colorado, pages 13-121, 1998. Project no. 94-27.

Huang, Y.W., L.T. Fan, and W.W. Olson, "Potential Application of Neural Networks to Hazardous Waste Processing," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 147-167, 1989.

Huang, Y.L., Y.W. Huang, and L.T. Fan, "An Artificial Intelligence Approach to the Synthesis of a Mass Exchanger Network for Hazardous Waste Minimization and Treatment," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 483-499, 1989.

Huang, Y.L., Y.W. Huang, and L.T. Fan, "A Knowledge-Based System for Synthesizing Highly Controllable Heat Exchanger Networks," *Proceedings of the 3rd Oklahoma Symposium on Artificial Intelligence*, Tulsa, Oklahoma, pages 270-271, 1989.

Huang, Y.L., G. Sunder, and L.T. Fan, "An Expert System for Cyanide Waste Minimization in Electroplating Plants," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 500-522, 1990.

Huang, Y.L., and L.T. Fan, "A Framework of Plant-Wide Hierarchical Control for Waste Minimization and Management," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 237-247, 1991.

Huang, Y.L., and L.T. Fan, "A Novel Approach for Synthesizing a Robust Controller with Decoupling Capability for a Complicated Multivariable Process System," *Proceedings of the 4th World Congress of Chemical Engineering*, Karlsruhe, Germany, Vol. 4, pages 12.2-21, 1991.

Huang, Y.L., Y.W. Huang, and L.T. Fan, "A Neural Network for Guiding Stream Matching in Heat Exchanger Network Synthesis," *Proceedings of the 4th World Congress of Chemical Engineering*, Karlsruhe, Germany, Vol. 4, pages 12.2-13, 1991.

Huang, W., E. Lee, J.F. Shimp, L.C. Davis, L.E. Erickson, and J.C. Tracy, "Effect of Plants and Trees on the Fate, Transport, and Biodegradation of Contaminants in the Soil and Groundwater," *Proceedings of the Twenty-First Annual Biochemical Engineering Symposium*, Colorado State University, Ft. Collins, Colorado, pages 167-176, 1991.

Huang, Y.L., and L.T. Fan, "Expert Systems Techniques in Waste Minimization," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 86-92, 1992.

Huang, Y.L., and L.T. Fan, "Intelligent Design and Control for In-Plant Waste Minimization," *Waste Minimization through Process Design*, A.P. Rossiter (Ed.), Mc-Graw Hill, New York, New York, 1994. Project no. 91-36.

Hughes, J.B., and G.F. Parkin, "The Effect of Influent Acetate Concentration on the Transformation of Chlorinated Aliphatic Compounds in Fixed-Film Anaerobic Filters," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 1-16, 1990.

Hughes, J.B., and G.F. Parkin, "The Effect of Electron Donor Concentration on the Transformation of Chlorinated Aliphatics," *In Situ and On-Site Bioreclamation*, Butterworths, Inc., pages 55-79, 1991.

Hughes, J.B., and G.F. Parkin, "The Effect of Mixtures of Xenobiotics and Primary Electron Donor on the Anaerobic Biotransformation of High Concentrations of Chlorinated Aliphatics," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 82-91, 1991.

Hurst, C.J., R.C. Sims, J.L. Sims, D.L. Sorensen, J.E. McLean, and S. Huling, "Polycyclic Aromatic Hydrocarbon Biodegradation as a Function of Oxygen Tension in Contaminated Soil," *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 20-32, 1995. URL: http://www.engg.ksu.edu/HSRC/95Proceed/home.html.

Illangasekare, T.H., "Flow and Entrapment of Non-Aqueous Phase Liquids in Hetergeneous Formations," *Physical Nonequillibrium in Soils: Modeling and Application*, H.M. Selima and L. Ma (Eds.), Ann Arbor Press, pages 417-435, 1998. Project no. 94-29.

Illangasekare, T.H., E.J. Armbruster, D.N. Yates, D. Szlag, and D. Reible, "Effect of Heterogeneity on Transport and Entrapment of Nonaqueous-Phase Waste Products in Aquifers," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 523-540, 1990.

Illangasekare, T.H., H. Rajaram, H.-S. Chao, and R. Compos, "An Experimental Database for the Evaluation of Theories for Upscaling in Modeling of Groundwater Flow, Solute Transport, and Multiphase Flow in Aquifers," *Proceedings of Selected Research in Environmental Quality*, Joint USAF/Army Contractor/Grantee Meeting, Panama City, Florida, 1997. Project no. 94-29.

Illangasekare, T.H., D. Szlag, J. Campbell, J. Ramsey, M. Al-Sheriadeh, and D. Reible, "Effects of Heterogeneities and Preferential Flow on Distribution and Recovery of Oily Wastes in Aquifers," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 216-236, 1991.

Illangasekare, T., D. Znidarcic, and M. Al-Sheriadeh, "Multiphase Flow in Porous Media," *Proceedings of the International Conference Centrifuge 1991*, H.Y. Ko, F.G. McLean, and A.A. Balkema (Eds.), Rotterdam, pages 517-523, 1991.

Illangasekare, T.H., E.J. Armbruster, D.N. Yates, and J. Wald, "Laboratory Evaluation of Conventional Multiphase Flow Models," *Computational Methods in Water Resources XI, Vol. 2: Mathematical Modeling in Water Resources*, Russel, Ewing, Brebbia, Gray, and Pinder (Eds.), Elsevier Applied Science, pages 289-296, 1992.

Illangasekare, T.H., "Transport and Entrapment Behavior of Immiscible Organic Waste Chemicals in Heterogeneous Aquifers: Implications on Modeling, Recovery, and Remediation," *Proceedings of 9th Annual Hazardous Waste Research Symposium*, Cincinnati, Ohio, 1993.

Illangasekare, T.H., and D. Szlag, "Use of a Three-Dimensional Groundwater Model for Retrospective Evaluation of Bioremediated Aquifer Contaminated with Organic Chemicals," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 1-11, 1993.

Isbell, L., S. Kapila, K.S. Nam, A.F. Yanders, and R.K. Puri, "Application of Support-Bonded Siloxanes and Supercritical Carbon Dioxide for Trace Analysis of Organic Compounds," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 113-122, 1990.

Itoh, H., K.J. Klabunde, and Y.-X. Li, "A Fourier Transform Infrared Photoacoustic Spectroscopy (FT-IR-PAS) Study of the Adsorption of Organophosphorus Compounds on Heat-Treated Magnesium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 588-608, 1991.

James, G.A., B.K. Warwood, A.B. Cunningham, P.J. Sturman, R. Hiebert, and J.W. Costerton, "Evaluation of Subsurface Biobarrier Formation and Persistence," *Proceedings of the 10th Annual*

Conference on Hazardous Waste Research, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 82-91. URL: http://www.engg.ksu.edu/HSRC/95Proceed/home.html.

Jennings, S.R., and J. Kruegar, "Clean Tailing Reclamation: Tailing Processing for Sulfide Removal and Vegetation Establishment," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, pages 62-75, 1997. Project no. 93-12.

Jennings, S.R., "Review of Acid-Base Account as a Predictive Tool in Drastically Disturbed Land Reclamation," *Seventh Billings Symposium on Disturbed Land Rehabilitation*, Montana State University, Bozeman, Montana, Reclamation Research Publication #9603, pages 2-8, 1996. Project no. 93-12.

Jones, W.L., K.B. Bucklin, A.K. Camper, and P. Stoodley, "Optimization of *In Situ* Biodegradability of Subsurface Soil Contaminants," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 29-43, 1989.

Kapila, S., J. Byun, K.S. Nam, M.H. Liu, R.K. Puri, and A.A. Elseewi, "A Supercritical Fluid Extraction-Based Closed Loop System for Decontamination of Soil," *Organohalogen Compounds*, Vol. 8, page 263, 1992.

Keefer, G.B., and G.J. Thies, "Metal Recovery and Reuse Using an Integrated Vermiculite Ion Exchange-Acid Recovery System," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 417-437, 1990. Project no. 3.

Khaleel, A., and K.J. Klabunde, "Iron Oxide on Magnesium Oxide Support as a New Decomposition Adsorbent for Chlorinated Hydrocarbons," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 146-150, 1993. Project no. 89-26, 92-03.

Khaleel, A., and K.J. Klabunde, "Iron Oxide on Magnesium Oxide Support as a New Decomposition Adsorbent for Chlorinated Hydrocarbons," *Proceedings of the NATO Advanced Study Institute on Nanophase Materials: Synthesis, Properties, and Applications*, Kluwer Academic Publishers, G.C. Hadjipanayis and R.W. Siegel (Eds.), Corfu, Greece, Vol. 260, pages 785-788, 1994. Project no. 89-26, 92-03.

Klabunde, K.J., J.V. Stark, O. Koper, C. Mohs, A. Khaleel, G. Glavee, D. Zhang, C.M. Sorenson, and G.C. Hadjipanayis, "Chemical Synthesis of Nanophase Materials," *Proceedings of the NATO Advanced Study Institute on Nanophase Materials: Synthesis, Properties, and Applications*, Kluwer Academic Publishers, G.C. Hadjipanayis and R.W. Siegel (Eds.), Corfu, Greece, Vol. 260, pages 1-19, 1994.

Klabunde, K.J., D.G. Park, J.V. Stark, O. Koper, S. Decker, Y. Jiang, and I. Lagadic, "Nanoscale Metal Oxides as Destructive Adsorbents: New Surface Chemistry and Environmental Applications," *NATO Meeting on Fine Particles Science and Technology*, Kluwer Academic Pub., pages 691-706, 1996. Project no. 89-26, 92-03.

Kohl, S.D., and J.A. Rice, "The Binding of Organic Contaminants to Humin," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 364-368, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/. Project no. 94-11.

Koper, O., Y.-X. Li, and K.J. Klabunde, "Destructive Adsorption of Chlorinated Hydrocarbons on Ultrafine (Nanoscale) Particles of Calcium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 265-285, 1992.

Koper, O., and K.J. Klabunde, "Comparison of Nanoscale Calcium Oxide versus Commercial Calcium Oxide with Respect to Decomposition of Carbon Tetrachloride," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 122-126, 1993. Project no. 89-26, 92-03.

Koper, O., and K.J. Klabunde, "Comparison of Nanoscale Calcium Oxide versus Commercial Calcium Oxide with Respect to Decomposition of Carbon Tetrachloride," *Proceedings of the NATO Advanced Study Institute on Nanophase Materials: Synthesis, Properties, and Applications*, Kluwer Academic Publishers, G.C. Hadjipanayis and R.W. Siegel (Eds.), Corfu, Greece, Vol. 260, pages 789-792, 1994. Project no. 89-26, 92-03.

Kross, B.C., and B. Pies, "Remediation of Pesticide Spills: Technology Transfer to Volunteer Firefighters," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 202-207, 1992.

Kruger, E.L., T.A. Anderson, and J.R. Coats, "Degradation of Atrazine in Pesticide-Contaminated Soils: Phytoremediation Potential," *Phytoremediation of Soil and Water Contaminants*, E.L. Kruger, T.A. Anderson, and J.R. Coats (Eds.), American Chemical Society Symposium Series, ACS Books, Washington, DC, 1997. Project no. 93-05.

Kruger, E.L., T.A. Anderson, and J.R. Coats (Eds.), "Phytoremediation of Pesticide-Contaminated Soils," *Proceedings of the 89th Annual Meeting of the Air and Waste Management Association*, paper #96-RP141.03, 1996. Project no. 93-05.

Lambert, M., G. Pierzynski, and G. Hettiarachchi, "The Use of Phosphorus in Sequestration of Lead and Cadmium in a Smelter Slag," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, pages 439-449, 1997. Project no. 93-07.

Lambert, M., G. Pierzynski, and G. Hettiarachchi, "Phosphorus Remediation of a Lead/Zinc Smelter Slag," *Extended Abstracts of the Fourth International Conference on the Biogeochemistry of Trace Elements*, Berkeley, California, pages 465-466, 1997. Project no. 93-07.

Lelinski, D., and J.D. Miller, "Removal of Volatile Organic Compounds from Contaminated Water Using Air-Sparged Hydrocyclone Stripping Technology," *Proceedings of the International Conference on Analysis and Utilization of Oily Wastes*, Gdansk, Poland, pages 53-62, 1996. Project no. 94-15.

Lewandowski, Z., "Biosorption of Metals from Aqueous Solutions," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 477-499, 1990.

Lewandowski, Z., G. Walser, R. Larsen, B. Peyton, and W.G. Characklis, "Biofilm Surface Positioning," *Environmental Engineering Proceedings 1990*, ASCE, pages 17-23, 1990.

Lewandowski, Z.L., and A.B. Cunningham, "Biofilm Process Fundamentals," *Bioremediation: Principles and Practice*, Technomics Publishers, Vol. 1, 1998. Project no. 94-28.

Li, Y.-X., O. Koper, and K.J. Klabunde, "Adsorption and Decomposition of Organophosphorus Compounds on Nanoscale Metal Oxide Particles. *In Situ* GC-MS Studies of Pulsed Microreactions Over Magnesium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 159-184, 1991.

Li, Y.-X., O. Koper, and K.J. Klabunde, "Nanoscale Metal Oxide Particles as Chemical Reagents: Destructive Adsorption of a Chemical Agent Simulant, Dimethylmethylphosphonate (DMMP) on Heat-Treated Magnesium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 120-142, 1991.

Li, Y.-X., J.R. Schlup, and K.J. Klabunde, "A Fourier Transform Infrared Photoacoustic Spectroscopy (FT-IR-PAS) Study of the Adsorption of Organophosphorus Compounds on Heat-Treated Magnesium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 588-608, 1991.

Li, Y.-X., H. Li, and K.J. Klabunde, "Destructive Adsorption of Chlorinated Benzene on Ultrafine (Nanoscale) Particles of Magnesium Oxide and Calcium Oxide," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 127-145, 1993. Project no. 89-26, 92-03.

Li, Y.X., H. Li, and K.J. Klabunde, "Destructive Adsorption of Chlorinated Benzene on Ultrafine (Nanoscale) Particles of Magnesium Oxide and Calcium Oxide," *Proceedings of the NATO Advanced Study Institute on Nanophase Materials: Synthesis, Properties, and Applications*, Kluwer Academic Publishers, G.C. Hadjipanayis and R.W. Siegel (Eds.), Corfu, Greece, Vol. 260, pages 793-796, 1994. Project no. 89-26, 92-03.

Li, Y.X., H. Li, and K.J. Klabunde, "Destructive Adsorption of Chlorinated Benzene on Ultrafine (Nanoscale) Particles of Magnesium Oxide and Calcium Oxide," *Environmental Science and Technology*, Vol. 28, pages 1248-1253, 1994. Project no. 89-26, 92-03.

Licht, L.A., "Ecolotree™ Poplar Tree Technology Provides Cost and Management Advantages for Landfills," *Proceedings of the Solid Waste Management Association of North America, 34th Annual Solid Waste Exposition*, GRG004, pages 197-204, September 1996.

Licht, L.A., "Popular Tree Roots for Water Quality Improvement," *Proceedings of the National Conference on Enhancing State's Lake Management Programs*, pages 55-61, 1990.

Licht, L.A., and J.L. Schnoor, "Poplar Tree Buffer Strips Grown in Riparian Zones for Biomass Production and Nonpoint Source Pollution Control," *Proceedings of the American Society of Agricultural Engineers*, Paper 902057, pages 1-21, 1990

Licht, L.A., "Ecolotree™ Buffer for Landfill Leachate Management: Installation and Operational Summary," *Proceedings of Air & Waste Management Association 87th Meeting*, Cincinnati, Ohio, Paper 94-WA86.03, 1994.

Licht, L.A., "*Populus spp.* (Poplar) Capabilities and Relationships to Landfill Water Management," *Proceedings of Air & Waste Management Association 87th Meeting*, Cincinnati, Ohio, Paper 94-WA86.02, 1994.

Lin, J., and R.S. Govindarajk, "Conductivity of Soils with Preferential Flow Paths," *Proceedings of the HSRC/WERC Joint Conference on the Environment*, pages 117-125, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Liu, M.H., S. Kapila, T.E. Clevenger, D.S. Viswanath, R.K. Puri, and A.F. Yanders, "Evaluation of Supercritical Fluid Extraction for Removal of Organic Contaminants from Soil," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 152-169, 1990.

Lo, Y.-H., A.F. Yanders, R.K. Puri, and S. Kapila, "Effect of Co-Pollutants on the Movement of Polychlorinated Dibenzo-P-Dioxins and Polychlorinated Dibenzofurans in Saturated Soils," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 77-88, 1990.

Makepeace, V.D., L.C. Davis, J. Dana, K. Selk, K. Smith, R.M. Hammaker, W.G. Fateley, and L.E. Erickson, "Measuring Contaminant Flux through Plants by Fourier Transform Infrared (FT-IR) Spectrometry," *Proceedings of the HSRC-WERC Joint Conference on the Environment, Albuquerque*, New Mexico, pages 577-582, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Marino, M.A., and J.C. Tracy, "Water and Solute Movement in a Rooted Soil," *Trends in Hydrology*, Research Trends, Council of Scientific Information (Ed.), Trivandrum, India, pages 359-371, 1995.

Mazac, O., I. Landa, W.E. Kelly, and J.H. Blaha, "A New Technique for Detecting Petroleum Pollution Around Underground Storage Tanks," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 12-20, 1993.

McDonald, J.P., C.A. Baldwin, and L.E. Erickson, "Practical Considerations for Implementation of a Field-Scale Bioremediation Project," *Proceedings of the 21st Annual Biochemical Engineering Symposium*, Colorado State University, Ft. Collins, Colorado, pages 121-130, 1991.

McDonald, J.P., C.A. Baldwin, and L.E. Erickson, "Rate Limiting Factors for *In Situ* Bioremediation of Soils Contaminated with Hydrocarbons," *Proceedings Fourth International IGT Symposium on Gas, Oil, and Environmental Biotechnology*, Gas Research Institute, Chicago, Illinois, pages 1-16, 1991.

McDonald, J.P, C.A. Baldwin, L.E. Erickson, and L.T. Fan, "Modeling Bioremediation of Soil Aggregates with Residual NAPL Saturation," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 346-365, 1993.

Miller, M., J. Dana, L.C. Davis, M. Narayanan, and L.E. Erickson, "Phytoremediation of VOC-Contaminated Groundwater Using Poplar Trees," *Proceedings of the 26th Annual Biochemical Engineering Symposium*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 42-51, 1997. Project no. 94-27.

Miller, C.M., R.L. Valentine, J.L. Stacy, M.E. Roehl, and P.J.J. Alvarez, "Chemical Oxidation and Toxicity Reduction of Pesticide-Contaminated Soils," *Bioremediation of Recalcitrant Organics*, R.E. Hinchee, D.B. Anderson, and R.E. Hoeppel (Eds.), Battelle Press, Columbus, pages 175-182, 1995.

Moats, M.S., and T.J. O'Keefe, "Optimization of Ferric Reduction in Di-Ethylehxyl Phosphoric Acid by Separate Galvanic Stripping," *Second International Symposium on Extraction and Processing for the Treatment and Minimization of Wastes*, V. Ramachandran and C.C. Nesbitt (Eds.), pages 673-684, 1996. Project no. 94-05.

Moats, M.S., C.M. Chang, and T.J. O'Keefe, "Recovery of Zinc from Residues by SX-Galvinic Stripping Process," *Third International Symposium on Recycling of Matals and Engineered Materials*, P.B. Queneau and R.D. Peterson, pages 545-561, 1995. Project no. 94-05.

Mohs, C., and K.J. Klabunde, "Preparation of Small Particles of Titanium (IV) Oxide," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 165-170, 1993. Project no. 89-26, 92-03.

Mohs, C., and K.J. Klabunde, "Preparation of Small Particles of Titanium (IV) Oxide," *Proceedings of the NATO Advanced Study Institute on Nanophase Materials: Synthesis, Properties, and Applications*, Kluwer Academic Publishers, G.C. Hadjipanayis and R.W. Siegel (Eds.), Corfu, Greece, Vol. 260, pages 121-124, 1994.

Nair, D.R., and J.L. Schnoor, "Modeling of Alachlor and Atrazine at a Small Plot in Amana, Iowa," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 89-112, 1990.

Nam, K.S., S. Kapila, A.F. Yanders, R.K. Puri, and D.S. Viswanath, "Supercritical Fluid Extraction and Cleanup Procedures for Determination of Xenobiotics in Biological Samples," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 138-151, 1990.

Narayanan, M., L.C. Davis, and L.E. Erickson, "Monitoring the Fate of Toluene and Phenol in the Rhizosphere," *Proceedings of the 23rd Annual Biochemical Engineering Symposium*, R. Harrison (Ed.), University of Oklahoma, Norman, Oklahoma, pages 46-53, 1993.

Narayanan, M., R.M. Green, L.E. Erickson, and L.C. Davis, "A Laboratory Study of the Fate of Trichloroethylene and 1,1,1-Trichloroethane in the Presence of Vegetation," *Proceedings of 24th*

Annual Biochemical Engineering Symposium, Rob Davis (Ed.), University of Colorado-Boulder, pages 110-118, 1994.

Narayanan, M., L.C. Davis, and L.E. Erickson, "Biodegradation Studies of Chlorinated Organic Pollutants in a Chamber in the Presence of Alfalfa Plants," *Proceedings of the 25th Biochemical Engineering Symposium*, University of Missouri, Columbia, Missouri, pages 11-20, 1995. Project no. 94-27.

Narayanan, M., L.C. Davis, L.E. Erickson, R.M. Hoffman., N.K. Russell, R.M. Hammaker, and W.G. Fateley, "Modeling and Analysis of Transport and Biodegradation in Laboratory Chambers with Plants," *Proceedings of the 5th World Congress of Chemical Engineering*, San Diego, California, AIChE, New York, Vol. 3, pages 694-699, 1996. Project no. 94-27.

Narayanan, M., J. Hu, L.C. Davis, and L.E. Erickson, "Effect of Water Content on Transport of Trichloroethylene in a Chamber with Alfalfa Plants," *Proceedings of the 26th Annual Biochemical Engineering Symposium*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 110-119, 1997. Project no. 94-27.

Narayanan, M., N.K. Russell, L.C. Davis, and L.E. Erickson, "Experimental and Modeling Studies of the Fate of Trichloroethylene in a Chamber with Alfalfa Plants," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 474-481, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/. Project no. 94-27.

Nedunuri, K.V., R.S. Govindaraju, L.E. Erickson, and A.P. Schwab, "Modeling of Heavy Metal Movement in Vegetated, Unsaturated Soils with Emphasis on Geochemistry," *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, Kansas State University, Manhattan, Kansas, pp. 57-66, 1995. Project no. 93-06.

Nedunuri, K.V., R.S. Govindaraju, A.P. Schwab, and L.E. Erickson, "Geochemical Modeling of Lead in Vadose Zone," *ASCE North American Water and Environment Congress*, CD-ROM, Anaheim, California, 1996. Project no. 93-06.

Neira, M.P., J.L. Watson, and T.J. O'Keefe, "The Effect of Entrained Di-2-Ethylhexyl Phosphoric Acid (D2EHPA) on Zinc Electrowinning," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 55-65, 1991.

Neira, M.P., and T.J. O'Keefe, "Zinc Electrowinning from Waste Oxide Generated Using Ausmelt Pyroprocessing," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 246-264, 1992.

Nieman, J.K., D.O. Kimball, R.C. Sims, and J.A. Rice, "Incorporation of PAH into Soil Components as Affected by Alternate Electron Acceptor Addition During Land Farming," *Proceedings of the 4th International Symposium of In Situ and On-Site Bioremediation*, Vol. 2, Battelle Press, Columbus, Ohio, Vol. 2, pages 181-184, 1997. Project no. 93-21.

O'Connor, J.T., and B.J. Brazos, "The Response of Natural Groundwater Bacteria to Groundwater Contamination by Gasoline in a Karst Region," *Proceedings of the Conference on Hazardous*

Waste Research, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 281-293, 1991. Project 89-17.

Okeson, S.J., T.H. Illangasekare, D.C. Szlag, and J.E. Ewing, "Modeling of Dissolution Transport of Nonaqueous-Phase Liquid Wastes in Heterogeneous Aquifers," *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 146-152, 1995. URL: http://www.engg.ksu.edu/HSRC/95Proceed/home.html.

Parkin, G.F., L.J. Weathers, P.J. Novak, and P.J.J. Alvarez, "Enhanced Anaerobic Bioremediation Using Elemental Iron," *Water Resources and Urban Environments-1998 Proceedings of the ASCE National Conference on Environmental Engineering*, Chicago, Illinois, pages 128-133, 1998. Project no. 93-02.

Parkin, G.F., D.T. Adamson, and J.B. Hughes, "Anaerobic Biotransformation of Mixtures of Chlorinated Aliphatic Hydrocarbons," *Proceedings of the AGU Annual Meeting*, San Francisco, California, 1997. Project no. 93-24.

Patel, B.B., S.T. Chou, and L.T. Fan, "Simulation of Waste Generation During Start-Up of an Interconnected Process Network," *Proceedings of the 10th Annual Conference on Hazardous Waste Research*, pages 271-280, Kansas State University, Manhattan, Kansas, 1995. Project no. 91-36.

Paterson, K.G., and J.L. Schnoor, "Fate and Transport of Alachlor and Atrazine in an Unsaturated Riparian Zone," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 561-591, 1990.

Peyton, R.L., S.H. Anderson, C.J. Gantzer, J.W. Wigger, and H. Wang, "X-Ray Computed Tomography as a Tool in Contaminant Transport Research," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 715-732, 1990.

Pierzynski, G.M., "Characterization of Lead and Zinc Mine Tailings and Heavy Metal-Contaminated Soils in Southeast Kansas," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 511-520, 1991.

Pierzynski, G.M., and A.P. Schwab, "Reducing Heavy Metal Availability to Soybeans Grown on a Metal-Contaminated Alluvial Soil," *American Society of Agronomy Meetings*, Minneapolis, Minnesota, page 53, 1992.

Pierzynski, G.M., and A.P. Schwab, "Reducing Heavy Metal Availability to Soybeans Grown on a Metal-Contaminated Soil," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 543-553, 1992.

Pierzynski, G.M., "Strategies for Remediating Trace Element-Contaminated Sites,"*Remediation of Soils Contaminated with Metals*, A.K. Iskandar and D.C. Adriano (Eds.), Science Reviews, Northwood, England, pages 67-84, 1997.

Pierzynski, G.M., G.M. Hettiarachchi, and J.K. Koelliker, "Methods for Assessing the Effects of Soil Degradation on Water Quality," *Methods of Assessment of Soil Degradation, Advances in Soil Science*, R. Lal, W. Blum, C. Valentine, and B.A. Stewart (Eds.), CRC Press, Boca Raton, Florida, pages 513-545, 1997. Project no. 93-07.

Pierzynski, G.M., J.L. Schnoor, M.K. Banks, J.C. Tracy, L.A. Licht, and L.E. Erickson, "Vegetative Remediation at Superfund Sites," *Mining and Its Environmental Impact–Issues in Environmental Science and Technology*, R.E. Hester and R.M. Harrison (Eds.), Royal Society of Chemistry, Vol. 1, pages 46-69, 1994.

Pierzynski, G.M., G. Hettiarachchi, M. Lambert, L.E. Erickson, D. Sweeney, and B. Hetrick, "Remediation of Metal-Contaminated Sites in the Tri-State Mining Region, U.S.A.," *Proceedings of the 16th World Congress of Soil Science*, Montpellier, France, CD-ROM, 1998.

Rao, D., and T.E. Clevenger, "Effect on the Mobility of Lead from a Landfill Located in a Mine Waste Site," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 495-510, 1991.

Rayavarapu, R., S.K. Banerji, and R.K. Bajpai, "Biodegradation of PCP by *Pseudomonas cepacia*," *Proceedings of the 20th Annual Biochemical Engineering Symposium*, pages 68-76, 1990.

Rayavarapu, R., S.K. Banerji, and R.K. Bajpai, "Biodegradation of PCP by *Pseudomonas cepacia*," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 47-62, 1990.

Rice, J.A., "Contaminant Binding to Humin," *Proceedings of the National Meeting of the American Waste Management Association*, Nashville, Tennesse, Abstract no. 96-RP141.02, 1996.

Roe, F., Z. Lewandowski, D. Chen, and R. Hughes, "Theoretical and Experimental Studies on Diffusion of Metal Ions and Reaction with Biopolymers," *Biohydrometallurgical Technologies: Proceedings of an International Biohydrometallurgy Symposium*, A.E. Torma, M.L. Apel, and C.L. Brierley, (Eds.), Jackson Hole, Wyoming, Vol. 2, pages 145-158, 1993.

Ruan, H., T.H. Illangasekare, B.P. Greimann, and I. Litaor, "Calibration of a Model for Preferential Flow in the Vadose Zone at the Column Scale," *Model CARE 96 (Calibration and Reliability in Groundwater Modeling) Poster Papers*, pages 215-224, 1996.

Russell, N.K., L.C. Davis, and L.E. Erickson, "A Review of Contaminant Transport to the Gas Phase Above Fields of Vegetation," *Proceedings of the 89th Annual Meeting and Exhibition of the Air and Waste Management Association*, Nashville, Tennessee, paper #96-RP141.01, 1996. Project no. 94-27.

Ryu, S.B., L.C. Davis, J. Dana, K. Selk, and L.E. Erickson, "Evaluation of Toxicity of Trichloroethylene for Plants," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 583-588, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/. Project no. 94-27.

Santharam, S.K., L.E. Erickson, and L.T. Fan, "Modeling the Fate of Polynuclear Aromatic Hydrocarbons in the Rhizosphere," *Proceedings of the 9th Annual Conference on Hazardous*

Waste Remediation, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Bozeman, Montana, pages 333-350, 1994.

Santharam, S.K., L.E. Erickson, and L.T. Fan, "Modeling the Fate of Pyrene in the Rhizosphere," *Proceedings of the 24th Annual Biochemical Engineering Symposium*, R.H. Davis (Ed.), University of Colorado, Boulder, pages 119-128, 1994.

Santharam, S.K., L.T. Fan, and L.E. Erickson, "Surfactant-Enhanced Extraction and Biodegradation of a Nonaqueous-Phase Liquid in Soil," *Proceedings of the Conference on Nonaqueous-Phase Liquids (NAPLs) in Subsurface Environment: Assessment and Remediation*, L.N. Reddi (Ed.), American Society of Civil Engineers, New York, pages 419-430, 1996. Project no. 94-27.

Schnoor, J.L., and V. Thomas, "Soil as a Vulnerable Environmental System," *Industrial Ecology and Global Change*, R. Socolow (Ed.), Cambridge University Press, Cambridge, United Kingdom, pages 233-244, 1994.

Schwab, A.P., "Chemical and Physical Characterization of Soils," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 326-344, 1992.

Schwab, A.P., and M.K. Banks, "The Impacts of Vegetation on the Leaching of Heavy Metals from Mine Tailings," *Proceedings of Air & Waste Management Association Annual Meeting*, Paper 93-WA-89.06, 1993.

Seybert, R.A., W.P. Walawender, and L.T. Fan, "Preliminary Evaluation of Carbon Tetrachloride Destruction in the KSU Bench-Scale Incinerator," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 426-451, 1989.

Shea, P.J., and S.D. Comfort, "Remediating Munitions-Contaminated Soils," *Abstracts and Proceedings of the 21st Annual RREL Research Symposium*, E.L. George (Ed.), EPA/600/R-95/012, U.S. EPA, Cincinnati, Ohio, pages 354-358, 1995.

Shimp, J.F., E. Lee, W. Huang, L.E. Erickson, J.C. Tracy, L.C. Davis, and J.L. Schnoor, "Concepts Involved in Developing Soil and Groundwater Remediation Strategies Using Plants," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 629-647, 1991.

Shimp, J.F., L.C. Davis, J.C. Tracy, E. Lee, Y. Huang, and L.E. Erickson, "Predictive Model for Contaminant Degradation in the Rhizosphere," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 317-325, 1992.

Shimp, J.F., J.C. Tracy, E. Lee, L.C. Davis, and L.E. Erickson, "Modeling Contaminant Transport, Biodegradation, and Uptake by Plants in the Rhizosphere," *Proceedings of the Twenty-Second Annual Biochemical Engineering Symposium*, Iowa State University, Ames, Iowa, pages 181-190, 1992.

Shue, S.L., R.E. Faw, and J.K. Shultis, "Fast Neutron Thermalization and Capture Gamma-Ray Generation in Soils," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 596-613, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Shultis, J.K., R.E. Faw, and F.A. Khan, "Methods for Determining Soil Contaminant Profiles from Prompt-Neutron Gamma Activation Data," *Proceedings of the HSRC-WERC Joint Conference on the Environment*, Albuquerque, New Mexico, pages 614-631, 1996. URL: http://www.engg.ksu.edu/HSRC/96Proceed/.

Sims, R.C., "Migration of the Major Wood Preservatives and the Potential for Groundwater, Surface Water, and Soil Contamination," *Proceedings of the Workshop on Utility Poles: Environmental Issues*, University of Madison-Madison, Wisconsin, 1997. Project no.93-21.

St. Clair, M.A., C. Mojonnier, and J. Schnoor, "Photochemical Treatment Process for Mine-Tailing Leachates," *Preprint Extended Abstracts, 204th National Meeting of the American Chemical Society*, Environmental Chemistry Division, Washington, D.C., ENVR40, 1992.

Stark, J.V., and K.J. Klabunde, "Nanoscale Magnesium Oxide Used to Adsorb SO_2 and CO_2," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 117-121, 1993. Project no. 89-26, 92-03.

Stark, J., and K.J. Klabunde, "Nanoscale Magnesium Oxide Used to Adsorb SO_2 and CO_2," *Proceedings of the NATO Advanced Study Institute on Nanophase Materials: Synthesis, Properties, and Applications*, Kluwer Academic Publishers, G.C. Hadjipanayis and R.W. Siegel (Eds.), Corfu, Greece, Vol. 260, pages 797-800, 1994. Project no. 89-26, 92-03.

Steichen, J.M., P. Barnes, and S. Siegele, "Atrazine Movement in Soil Compared with PRZM and GLEAMS Models," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 12-29, 1991.

Sturman, P.J., W.L. Jones, and W.G. Characklis, "Interspecies Competition in Colonized Porous Pellets," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 66-70, 1991.

Sturman, P.J., W.L. Jones, W.G. Characklis, and A.B. Cunningham, "Interspecies Competition in Colonized Porous Pellets," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 219-245, 1992.

Sturman P.J., A.B. Cunningham, and P. Stewart, "A Scale-Up Approach for the Design and Operation of *In Situ* Bioremediation Systems," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan Kansas, pages 85-92, 1993.

Sturman, P.J., P. Stewart, R. Sharp, J. Wolfram, and A.B. Cunningham, "Scale-Up Implications of Respirometrically Determined Microbial Kinetic Parameters," *Proceedings of the Second International Symposium on In-Situ and On-Site Bioreclamation*, San Diego, California, pages 300-304, 1993.

Szlag, D.C., and T.H. Illangasekare, "Experimental Investigation and Modeling of Immiscible Liquid Entrapment in Porous Media," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 127-143, 1992.

Szlag, D., and T.H. Illangasekare, "Dissolution of Trapped Nonaqueous Phase Liquids in Heterogeneous Aquifers and Determination of Mass Transfer Coefficients," *Proceedings of the 8th Annual Conference Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 107-115, 1993.

Szlag, D.C., T.H. Illangasekare, T. Fairbanks, D. Znidarcic, D. Kampbell, and J.T. Wilson, "Retrospective Evaluation of a Bioremediated Aquifer Contaminated with Organic Chemicals-Part Model Application," *Proceedings of the 86th Annual Meeting of the Air & Waste Management Association*, Denver, Colorado, Paper No. 83-TP-65.01, 1993.

Szlag, D.C., T.H. Illangasekare, and J.T. Wilson, "Use of a Three-Dimensional Groundwater Model for Retrospective Evaluation of a Bioremediated Aquifer Contaminated with Organic Chemicals," *Proceedings of 1993 Groundwater Modeling Conference*, International Groundwater Modeling Center, Colorado School of Mines, Golden, Colorado, pages 5.21-5.30, 1993.

Szlag, D.C., and T.H. Illangasekare, "Dissolution of NAPLs in Heterogeneous Porous Medium at Greater Residual Saturation," *Proceedings of the 9th Annual Conference on Hazardous Waste Remediation*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Bozeman, Montana, pages 25-34, 1994.

Szlag, D.C., and T.H. Illangasekare, "Rate-Limited Dissolution of Entrapped Nonaqueous-Phase Liquids in Heterogeneous Soils," *Proceedings of the 1994 Groundwater Modeling Conference*, J.W. Warner and P. van der Heijde (Eds.), International Groundwater Modeling Center, Ft. Collins, Colorado, pages 425-432, 1994.

Till, B.A., L.J. Weathers, and P.J.J. Alvarez, "Fe^0-based Bioremediation of Nitrate-Contaminated Waters," *In Situ and On-Site Bioremediation, Vol. 3*, B.C. Alleman and A. Leeson (Eds.), Battelle Press, Columbus, Ohio, pages 367-372, 1997. Project no. 93-02.

Tracy, J.C., L.E. Erickson, J.F. Shimp, and L.C. Davis, "Modeling the Beneficial Effects of Vegetation in the Management of Landfill Leachates," *Proceedings of the Air & Waste Management Association's 1991 Annual Meeting and Exhibition*, Paper 92-27.03, pages 1-16, 1992.

Tracy, J.C., and J. Brummer, "Estimation of the Hydraulic Flow Parameters for the Alluvial Aquifer Underlying the Riley County Landfill," *Proceedings of the 1993 International Groundwater Modeling Conference*, International Groundwater Modeling Conference, Golden, Colorado, pages 1-11 to 1-20, 1993.

Tracy, J.C., L.E. Erickson, and L.C. Davis, "Rate-Limited Degradation of Hazardous Organic Contaminants in the Root Zone of a Soil," *Proceedings of the 86th Annual Meeting of the Air & Waste Management Association*, Paper No. 93-WA-89.02, 1993.

Tracy, J.C., H. Ramireddy, L.E. Erickson, and L.C. Davis, "Effects of Climatological Variability on the Performance of Vegetative Systems in Remediating Contaminated Soil," *Proceedings of the*

87th Annual Meeting of the Air & Waste Management Association, Paper No. 94-WA-86.01, 1994.

Tuitemwong, P., B.M. Sly, S. Dhawan, L.E. Erickson, and J.R. Schlup, "Microcosm Treatability of Soil Contaminated with Petroleum Hydrocarbons," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages 893-925, 1990.

Tuitemwong, P., L.E. Erickson, X. Yang, and L.T. Fan, "Effects of Depth of a Soil Column on the Biodegradation of Palmitate," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 601-615, 1992.

Turner, J.P., M.L. Dennis, Y. Osman, J. Chase, and L.A. Bulla, "Biofilm Treatment of Soil for Waste Containment and Remediation," *Proceedings of the International Containment Technology Conference*, U.S. Department of Energy, DuPont Company, and U.S. Environmental Protection Agency, pages 672-678, 1997. Project no. 94-26.

Utamapanya, S., K.J. Klabunde, and J. Schlup, "Nanoscale Metal Oxide Particles/Clusters as Chemical Reagents. Synthesis and Properties of Ultra-High Surface Area Magnesium Oxide," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 170-203, 1990.

Valentine, R.L., A.H. Wang, and C. Miller, "Hydrogen Peroxide Decomposition and Organic Contaminant Loss in the Presence of Iron Oxides," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 185-196, 1991.

Varga, J.B., F. Friedler, and L.T. Fan, "Risk Reduction through Waste Minimizing Process Synthesis," *Proceedings of the 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium*, Cincinnati, Ohio, pages 359-363, 1995. Project no. 91-36.

Venkatraman, A., W.P. Walawender, S.M. Chern, and L.T. Fan, "Applications of Mass Spectrometry in Monitoring Incineration Processes," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 522-542, 1992.

Walser, G.S., T.H. Illangasekare, and A.T. Corey, "Retention of Liquid Contaminants in Layered Soils," *Proceedings of the 9th Annual Conference on Hazardous Waste Remediation*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Bozeman, Montana, pages 35-48, 1994.

Walton, C.W., "Material Recovery and Treatment Methods Used in the Chromium Electroplating Process," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. II, pages, 652-672, 1990.

Walton, C.W., A.C. Hillier, and G.L. Poppe, "Process Options for Waste Minimization and Metal Recovery for the Metal Finishing Industries," *Proceedings of the International Conference on Pollution Prevention: Clean Technologies and Clean Products*, EPA/600/9-90/039, U.S. EPA, Washington, DC, pages 703-712, 1990.

Walton, C.W., K.J. Loos, and T.A. Lewis, "Application of Electrodialysis Techniques to Remediation of Heavy Metal-Contaminated Waters," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 552-560, 1991.

Walton, C.W., K. Briggs, and K.J. Loos, "Waste Minimization and Remediation in the Metal Finishing Industries," *Industrial Environmental Chemistry I: Waste Minimization in Industrial Processes and Remediation of Hazardous Wastes*, D.T. Sawyer and A.E. Martell (Eds.), Plenum Publishing Corporation, New York, pages 71-87, 1992.

Wang, H., R.L. Peyton, and S.H. Anderson, "Estimation of Small-Scale Porosity, Velocity, and Hydraulic Conductivity in Porous Media Using X-Ray Computed Tomography: Theory and Model Testing," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 609-623, 1991.

Wang, H., R.L. Peyton, S.H. Anderson, and C.J. Gantzer, "Simulation of Three-Dimensional Transport of Hazardous Chemicals in Heterogeneous Soil Cores Using X-Ray Computed Tomography," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 39-56, 1992. Project no. 89-14.

Wang, J., S.K. Banerji, and R.K. Bajpai, "Migration of Pentachlorophenol through Soil Columns in Presence of a Nonaqueous Phase," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 57-65, 1992.

Wang, J., S.K. Banerji, and R.K. Bajpai, "Migration of PCP in Unsaturated and Saturated Soils," *Proceedings of the 22nd Annual Biochemical Engineering Symposium*, Iowa State University, Ames, Iowa, pages 11-20, 1992.

Wang, W., J.L. Schnoor, and J. Doi (Eds.), *Volatile Organic Compounds in the Environment*, ASTM, West Conshohocken, PA, 1996. Project no. 95-29.

Watanabe, H., J.M. Steichen, P. Barnes, N.L. Watermeier, P.J. Jasa, D.P. Shelton, and E.C. Dickey, "Water Quality Aspects of Tillage, Soil Type, and Slope. Part II: Atrazine and Alachlor Losses," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 166-181, 1992.

Watermeier, N.L., P.J. Jasa, D.P. Shelton, E.C. Dickey, H. Watanabe, and J.M. Steichen, "Water Quality Aspects of Tillage, Soil Type, and Slope. Part I: Runoff and Soil Erosion," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 149-165, 1992.

Waters, C.Y., M.K. Banks, and A.P. Schwab, "Zinc Movement in Mine Tailings Amended with Organics," *Proceedings of the CSCE-ASCE National Conference, Environmental Division*, Montreal, Canada, pages 237-241, 1993.

Weathers, L.J., and G.F. Parkin, "Metallic Iron-Enhanced Biotransformation of Carbon Tetrachloride and Chloroform under Methanogenic Conditions," *Third International In Situ and*

On-Site Bioreclamation Symposium, R.E. Hinchee, A. Leeson, and L. Semprini (Eds.), Vol. 3, pages 117-122, 1995.

Weathers, L.J., G.F. Parkin, P.J. Novak, and P.J.J. Alvarez, "Methanogens Couple Anaerobic Fe(0) Oxidation and $CHCl_3$ Reduction," *Preprints of Papers, 209th ACS National Meeting*, American Chemical Society, Anaheim, California, 1995.

Wei, S.M., S.K. Banerji, and R.K. Bajpai, "Pentachlorophenol Interactions with Soil," *Proceedings of the 20th Annual Biochemical Engineering Symposium*, pages 159-168, 1990.

Wei, S.M., S.K. Banerji, and R.K. Bajpai, "Pentachlorophenol Interactions with Soil," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, Vol. I, pages 322-346, 1990.

Wetzel, S., M.K. Banks, and A.P. Schwab, "Effects of the Rhizosphere on the Degradation of Pyrene and Anthracene in Soil," *Phytoremediation of Soil and Water Contaminants*, E.L. Kruger, T.A. Anderson, and J.R. Coats. (Eds.), American Chemical Society Symposium Series 664, pages 254-263, 1997.

Wildcat, D.R., G.L. Godfrey, M.D. Tosse, D.L. Tillison, S.C. Grant, and L.E. Erickson, "The NAOMI Program: Developing Hazardous Substance Programs at Native American and Other Minority Educational Institutions," *Proceedings of the 9th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Montana State University, Bozeman, Montana, pages 361-365, 1994.

Wildenschild, D., K.H. Jensen, T.H. Illangasekare, and D. Znidarcic, "Identification of Hydraulic Parameters for Unsaturated Flow Using Combined Direct Measurements and Inverse Solution Techniques," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 21-34, 1993.

Wu, X., and L.C. Davis, "Detection of Specific Microorganisms Using the Arbitrary Primed PCR in the Bacterial Community of the Vegetated Soil," *Proceedings of the 26th Annual Biochemical Engineering Symposium*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 120-126, 1997. Project no. 94-27.

Wu, X., L.C. Davis, and L.E. Erickson, "Examining the Fate of Released Pseudomonas putida Fl in Rhizosphere Environments," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant and J.P. McDonald (Editors), Kansas State University, pages 492-499, 1997. Project no. 94-27.

Wu, J.C., L.T. Fan, and L.E. Erickson, "Modeling and Simulation of Bioremediation of Contaminated Soil: A Case Study with Recycle of Nutrient Solution," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 121-146, 1989.

Wu, X., L.C. Davis, and L.E. Erickson, "Examining the Fate of Released Pseudomonas Putida F1 in Rhizosphere Environments," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kanas State University, pages 492-499, 1997.

Yang, X., L.E. Erickson, and L.T. Fan, "Dispersive-Convective Transport in the Biorestoration of Contaminated Clay Layers," *Proceedings of the Conference on Hazardous Waste Research*, L.E. Erickson, S.C. Grant, and J.P. McDonald (Eds.), University of Colorado, Boulder, Colorado, pages 581-600, 1992.

Yang, X., L.E. Erickson, and L.T. Fan, "Modeling of Dispersive-Convective Characteristics in Bioremediation of Contaminated Soil," *Proceedings of the 22nd Annual Biochemical Engineering Symposium*, P.J. Reilly (Ed.), Iowa State University, Ames, Iowa, pages 191-200, 1992.

Yang, X., L.E. Erickson, and L.T. Fan, "Mass Transfer in the Bioremediation of Soils Contaminated with Trapped Nonaqueous-Phase Liquids," *Proceedings of the 23rd Annual Biochemical Engineering Symposium*, Norman, Oklahoma, pages 110-119, 1993.

Yang, X., L.E. Erickson, and L.T. Fan, "Transport Properties of Toluene as a Nonaqueous-Phase Liquid in Groundwater," *Proceedings of the 8th Annual Conference on Hazardous Waste Research*, L.E. Erickson, D.L. Tillison, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, Manhattan, Kansas, pages 313-330, 1993.

Zawaideh, L.L. and T.C. Zhang, "Effect of pH and Addition of an Organic Buffer (HEPES) on Nitrate Transformation on Fe^0-Water System," *Water Quality International 1998: Proceedings of the IAWQ 19th Biennial International Conference*, Vancouver, Canada, Book 7, pages 108-115, 1998. Project no. 95-32.

Zawaideh, L.L., C.F. Chew, and T.C. Zhang, "Remediation of Nitrate-Containing Water and Soil by Fe^0-Promoted Processes," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, pp. 77-97, 1997. Project no. 95-32.

Zhang, Q., J. Hu, L.E. Erickson, and L.C. Davis, "Effect of Air Sparging on Fate and Transport of Trichloroethylene in Chambers with Alfalfa Plants," *Proceedings of the 12th Annual Conference on Hazardous Waste Research*, L.E. Erickson, M.M. Rankin, S.C. Grant, and J.P. McDonald (Eds.), Kansas State University, pages 564-573, 1997. Project no. 94-27.

Zhang, Q., B. Goplen, S. Vanderhoof, L.C. Davis, and L.E. Erickson, "Fate and Effect of Trichloroethylene as Nonaqueous-Phase Liquid in Chambers with Alfalfa," *Proceedings of the 26th Annual Biochemical Engineering Symposium*, L.E. Erickson (Ed.), Kansas State University, Manhattan, Kansas, pages 154-163, 1997. Project no. 94-27.

Zhang, S., and C.L. Hansen, "Biological Detoxification of Mercury-Contaminated Soil," *American Society of Agricultural Engineering*, ASAE Summer Meeting, Albuquerque, New Mexico, Paper # 91-6006, 1991.

Znidarcic, D., T. Illangasekare, and M. Manna, "Laboratory Testing of and Parameter Estimation for Two-Phase Flow Problems," *Proceedings of the Geotechnical Engineering Congress*, McLean, Campbell, and Harris (Eds.), ASCE, New York, pages 1078-1089, 1991.

E. PROJECT REPORTS

Alvarez, P.J.J., G.F. Parkin, J.L. Schnoor, and J. Fang, "Biogeochemical Interactions in Zero-Valent Iron Walls," *U.S. EPA 1996-1998 Bioremediation Research Program Review September 23-24*, EPA/600/F-98/122, page 32, 1998. Project no. 93-02.

Bajpai, R.K., S.K. Banerji, R.K. Puri, and M.E. Zappi, "Remediation of Soils Contaminated with Wood Treatment Chemicals (PCP and Creosote)," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-08.

Balakrishnan, N., "NAOMI Summer Research Cooperation: Speciation of Arsenic," Progress Report, Haskell Environmental Research Studies Center, Haskell Indian Nations University, Lawrence, Kansas, 1994.

Banerji, S., "Biodegradation of Chelating Agents Used in Chelating Extraction of Heavy Metals from Contaminated Soil," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1996.

Banerji, S.K., and R.K. Bajpai, "Migration and Biodegradation of Pentachlorophenol in Soil Environment," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 7.

Banks, M.K., B.A.D. Hetrick, and A.P. Schwab, "Impact of Soil Microflora on Revegetation Efforts in Southeast Kansas," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 90-11.

Banks, M.K., R.S. Govindaraju, and A.P. Schwab, "Bioremediation of Petroleum-Contaminated Soil Using Vegetation," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Bates, D.K., "Hazardous Substance Research Center Bibliography," Kansas State University, Manhattan, Kansas, 1991.

Boronina, T., and K.J. Klabunde, "Scrubbing Groundwater with Metal Cuts the Contaminants," *Chemecology*, Vol. 24, No. 7, page 7, September 1995. Project no. 89-26, 92-03.

Characklis, W.G., A.B. Cunningham, W.L. Jones, and Z. Lewandowski, "*In Situ* Bioremediation of Organic Groundwater Contaminants," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-23.

Clean Sites, Inc., Hazardous Substance Research Center, and EPA Region VIII, "Forum Report on PRP Incentives to Speed Up Settlements and Accelerate Cleanups," Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1993.

Clevenger, T.E., and E.J. Hinderberger, "Reclamation of Metal- and Mining-Contaminated Superfund Sites Using Sewage Sludge/Fly Ash Amendments," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 2.

Coats, J.R., and T.A. Anderson, "Use of Vegetation to Enhance Bioremediation of Surface Soils Contaminated with Pesticide Wastes," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 93-05.

Comfort, S.D., P.J. Shea, D.L. McCallister, and W.L. Powers, "The Fate and Transport of Munitions Residues in Contaminated Soils," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 92-24.

Cunningham, A.B., and J.W. Costerton, "Microbial Transport in Porous Media," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 91-25.

Cunningham, A.B., P.J. Sturman, and B.K. Warwood, "Microbial Process Engineering Concepts," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994.

Cunningham, A.B., "Evaluation and Modeling of Subsurface Biobarrier Formation and Persistence," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-28, 93-11.

Cunningham, A.B., P.J. Sturman, B.K. Warwood, and N. Zelver, "Engineering Scaleup of *In Situ* Bioremediation Processes: A Workshop on Biotreatability," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Dahab, M.F., and W.E. Woldt, "Development of Pollution Prevention Programs for Small Quantity Generators in EPA Regions VII and VIII," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Davis, L.C., and L.E. Erickson, "Plant-Assisted Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances: Experimental and Modeling Studies," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-27.

Doucette, W.J., B. Bugbee, and D.K. Stevens, "Fate of Trichloroethylene (TCE) in Plant/Soil Systems: Evaluating Phytoremediation," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 95-10.

Dupont, R.R., D.L. Sorensen, and W.J. Doucette, "Evaluation of Biosparging Performance and Process Fundamentals for Site Remediation," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995. Project no. 93-20.

Erickson, L.E., and L.T. Fan, "Development of *In Situ* Biodegradation Technology," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 6.

Erickson, L.E., and L.T. Fan, "Remediation of Soil Contaminated with an Organic Phase," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 91-29.

Fan, L.T., "Experimental Study of Stabilization/Solidification of Hazardous Wastes," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 1.

Fan, L.T., "Computer-Aided Design and Control of Systems for Treatment of Hazardous Waste and Minimization of Waste Production," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1993. Project no. 14.

Fan, L.T., "Intelligent Process Design and Control for the Minimization of Waste Production and Treatment of Waste," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 91-36.

Faw, R.E., J.K. Shultis, B.C. Letellier, S.L. Shue, and F.A. Khan, "Application of PGNAA Remote Sensing Methods to Real-Time, Non-Intrusive Determination of Contaminants Profiles in Soils," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 94-02.

Ghosh, S., "Biodetoxification of Hazardous Solid Wastes by Staged Anaerobic Fermentation Conducted at Separate Redox and pH Environments," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-06.

Ghosh, S., "Removal of Heavy Metals from Hazardous Wastes by Protein Complexation for Their Ultimate Recovery and Reuse," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 4.

Glasgow, L.A., "Vadose Zone Decontamination by Air Injection," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 11.

Godfrey, G.L., W.M. Griswold, and B.A. Leven, "Collaborative Environmental Seminar Series," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. TR96-05.

Godfrey, G.L., "Survey of Environmental Concerns on Native American Tribal Lands," Progress Report, Haskell Environmental Research Studies Center, Haskell Indian Nations University, Lawrence, Kansas, 1994.

Grant, S.C., "Conference on Superfund Settlement Incentives," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994.

Grant, S.C., "Public Environmental Information Services," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Griswold, W., "The Native American and Other Minority Institutions Program," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997.

Gruber, W. (science writer) with K.J. Klabunde and S. Mahashwari, "Ultrafine Metal Oxides Dismantle Chlorinated Organics," *Environmental Engineering World*, pages 36-37, July-August, 1995. Project no. 89-26, 92-03.

Hamdi, S., “A Preferential Flow Model, PREF, with User’s Manual,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992.

Hansen, C.L., and D.K. Stevens, “Optimal Bioreactor Design for Biological Removal of Mercury,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-09.

Hayter, R.B., and S.C. Grant, “Training and Technology Transfer Programs Management and Operation,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Hetrick, B.A.D., G.M. Pierzynski, R.S. Govindaraju, L.E. Erickson, and D. Sweeney, “Vegetative Interceptor Zones for Containment of Heavy Metal Pollutants,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 93-07.

Hong, A., R.W. Okey, and S.K. Banerji, “Chelating Extraction of Heavy Metals from Contaminated Soils,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 93-22.

Hunter, R.S., and F.D. Culver, “Computer Method to Estimate Safe Level Water Quality Content Rations for Organic Chemicals,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1991. Project no. 15.

Illangasekare, T.H., “Distribution and Recovery of Refinery Waste Products in Groundwater Aquifers: Experimental Study and Model Evaluation,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-01.

Illangasekare, T.H., “Modeling for Design and Testing of Treatment and Remediation Technologies for Aquifer Soils Contaminated with Organic Waste Chemicals,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 91-10.

Illangasekare, T.H., D. Znidarcic, G. Walser, and J. Weaver, “An Experimental Evaluation of Two Sharp-Front Models for Vadose Zone Nonaqueous-Phase Liquid Transport,” U.S. EPA Report EPA/600/R-94/197, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, 1994.

Illangasekare, T.H., “Extension of Laboratory-Validated Soil and Groundwater Treatment and Remediation Technologies to Field Problems in Aquifer Soil Contamination by Organic Waste Chemicals,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-29.

Inskeep, W.P., C.G. Johnston, and J.M. Wraith, “Effects of Surfactants on the Bioavailability and Biodegradation of Contaminants in Soils,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-09.

Kapila, S., D.W. Armstrong, and R.K. Puri, “Laboratory and Field Evaluation of Upward Mobilization and Photodegradation of Polychlorinated Dibenzo-P-Dioxins and Furans in Soil,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 91-04.

Kapila, S., D. Forciniti, and D.W. Armstrong, “Laboratory and Field Evaluation of Upward Mobilization and Photodegradation of Polychlorinated Aromatics in Soil,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995. Project no. 93-16.

Keefer, G.B., and G.J. Thies, “Metal Recovery and Reuse Using an Integrated Vermiculite Ion Exchange-Acid Recovery System,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1990. Project no. 3.

Kelly, W.E., J. Rohde, G.B. Keefer, and W.E. Woldt, “A Short Course on Remediation of Contaminated Soils and Sediments,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Klabunde, K.J., “Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 89-26, 92-03.

Klabunde, K.J., “Nanoscale Metal Oxide Particles as Reagents for Destruction and Immobilization of Hazardous Substances in Air, Water and/or as an Alternative to Incineration,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 95-04a.

Kross, B.C., “Removal of Nitrogenous Pesticides from Rural Well Water Supplies by Enzymatic Ozonation Process,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1991. Project no. 16.

Kubichek, R.F., J.J. Cupal, and W.P. Iverson, “Identifying Groundwater Threats from Improperly Abandoned Boreholes,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-24.

Leven, B.A., “Technical Outreach Services for Communities,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998.

Leven, B.L., and S.C. Grant, “Research and Re-education for Displaced Defense Personnel Program,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Lewandowski, Z., “Heavy Metals Removal from Dilute Aqueous Solutions Using Biopolymers,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-22.

Lewandowski, Z., “Heavy Metals Removal from Contaminated Water Solutions,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995. Project no. 92-08.

Licht, L.A., “Riparian Poplar Tree Buffer Impact on Non-Point Source Surface Water Contamination: A Paired Agricultural Watershed Study,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 91-03.

Logan, R.A., “The News Media Manual: A Guide for Hazardous Substance Research Centers,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992.

Miller, J.D., “Removal of Chlorinated Hydrocarbons from Contaminated Water Using Air-Sparged Hydrocyclone Technology,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 94-15.

Munshower, F.F., “Clean Tailing Reclamation, Acid-Producing Metalliferous Waste Reclamation by Material Reprocessing and Vegetative Stabilization,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 93-12.

Niemeyer, S.M., W.E. Woldt, M.F. Dahab, and R.D. Grisso, “Waste Management: Development of Pollution Prevention Educational Materials for Farms and Small Acreages,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

O'Connor, J.T., and B.J. Brazos, “The Response of Natural Groundwater Bacteria to Groundwater Contamination by Gasoline in a Karst Region,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1991. Project no. 89-17.

O'Keefe, T.J., and J.L. Watson, “The Characterization and Treatment of Hazardous Materials from Metal/Mineral Processing Wastes,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 17.

O’Keefe, T.J., “Design and Development of an Innovative Industrial-Scale Process to Economically Treat Waste Zinc Residues,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-05.

Parkin, G.F., and D.T. Gibson, “Feasibility of *In Situ* Anaerobic Bioreclamation of Mixtures of Toxic Chemicals,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 5.

Parkin, G.F., and D.T. Gibson, “Feasibility of Using Genetically Engineered Bacteria to Degrade Trichloroethylene in Activated-Sludge Systems,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992.

Parkin, G.F., and L.J. Weathers, “The Effect of Redox Conditions on Transformations of Carbon Tetrachloride,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 91-08.

Parkin, G.F., “Application of Anaerobic and Multiple-Electron-Acceptor Bioremediation to Chlorinated Aliphatic Subsurface Contamination,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 93-24.

Parkin, G.F., “Formation and Transformation of Pesticide Degradation Products under Various Electron Acceptor Conditions,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995. Project no. 91-07.

Parkin, G.F., L.J. Weathers, J.L. Schnoor, and P.J.J. Alvarez, “The Role of Metallic Iron in the Biotransformation of Chlorinated Xenobiotics,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 93-02.

Peyton, R.L., and S.H. Anderson, "Simulation of Three-Dimensional Transport of Hazardous Chemicals in Heterogeneous Porous Media Using X-Ray Computer Tomography," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-14.

Pierzynski, G.M., and A.P. Schwab, "Reducing Heavy Metal Availability to Perennial Grasses and Row-Crops Grown on Contaminated Soils and Mine Spoils," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1993. Project no. 89-30.

Pierzynski, G.M., L.E. Erickson, S.C. Grant, L.C. Davis, L.A. Licht, and J.L. Schnoor, "The Use of Poplar Trees in Remediating Heavy Metal-Contaminated Sites," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995. Project no. 92-05.

Reclamation Research Unit, "Geochemical Characterization of Sulfide Mineral Weathering for Remediation of Acid-Producing Mine Wastes," Reclamation Research Publication No. 9203-1, pages 1-167, Montana State University, Bozeman, Montana, 1992.

Rice, J.A., "Contaminant Binding to the Humin Fraction of Soil Organic Matter," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-11.

Schaefer, V.R., and S.R. Burckhard, "Development of a Systematic Methodology for Optimally Designing Vegetative Systems for Remediating Contaminated Soil and Groundwater," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-12.

Schlup, J.R., "Adsorption of Hazardous Substances onto Soil Constituents," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1991. Project no. 18.

Schnoor, J.L., and G.F. Parkin, "Modeling Dissolved Oxygen, Nitrate, and Pesticide Contamination in the Subsurface Environment," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 10.

Schnoor, J.L., and L.A. Licht, "Deep-Rooted Poplar Trees as an Innovative Treatment Technology for Pesticide and Toxic Organics' Removal from Groundwater," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1993. Project no. 89-10.

Schnoor, J.L., and L.A. Licht, "Innovative Treatment and Bank Stabilization of Metals-Contaminated Soils and Tailings Along Whitewood Creek, South Dakota," Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 90-05.

Schnoor, J.L., and J.G. Burken, "Uptake of BTEX Compounds and Metabolites by Hybrid Poplar Trees in Hazardous Waste Remediation," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-25.

Schnoor, J.L., L.A. Licht, and C. Just, "Metals Soil Pollution and Vegetative Remediation," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995. Project no. 92-11.

Schnoor, J.L., A. Dietz, and C.Just, “Plant-Enzyme Systems for the Phytoremediation of Chlorinated Aliphatics in Contaminated Soils,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 95-29.

Schwab, A.P., M.K. Banks, and B.A. Leven, “Field Vegetation of an Optimal Design Methodology for Vegetative Remediation of Sediments from the Central Vehicle Wash Facility, Custer Hill, Fort Riley, Kansas,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. SP96-Riley.

Schwab, A.P., M.K. Banks, L.E. Erickson, and J.C. Tracy, “Fate and Transport of Heavy Metals and Radionuclides in Soil: The Impacts of Vegetation,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 93-06.

Segar, R.L., “Trichloroethene (TCE) Cometabolism in Fluidized-Bed Bioreactors,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 94-07.

Shue, S.L. “Using BibTeX for PGNAA Reports,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Shue, S.L. “Use of the Discrete Ordinates Code DANTSYS in Neutron Transport,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1996.

Shue, S.L., and R.R. Faw, “Penetration of 14-MeV Neutrons into Representative Soils,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1996.

Shultis, J.K., “Format Style for PGNAA Project Reports: A Special LATEX Style,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Shultis, J.K., R.E. Faw, and F.A. Khan, “Mathematical Models and Analysis for PGNAA of Soil,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1996.

Sims, J.L., and R.C. Sims, “Development of a ‘State of the Science and Technology’ Report on Site Characterization Technologies,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. TR97-07.

Sims, J.L., and R.C. Sims, “Guidance for the Use of Prepared-Bed Land Treatment as a Bioremedial Technology,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Sims, R.C., “Field-Scale Bioremediation: Relationship of Parent Compound Disappearance to Humification, Mineralization, Leaching, and Volatilization of Transformation Intermediates,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 93-21.

Sims, R.C., “Libby, Montana, Superfund Site: Prepared-Bed Bioremediation in Buried Lifts as Affected by Oxygen Concentration in Soil Gas,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Steichen, J.M., P.L. Barnes, E.C. Dickey, and D.P. Shelton, “Alachlor and Atrazine Losses from Runoff and Erosion in the Blue River Basin,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 89-31.

Tosee, M.D., “Report and Assessment of Tribal Environmental Concerns,” Progress Report, Haskell Environmental Research Studies Center, Haskell Indian Nations University, Lawrence, Kansas, 1994.

Tracy, J.C., L.E. Erickson, L.C. Davis, and J.L. Schnoor, “Modeling the Use of Plants in Remediation of Soil and Groundwater Contaminated by Hazardous Organic Substances,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1994. Project no. 90-13.

Turner, J.P., L.A. Bulla, and Q.D. Skinner, “Biofilm Barriers for Waste Containment,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1997. Project no. 94-26.

Valentine, R.L., “*In Situ* Soil and Aquifer Decontamination Using Hydrogen Peroxide and Fenton's Reagent,” Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-11.

Viswanath, D.S., S. Kapila, and T.E. Clevenger, “Development, Characterization, and Evaluation of Adsorbent Regeneration Processes for Treatment of Hazardous Waste,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 13.

Walawender, W.P., and L.T. Fan, “Thermochemical Treatment of Hazardous Wastes,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1991. Project no. 12.

Walser, G., T.H. Illangasekare, J. Weaber, and D. Znidarcic, “An Experimental Evaluation of Two Sharp-Front Models for Vadose Zone Nonaqueous-Phase Liquid Transport,” Completion Report, U.S. EPA Kerr Laboratory, EPA/600/R-94/197, 1994.

Walton, C.W., “An Electrochemical Method for Acid Mine Drainage Remediation and Metals Recovery,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 89-19.

Wang, X., “Use of the BUGLE-93 Cross Section Library,” Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1995.

Whiting, B.H.J., “NAOMI Summer Research Cooperation,” Progress Report, Haskell Environmental Research Studies Center, Haskell Indian Nations University, Lawrence, Kansas, 1994.

Yanders, A.F., and S. Kapila, “Time Dependent Movement of Dioxin and Related Compounds in Soil,” Final Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1992. Project no. 9.

Zhang, T.C., P.J. Shea, and S.D. Comfort, "Simultaneous Transformation of Atrazine and Nitrate in Contaminated Water, Sediment, and Soil by Zero-Valent Iron-Promoted Processes," Progress Report, Hazardous Substance Research Center, Kansas State University, Manhattan, Kansas, 1998. Project no. 95-32.

F. THESES/DISSERTATIONS

Abedeen, F., "Microbial Processes in Porous Media," M.S. Thesis, Montana State University, Bozeman, 1990.

Adamson, D.T., "Biotransformation of Mixtures of Carbon Tetrachloride, Perchloroethylene, and 1,1,1-Trichloroethane," M.S. Thesis, University of Iowa, Iowa City, 1996. Project no. 93-24.

Al-Sheriadeh, M.S., "Numerical Modeling of Transport of Nonaqueous-Phase Contaminants in Heterogeneous Aquifers," Ph.D. Dissertation, University of Colorado, Boulder, 1993.

Aoki, D.F., "The Uptake of Arsenic and Cadmium in Mine Tailings by Poplar Trees," M.S. Thesis, University of Iowa, Iowa City, 1992.

Armbruster, E.J., "Study of Transport and Distribution of Lighter-than-Water Organic Contaminants in Groundwater," M.S. Thesis, University of Colorado, Boulder, 1991.

Arunachalam, M., "Microbial Degradation of Polycyclic Aromatic Hydrocarbons in Rhizosphere Soil," M.S. Thesis, Kansas State University, Manhattan, Kansas, 1995.

Atteya, M., "The Use of Magnesium Oxide as a Model Compound for Decomposing Air Pollutants and Other Compounds," M.S. Thesis, Kansas State University, Manhattan, 1990.

Berkey, J., "Tracer Studies for Evaluation of *In Situ* Air Sparging and In-Well Aeration System Performance at a Gasoline Contaminated Site in Layton, Utah," M.S. Thesis, Utah State University, Logan, Utah, 1998. Project no. 93-20.

Bier, E.L., "Abiotic Remediation of RDX-Contaminated Water and Soil," M.S. Thesis, University of Nebraska, Lincoln, 1997. Project no. 92-24.

Brady, J., "The Design of a Subsurface Irrigation System Utilizing Poplar Trees for Nitrate Removal from Agricultural Drainage Water," M.S. Thesis, University of Iowa, Iowa City, 1990.

Burckhard, S., "The Impact of Vegetation on the Transport of Heavy Metals from Contaminated Soils," Ph.D. Dissertation, Kansas State University, Manhattan, 1997. Project no. 93-06.

Burken, J.G., "Vegetative Uptake by *Populus* spp. and Mineralization of Atrazine in Variable Soil Types," M.S. Thesis, University of Iowa, Iowa City, 1993.

Cady, J.C., "Gasification Techniques in Waste Treatment," Ph.D. Dissertation, University of Missouri, Columbia, 1990.

Campbell, J.A., "Nonaqueous-Phase Liquid (NAPL) Flow through Heterogeneous Porous Media: Experimental Study and Conceptual Sharo-Front Model Development," M.S. Thesis, University of Colorado, Boulder, 1993.

Christ, S.J., “Sequential Transformation of Carbon Tetrachloride, Perchloroethylene, and 1,1,1-Trichloroethane Using Methanogenic and Methanotrophic Conditions,” M.S. Thesis, The University of Iowa, Iowa City, 1996.

Coffin, D., “Considerations in the Design of Cost-Effective Soil Venting Processes,” M.S. Thesis, Kansas State University, Manhattan, 1991.

Coyle, C.G., “Aerobic Phenol-Induced TCE Degradation in Completely Mixed, Continuous Culture Reactors,” M.S. Thesis, University of Iowa, Iowa City, 1990.

Currence, D.W., “Biodegradation of Pentachlorophenol by Mixed Culture,” M.S. Thesis, University of Missouri, Columbia, 1992.

Dave, S., “Use of Chemical Speciation to Determine the Leachability of Lead Mine Tailings,” M.S. Thesis, University of Missouri, Columbia, 1991.

Dennis, M.L., “Hydraulic Conductivity of Compacted Soil Treated with Biofilm,” M.S. Thesis, University of Wyoming, Laramie, 1996. Project no. 94-26.

Dhawan, S., “Modeling and Simulating Bioremediation in Aggregated Soils,” M.S. Thesis, Kansas State University, Manhattan, 1991.

Dietz, A.C., “Uptake and Accumulation of Trichloroethylene by Garden Vegetables,” M.S. Thesis, University of Iowa, Iowa City, 1996. Project no. 95-29.

Doughten, R.A., “Biodegradation of 2,4-Dichlorophenoxyacetic Acid (2,4-D) and Pentachlorophenol in Soils,” M.S. Thesis, Montana State University, Bozeman, 1997. Project no. 94-09.

Ewing, J., “Effects of Dimensionality and Heterogeneity on Surfactant-Enhanced Solubilization of Nonaqueous-Phase Liquids in Porous Media,” M.S. Thesis, University of Colorado, Boulder, 1996.

Fairbanks, T., “Light Nonaqueous-Phase Fluid Barriers in Initially Water-Saturated Heterogeneous Porous Media,” M.S. Thesis, University of Colorado, Boulder, 1993.

Fleming, R., “Effects of the Rhizosphere Microflora on Leaching of Zinc from Mine Tailings,” M.S. Thesis, Kansas State University, Manhattan, 1992.

Foeller, J., “Cometabolism of Trichloroethene (TCE) in a Fluidized-Bed Reactor,” M.S. Thesis, University of Missouri-Columbia, Columbia, 1998. Project no. 94-07.

Freier-Coppinger, R. “Sorption of 1,1,1-Trichloroethane, Chloroform, and Dichloromethane into Soil Organic Matter,” M.S. Thesis, University of Iowa, Iowa City, 1989.

Gandhi, P., “Role of Biodegradation in Traditional and Innovative Subsurface Remediation Technologies,” M.S. Thesis, Kansas State University, Manhattan, 1994.

Ghoshal, S., “Photodegradation of PCP in Aqueous and Soil Systems,” M.S. Thesis, University of Missouri, Columbia, 1991.

Ginn, J.S., “Biodegradation and Metabolites of PAHs, Including Phenanthrene and Anthracene, in Soil,” Ph.D. Dissertation, Utah State University, Logan, 1997. Project no. 93-21.

Gregory, K.B., “Enhanced Biotransformations of Carbon Tetrachloride, Tetrachloroethene, and 1,1,1-trichloroethane Using Elemental Iron,” M.S. Thesis, University of Iowa, Iowa City, 1997. Project no. 93-02.

Gu, J., “Biodegradation of Some Commercially Used Solubility Enhancers and Their Toxicity on Growth of Microorganisms,” M.S. Thesis, University of Missouri, Columbia, Missouri, 1996. Project no. 94-08.

Hall, B.L., “Evaluation of Air Injection Remediation Technologies for Contaminated Soil and Groundwater: Instrumentation Development and Field Trials,” Ph.D. Dissertation, Utah State University, Logan, Utah, 1998. Project no. 93-20.

He, Y., “Adsorption and Transport of Zinc and Lead in Soil as Affected by Organic Ligands,” Ph.D. Dissertation, Kansas State University, 1997. Project no. 93-06.

Held, R, “Transport of Dense Organic Fluids in Saturated Soils,” M.S. Thesis, University of Colorado, Boulder, 1993.

Helland, B.R., “Dechlorination of Carbon Tetrachloride with Zero-Valent Iron,” M.S. Thesis, University of Iowa, Iowa City, 1996.

Henderson, C.T., “The Effects of Vegetation on the Mobility and Oxidation State of Chromium in Soil,” M.S. Thesis, Kansas State University, 1997. Project no. 93-06.

Hsieh, C.M., “Biodegradation of PCP in Soils by *Phanerochaete Chrysosporium*,” M.S. Thesis, University of Missouri, Columbia, 1991.

Hughes, J.B., “Anaerobic Biotransformation of Chlorinated Aliphatics: Interactions with Primary Substrate Utilization and Effects of Mixtures,” Ph.D. Dissertation, University of Iowa, Iowa City, 1992.

Hundal, L.S., “TNT Sorption and Fate in Munitions-Contaminated Soil: Implications for Abiotic Remediation,” Ph.D. Dissertation, University of Nebraska, Lincoln, 1997. Project no. 92-24.

Hurst, C.J., “Prepared-Bed Bioremediation at the Libby, Montana, Superfund Site,” M.S. Thesis, Utah State University, Logan , 1996. Project no. 93-21.

Hwang, S.J., “Optimal Removal Conditions of Alachlor in an Ozone-Sparged Reactor,” M.S. Thesis, University of Iowa, Iowa City, Iowa, 1990.

Isbell, L., “Evaluation of Coupled Solid Phase Extraction and Desorption with Supercritical CO_2 for Ultra-Trace Analysis of Xenobiotics in Aquatic Systems,” M.S. Thesis, University of Missouri, Columbia, 1990.

Jennings, S.R., “Geochemical Characterization of Sulfide Mineral Weathering for Remediation of Acid-Producing Mine Wastes,” M.S. Thesis, Montana State University, Bozeman, Montana, 1993. Project no. 93-12.

Johnson, E., “Dispersion of Volatile Organic Chemical Vapor in Heterogenous Soils,” M.S. Report, University of Colorado, Boulder, 1996.

Kalia, P., “Modeling Cometabolism in Biofilm Reactors,” M.S. Thesis, University of Missouri, Columbia, 1996. Project no. 94-07.

Khaleel, A., “Iron Oxide on Magnesium Oxide as a New Destructive Adsorbent for Chlorinated Hydrocarbons,” M.S. Thesis, Kansas State University, Manhattan, 1993.

Koper, O., “Properties of High Surface Area Calcium Oxide and Its Reactivity Towards Chlorocarbons,” Ph.D. Thesis, Kansas State University, Manhattan, 1996. Project no. 89-26, 92-03.

Kruger, E.L., “Enhanced Degradation of Herbicide Wastes in Soil: Implications for Bioremediation of Agrochemical Dealer Sites,” Ph.D. Dissertation, Iowa State University, Ames, 1996. Project no. 93-05.

Kurimski, L.J., “Physiochemical Factors of Iron Photoproduction and a Metals Removal Process for Mine Tailings,” M.S. Thesis, University of Iowa, Iowa City, 1994.

Lay, J., “Surfactant Interaction with Soils,” M.S. Thesis, University of Missouri, Columbia, Missouri, 1997. Project no. 94-08.

Lee, E., “The Fate of Polycyclic Aromatic Hydrocarbons in the Rhizosphere of *Fesuca arundinacea*,” Ph.D. Dissertation, Kansas State University, Manhattan, Kansas, 1996.

Leung, K., “A Conductivity Tracer Test for Biofilm Reactors,” M.S. Thesis, University of Missouri, Columbia, 1996. Project no. 94-07.

Li, W., “Reductive Degradation of Chlorinated Ethylenes by Zero-Valent Zn in Aqueous Solution,” M.S. Thesis, Kansas State University, Manhattan, 1997. Project no. 95-04a.

Li, Z.M., “Remediating TNT-Contaminated Water and Soil by Fenton Oxidation,” Ph.D. Dissertation, University of Nebraska, Lincoln, 1996. Project no. 92-24.

Licht, L.A., “Poplar Tree Buffer Strips Grown in Riparian Zones for Biomass Production and Non-Point Source Pollution Control,” Ph.D. Dissertation, University of Iowa, Iowa City, 1990.

Liu, M.H., “Evaluation of Supercritical Fluid Extraction for the Removal of Chlorinated Xenobiotics from Soil,” Ph.D. Dissertation, University of Missouri, Columbia, 1992.

Lo, Y.-H., “Studies on the Persistence of Polychlorinated Dibenzo-P-Dioxin (PCDD) and Polychlorinated Dibenzofuran (PCDF),” M.S. Thesis, University of Missouri, Columbia, 1990.

Lundman, R.W. “Transport of Substrate and Biomass in a Packed-Bed Reactor,” M.S. Thesis, Montana State University, Bozeman, 1992.

Mahashwari, S., “Bench-Scale Process Development Studies for Destructive Adsorption of Chlorocarbons,” M.S. Thesis, Kansas State University, Manhattan, 1996. Project no. 89-26, 92-03.

Manna, M., "Suction-Saturation Measurement in Soils Using the Flow Pump Technique," M.S. Thesis, University of Colorado, Boulder, 1991.

Martin, J.L., "Metabolism of 2,4,6-trinitrotoluene (TNT) by *Pseudomonas savastanoi*," M.S. Thesis, University of Nebraska, Lincoln, 1995. Project no. 92-24.

McDonald, J.P., "Transport Limitations Associated with Traditional and Innovative Sub-Surface Remediation Technologies," M.S. Thesis, Kansas State University, Manhattan, 1994.

McEachern, C., "Up-Scaling of Flow and Transport of Jet Fuels in Near-Surface Environments Under Conditions of Bioactivity," M.S. Thesis, University of Colorado, Boulder, 1998. Project no. 94-29.

Menon, R., "Adsorption of Mercury Vapor by Activated Carbon," M.S. Thesis, Utah State University, Logan, 1991.

Miller, C., "Filter Media Surface Catalyzed Hydrogen Peroxide Decomposition and Oxidation of Selected Contaminants," M.S. Thesis, University of Iowa, Iowa City, 1992.

Mogallapu, S., "Analysis of a Waste Management Option for Titanium Electrochemical Machining," M.S. Thesis, University of Nebraska, Lincoln, 1992.

Nair, D.R., "Atrazine Fate Modeling and Mineralization Studies in Soil-Plant Systems," Ph.D. Dissertation, University of Iowa, Iowa City, 1991.

Nam, K.S., "Application of Supercritical Fluid Extraction and Multidimensional Chromatography for Multiresidue Determinations," Ph.D. Dissertation, University of Missouri, Columbia, 1991.

Narayanan, M., "Modeling the Movement and Fate of Contaminants in an Experimental Chamber with Alfalfa Plants," Ph.D. Dissertation, Kansas State University, Manhattan, 1998. Project no. 94-27.

Nieman, J.K.C., "Binding of PAH to Soil Humic Materials During Prepared Bed Treatment of Contaminated Soil," M.S. Thesis, Utah State University, Logan, 1998. Project no. 93-21.

Novak, P.J., "Formation and Transformation of Alachlor and Atrazine Degradation Products under Various Electron Acceptor Conditions," M.S. Thesis, University of Iowa, Iowa City, 1994.

Novak, P.J., "Enhanced Dechlorination of Carbon Tetrachloride and Chloroform in the Presence of Elemental Iron and Methanogenic Bacteria," Ph.D. Dissertation, University of Iowa, Iowa City, 1997. Project no. 93-02.

Orazio, C.E., "Persistence and Transport of Organochlorine Contaminants in Soils," Ph.D. Dissertation, University of Missouri, Columbia, 1992.

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.

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.

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.

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 & 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.

INDEX

R

S

T

U

V

W

X

Z