Innovative Ground-Water Remediation Technologies: Publications and Conference Proceedings

1990-1996

U.S. Environmental Protection Agency
Technology Innovation Office
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Foreword

This bibliography identifies reports, journal articles, and conference proceedings published from 1990 to 1996 that focus on innovative technologies for the remediation of contaminated ground water. The purpose of this document is to provide a guide to publications that may be useful in evaluating the development of these types of technologies. Records were obtained from a comprehensive search of the following files contained in the Knight-Ridder (formerly Dialog) collection of online electronic databases: BIOSIS Previews; NTIS (National Technical information Service); ISMEC: Mechanical Engineering Abstracts; IAC PROMPT; Oceanic Abstracts; Enviroline; Pollution Abstracts; Aquatic Sciences and Fisheries Abstracts; CAB Abstracts; GeoArchive; Environmental Bibliography; Life Sciences Collection; TULSA (Petroleum Abstracts); IAC Business A.R.T.S.; GeoRef; FLUIDEX (Fluid Engineering Abstracts); Energy Science and Technology; Nuclear Science Abstracts; Water Resources Abstracts; PASCAL; IAC Trade & Industry Database; WATERNET; GEOBASE; Analytical Abstracts; IAC Newsletter Database. Those records which indicated significant coverage of ground-water remediation technologies, modeling related to remediation, or electrokinetics were included. Records were reviewed and organized according to primary technology focus. This bibliography includes publications issued by the Federal government, private corporations and academia.

Notice

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SURVEYS/COMPENDIUMS/MULTIPLE TECHNOLOGY REPORTS

GENERAL

1996:

Treatment Technologies for Contaminated Groundwater: A Literature Review
Mulira, J. E., Ontario Ministry of Environment & Energy, Science & Technology Branch, Landfill Technology & Site Remediation Section, Toronto.
Report No.: ISBN-0-7778-4837-6; NTIS Number: MIC-96-02782 1996 107p

The primary purpose of this report is to review the various groundwater treatment technologies that have been developed and are commercially available, are in a state of development, or are in the process of being tested. Introductory chapters provide background on the problem of groundwater contamination, notably by non-aqueous phase liquids, and on the selection of an appropriate treatment technology. Subsequent chapters review conventional technologies, including bioremediation, air stripping, carbon adsorption, and the use of physical barriers; innovative technologies such as electrokinetics, application of polymers, enzyme detoxification, dehalogenation with metal catalysts, and adsorptive filtration; and remediation strategies appropriate for non-aqueous phase liquids. The appendix includes a review of pump-and-treat systems, a summary table of the technologies reviewed, and a table of groundwater treatment projects.

Application of Innovative Remediation Technologies at Superfund Sites Continues to Increase
Hazard Waste Consult Vol 14 No 3 May-Jun 1996 p 1.25(4)
(Full text available from Congressional Information Service, 1-800-227-2477 Article order code: A)

Innovative remediation technologies are increasingly being demonstrated at Superfund sites. Novel soil remediation and groundwater cleanup systems, including in situ or ex situ bioremediation, air sparging, phytoremediation, and solvent extraction, have been applied to source control remedial action, groundwater treatment, and removal action phases to some extent. The number and types of projects completed or continuing at Superfund sites are surveyed. Of the 297 process applications selected by EPA, 44% are now in the design phase, 42% are under construction, and 14% are completed.

Beyond "Pump and Treat"
Kim, Irene; Ondrey, Gerald
Chem Eng Vol 103 No 3 Mar 1996 pp 30-34
(Full text available from Congressional Information Service at 1-800-227-2477.)

Economic factors are forcing environmental remediation services to clean up sites faster and more cost-effectively. A variety of new cleanup and containment technologies have been developed to assist in these efforts. However, most CPI customers are reluctant to experiment with new technologies. These customers typically prefer the standard "pump and treat" cleanup strategies, which are easily approved by the EPA and local regulators. However, the new technologies are making inroads into the field of environmental cleanup. Several of the most prominent success stories are reviewed. The benefits to be gained from air sparging and air stripping methods are discussed. Air sparging techniques can be combined with vapor extraction to achieve very competitive site remediation.

Evaluation of Improved Technologies for the Removal of Sr90 and Cs137 from Process Wastewater and Groundwater: FY 1995 Status
Bostick, D.T.; Arnold, W.D.; Burgess, M.W.; McTaggart, D.R.; Taylor, P.A.
Oak Ridge National Lab., TN.
Sponsor: Department of Energy, Washington, DC.
Report No.: ORNL/TM-13099; NTIS Number: DE96009669 Mar 96 78p

A number of new sorbents are currently being developed for the removal of Sr-90 and Cs-137 from contaminated, caustic low-level liquid waste (LLLW). The goal of this subtask is to evaluate the new sorbents to determine whether their associated treatment technology is more selective for the decontamination of wastewater streams than that of currently available processes. Activities during fiscal year 1995 have included completing the characterization of the standard treatment technology, ion exchange on chabazite zeolite. Strontium and cesium sorption on sodium-modified zeolite was observed in the presence of elevated concentrations of wastewater components: sodium, potassium, magnesium, and calcium. Radionuclide sorption on the pretreated zeolite was also determined under dynamic flow conditions.

1995:

Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation (Fourth Edition)
Federal Remediation Technologies Roundtable
Report No.: EPA/542/B-95/004; NTIS Number: PB96-145099 Oct 1995 57p

This bibliography provides a list of titles and ordering information for publications on innovative technology development and demonstration issued by member agencies of the Federal Remediation Technologies Roundtable. The bibliography focuses on innovative technologies that provide for the treatment of hazardous wastes. The bibliography is organized by media or technology type, and it is further categorized by the issuing Agency. Information on ordering listed publications can be found at the end of the bibliography.

Remediation Technologies Screening Matrix and Reference Guide, Second Edition (on CD-ROM) (Data file)
Department of the Army, Washington, DC
NTIS Number: PB96-500558; 1 CD-ROM GRAI9607 1995
Contains search and retrieval software. The datafile is on one disc.

This guide is intended to be used to screen and evaluate candidate cleanup technologies for contaminated installations and waste sites in order to assist remedial project managers (RPMs) in selecting a remedial alternative. The guide allows the user to gather essential descriptive information on the respective treatment technologies, incorporating cost and performance data to the maximum extent available. The guide focuses primarily on demonstrated technologies with available performance data; however, emerging technologies may be more appropriate in some cases based upon site conditions and requirements. As more is learned about these developing technologies, the guide will be updated accordingly. These technologies, both demonstrated and emerging, are applicable at all types of site cleanups: Superfund, DOD, DOE, RCRA, state, private, etc.

Selected Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation: A Bibliography of EPA Information Resources. Winter Update, January 1995
Environmental Protection Agency, Washington, DC. Technology Innovation Office.
Report No.: EPA/542/B-95/001; NTIS Number: PB95-201653 Jan 1995 9p

This bibliography provides a list of US EPA information resources describing various innovative treatment technologies relating to Superfund and Resource Conservation and Recovery Act (RCRA). It contains sections on: Conferences and international surveys; Technology survey reports and guidance; Treatability studies; Ground water; Thermal treatment; Bioremediation; Soil vapor extraction and enhancements; Soil washing treatment; Physical and chemical treatment; Technical support; Community relations; Bulletin board systems and databases; Technology newsletters; Federal Remediation Technologies Roundtable reports; and Innovative Site Remediation Technology monographs. Information on how and where to get these reports is provided.

Innovative Treatment Technologies: Annual Status Report (Seventh Edition). Applications of New Technologies at Hazardous Waste Sites
Fiedler, L.
Environmental Protection Agency, Washington, DC, Technology Innovation Office.
Report No.: EPA/542/R-95/008; NTIS Number: PB96-131693 Sept 1995 87p

This report documents the status of application of innovative treatment technologies in the Superfund program. It presents information on some, but not all, projects applying innovative treatment technologies at non-superfund sites such as those subject to corrective action under the Resource Conservation and Recovery Act (RCRA) and those being addressed by the Department of Defense (DoD), and the Department of Energy (DOE). We have expected the report to include many new innovative projects selected by the EPA in fiscal year 1994 and numerous graphics and tables to assist the reader on understanding the data.

Subsurface Volatilization and Ventilation System (SVVS): Innovative Technology Evaluation Report
King, J.; Beckman, S.; Kitaplioqlu, O.
Illinois Environmental Protection Agency, Springfield, IL
Bureau of Water Publication Aug 1995 (108 p)
Report Number(s): PB-96-116488

This report summarizes the findings of a Demonstration Test of Brown and Root Environmental's Subsurface Volatilization and Ventilation System (SVVS) process. Under the SITE program, the technology was evaluated to determine its effectiveness in reducing volatile organic contamination in the vadose zone of the former 'dry well area' of the Electro-Voice facility after one year of treatment. The SVVS process is an integrated technology that utilizes the benefits of soil vapor extraction/air sparging and in-situ bioremediation for the treatment of subsurface organic contamination in soil and groundwater. Demonstration results showed that the SVVS achieved an overall 80.6% reduction in the sum of the seven critical VOCs in the vadose zone, exceeding the vendors claims. Reductions of 81.5% were achieved in the 'sludge' layer, and between 97.8% and 99.8% for the other vadose zone layers.

Ground Water Currents: Developments in Innovative Ground Water Treatment, Issue No 13, September 1995

Environmental Protection Agency, Washington, DC. Office of Solid Waste and Emergency Response.
Report No.: EPA/542/N-95/006; NTIS Number: PB96-114814 Sep 1995 5p

Contents: Ground Water Remediation Center; A solution to bioremediation's soil plugging; Bioremediation video; VISITT 4.0 update; Update on ZENON pervaporation; and Site search-NAPL contaminated site wanted.

Ground Water Currents: Developments in Innovative Ground Water Treatment, Issue No 12, July 1995

Environmental Protection Agency, Washington, DC. Office of Solid Waste and Emergency Response.
Report No.: EPA/542/N-95/004; NTIS Number: PB95-263901 Jul 1995 6p

Contents: Tracers detect aquifer contamination; Natural attenuation of hexavalent chromium; New wellhead analytic model; and Metal-enhanced abiotic degradation of VOCs.

Ground Water Currents: Developments in Innovative Ground Water Treatment, Issue No 11, April 1995

Environmental Protection Agency, Washington, DC. Office of Solid Waste and Emergency Response
Report No.: EPA/542/N-95/002; NTIS Number: PB95-220679 Apr 1995 6p

Contents: Hydrocarbon filtration recovery system; Bioreactor and membrane for volatile organic compounds (VOC); Ultrasound examined for in situ monitoring; and Dense nonaqueous phase liquids (DNAPL) technologies evaluated.

NATO/CCMS Pilot Study: Evaluation of Demonstrated and Emerging Technologies for the Treatment and Clean Up of Contaminated Land and Groundwater (Phase 2). Interim Status Report Number 203

Environmental Management Support, Inc., Silver Spring, MD
Report No.: EPA/542/R-95/006; NTIS Number: PB95-227849 May 1995 62p

The document provides an interim status report on the second phase of a Pilot Study designed to share information among countries on innovative treatment technologies. The report is divided into four parts. The first part contains abstracts of each of the technical case studies sanctioned by the Pilot Study prior to September 1994. The second part of the report contains preliminary information on 15 projects newly accepted by the Pilot Study in September 1994. The table on page 30 provides an overview of these projects. The third part contains summaries of guest presentations of general interest made at Pilot Study meetings. The fourth section of the report contains a brief description of NATO fellowships projects.

Groundwater Cleanup Technology Alternatives

Environmental Problems & Remediation Nov 1, 1995 p. N/A

This National Research Council document addresses concerns about the capability of existing technologies to restore contaminated ground water to drinking water standards. It: examines how the physical, chemical, and biological characteristics of the subsurface environment, as well as the properties of contaminants, complicate the cleanup task; reviews the limitation of widely used conventional pump-and-treat cleanup systems; presents detailed case studies; evaluates a range of innovative cleanup technologies and the barriers to their full implementation; and presents specific recommendations for policies and practices in evaluating contaminated sites, in choosing remediation

technologies, and in setting appropriate cleanup goals. (Order this ENVIRONMENTAL PROBLEMS & REMEDIATION reviewed report from InfoTeam Inc., P.O. Box 15640, Plantation, FL 33318-5640; Phone 305 (or 954) 473-9560, Fax 305 (or 954) 473-0544: Report No N951108; Sep. 1994, 317 pp. Price: $339.00, prepaid.)

Developing Innovative Environmental Technologies for DOE Needs
Devgun, J. S.; Sewell, I. O.; DeGregory, J.
Argonne National Lab., IL.
Proceedings: Intersociety Energy Conversion Conference, Orlando, FL 30 Jul - 5 Aug 1995
Report No.: ANL/CMT/CP-86433; NTIS Number: DE95014242 1995 11p

Environmental restoration and waste management activities at US Department of Energy (DOE) facilities are diverse and complex. Contamination at DOE sites and facilities includes radionuclides, chlorinated hydrocarbons, volatile organic compounds, non-aqueous phase liquids, and heavy metals, among others. Soil and groundwater contamination are major areas of concern and DOE has focused very significant efforts in these areas. Relevant technology development activities are being conducted at DOE's own national laboratories, as well as through collaborative efforts with other federal agencies and the private sector. These activities span research and development (R&D) of new concepts and techniques to demonstration and commercialization of mature technologies. Since 1990, DOE has also supported R&D of innovative technologies through interagency agreements with US Environmental Protection Agency (EPA), US Department of Defense, the National Science Foundation, and others.

Proceedings of the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management, Pittsburgh, PA 1995
Vidic, Radisav D. (Ed.); Pohland, Frederick G. (Ed.)
Publisher: ASCE 746p

The proceedings contains 93 papers. Topics discussed include waste site remediation, soil vapor extraction, drinking water treatment, risk assessment, contaminant transport modeling, barriers for waste containment, innovative waste treatment technology, in situ biological treatment, soil washing technologies, pump and treat technologies, site assessment, nutrient removal, groundwater cleanup, mobilization and transport of contaminants in subsurface, biosolids management, pollution control, adsorption technologies for hazardous waste treatment, radioactive waste treatment, air emission control, landfill construction and stability, phytoremediation and air pollutants impact.

AECL Remediation Technology Development and Demonstration
Buckley, L.P.; Vijayan, S.; Wong, P.C.F.; Daughney, S.R.
Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada, Chalk River Labs Proceedings: Volume 2: Management of Low-level Waste and Remediation of Contaminated Sites and Facilities, Fifth International Conference on Radioactive Waste Management and Environmental Remediation -- ICEM '95, Berlin (Germany) 3-9 Sep 1995 pp 1439-1442
Publisher: New York, NY: American Society of Mechanical Engineers 1995
Report Number(s): CONF-950917

Several innovative remediation technologies for the treatment of contaminated soils, groundwater, waste water and organic liquids are being actively pursued at the Chalk River Laboratories of Atomic Energy of Canada Limited. The contamination is usually a mixture of radioactive and hazardous species. The treatment objective is to maximize the recovery of clean material and to minimize the

volume of secondary waste arising from the remediation steps. The projects, developed in a laboratory, are tested with actual contaminated materials. The technology is then applied to contaminated sites at Chalk River, to determine its feasibility and to gather information on its efficiency and cost effectiveness. Technology has been developed to remove Sr-90 from groundwater to less than 2 Bq/L. The technology demonstration, initially cost-shared with the United States Department of Energy (USDOE), has now treated in excess of 2 million liters of groundwater. Technology is also available to strip Sr-90 from soil both in situ and ex situ. A treatability study was conducted for the removal of uranium, radium and arsenic from groundwater obtained from a land area contaminated by uranium refining operations. Mixed-waste processing has been developed for the removal of uranium from organics to permit alternative treatment of the separated fractions. A horizontal pulsed column and a more conventional mixer/separator system extract uranium from the organic, to allow recycle of the uranium as yellowcake and to allow destruction of the hazardous organic fraction.

Emerging Technologies for Hazardous Waste Management V
Tedder, W.; Pohland, F.G. (eds.)
1995 309 pp
Publisher: American Chemical Society, Washington, DC

Presents a summary of remedial technologies for contaminated soils and ground waters. Examines treatment combinations for remediation of Superfund sites. Provides a listing of critical technology needs in hazardous waste site remediation. Discusses new developments in soil cleaning, resource recovery, nitrification, thermal destruction, chemical oxidation and catalysis, extraction and precipitation, and biological degradation for in situ and ex situ remediation.

Stakeholder Acceptance Analysis: In-Well Vapor Stripping, In-Situ Bioremediation, Gas Membrane Separation System (Membrane Separation)
Peterson, T.
Battelle-Seattle Research Center, WA
Report No.: PNNL-10912;BSRC-800/95/021; NTIS Number: DE96005841 Dec 1995 70p

This document provides stakeholder evaluations on innovative technologies to be used in the remediation of volatile organic compounds from soils and ground water. The technologies evaluated are; in-well vapor stripping, in-situ bioremediation, and gas membrane separation.

Operation and Maintenance of Remediation Systems
Katin, R.A.
Groundwater Technology, Inc., Concord, CA
Proceedings of HAZMACON '95: Hazardous Materials Management Conference and Exhibition, San Jose, CA 4-6 Apr 1995 pp 224-232
Publisher: Oakland, CA: Association of Bay Area Governments 1995
Report Number(s): CONF-9504134

Soil and groundwater contamination are relatively common. Many new companies have been created to enter this growing market. Much of the cost associated with a remediation system is a function of the remediation system design. There is a onetime capital cost associated with new equipment, and there is a continual recurring operation and maintenance (O M) cost. The remediation method selected has a significant effect on O M cost. Treatment methods, such as carbon and resin beds, typically have a low capital cost, but a high O M cost however, regardless of the remediation system

selected, a good design can minimize unnecessary O M costs. Typically, site visits are necessary to record data and collect samples to evaluate remediation system progress. If inexpensive preventive maintenance is not conducted, costly, major corrective maintenance may be required later. The purpose of this paper is to provide the practicing plant engineer or small business person with sufficient information regarding remediation systems enabling him to recognize a good design and aspects of a good design which will allow ease of operation and maintenance. Remediation systems to be reviewed include: air strippers; oil/water separators; vacuum extraction systems; catalytic and thermal incinerators; carbon beds; air sparging systems; and biological treatment systems.

Remediation Alternatives for Low-Level Herbicide Contaminated Groundwater
Conger, R.M.
BASF Corp., Geismar, LA
Proceedings: American Association of Petroleum Geologists (AAPG) Gulf Coast Section meeting Baton Rouge, LA 25-27 Oct 1995
AAPG Bulletin Vol 79 No 10 Oct 1995 pp 1556-1557

In early 1995, an evaluation of alternatives for remediation of a shallow groundwater plume containing low-levels of an organic herbicide was conducted at BASF Corporation, a petrochemical facility located in Ascension Parish, Louisiana. The contaminated site is located on an undeveloped portion of property within 1/4 mile of the east bank of the Mississippi River near the community of Geismar. Environmental assessment data indicated that about two acres of the thirty acre site had been contaminated from past waste management practices with the herbicide bentazon. Shallow soils and groundwater between 5 to 15 feet in depth were affected. Maximum concentrations of bentazon in groundwater were less than seven parts per million. To identify potentially feasible remediation alternatives, the environmental assessment data, available research, and cost effectiveness were reviewed. After consideration of a preliminary list of alternatives, only two potentially feasible alternatives could be identified. Groundwater pumping, the most commonly used remediation alternative, followed by carbon adsorption treatment was identified as was a new innovative alternative known as vegetative transpiration. This alternative relies on the natural transpiration processes of vegetation to bioremediate organic contaminants. Advantages identified during screening suggest that the transpiration method could be the best remediation alternative to address both economic and environmental factors. An experiment to test critical factors of the vegetatived transpiration alternative with bentazon was recommended before a final decision on feasibility can be made.

Soil Flushing, Iron Coprecipitation, and Ceramic Membrane Filtration: Innovative Technologies for Remediating Arsenic-Contaminated Soil and Groundwater
Redwine, J.C.
Southern Company Services, Inc., Birmingham, AL
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 pp 1129-1132
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

This paper provides a brief description and case study of soil flushing to treat contaminated groundwater. Selected reagents may be added to the flushing water to enhance contaminant removal. In the iron coprecipitation process, and iron salt is added to the contaminated water and the pH is adjusted to induce precipitation of iron oxyhydroxides. During floc formation, trace elements adsorb onto the iron floc. Cross-flow ceramic membrane filtration can be used to remove any remaining contaminant in

the feed stream. In field tests, an arsenic plume flushed with citric acid was reduced by 73 percent after 6 months of treatment.

Evaluation of an Integrated Treatment System for MGP Site Groundwaters
Scheible, O. Karl; Grey, Gary M.; Maiello, Joy A.
HydroQual Inc, Mahwah, NJ
Bioremediation of Recalcitrant Organics Vol 7 1995 pp 63-72
(Full text available from Congressional Information Service: 1-800-227-2477)

At a former manufactured gas plant (MGP) site in New Jersey, bench- and pilot-scale investigations were conducted to develop and demonstrate an integrated treatment system for contaminated groundwaters. The integrated treatment system consisted of dissolved-air flotation, a carbon-based fluidized-bed bioreactor, and granular activated C adsorption. The data showed that dissolved-air flotation was able to reduce PAH levels to approximately 200 (gr)mg/l and VOCs to approximately 2500 (gr)mg/l. The Shallow Tray air stripper reduced both VOCs and PAHs to levels less than detection. Carbon adsorption provided a further reduction of COD. Air stripping and biological treatment were found to be capable of complete treatment for low to moderately contaminated waters.

Innovative Techniques for Isolating Contaminant Plumes
Hazard Waste Consult Vol 13 No 7 Nov-Dec 95 p 1.16(4)
(Full text available from Congressional Information Service, 1-800-227-2477; Article order code: A)

Three new technologies offer improved alternatives for isolating contaminant plumes at hazardous waste sites. The SoilSawTM barrier system forms a mixed-in-place slurry wall by use of a continuous wall-forming process. Relative to conventional slurry wall methods, barrier wall quality is consistently higher and deeper walls can be established. The circulating air barrier system can also serve as a leak detection and monitoring technology. Field tests have demonstrated the efficacy of ground freezing in forming underground containment barriers.

Design Considerations for VOC Removal
Millett, P C
Foster Wheeler Environ. Corp., Boston, MA
Journal of the New England Water Works Association Vol 109 No 2 1995 pp 140-148

Approximately 50% of the United Stares drinking water supplies and drawn from groundwater. Of these supplies, approximately 25% have been detected with Volatile Organic Chemicals (VOCS) above the maximum contaminant levels (MCLs) established with the 1986 amendments to the Safe Drinking Water Act. As VOCs are known cancer-causing agents, their presence in groundwater is a real concern for the drinking water suppliers throughout the country. The source of VOCs contamination can be traced to landfill leachate, hazardous waste disposal sites, wastewater lagoons, underground storage tanks and accidental spills. Commonly encountered VOCs include chemicals such as trichloroethylene (TCE), trichloroethane (TCA), tetrachloroethylene (PCE), and a family of petroleum compounds known as BTEX, (Benzene, Toluene, Ethylene, and Xylene). All VOCS and man-made organic chemicals and their presence typically indicates some historical presence typically indicates some historical industrial activity. This paper addresses the design considerations of the background of VOCs and their impact on drinking water, treatment techniques and their applicability are discussed from the perspective of the design engineer to address suitability, typical design criteria, practical design considerations, and relative cost estimates. The proven technologies of packed tower aeration (PTA) and granular activated

carbon (GAC) are discussed in detail. These technologies are considered Best Available Technologies (BAT) by the EPA. New and emerging technologies such as advanced oxidation and biological processes are discussed briefly to give the reader an overview of some of the research and innovation in this field. Relative cost estimates are also presented.

1994:

Groundwater Cleanup Realities Test Old Ways, New Approaches
Rubin, Debra K.
Engineering News-Record Vol 233 No 7 Aug 15 1994 pp 30-34

The pump-and-treat approach to groundwater cleanup has been met with opposition, prompting regulators to search for new approaches. The pump-and-treat method has been proven unreliable for ridding the groundwater of inaccessible toxic contaminants. Contaminants such as non-aqueous phase liquids (NAPLs) sink to spots situated far from migrating groundwater plumes. To solve this, technologies under study include metal-enhanced reductive dehalogenation in which mixture of sand and iron fillings dechlorinize groundwater organics. In situ reactive barriers are also eyed to treat contaminant plumes as they pass through walls within the aquifer. Other technologies are described.

Evaluation of Technologies for In-Situ Cleanup of DNAPL Contaminated Sites. Final Report, October 1991-June 1993
Grubb, D.G.; Sitar, N.
California Univ., Berkeley, CA. Dept. of Civil Engineering
Aug 1994 (190 p)
Report Number(s): PB-94-195039

Ground-water contamination by non-aqueous phase liquids poses one of the greatest remedial challenges in the field of environmental engineering. Denser-than-water non-aqueous phase liquids (DNAPLs) are especially problematic due to their low water solubility, high density, and capillary forces arising from interfacial tension between the DNAPLs and water. The problems associated with current pump-and-treat remedial approaches have served as the impetus to develop alternative technologies to accelerate in-situ DNAPL contamination remediation. The report provides a review and technical evaluation of in-situ technologies for remediation of DNAPL contamination occurring below the ground-water table. Various in-situ technologies are reviewed and are evaluated on the basis of their theoretical background, field implementation, level of demonstration and performance, waste, technical and site applicability/limitations, and cost and availability.

Accelerating Underground Storage Tank Corrective Action -- II. Proceedings of The International Specialty Conference
St. Louis, MO, 10-12 Mar 1994
Publisher: Pittsburgh, PA: Air and Waste Management Association 1994 (146 p)
Report Number(s): CONF-940333

The primary objective of this conference was to present and facilitate open discussion of regulatory, technical, and management processes that have been used to speed up and reduce the costs of site assessment and remediation. Given the large number of releases (more than 200,000), regulators, state fund administrators, consultants, contractors, and owners are considering new technologies and processes that will speed up the corrective action process. Experience has shown that shortening the

time in the investigation and remedial action planning of underground storage tank (UST) cleanup projects can improve protection of human health and the environment, and reduce costs. UST regulators, owners, consultants, and contractors were able to learn and explore the latest UST corrective action issues, including: exposure and risk assessment; expedited site assessment; cost control and contract management; measuring performance; in situ remediation technologies; and institutional controls for contaminated properties. Individual papers have been processed separately for inclusion in the appropriate data bases.

Pump-and-Treat is Not the Only Solution to Aquifer Remediation
Odermatt, J.R.
County of San Diego's Site Assessment and Mitigation Div., San Diego, CA
Environmental Solutions Vol 7 No 6 Jun 1994 pp 86

The Environmental Protection Agency recently surveyed remediation technologies used at petroleum-contaminated sites in 22 states. About 96 percent of underground storage tank (UST) corrective action sites used some form of pump-and-treat technology to remediate contaminated groundwater. However, using only pump-and-treat technology is not a cost-effective approach to aquifer remediation. Pump-and-treat may be more appropriate for containing plumes or for use in initial emergency response actions at sites and massive NAPL releases to groundwater. As of 1990, 68 percent of Superfund records of decision selected pump-and-treat as the final remedy for aquifer remediation. However, of 13 sites where the remedial alternative objective was to restore the aquifer to health-based levels, only one pump-and-treat method has succeeded. Except in cases where human health and the environment are threatened, long-term active technologies, such as pump-and-treat, may not be warranted. Groundwater monitoring and possible wellhead treatment may be perceived as time-consuming processes; however, at many sites, this long-term approach may be far less costly and just as effective as other long-term strategies based on exclusive use of pump-and-treat technology.

Restoring Contaminated Groundwater: An Achievable Goal
MacDonald, J.A., National Research Council, Washington, DC;
Kavanaugh, M.C., ENVIRON Corporation, Emeryville, CA
Environmental Science and Technology Vol 28 No 8 Aug 1994 pp 362A-368A

According to a new National Research Council (NRC) study published this month, groundwater restoration may be possible for sites with relatively simple contamination scenarios, but for the most complex sites, which includes the majority of Superfund sites, existing technologies may be unable to restore significant areas to health-based standards. In addition to analyzing conventional pump-and-treat systems, the committee evaluated innovative groundwater and soil cleanup technologies currently under testing and development. Based on its review of the technical, economic, and policy issues raised by the societal goal of cleaning up contaminated groundwater, the committee identified four key areas where change is needed to improve regulation of the cleanup process. The first area is the setting of groundwater cleanup standards by regulatory agencies. The second area the committee found in need of change is in incentives to use innovative technologies. Third, the committee recommends the use of expert panels in technical feasibility evaluations at complex sites. Finally, the committee emphasizes the importance of systematic and continued evaluation of subsurface remediation efforts around the country. 11 refs., 2 tabs.

Capabilities of Enhanced Pump-and-Treat and Alternative Technologies

Bouwer, E.J.; Kavanaugh, M.; Ward, H.
Johns Hopkins Univ., Baltimore, MD, Geography and Environmental Engineering
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 pp 841-842

Numerous innovative technologies exist that have the potential to improve significantly the efficiency of ground water cleanups, especially when technologies suited to specific types of contaminants or specific hydrogeological environments are combined. Conventional pump-and-treat systems are used at approximately three-quarters of sites with contaminated ground water. Innovative technologies can be divided into two categories: enhanced pump-and-treat systems,"which require the pumping of fluids, and alternative technologies," which do not require pumping. Conventional pump-and-treat systems pump relatively large volumes of water with relatively low contaminant concentrations. Because of the slow rates of contaminant desorption and dissolution, these systems must displace many volumes of aquifer water to flush out contaminants. Conventional pump-and-treat systems are therefore an inherently inefficient method for removing contaminants, even if they are effective in some cases. The enhanced pump-and-treat systems improve the efficiency of contaminant removal and lessen pumping requirements under certain conditions. These technologies can enhance contaminant removal and destruction compared to conventional systems, but each requires pumping fluids through the subsurface and will therefore have some of the same limitations as conventional pump-and-treat systems. Conventional pump-and-trade systems and the enhancements require a continuous energy input for pumping water or air. The alternative approaches do not require a continuous energy input and therefore may be less costly. These methods show promise, but they are in the development stage, and their long-term effectiveness has not yet been demonstrated.

Ground Water Remediation Modular Approach Using Multiple Technologies

Mizerany, J.
Geraghty and Miller Inc., Tampa, FL
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 p 856

Shallow ground water at a manufacturing facility in Sarasota, Florida, was impacted by historical practices that caused releases of sodium, sulfate, PCE, and TCE to the ground water. A risk assessment was used successfully to limit remediation to PCE, TCE, and daughter compounds. Due to closure time frames for the RCRA units and the need to remediate a large portion of the site a portable system based on dewatering system technology for recovery and air stripping technology for treatment was selected. The presentation will discuss the factors that were considered in selection of this technology including: A dewatering type system provides the ability to not only recover ground water but also to act as a vapor extraction system for the dewatered sediments which is attractive for remediating VOCs. Furthermore, portions of the well point system can be isolated and can be easily converted to an air sparging system if the need arises to switch to this technology in order to achieve target concentrations. In addition, the presentation will summarize system performance for areas that contain both high and low concentrations of VOCs, and it will address the challenge of determining when target levels are achieved and the well points can be relocated to new areas for cleanup. This last item will focus on the phenomenon of achieving asymptotic levels below MCLs under pumping conditions only to have the concentration rise above MCLs or risk-based concentration levels under static conditions.

Federal Environmental Restoration III and Waste Minimization II Conference and Exhibition: Proceedings, Volume 1
New Orleans, LA, 25-29 Apr 1994
Publisher: Rockville, MD Hazardous Materials Control Resources Institute, 1994 (783 p)
Report Number(s): CONF-940499

This conference was held April 27--29, 1994. in New Orleans, Louisiana. The purpose of this conference was to provide a forum for exchange of state-of-the-art information on environmental restoration and waste minimization. Papers are divided into the following sessions: Contaminated soil treatment; Bioremediation; Groundwater; Mixed waste; DOE initiatives; Agency programs; Air pollution standards; Explosives and munitions; Decontamination; RCRA; Legal issues; Panel discussion--Federal environmental restoration; Health and safety; Corps of Engineer activities; Base management; Underground tanks; Special issues; Design and construction; and Incineration. Individual papers have processed separately for inclusion in appropriate data bases.

Superfund XV Conference Proceedings. Volume 1 SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994
Publisher: Rockville, MD Hazardous Materials Control Resources Institute, 1994 (866 p)
Report Number(s): CONF-941189

This conference was held November 29--December 1, 1994 in Washington, D.C. The purpose of this conference was to provide a forum for exchange of state-of-the-art information on Superfund. Papers are included on the following topics: bioremediation; building decontamination; environmental policy issues; federal environmental restoration; groundwater remediation; innovative sampling and analytical technologies; laboratory methods; metals management; mixed wastes; PCB waste management; remediation technology and case studies; and risk assessment. Individual papers have been processed separately for inclusion in the appropriate data bases.

Techniques for Successful Implementation of In-Situ Remediation Systems
Fulton, D.E.
OHM Remediation Services Corp., Trenton, NJ
Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994
pp 91-96
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

Successful completion of soil and groundwater remediation projects involves the integration of services provided by a multi disciplined team of design engineers/scientists and remedial contractors. While the necessity for integrated and sequential activities is well understood and practiced within their respective disciplines, the transition from design phase to construction phase has historically been more discontinuous. As the remediation industry rapidly matures with the emergence of applied innovative technology and a greater demand for on-site remedies, emphasis on this transitional phase becomes even more important. Subsequently, selecting and implementing cost-effective technologies requires a defined working process that emphasizes the integrated relationship between the design engineer/scientist and remedial contractor. Therefore, the transition phase between the preparation of detailed specifications and field implementation is the critical junction which has the greatest impact on

the overall success of the remediation project. This paper focuses on methods and techniques that facilitate an effective design and construction program within the transition phase.

Comparative Costs of Ground-Water Restoration: Pump-and-Treat vs. Containment
Sawyer-Cann, H., DynCorp Viar, Alexandria, VA. Environmental Services Division;
Breeden, R., Environmental Protection Agency, Washington, DC. Hazardous Site Control Div.
Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 291-297
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

As the national experience in hazardous waste management and remediation has grown over the last decade, the potential magnitude of the problems associated with restoring contaminated groundwater is becoming more and more apparent. The frequency of aquifer contamination combined with the technical limitations of removing contaminants from the subsurface environment have combined to escalate the costs of ground-water remedial efforts. In some cases, an alternative to implementing a classic pump-and-treat remedial system exists, namely, physical containment of subsurface contamination. Implementation of a containment system must also meet the strict requirement of overall protection of human health and the environment. In an effort to define the various costs associated with pump-and-treat remediation and physical containment of contamination, the Hazardous Site Control Division of the Environmental Protection Agency began a study in early 1994. to collect historical cost information on a wide variety of sites where ground-water pump-and-treat and/or physical containment was the remedial action. The sample of sites included in the analysis is comprised of federal state, and privately-funded remedial actions. The study evaluates more than 50 sites whose combined cost of ground-water remediation exceeds 400 million dollars.

Remediation of Toxic Particles From Groundwater
Nuttall, H.E.; Kale, Rahul
Univ of New Mexico, Albuquerque, NM
Proceedings: Symposium on Hazardous Waste Treatment, Prague, Czech Repub, August 29-Sept 03 1993
Journal of Hazardous Materials V 37 N 1 Apr 1994 pp 41-48
The presence of radioactive colloids (radiocolloids) in groundwater has been documented in several studies. There is significant evidence to indicate that these colloids may accelerate the transport of radioactive species in groundwaters. Because field experiments are often fraught with uncertainties, colloid migration in groundwater is an area of active research and the role and existence of radiocolloids is being investigated. This paper describes an ongoing study to characterize groundwater colloids, to understand the geochemical factors affecting colloid transport in groundwater, and to develop an in-situ colloid remediation process. The colloids and suspended particulate matter used in this study were collected from a perched aquifer site (located at Los Alamos National Laboratory's Mortandad Canyon in Northern New Mexico) that has radiation levels several hundred times the natural background and where previous researchers have measured and reported the presence of radiocolloids containing plutonium and americium. At this site, radionuclides have spread over several kilometers. Inorganic colloids collected from water samples are characterized with respect to concentration, mineralogy, size distribution, and electrophoretic mobility (zeta potential), and radioactivity levels. The methods used to investigate the physiochemical factors affecting colloid transport and some of the preliminary results are

presented. These include a description of a colloid transport model and the corresponding computational code, water analyses, characterization of the inorganic colloids, and a conceptual description of a process for in-situ colloid remediation using the phenomenon of polyelectrolyte capture. An overview of this project is presented and preliminary test results are described. (Author abstract) 14 Refs.

An Environmentalist's Perspective on Alternatives to "Pump And Treat" for Ground Water Remediation
Ross, D. Lauren, Consultant
Ground Water Monitoring & Remediation Vol 13 No 4 1994 pp 92-94
Abstract not available.

1993:

Breaking New Ground in Groundwater Remediation
Farrell, M.
Hazmat World Vol 6 No 1 Jan 1993 pp 28-30
Many environmental remediation experts believe a large portion of their industry's future lies just below the surface -- in the nation's polluted aquifers. EPA estimates that more than 1.5 million underground petroleum storage tanks exist in the US, excluding the tens of thousands containing home heating oil, which are not subject to federal regulation. Since 1988, state environmental agencies have reported to EPA more than 166,000 incidents involving leaking underground petroleum storage tanks, and continue to report an additional 50,000 new releases each year. By the mid-1990s, EPA estimates states will have identified more than 300,000 USTs leaking petroleum products into soil and groundwater. Traditional methods of recovering and treating contaminated groundwater have been limited almost entirely to vertical well techniques. These techniques involve using high-pressure drills to bore vertical wells over a contaminant source and pumping contaminants to the surface for treatment.

Comparison of Treatment Alternatives for Removing Chlorinated Hydrocarbons from Contaminated Groundwater
Larson, Alan C.; Iman, Jeffrey L.
Baker Environmental Inc, Coraopolis, PA
Proceedings: 25th Mid-Atlantic Industrial Waste Conference, College Park, MD, July 07-09, 1993 pp 523-528
Publisher: Technomic Publ Co Inc, Lancaster, PA 1993
The costs of various treatment alternatives for removing high concentrations of chlorinated hydrocarbons from the contaminated groundwater is detailed. Air stripping, liquid phase activated carbon, and advanced oxidation were identified as potential treatment alternatives to remove contaminants observed in groundwater well monitoring data. Air stripping with catalytic oxidation of off-gas emissions was selected as the preferred alternative based on bench scale testing, computer modeling and an economic analysis. A description of the groundwater contaminants, potential treatment alternatives, treatability studies and an economic analysis is presented. The economic analysis indicates that air stripping is the most cost effective process even when catalytic oxidation is used for treatment of air emissions from the air stripper must be considered. the high costs of activated carbon and are associated with the requirements of carbonge due to rapid breakthrough or vinyl chloride. High

activated carbonge is dosing rates and long residence times are required for removing 1,1, 1, trichloroethane with the advanced oxidation process. 4 Refs.

Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration: Interim Report (Final)
Environmental Protection Agency, Washington, DC. Office of Solid Waste and Emergency Response, Sep 1993 (30 p)
Report Number(s): PB-93-963507 EPA--540/R-93/080

The document outlines EPA's approach to evaluating the technical impracticability of attaining required ground-water cleanup levels and establishing alternative, protective remedial strategies where restoration is determined to be technically impracticable.

Bioaccumulation of Radionuclides and Metals by Microorganisms: Potential Role in the Separation of Inorganic Contaminants and for the In Situ Treatment of the Subsurface
Bolton, H. Jr.; Wildung, R.E.
Pacific National Lab., Richland, WA
Proceedings: First Hanford Separation Science Workshop Pacific Northwest Lab., Richland, WA 23-25 Jul 1991 pp II.135-II139
Published: May 1993
Report Number(s): PNL-SA-21775 CONF-9107153; Order Number: DE93016925

Radionuclide, metal and organic contaminants are present in relatively inaccessible subsurface environments at many U.S Department of Energy (DOE) sites. Subsurface contamination is of concern to DOE because the migration of these contaminants into relatively deep subsurface zones indicates that they exist in a mobile chemical form and thus could potentially enter domestic groundwater supplies. Currently, economic approaches to stabilize or remediate these deep contaminated zones are limited, because these systems are not well characterized and there is a lack of understanding of how geochemical, microbial, and hydrological processes interact to influence contaminant behavior. Microorganisms offer a potential means for radionuclide and metal immobilization or mobilization for subsequent surface treatment. Bioaccumulation is a specific microbial sequestering mechanism wherein mobile radionuclides and metals become associated with the microbial biomass by both intra- and extracellular sequestering ligands. Since most of the microorganism in the subsurface are associated with the stationary strata, bioaccumulation of mobile radionuclides and metals would initially result in a decrease in the transport of inorganic contaminants. How long the inorganic contaminants would remain immobilized, the selectivity of the bioaccumulation process for specific inorganic contaminants, the mechanism involved, and how the geochemistry and growth conditions of the subsurface environment influence bioaccumulation are not currently known. This presentation focuses on the microbial process of immobilizing radionuclides and metals and using this process to reduce inorganic contaminant migration at DOE sites. Background research with near-surface microorganisms will be presented to demonstrate this process and show its potential to reduce inorganic contaminant migration. Future research needs and approaches in this relatively new research area will also be discussed.

Innovative Technologies for Investigating and Remediating Subsurface Hydrocarbon Releases
Keller, K.K.
Burlington Environmental Inc., Columbia, IL

Proceedings: Seventh National Outdoor Action Conference and Exposition, Las Vegas, NV, 25-27 May 1993 pp 71-85
Publisher: Dublin, OH Ground Water Management, 1993
Report Number(s): CONF-9305192

Subsurface hydrocarbon releases are difficult to remediate at operating manufacturing facilities. The need to maintain production and limit worker exposure to hazardous materials can pose significant challenges. Three innovative technologies (a mobile, self-contained sampling/analysis system; a customized trenching machine; and a horizontal soil-vapor/groundwater recovery system) were used at a facility undergoing fast-track expansion. Volatile organic compounds (VOCs) had impacted soil and groundwater beneath the manufacturing building. Before the building could be expanded, the known releases had to be defined and a remediation system installed. The remediation system is cost-effective and practical. Burlington Environmental Inc. used its RECON Multimedia Sampling and Analysis System to rapidly define the extent of VOCs, both horizontally and vertically. Soil from four depth profiles was sampled beneath the building. These samples were analyzed on site using the RECON System's laboratory-grade gas chromatograph. Subsequent sampling locations were selected while the sampling team was still on site. Ground water monitoring wells were also installed. Based on these investigation results and site modeling, options for remediating soil and groundwater were reviewed. A series of three horizontal collector pipes (recovery trenches) buried below the groundwater surface was selected. Groundwater and soil treatment systems were then constructed. Groundwater and soil-vapor are collected from the downslope end of each trench and piped to the treatment systems. These innovative technologies were an effective, economical, and rapid means to investigate and remediate the VOC releases at this manufacturing facility. 5 figs.

Stepwise Approach Selects Most Effective Remediation Alternative
Anon
Oil and Gas Journal Vol 91 No 46 Nov 15 1993 pp 68-70
Storage tank owners and operators are increasingly faced with remediating the subsurface beneath tanks that have leaked petroleum products. Often these releases have occurred over several years and the hydrocarbons have migrated and contaminated large volumes of soil and groundwater. Determining the most-effective, lowest cost way to perform this remediation is vital to minimizing environmental expenditures and maintaining profit margins. Eric Deever, national oil and gas program manager for Environmental Science & Engineering Inc., VA., has developed a technique for selecting the most appropriate remediation alternative for a particular site. An unpublished report outlining the processes selection technique includes an expandable matrix of treatment technologies to facilitate the selection process.

Remediation Process Technology for Ground Water
Buckley, L.P.; Vijayan, S.; Wong, P.C.
AECL Research, Chalk River, Ontario, Canada Waste Management Systems Div.
Proceedings: 1993 International Conference on Nuclear Waste Management and Environmental Remediation, Volume 2: High Level Radioactive Waste and Spent Fuel Management, Prague, Czech Republic, 5-11 Sept 1993 pp 33-39
Publisher: New York, NY American Society of Mechanical Engineers, 1993
Report Number(s): CONF-930906

The operation of industrial facilities has generally resulted in contamination of the surrounding soils and ground water. A variety of methods have been proposed for the remediation of contaminated sites.

This paper presents new process technology that is capable of performing treatment on ground water or soil washing leachates. The process is targeted to treat low levels of radioactivity, organics and heavy metals present in the aqueous solutions, to be easily transported and provide simple operation on-site and provide an effluent that meets the specified discharge quality. The purification process involves sequential chemical treatment and filtration. The paper will describe the development of the technology and review the current progress in its use to remediate contaminated sites at Chalk River. The application of the process technology has demonstrated that the ambitious goal of setting the effluent targets to meet the drinking water standards was realized. A comparison of the process technology with typical unit operations processes will be provided, to allow an understanding of how competitive the process technology is. Repeated demonstrations are now needed to establish processing costs.

Aquifer Restoration: Pump and Treat and the Alternatives
Nyer, E.K.
Geraghty and Miller Inc., Tampa, FL
Ground Water Monitoring and Remediation Vol 13 No 1 Winter 1993 pp 89-92

This article summarizes papers that were presented at a seminar for NGWA's AGWSE Division held September 30 - October 2, 1992 in Las Vegas, Nevada. The presentations addressed the problems that have occurred with pump and treat in remediation of contaminated ground water. The alternative technologies available to replace pump and treat were evaluated. All of the speakers found pump and treat to be an excellent method to control plume movement, but were unable to remediated the site with this technique.

Dealing with DNAPLS Calls for New Site Investigation, Remediation Strategies
Moore, M.B.; Krumhansl, R.
ENSR Consulting and Engineering, Acton, MA
Hazmat World Vol 6 No 8 Aug 1993 pp 60-61

Dense, non-aqueous phase liquids (DNAPLS) have caught the attention of industry, regulators and the public. These hazardous liquids pose particular difficulties and require unique site remediation approaches. DNAPL is a group of hydrocarbon-based liquids heavier than--and which sink in--water. DNAPL compounds are classified into three groups, based on physical characteristics: Chlorinated solvents, creosote and coal tar, and PCBs. DNAPL usually is found in complex mixtures when present at a cleanup site. DNAPL contaminants have been detected at thousands of locations in North America. Because DNAPLs are used widely in industrial and retail operations, typical historical disposal practices suggest contamination will be found at thousands of additional sites. For example owners of a metal fabricating facility who disposed degreasing solvents at town-designated locations in a municipal landfill have been found liable for millions of dollars in Superfund characterization and cleanup costs. New technologies are being developed for site characterization and remediation. Unique site approaches are necessary, say regulators; staying abreast of DNAPL developments may save companies thousands of dollars in site investigation and cleanup.

Moving Beyond Pump-and-Treat
Hasbach, A.
Pollution Engineering Vol 25 No 6 15 Mar 1993 pp 36-39

DNAPLs such as chlorinated solvents, creosotes, and PCB oils migrate downward through both the unsaturated and saturated zones of the subsurface environment. Pump-and-treat methods will not

achieve complete clean-up at DNAPL sites. The EPA's Technology Innovation office has identified technologies that hold promise for either treating groundwater in place or improving the solubility of contaminants to enhance pump-and-treat. This article briefly reviews in situ treatment, pump-and-treat enhancement, and enhanced recovery technologies. The correct solution will be varied and site specific. A new technology center at the EPA's Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma will serve as a clearinghouse for both public and private research into groundwater contamination.

1992:

Innovative Treatment Technologies: Status and Use at Superfund Sites
Kingscott, J.; Fiedler, L.
EPA, Washington, DC
Hazardous Materials Control/Superfund 92: 13th Annual Conference and Exhibition, Washington, DC, 1-3 Dec 1992 pp 648-652
Publisher: Greenbelt, MD Hazardous Materials Control Resources Institute 1992
Report Number(s): CONF-921235

The US EPA's Office of Solid Waste and Emergency Response is seeking to further the use of innovative hazardous waste treatment technologies in the programs it administers. In order to achieve more permanent remedies, the Agency is encouraging the use of new or innovative technologies capable of treating contaminated soils and groundwater more efficiently, less expensively, and in a manner more acceptable to the public. This paper provides a status of the application of these technologies at Superfund sites and discusses projected future trends.

Environmental Restoration/Waste Management: Applied Technology Semiannual Report, January--June 1992
Adamson, M.; Kline-Simon, K. eds.
Lawrence Livermore National Lab., CA
1992 35 p
Report Number(s): UCRL-LR-112400-92-1 Order Number: DE93041099

This is the first issue from the Lawrence Livermore National Laboratory of The Environmental Restoration/Waste Management-Applied Technology ER/WM-AT Semiannual Report, a continuation of the Advanced Processing Technology APT Semiannual Report. The name change reflects the consolidation of the APT Program with the Environmental Restoration and Waste Management Program to form the Environmental Restoration/Waste Management-Applied Technology ER/WM-AT Program. The Livermore site mirrors, on a small scale, many of the environmental and waste management problems of the DOE Complex. The six articles in this issue cover incineration-alternative technologies, process development for waste minimization, the proposed Mixed Waste Management Facility, dynamic underground stripping, electrical resistance tomography, and Raman spectroscopy for remote characterization of underground tanks.

Innovative Treatment Technologies: Semi-Annual Status Report. Third Edition
Fiedler, L.
Environmental Protection Agency, Washington, DC, Office of Solid Waste and Emergency Response
April 1992 91 p

The twice-yearly report contains site-specific information on Superfund sites both remedial and emergency response actions where innovative treatment technologies have been or are being used. Innovative treatment technologies are treatment technologies for which a lack of data on cost and performance makes their selection and use at Superfund sites more difficult. The report documents the use of the following innovative treatment technologies to treat ground water in situ, soils, sediments, sludge, and solid-matrix wastes; bioremediation ex situ, bioremediation in situ, chemical treatment, dechlorination, in situ flushing, in situ vitrification, soil vapor extraction, soil washing, solvent extraction, thermal desorption, and other technologies. The report includes information on 210 applications of innovative treatment technologies for Superfund remedial actions and 18 applications for emergency response actions. The April 1992 issue updates the status of each project listed in the September 1991 report. Additions to the report include 70 innovative treatment technologies selected for remedial actions in Fiscal Year 1991 Superfund Records of Decision RODs and more detailed information on completed projects.

Innovative Soil and Groundwater Remediation of Volatile Organic Compounds
Dent, M.J.; Novotny, J.F.; Weeks, M.W.
O'Brien and Gere Engineers, Inc., Syracuse, NY
Proceedings: Research and Development 92: National Research and Development Conference on the Control of Hazardous Materials, San Francisco, CA, 4-6 Feb 1992 pp 226-231
Published: 1992

As a result of increased environmental liabilities at industrial facilities throughout the United States over the past decade, the implementation of innovative, cost-effective technologies to remediate soil and groundwater contamination is becoming more common-place. These innovative technologies are being developed to correct past sins' without excessive remediation costs which may ultimately affect a company's profitability and survival in today's competitive marketplace. This paper focuses on a specific soil and groundwater remediation program that was implemented to mitigate the effects of VOCs in the soil and groundwater. The remediation project discussed herein is associated with a Tennessee manufacturing facility that is engaged in the assembly of components for automotive use. The facility previously operated two solvent degreasers and currently maintains several petroleum storage tanks at the site. During site excavation associated with a sprinkler pipeline repair in June 1989, organic odors were detected.

A State-of-the-Art Review of Remedial Technologies for Petroleum Contaminated Soils and Groundwater Data Requirements and Efficacy Information
Rorty, M., Roy F. Weston, Inc., Walnut Creek, CA;
Preslo, L.M., ICF Kaiser Engineers, Inc., San Francisco, CA;
Scheinfeld, R.A., Roy F. Weston, Inc., West Chester, PA;
McLearn, M.E., Electric Power Research Institute, Palo Alto, CA
Proceedings: First Annual West Coast Conference on Hydrocarbon Contaminated Soils and Groundwater, Newport Beach, CA , Feb 1990 pp 223-236
Publisher: Chelsea, MI Lewis Publishers 1992
Report Number(s): CONF-9002214

This paper reports the results of a study funded by the Electric Power Research Institute EPRI to update EPRI CS-5261, Remedial Technologies for Leaking Underground Storage Tanks. The present study describes, evaluates, and updates available technologies for remediating soils and groundwater containing petroleum products released from underground storage tanks USTs or from other discharges, leaks, or spills. In particular, this study provides an update of the technologies included in the first

study, presents a number of new case studies, and focuses on efficacy data as well as data needed to properly assess and design the remedial alternatives for a particular site. Regulatory acceptance of specific technologies also is included.

Cost-Effective Alternative Treatment Technologies For Reducing the Concentrations of Methyl Tertiary Butyl Ether and Methanol in Groundwater
Truong, K.N.; Parmele, C.S.
IT Corp., Knoxville, TN
Proceedings: First Annual West Coast Conference on Hydrocarbon Contaminated Soils and Groundwater, Newport Beach, CA , Feb 1990 pp 461-486
Publisher: Chelsea, MI Lewis Publishers 1992
Report Number(s): CONF-9002214

This chapter describes an engineering assessment of eight treatment technologies conducted by IT Corporation IT for the American Petroleum Institute API for removing methyl tertiary butyl ether MTBE or methanol and benzene, toluene, xylene BTX in the three following groundwater treatment scenarios: removal of MTBE to 10 parts per billion ppb by eight technologies; removal of methanol to 10 ppb by four selected technologies; removal of methanol to 1,000 ppb by two selected technologies at several combinations of BTX inlet concentrations and flow rates. The following eight technologies were evaluated for removing 20 parts per million ppm of MTBE from groundwater that also contained 20 ppm total BTX: air stripping with aqueous-phase carbon adsorption; air stripping with off-gas incineration and aqueous-phase carbon adsorption; air stripping alone; heated air stripping.

The Importance of Hydrogeologic Controls on Remedial Action Alternatives
Maslia, Morris L.; Aral, Mustafa M.; Gill, Harold E.
GeoSyntec Consult., Norcross, GA; Ga. Institute Tech.
Proceedings: 41st Annual Meeting of the Southeastern Section of the Geological Society of America, Winston-Salem, NC, March 18-20, 1992
Abstracts with Programs-Geological Society of America Vol 24 No 2 p 53

This paper presents a simple yet effective approach and methodology for the problem of evaluating ground-water remedial alternatives at a waste disposal site, and discusses the application of this approach in a case study. The attainment areas, which represent the areas outside the contaminant source itself in which remediation is required, are first identified. Simulation of ground-water flow in three dimensions, augmented by fluid particle tracking, is utilized to evaluate the travel times of ground water through the attainment areas. The mixed linear reservoir or "batch flush" model is then used to estimate the number of pore volumes which must be flushed through each attainment area in order to achieve remediation. The travel times are used in conjunction with this pore volume figure to estimate the time required for cleanup under each alternative. By comparing the cleanup time, the costs, and other features of each alternative, a cost-effective remedy for the study site can be determined. While the development of remedial alternatives and the choice of the most cost-effective remedy are highly site-specific, the approach and methodology outlined in this paper have general applicability. The results presented herein also provide insight into the difficulties and special considerations associated with modeling and analyzing remedial alternatives.

1991:

Opportunities For An Innovative Superfund Cleanup in Water-Scarce California
Praskins, W.
EPA, San Francisco, CA
Proceedings: Hazardous Materials Control/Superfund '91: 12th National Conference, Washington, DC 3-5 Dec 1991 pp 193-195
Published: 1991

The San Gabriel Valley Superfund Sites share several characteristics with Superfund sites throughout the country: contamination of groundwater; the presence of PCE, TCE and other organic solvents; and the use of pump-and-treat systems to remove contaminants from groundwater. In most ways, however, the San Gabriel Valley Superfund Sites are unique. The area of contamination is large tens of square miles, the aquifer is deep up to thousands of feet and the number of people potentially affected by the contamination actually living on the sites exceeds one million. Moreover, community involvement in the sites includes more than the usual array of public interest groups and PRPS. It includes 45 water purveyors which supply San Gabriel water to wholesale or retail customers; four water districts which supply imported water to supplement San Gabriel's groundwater supplies; a court-appointed "Watermaster" responsible for administering the judicial decision allocating water rights in the basin; and other agencies which have been created to manage, transport or distribute water in California. This paper first describes some of the San Gabriel sites unique characteristics in more detail. The paper then examines the largest operable unit currently planned for the San Gabriel Valley Sites, the Baldwin Park Operable Unit and the potential for conjunctive use to be selected as the remedy. The attraction of a conjunctive-use remedy is that it could both meet Superfund's remedial objectives and improve the supply of water to Southern California.

Review of Natural and Artificial Denitrification of Groundwater
Hiscock, K. M.; Lloyd, J. W.; Lerner, D. N.
Univ of Birmingham, Birmingham, Engl
Water Research Vol 25 No 9 Sept 1991 pp 1099-1111

An approach to securing low nitrate supplies is to take advantage of the bacterially mediated process of dentrification. This paper reviews the factors controlling dentrification and describes the evidence for denitrification in the groundwater environment. It is found that natural denitrification, although not extensive, does occur in a variety of aquifers where there is a sufficient source of oxidizable organic carbon. However, natural processes cannot be expected to remove the large quantity of nitrate now present in many aquifers. Water treatment processes that stimulate artificial denitrification by the injection of the required nutrients are under development, and may offer a simple and inexpensive method of nitrate removal. This paper reviews the various above-ground and underground techniques to determine the advantages and disadvantages of this approach compared with other nitrate removal technology. It is concluded that artificial denitrification as an above-ground process affords the best nitrate removal rates and process control. Compared with alternative technology, namely ion exchange, above-ground biological treatment does not generate large quantities of waste product, but is more difficult to automate. Edited author abstract 52 Refs.

1990:

In-Situ and On-Site Technologies and Overview
Freestone, F.J.
Technical Support Branch, ORD, RREL, U.S. EPA, Edison, NJ

Proceedings: Conference on In-Situ and On-Site Remediation of Contaminated Soil and Groundwater, Lyngby Denmark, 4 Apr 1990 pp 1-11

A broad analysis of and perspective on the characteristics and measured performance of in-situ and on-site treatment technologies available for remediation of contaminated soils, groundwater and associated debris at hazardous waste sites. Included in the analysis is information from U.S. and European sources. Available data are appended from nine recently completed field demonstrations from the U.S. Environmental Protection Agency EPA Superfund Innovative Technology Evaluation SITE program. The most frequently applied technology areas appear to be on-site thermal treatment for organics, on-site and in-situ solidification/stabilization technologies for most inorganics and metals, traditional on-site water treatment techniques, and soil vapor extraction for volatile organic compounds. Rapidly developing areas include bioremediation technologies, and concentration technologies. Two of the weakest areas include materials handling for such situations as excavating buried drums and soils with volatiles safely, and performing physical and chemical site characterization using technology-sensitive parameters. An area worthy of international cooperatin is that of performing benchscale screening and treatability studies, including the specification of key parameters needing measurement, techniques for such measurement and for interpretation, storage and retrieval of resulting data. We are in the process of evaluating existing treatability study data on soils and debris, and will be installing that data onto an on-line information system available to the public world-wide. AB 10 refs.

Current Practice and Applications of Ground Water and Soil Contamination/Remediation: Successes and Failures

Canter, L W

Ground Water and Soil Contamination Remediation: Toward Compatible Science, Policy, and Public Perception

National Academy Press 1990

From a national perspective, the estimated amounts of money required for cleanup of contaminated soil and ground water are staggering. Several recent comparative studies have identified limitations and deficiencies in the implemented cleanup efforts. Some of the technically oriented reasons typically associated with perceived and actual failures of cleanup efforts include the following: frequent selection and use of technologies without considering the uniqueness of the cleanup needs use of technologies dependent on subsurface transport and fate processes without adequate understanding of the contaminant plume lack of clear protocols on site characterizations and development of technology design criteria inability to achieve uniform mixing in the subsurface limitations of ground water flow and solute transport models for evaluating proposed remediation schemes uncertainty in cleanup standards and concentrations lack of systematic comparisons of alternative technologies competing objectives increasing development of technologies, providing more choices cleanup programs focused on only one aspect of the site problem. Control technologies can be broken into three major categories: physical control measures, postextraction ground water treatment measures and in situ treatment measures. Technical needs to enhance cleanup activities include: expert systems, a systematic approach that would enable geographical problem prioritization at remediation sites, remediation plans, follow-up comparative studies, information on expenditures, increased communication of information among scientists and engineers, and communication of information relative to risks and risk reductions.

Innovative Hazardous Waste Treatment Technology

Freeman, H.M.; Sferra, P.R.

U.S. Environmental Protection Agency, Cincinnati, Ohio, Hazardous Waste Engineering Research Lab
1990 256p

This book contains technical overviews of new processes for reducing hazardous waste volume. These processes are based upon physico-chemical principles. Topics include: vacuum extraction for cleanup of soils and groundwater; catalytic hydrodechlorination; stripping technology; and recovery and disposal of nitrate wastes.

Treatment Options for Water Supplies Contaminated With DBCP and Other Pesticides
Wong, Joseph M.
Brown and Caldwell Consultants, Walnut Creek, CA
Public Works Vol 121 No 7 Jun 1990 pp 78-81

Contamination of water supplies by pesticides or herbicides is a significant public health problem because of the widespread application of pesticides in large-scale agriculture and in forest areas. A recent report prepared by the California Department of Food and Agriculture summarized the results of pesticide residue tests submitted to that agency between September 1987 and June 1988 by county, state and federal agencies. Investigators detected residues in 14 of the 41 counties where 2,977 wells were sampled. Of the 179 pesticide related compounds tested, 10 chemicals were detected: 1,2-dichloropropane 1,2-D, 1,2,-dibromo-3-chloropropane DBCP, dichlorodiphenyl-dichloroethylene DDE, dichlorodiphenyltrichloroethane DDT, atrazine, bentazon, chlorothal-dimethyl, simazine, trifluralin, and xylene. As in previous years, DBCP was the pesticide most frequently detected. Four alternative treatment methods can potentially remove DBCP and other pesticides from groundwater. The technology is definitely available. In deciding which method to use, investigators should evaluate each alternative in relation to the specific conditions of the project. Pilot testing may be required to identify the most cost-effective and technically desirable remediation method. 17 Refs.

New Technologies for Cleaning Up Contaminated Soil and Groundwater
Olfenbuttel, Bob
Battelle, Columbus, OH
Battelle Today Vol 65 Dec. 1990 pp 3-6
Abstract not available.

BIOLOGICAL SURVEYS

1995:

Perspective and Limits in Biodegradation
Zehnder, A. J. B.
Swiss Federal Institute for Environmental Science and Technology EAWAG, Switzerland
Proceedings of the SCOPE Workshop on Soil and Groundwater Pollution, Cesky Krumlov, Czech Republic, June 6-7 1994 pp 31-35
Publisher: Kluwer Academic Publishers Dordrecht, Netherlands 1995
Conference paper Pollutant biodegradation is discussed briefly and factors controlling the biodegradation process are outlined. Areas discussed include those of microbial activity at interfaces, solid surfaces and subsequent pollutant bioavailability; microbial adaptation to new environments, local conditions, and possible substrates; and threshold concn and physicochemical factors considered important in evaluating biodegradation kinetics. 4 ref.

Bioremediation
Innovative Site Remediation Technology. Volume 1: Bioremediation: pp 0-288 1995
American Academy of Environmental Engineers
Editors: Anderson, W. C.
Publisher: Springer-Verlag, Berlin, Germany
The application of natural and enhanced bioremediation technology is discussed in this monograph whose principal objective is to provide guidance during the selection of appropriate technologies as well as advising both regulatory agencies and the public about the conditions under which bioremediation may be applicable. The monograph addresses innovative bioremediation technologies that have been sufficiently developed to be applicable to full-scale applications: laboratory- and pilot-scale studies are included as appropriate. The main focus of the monograph is site remediation and waste treatment such as for soils, sludges, filter cake, air, and water. The information provided has been prepared with generally recognized engineering principles and practices and therefore provided general information only. Chapter titles are as follows: (2) process summary; (3) process identification and description; (4) potential applications; (5) process evaluation; (6) limitations; and (7) technology prognosis. The four appendices list case studies, glossary of terms, acronyms, and references.

Assessment of Bioremediation Technologies: Focus on Technologies Suitable for Field-Level Demonstrations and Applicable to DOD Contaminants (Final Rept)
Andrews, A. M.; Dugan, R. E.
Institute for Defense Analyses, Alexandria, VA.
Report No.: IDA-D-1672; IDA/HQ-95-46444; NTIS Number: AD-A301 147/5 Jun 1995 116p

Bioremediation is a viable, cost-effective treatment for environmental contaminants. Research activities continue to uncover new bioremediation technologies, increasing the need for field-level demonstrations. The goal of this study is to identify bioremediation technologies that have demonstrated viability in laboratory or pilot studies, but require additional field demonstrations to determine the capabilities and limitations of the technology. In selecting technologies that would be of interest to the DOD, the service-identified research and development priorities for cleanup were considered, and those contaminants amenable to bioremediation were identified. These contaminants included halogenated and non-halogenated hydrocarbons, energetics, and inorganics. Technologies that are promising at either laboratory or pilot scales and are in need of demonstrations for validation under field conditions include bioreactors for the treatment of energetics, in situ anaerobic/aerobic sequential treatment of chlorinated hydrocarbons, constructed wetlands, and white rot fungus. We strongly recommend the first three technologies as candidates for field-level demonstrations; the fourth we recommend less enthusiastically. Beyond our primary recommendations, we make note of two other technologies of interest: microbial mats and systems capable of assessing and monitoring bioremediation activities.

Bioremediation of Contaminated Groundwater

Hickey R F; Wagner D; Sunday A; Groshko V; Heine R; Rajan R; Hayes T
EFX Systems, Lansing, MI

Molecular Marine Biology and Biotechnology Vol 4 No 4 1995 pp 306-312

Historically, remediation of groundwater contaminated with benzene, toluene, ethylbenzene, and xylenes (BTEX) and other petroleum hydrocarbons was performed using granular activated carbon (GAC) to adsorb the pollutants in pump-and-treat-type systems or by air stripping these volatile compounds. In most locales, when air stripping is used, it is now required that the stripped volatile organic compounds be captured on GAC. Although these physicochemical approaches are effective in removing BTEX, they have several drawbacks. These processing options are costly, and they simply transfer the BTEX from the water to the GAC. An alternative to physicochemical remedial techniques is biological treatment, which results in the complete oxidation of the contaminants being treated. However, regulatory personnel and design engineers have a greater degree of uncertainty about the ability of biological treatment to meet their stringent performance requirements. An initial laboratory-scale pilot effort was conducted over four years ago to determine the efficacy of treating groundwater contaminated with BTEX in a biological fluidized bed reactor system in which granular activated carbon is used as the biomass carrier (GAC-FBR system). This system combines the advantages of biological treatment with the positive removal provided by GAC adsorption. Results demonstrated that BTEX could be degraded down to less than 1.0 mu-g/liter at liquid retention times of six minutes. During the past four years an extensive effort has been made to use the GAC-FBR system for treating a variety of gas and oil industry effluent streams. Presented are two case studies of results that include work conducted at pilot- and field-scale on treating groundwater contaminated with petroleum hydrocarbons.

A Review of Bioremediation of Contaminated Soils and Groundwater

Ritter W F; Scarborough R W
Agricultural Engineering Dept., Univ. Delaware, Newark, DE

Journal of Environmental Science and Health Part A: Environmental Science and Engineering & Toxic and Hazardous Substance Control Vol 30 No 2 1995 pp 333-357

The paper discusses bioremediation of contaminated groundwater and soils. Research needs for bioremediation are also discussed. Forms of bioremediation practiced today are the microbiological

approach, which involves augmentation of the contaminated site with one or more species of contaminant-specific degrading organisms, and the microbial ecology approach, which involves adjusting certain physical and chemical factors at a site to enhance degradation. The microbial approach can be used at most sites. Contaminated soils may be bioremediated by in-situ techniques, landfarming, composting or in slurry bioreactors. Anaerobic biodegradation may offer an effective alternative to aerobic in-situ bioremediation for some compounds. Chlorinated aliphatic and hetercyclics have been degraded anaerobically. Petroleum hydrocarbons are the most easily bioremediated compounds. White rot fungus Phanerochaete chrysosporium will degrade many PAH compounds found in creosote. Bioremediation is also being used to remediate soils contaminated with explosives.

Bioremediation of Chlorinated Solvents and Diesel Soils
Huismann, Scott S.; Peterson, Mark A.; Jardine, Richard J.
ENSR, Florence, AL
Proceedings of the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management Pittsburgh, PA 1995 pp 173-180
Publisher: ASCE

The United States Army, the Tennessee Valley Authority (TVA) and ENSR collaborated to perform an innovative enhanced bioremediation project at Fort Gillem in Atlanta, Georgia. The objective of the project was to remediate six hundred cubic yards of soil affected by a mixture of chlorinated compounds and petroleum hydrocarbons which posed a threat to uppermost groundwater and private drinking water wells. ENSR completed a demonstration project in which the effects of bioremediation on both chlorinated compounds and petroleum hydrocarbons were measured. In addition, ENSR also monitored bioremediation through periodic sampling of air, soil, and water.

Ground Water for Bioremediation
Thomas, J. Michele; Ward, Calvin H.
Rice Univ, Houston, TX
Proceedings of the Specialty Conference on Geotechnical Practice in Waste Disposal. Part 2 (of 2) New Orleans, LA, 1995 pp 1456-1466
Publisher: ASCE, Geotechnical Special Publication No 46/2 1995

Contaminated ground water can be treated in situ or ex situ by several technologies. Natural bioremediation (bioattenuation) involves only monitoring the fate of contaminants, and is used at sites where human health and the environment are not at risk. More aggressive in situ treatment may be achieved through liquid delivery or air sparging. Liquid delivery can involve injecting limiting nutrients and an electron acceptor, either oxygen, nitrate, or sulfate in an aqueous solution. Air sparging is an alternative method to liquid delivery and involves sparging air into the formation at high pressure. Emerging ground water treatment technologies include funnel-and-gate, permeable wall injection systems, and use of solid oxygen-releasing compounds. Ground water can be extracted and treated at the surface when in situ methods are not effective. (Author abstract) Refs.

In Situ Bioremediation of Chlorinated Solvents

Sack, W.A.; Carriere, P.E.; Whiteman, C.S.; Davis, M.P.; Raman, S.; Cuddeback, J.E.
West Virginia Univ., Morgantown, WV

Proceedings: Hazardous and Industrial Wastes: The Twenty-Seventh Mid-Atlantic Industrial Waste Conference, Bethlehem, PA, 9-12 Jul 1995 pp 849-858
Publisher: Lancaster, PA: Technomic Publishing Co., Inc. 1995
Report Number(s): CONF-9507204

In situ bioremediation of chlorinated organic is receiving growing support and widespread testing in the field. It is an attractive alternative with the potential to destroy contaminants almost completely. The research seeks to exploit the natural symbiotic relationship between methanogenic and methanotrophic microorganisms. The methanogens are able to carry out anaerobic reductive dehalogenation of highly chlorinated solvents while producing methane. The methanotrophs in turn utilize the end products of the methanogens, including the methane, to aerobically degrade the residual CAH compounds to environmentally acceptable end products. Both groups of organisms degrade the CAH compounds cometabolically and require a primary substrate. The purpose of the research is to evaluate and optimize the ability of methanotrophic, methanogenic, and other selected bacteria for cost-effective biotransformation of TCE and other volatile organic compounds (VOCs). This paper describes initial studies using separate anaerobic and aerobic columns. As soon as the initial column studies are complete, the anaerobic and aerobic columns will be combined in both sequential and simultaneous modes to evaluate complete CAH destruction.

Efficacy of Monitoring In Situ Bioremediation of Fossil Fuel Using the Mesocosm System

Borchert, S.M.; Mueller, J.G., SBP Technologies, Inc., Gulf Breeze, FL;
Coffin, R.B.; Trust, B.; Kelly, C., Environmental Protection Agency, Gulf Breeze, FL Environmental Research Lab.;
Schultz, W.W., Naval Research Lab., Washington, DC;
Cifuentes, L., Texas A and M Univ., College Station, TX Dept. of Oceanography; Checkai, R.T.; Gervasoni, T.R., Army-ERDEC, Aberdeen Proving Ground, MD

Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1165-1169
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

7 With in situ bioremediation applications being recommended frequently out of practical and economic necessity, cost-efficient and effective implementation strategies need to be developed and/or refined. At the same time, unequivocal approaches for demonstrating in situ bioremediation of target contaminants need to be established. Toward this end, the authors have developed and refined innovative in situ soil and groundwater bioremediation strategies on a pilot and full-scale, including monitoring approaches using stable carbon isotope biogeochemistry to assess progress during in situ bioremediation of fossil fuels (more specifically PAHs and BTEX). To evaluate rigorously and assess these technologies, the authors have initiated mesocosm studies. The Mesocosm system is installed at the Process Engineering Facility, US Army Aberdeen Proving Ground, Maryland. This system integrates two technologies: a modification of the proven UVB technology, which creates a vertical groundwater circulation, and an in situ bioreactor. Incorporated into this system are four soil columns of approximately two meter height with a diameter of 60 cm, allowing them to model and test the efficacy of monitoring and biodegradation in a controlled environment. Parallel field studies currently at two sites will comparatively define the fate and effect of parent compounds and biotransformation products

for mass balances (by monitoring natural abundance of stable carbon isotope ratios 13C/12C using a GC/IRMS, the fate of organic compounds can be measured).

Field Experiments on In Situ Bioremediation: Moffett Federal Airfield and Edwards AFB
Goltz, M.N.; Hopkins, G.D.; Kawakami, B.T.; McCarty, P.L.
Stanford Univ., CA
Ground Water Vol 33 No 5 Sep-Oct 1995 p 835

A trichloroethylene (TCE) ground water plume at Edwards AFB in Southern California is being used to demonstrate in situ aerobic cometabolic bioremediation in the field. The bioremediation system that will be demonstrated at Edwards was developed over nine years of research and testing in the laboratory and at a pilot field site located at Moffett Federal Airfield in Mountain View, California. Studies conducted at the Moffett field site have demonstrated that TCE can be effectively biodegraded cometabolically through the introduction into the subsurface of a primary substrate and an oxygen source to support the growth and energy requirements of a native population of microorganisms. A system to demonstrate the feasibility of in situ aerobic cometabolic bioremediation is presently being constructed at Edwards, using an area of the plume having TCE concentrations ranging up to 1 mg/L. A major objective of the Edwards study will be to investigate how a primary substrate and an oxygen source can be efficiently mixed and transported to indigenous microorganisms, in order to promote cometabolic degradation of TCE. In this presentation, the earlier studies at Moffett, as well as the preliminary modeling work and site characterization which have been conducted in preparation for the Edwards demonstration, will be presented. In addition, problems encountered and lessons learned bringing an innovative technology from the laboratory to the field will be discussed.

1994:

The Evolution of a Technology: The In Situ Bioremediation of Hydrocarbons
Brown, R.A., Groundwater Technology, Inc., Trenton, NJ;
Norris, R.D., Eckenfelder, Inc., Nashville, TN
Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 13-22
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

Hydrocarbon contamination of soils and groundwater is a significant problem due to the large quantities of hydrocarbons transported and stored. In situ bioremediation was one of the first remediation technologies to successfully address both dissolved and adsorbed-phase hydrocarbon contamination. Pioneering work by Richard L. Raymond be in 1972 demonstrated the commercial potential of in situ bioremediation. In the early 1980s it was recognized that the lack of an efficient oxygen supply limited implementation of the technology. Early systems used diffusers to saturate injected water with air. These systems, however, introduced limited amounts of oxygen and were prone to fouling. The innovation of using hydrogen peroxide (H2O2) provided oxygen at a rate up to two orders of magnitude faster than did the existing technology. Although H2O2 was used successfully at a number of sites, problems including too rapid decomposition, gas blockage, and inefficient use were encountered at other sites. Subsequently, alternatives such as the use of nitrate as an electron acceptor, bioventing, and air sparging have been evaluated and implemented based on cost and/or technical advantages. This paper discusses the evolution of in situ bioremediation from the early use of in well

aeration to the current use of air sparging. Much of the evolution of in situ bioremediation of hydrocarbons has been a search for a cost effective electron acceptor. This paper examines the driving forces behind the use of oxygen, H2O2, and alternative electron acceptors in the development of in situ bioremediation.

In-Situ Bioremediation: Or How to Get Nutrients to All the Contaminated Soil
Jackson, D.S.; Scovazzo, P.
KEMRON Environmental Services, Inc., McLean, VA
Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 52-58
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

Petroleum contamination is a pervasive environmental problem. Bioremediation is winning favor primarily because the soil may be treated on site and systems can be installed to operate without interfering with facility activities. Although bioremediation has been utilized for many years, its acceptance as a cost-effective approach is only now being realized. KEMRON applied in-situ bioremediation at a retired rail yard which had maintained a diesel locomotive refueling station supplied by two 20,000 gallon above ground storage tanks. Contamination originated from both spillage at the pumps and leaking fuel distribution lines. The contamination spread over a 3 acre area from the surface to a depth of up to 20 feet. Levels of diesel contamination found in the soil ranged from less than a 100 ppm to more than 25,000 ppm. The volume of soil which ultimately required treatment was more than 60,000 cubic yards. Several remedial options were examined including excavation and disposal. Excavation was rejected because it would have been cost prohibitive due to the random distribution of the contaminated soil. In-situ Bioremediation was selected as the only alternative which could successfully treat all the contaminated soils. This paper focuses on how KEMRON solved four major problems which would have prevented a successful remediation project. These problems were: soil compaction, random distribution of contaminated soils, potential free product, and extremely high levels of dissolved iron in the groundwater.

Biological Processes at Saints Hill Water-Treatment Plant, Kent
Bourgine, F.P.; Gennery, M.; Chapman, J.I.; Kerai, H.; Green, J.G.; Rap, R.J.; Ellis, S.; Gaumard, C.
Dynamco Ltd, UK
Journal of the Institution of Water and Environment Management Vol 8 No 4 Aug 1994 pp 379-391

The new treatment plant at Saint's Hill has been operating since May 1992 and biologically treats ground-water to remove iron, ammonium/ammonia and manganese. The paper describes the project, the processes involved, the significance of pilot-plant studies, the different stages of commissioning and plant efficiency. This method of treatment, although new to the UK, is well-established in France, and reference to existing plants using the processes is made for purposes of indicating the range of applicability of biological treatment processes. Specific conditions are required for biological processes. Not all raw waters can be economically treated to produce an environment which is appropriate for bacterial activity. Conditions for biological iron and manganese removal are different. The paper illustrates the importance of pilot studies to establish the feasibility of biological processes and to determine the design parameters for industrial-scale works. (Author abstract) 6 Refs.

Making Bioremediation Work Well for You
Glanz, James
Research & Development Vol 36 No 9 Aug 1994 pp 19-20

Environmental engineers are turning to bioremediation for a safe and integrated approach to rid the environment of pollutants. Defined roughly as the enhancing of natural processes of biodegradation, bioremediation involves microbial and physical processes which work synergistically. Examples of such enhancements include adding oxygen or nitrates and sulfates to contaminated soil and water. Advanced techniques use genetically engineered microbes. Applied correctly, bioremediation promises faster, cheaper and safer alternative to conventional techniques.

Bioremediation: A Competitive Alternative for the Cleanup of Contaminated MGP Sites
Cutright, Teresa J.; Lee, Sunggyu
Univ of Akron, Akron, OH
Energy Sources Vol 16 No 2 Apr-Jun 1994 pp 269-277

Polycyclic aromatic hydrocarbons (PAHs) are characteristically highly carcinogenic, microbial recalcitrant, and accumulate easily in soil and groundwater. This contributes to the increasing environmental concern of contamination from PAHs. PAH contamination occurs primarily from leaking underground storage tanks and manufactured gas plant (MGP) sites. In this work, contaminated soil was analyzed for feasibility of cleanup via bioremediation, and selection criteria for the microorganisms were developed for the specificity of a MGP site. The bioremediation process was compared with the ex-situ processes of coal agloflotation, solvent extraction, and supercritical fluid extraction. (Author abstract) Refs.

1993:

Ground-Water Microbiology and Geochemistry
Chapelle, F.
Geological Survey, Columbia, SC
Publisher: New York, NY John Wiley and Sons 1993 (448 p)

This book is an excellent reference for anyone interested in bioremediation, organic contamination, microbial occurrence in ground water, or natural ground-water chemistry. The book has three parts: an introduction to microbiology, microbial occurrence in ground-water systems, and biodegradation of contaminated ground water. The author's approach was to review existing literature on these topics. The topics covered are diverse, but presented with clear definitions and context. In discussing bioremediation, the author dispels some of the mystique of disappearing contaminants. Among other topics, microbial acclimation to new chemicals is shown to influence degradation rates, and suggested areas for new research include understanding acclimation of competitive organisms and metabolic constraints on processes.

Performance and Cost Evaluation of Bioremediation Techniques for Fuel Spills. Book Chapter
Ward, C.H.; Wilson, J.T.; Kampbell, D.H.; Hutchins, S.
Environmental Protection Agency, Ada, OK. Robert S. Kerr Environmental Research Lab 1993 Report Number(s): PB-93-175545; EPA--600/A-93/073

Soils and ground water beneath the US Coast Guard Air Station at Traverse City, MI, have been contaminated with separate spills of aviation gasoline and JP-4 jet fuel. Contamination from both

plumes has affected a shallow water table aquifer consisting of a medium grained sand. This site has been the location of a cooperative effort between the US Coast Guard and US EPA to extensively characterize the site to determine three dimensional extent of contamination, local hydrogeology, geochemistry of the solids and water, and nature of microbial activity. Evaluation concerning feasibility and cost of three innovative bioremediation techniques has also been completed at the Air Station. One evaluation demonstrated the use of hydrogen peroxide as the electron acceptor to enhance aerobic biodegradation in a portion of the aviation gasoline area. Nitrate was used as the electron acceptor for a portion of the JP-4 jet fuel contamination. Bioventing of a second portion of the aviation gasoline contamination was the third innovative technique evaluated. Each treatment reduced benzene levels to less than 5 micrograms/l, with 25% to 60% reduction in total fuel levels. For these evaluations, bioventing had the lowest capital and operating costs, followed by nitrate addition and finally hydrogen peroxide.

Bioremediation: a Natural Solution
Hicks, B.N.; Caplan, J.A.
ESE Biosciences Inc., Raleigh, NC
Pollution Engineering Vol 25 No 2 Jan 1993 pp 30-33

Bioremediation is an attractive remediation alternative because most full-scale bioremediation projects involve cost-effective contaminant treatment on-site. Recently, large scale bioremediation projects have included cleanups of ocean tanker spills, land-based chemical spills, and leaking chemical and petroleum storage tanks. Contaminated matrices have included beaches, soils, groundwater, surface waters (i.e., pits, ponds, lagoons), process waste streams and grease traps. Bioremediation is especially cost-effective when both soil and groundwater matrices are impacted because one remediation treatment system can be design to treat both media simultaneously in place. The primary advantages of in situ bioremediation include: on-site destruction of contaminants; accelerated cleanup time; minimal disruption to operations; lower remediation costs; and reduction of future liability.

Bugs Digest Chlorinated Organics
Chemical Engineering Vol 100 Supplement 2 Feb 1993 p 21

This article describes a new bioreactor that uses a consortium of aerobic bacteria to biodegrade chlorinated aromatic hydrocarbons. Methanotrophic bacteria are cultivated for their MMO enzyme. After the MMO enzyme breaks down the chlorinated organics by oxidation, non-methanotrophic bacteria consume the byproducts. Pilot-scale testing has demonstrated successful treatment of groundwater containing coal-tar constituents, toluene, trichloroethylene, vinyl chlorides, chlorobenzene, and methyl methacrylate from three Superfund sites.

1992:

Laboratory Evaluation of Aerobic Biotreatment for Remediation of a Low Level Organics Contaminated Groundwater
Zappi, M.E.; Fleming, E.C.; Cullinane, M.J., Environmental Lab., Vicksburg, MO;
Hearnen, D.E.; Coyle, C.G., USAE District, Kansas City, MO
Hazardous Materials Control/Superfund 92: 13th Annual Conference and Exhibition, Washington, DC, 1-3 Dec 1992 pp 467-473
Publisher: Greenbelt, MD Hazardous Materials Control Resources Institute 1992

Report Number(s): CONF-921235

The Lang Superfund Site is located in Pemberton Township, New Jersey. The groundwater from the Lang site is characterized by low level VOC contamination. As part of the design phase of the site remediation efforts, a bench-scale evaluation of aerobic biotreatment was performed by theE Waterways Experiment Station in conjunction with the E District, Kansas City. The low levels of organic contamination result in a system influent biochemical oxygen demand (BOD) that is expected to be only 35 mg/L. This BOD concentration was considered challenging to an aerobic bioreactor in that it is only twice as high as a typical effluent from an active aerobic bioreactor. The evaluation was performed using 2-L chemostats which were operated as activated sludge systems. The results indicate that aerobic biotreatment was capable of reaching treatment goals. Based on the results of this study, the design of aerobic biotreatment systems for site remediation has been completed and construction is expected to be initiated in the near future.

Critical Review of In Situ Bioremediation: Topical Report, January 1990-March 1992
Rittmann, B.E.; Valocchi, A.J.; Seagren, E.; Ray, C.; Wrenn, B.
Illinois Univ. at Urbana-Champaign, Newmark Civil Engineering Lab 1992 185pp

In situ bioremediation, which is the managed, in-place cleanup of contaminated groundwater aquifers and surface soils by microorganisms, is a promising technology because it is versatile and can have significant economic advantages. Many common contaminants are biodegradable, and new microbial capabilities for degradation are being discovered all the time. Success in the field and in laboratory studies point out the promise. On the other hand, the promises are not yet fulfilled, mainly because of the complexity of the subsurface situation. The report provides a comprehensive and in-depth critical review of in situ bioremediation. It is organized to evaluate the possibilities and restrictions inherent in all facets of in situ bioremediation, including microbiology, hydrodynamics, engineering, and its legal and other nontechnical aspects. Several of the key conclusions are illustrated by case studies of successful field projects. Finally, the research needed to advance in situ bioremediation to become a reliable and acceptable tool is outlined. Contracts GRI-5086-253-1383, GRI-5090-253-1930 Prepared in cooperation with North Dakota Univ., Grand Forks. Energy and Environmental Research Center. Sponsored by Gas Research Institute, Chicago, IL., and Department of Energy, Morgantown, WV. Morgantown Energy Technology Center.

1990:

Bioremediation in the Field: Number 1, November 1990
Environmental Protection Agency, Washington, DC.
Office of Solid Waste and Emergency Response
Nov 1990 18p

The Bioremediation Field Initiative is designed to provide EPA and State project managers, consulting engineers, and industry with timely information regarding new developments in the application of bioremediation. These applications include the cleanup of abandoned waste sites, industrial facilities, leaking underground storage tanks and ground water impacted from these sources. The Technology Innovation Office TIO, an office within the Office of Solid Waste and Emergency Response OSWER, in conjunction with the Office of Research and Development's ORD Office of Technology Transfer and Regulatory Support, will produce the bulletin on a regular basis to serve as the principal information transfer mechanism for the Bioremediation Field Initiative.

PHYSICAL/CHEMICAL SURVEYS

1995:

Emerging Abiotic In Situ Remediation Technologies for Ground Water and Soil: Summary Report
Environmental Protection Agency, Washington, DC. Office of Solid Waste and Emergency Response
Report No.: EPA/542/S-95/001; NTIS Number: PB95-239299 Apr 1995 4p

The document summarizes the status and trends in the development of abiotic technologies to treat contaminated ground water in-place or increase contaminant solubility and mobility to improve their removal by pumping. It is an overview of six status reports that document demonstrations and research on specific emerging abiotic technologies. The information will allow stakeholders to understand the current investments in emerging abiotic technologies and make more informed decisions concerning their use for remediation. The document and the underlying status reports do not cover trends in the use of bioremediation. EPA has other resources summarizing the progress of bioremediation technologies.

Vapor Extraction, Air Sparging, and Bioventing in Combination Form a Technically and Cost Effective Scenario to Remediate Petroleum Hydrocarbons
Brown, D.A.; Baker, J.N., Parsons Engineering Science, Inc., Liverpool, NY;
Mailloux, M.P., Chevron U.S.A. Products Co., Inc., Atlanta, GA
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1155-1164
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

When the appropriate site conditions exist, air sparging, vapor extraction and bioventing can be combined to form a technically and cost effective scenario to remediate petroleum hydrocarbon contaminated soils. A former Gulf Terminal in Upstate New York meets these conditions. The site geology consists of highly permeable sands and gravels with only trace amounts of silt. The groundwater table is approximately 15 feet below the ground surface which provides an ideal vadose zone. The site contaminants are petroleum fuel residuals primarily from the former storage and transfer of gasoline distillates. A series of pilot studies were conducted at the site in July, August, and September of 1994 to determine the validity of the proposed technologies. Based on the pilot study results, it was determined that the combined technologies of soil vapor extraction, air sparging, and bioventing could be used to effectively remediate the site. Using the pilot study data as the design basis, Parsons ES designed and installed a full-scale remediation system to address both the vadose and phreatic zone contaminants. The SVE portion of the system was placed into operation in April of 1995, and to date has removed over 12,000 pounds of petroleum hydrocarbons, including over 30 pounds of benzene. The overall costs for remediating the site including pilot studies, detailed design, system installation, and one year of operation are estimated at $5.60 per cubic yard for the estimated 35,000 cubic yards of contaminated soil at the site. The pilot study, full-scale operational results, and projected remediation costs are the focus of this paper.

Treatability of Subsurface-Derived Fluids from a Former Manufactured Gas Plant
Pergrin, D.E.; MacFarlane, I.D.; Miller, P.J.; McCleary, G.D., EA Engineering, Science, and Technology, Inc., Sparks, MD;
Walden, R.H.; Coster, D.; Logan, C.M., Baltimore Gas and Electric Co., MD
Proceedings: Innovative Technologies For Site Remediation and Hazardous Waste Management: The National Conference, Pittsburgh, PA 23-26 Jul 1995 pp 219-229
Publisher: New York, NY: American Society of Civil Engineers 1995
Report Number(s): CONF-9507173

Treatment of ground water from former manufactured gas plant (MGP) sites can be both costly and technically difficult. This paper presents results from a 3-month continuous pilot study (15 gpm average) which utilized physical separation processes, chemical oxidation systems, a fluidized biological reactor, carbon adsorption, and air stripping. The presentation will focus on operational data including removal efficiencies, process flexibility, full-scale design projections, and comparative costs between some treatment technologies. Construction of a full-scale treatment system utilizing the pilot test data is currently underway.

1992:

Groundwater Treatability Studies at a Former Chemical Munitions Burial Site
Powels, C.C., Army Aberdeen Proving Ground, MD;
Zirps, N.A.; LaCaria, T.M., ICF Kaiser Engineers, Inc., Pittsburgh, PA
Proceedings: 1992 Hazardous Materials Control Research Institute Federal Environmental Restoration Conference And Exhibition, Vienna, VA 15-17 April 1992 pp 93-100
Publisher: Greenbelt, MD, Hazardous Materials Control Resources Institute 1992

The past disposal of chemical-agent wastes, munitions, and other hazardous materials at Old O-Field, Aberdeen Proving Ground, Maryland, has impacted the groundwater at the site as well as the interconnected surface water. Three potentially viable treatment alternatives were identified during the feasibility study process as follows: chemical precipitation/air stripping/carbon adsorption; chemical precipitation/ultraviolet-oxidation; chemical precipitation/activated sludge/carbon adsorption. A series of treatability studies was conducted using groundwater extracted directly from the aquifers at Old O-Field in an effort to select an on-site treatment alternative for removing and/or destroying the unusual and extensive array of contaminants found in the groundwater and to demonstrate the overall effectiveness of the treatment alternatives in meeting treatment goals. Bench-scale treatability studies were initially conducted for the three treatment alternatives using laboratory-sized equipment. This series of tests provided comparative data on the ability of each unit process and treatment alternative to remove or destroy the unique array of contaminants. Bench-scale treatability study results were used to identify effective treatment alternatives for further evaluation in a pilot-scale treatability study. Pilot-scale tests were then conducted at Old O-Field using full-sized treatment equipment in order to evaluate and compare the effectiveness and implementability of the selected alternatives under actual field conditions. Water quality standards or criteria are lacking for several key chemicals of concern at Old O-Field. In addition, toxicity information for complex mixtures of organic contaminants and metals is incomplete. A series of biotoxicity studies on aquatic species was performed as part of the treatability study program to measure treatment system performance as a function of overall reduction of toxicity.

MODELING AND ASSESSMENT TOOLS

1996:

Analytical Model for Heterogeneous Reactions in Mixed Porous Media
Hatfield, K.; Burris, D.R.; Wolfe, N.L.
Univ of Florida, Gainesville, FL
Journal of Environmental Engineering Vol 122 No 8 Aug 1996 pp 676-684

The 'funnel/gate system' is a developing technology for passive ground-water plume management and treatment. This technology uses sheet pilings as a funnel to force polluted ground water through a highly permeable zone of reactive porous media (the gate) where contaminants are degraded by biotic or abiotic heterogeneous reactions. This paper presents a new analytical nonequilibrium model for solute transport in saturated, nonhomogeneous or mixed porous media that could assist efforts to design funnel/gate systems and predict their performance. The model incorporates convective/dispersion transport, dissolved constituent decay, surface-mediated degradation, and time-dependent mass transfer between phases. Simulation studies of equilibrium and nonequilibrium transport conditions reveal manifestations of rate-limited degradation when mass-transfer times are longer than system hydraulic residence times, or when surface-mediated reaction rates are faster than solute mass-transfer processes (i.e., sorption, film diffusion, or intraparticle diffusion). For example, steady-state contaminant concentrations will be higher under a nonequilibrium transport scenario than would otherwise be expected when assuming equilibrium conditions. Thus, a funnel/gate system may fail to achieve desired ground-water treatment if the possibility of mass-transfer-limited degradation is not considered. (Author abstract) 38 Refs.

Systematically Selecting an Alternative to Remediate Soil Contaminating Groundwater
Elmore, Andrew Curtis
Woodward-Clyde Federal Services, Overland Park, KS
Remediation Vol 6 No 2 Spring 1996 pp 43-57

A systematic framework is presented for selecting a soil remediation alternative at a hazardous-waste site using data from the site remedial investigation and feasibility study. Three steps are involved: development of a decision tree from the study data; selection of mathematical models that represent the migration of chemicals from the leaching soils to groundwater in the saturated zone and the pump-and-treat removal of the chemicals; and development of the restoration time-frame probability distribution for each remedial alternative using Monte Carlo techniques. The methodology is illustrated by application to a hypothetical site.

Monitoring Networks in Fractured Rocks: A Decision Analysis Approach
Jardine, K.; Smith, L.; Clemo, T.
Univ. of British Columbia, Vancouver, British Columbia, Canada Dept. of Geological Sciences
Ground Water Vol 34 No 3 May-Jun 1996 pp 504-518

Hydrogeological decision analysis is applied to the design of a performance monitoring network at a waste management facility overlying fractured bedrock. The objective of the monitoring system is to detect contaminants before they reach a regulatory compliance boundary in order to enable early and less costly on-site remediation, and avoid the potentially more costly consequences of failure. Features in the design of the monitoring network include the number of monitoring wells to be installed and their locations, where in each borehole to position discrete monitoring zones, and how often to take water

samples. The decision model identifies the preferred monitoring strategy as the design alternative that minimizes the sum of the monitoring costs and the expected costs of failure and on-site remediation. When the probability of contaminants migrating to the compliance boundary is small during the compliance period, changes in the probability of detection brought about by a more intense monitoring effort do not affect the expected cost of failure much; in these instances, the decision model may point to a reduced effort in performance monitoring.

1995:

New Breed of Innovative Ground Water Modeling
Gelinas, R.; Doss, S.; Ziagos, J.; McKereghan, P.; Vogele, T.
Lawrence Livermore National Lab., CA
Proceedings: Environmental Remediation Conference: Committed To Results, Denver, CO 13-18 Aug 1995
Report No.: UCRL-JC-120613; NTIS Number: DE96000394 Jul 1995 10p

Lack of data necessitates non-unique interpolations that can distort modeled distributions of contaminants and essential physical properties (e.g., permeability, porosity). These properties largely determine the rates and paths that contaminants may take in migrating from sources to receptor locations. We apply both forward and inverse model estimates to resolve this problem because coupled modeling provides the only way to obtain constitutive property distributions that simultaneously simulate the flow and transport behavior observed in borehole measurements. Fundamentally new modeling concepts and novel software have emerged recently from two decades of research on self-adaptive solvers of partial differential equations (PDEs). We have tested a revolutionary software product, PDEase, applying it to coupled forward and inverse flow problems. In the Superfund cleanup effort at Lawrence Livermore National Laboratory's (LLNL) Livermore Site, the new modeling paradigm of PDEase enables ground water professionals to simply provide the flow equations, site geometry, sources, sinks, constitutive parameters, and boundary conditions. Its symbolic processors then construct the actual numerical solution code and solve it automatically. Powerful grid refinements that conform adaptively to evolving flow features are executed dynamically with iterative finite-element solutions that minimize numerical errors to user-specified limits. Numerical solution accuracy can be tested easily with the diagnostic information and interactive graphical displays that appear as the solutions are generated.

The Management of Movement of a Contamination Spot in Ground Water Using Optimization Modeling
Borevsky, B.V.; Borevsky, L.V.; Ershov, G.E.; Ugorets, V.I.
Hydrogeoecological Research and Design Co., Moscow (Russian Federation)
Proceedings: Volume 2: Management of Low-level Waste and Remediation of Contaminated Sites and Facilities, Fifth International Conference on Radioactive Waste Management and Environmental Remediation -- ICEM '95, Berlin (Germany) 3-9 Sep 1995 pp 1307-1311
Publisher: New York, NY: American Society of Mechanical Engineers 1995
Report Number(s): CONF-950917

Regulating the movement of a pollution spot in ground water is suggested by creating a system of pumping and injection wells and a necessary field of hydraulic gradients between them. Definition scheme of location and operating regime is made on the basis of an optimization model in hydrodynamic formulation with the following control of optimal solution on the mass transfer model.

The mathematical formulation of the optimization problem, methods and results of solution for two real objects are presented in this paper. The methodology may be used for solving a wide range of problems related both to elimination of existing pollution spots and creating new pollution contours of a desired configuration in the course of underground disposal of liquid wastes.

Groundwater Modeling in RCRA Assessment, Corrective Action Design and Evaluation
Rybak, I.; Henley, W.
Benchmark Engineering Inc., Birmingham, AL)
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1431-1440
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

Groundwater modeling was conducted to design, implement, modify, and terminate corrective action at several RCRA sites in EPA Region 4. Groundwater flow, contaminant transport and unsaturated zone air flow models were used depending on the complexity of the site and the corrective action objectives. Software used included Modflow, Modpath, Quickflow, Bioplume 2, and AIR3D. Site assessment data, such as aquifer properties, site description, and surface water characteristics for each facility were used in constructing the models and designing the remedial systems. Modeling, in turn, specified additional site assessment data requirements for the remedial system design. The specific purpose of computer modeling is discussed with several case studies. These consist, among others, of the following: evaluation of the mechanism of the aquifer system and selection of a cost effective remedial option, evaluation of the capture zone of a pumping system, prediction of the system performance for different and difficult hydrogeologic settings, evaluation of the system performance, and trouble-shooting for the remedial system operation. Modeling is presented as a useful tool for corrective action system design, performance, evaluation, and trouble-shooting. The case studies exemplified the integration of diverse data sources, understanding the mechanism of the aquifer system, and evaluation of the performance of alternative remediation systems in a cost-effective manner. Pollutants of concern include metals and PAHs.

Steps Involved with Defining and Remediating a TCE Source Area
Mack, J.P.; Duligall, A.S.
McLaren/Hart Environmental Engineering Corporation, Warren, NJ
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 p 1182
Publisher: Washington, DC: American Chemical Society 1995
Report Number(s): CONF-9509139

Perhaps one of the most difficult tasks faced in the environmental arena today is to remediate sites contaminated with chlorinated solvents. For a variety of reasons, conventional approaches have proven ineffective, requiring the consideration and implementation of alternative Risk-Based Remediation Strategies (RBRS). McLaren/Hart negotiated and implemented a RBRS approach for a site where TCE (trichloroethylene) had contaminated a shallow aquifer system. The approach is based upon an in-depth understanding of site conditions, the conceptual model of Dense Non Aqueous Phased Liquids (DNAPL) migration in the subsurface, an ability to carefully locate and remediate the source area of the TCE plume and computer modeling, which demonstrated that natural attenuation would be acceptable for the existing plume. Using the targeted source and the results of the pilot test, a full scales remediation system was designed. The three dimensional image of the source mass provided critical

information for accurate design of the air sparging delivery system. Since sparge wells have a limited radius of influence, exact placement is essential for optimum efficiency. By carefully defining the boundaries of the area requiring remediation, the exact number, screen placement, operating pressures and system flexibility could be properly specified. Ultimately the air sparging system remediated the area so that a natural remediation compliance program could be implemented.

Gaussian Modeling of Contaminant Plumes
Blackwelder, L.S.; Smoot, J.L.
Univ. of Tennessee, Knoxville, TN, Dept. of Civil and Environmental Engineering
Proceedings: Innovative Technologies For Site Remediation and Hazardous Waste Management: The National Conference, Pittsburgh, PA 23-26 Jul 1995 pp 79-85
Publisher: New York, NY: American Society of Civil Engineers 1995
Report Number(s): CONF-9507173

The Gaussian plume model is based on the concept that a groundwater contaminant plume in a homogeneous medium can be modeled by a combination of discrete releases from a point source. Each of the instantaneous releases is represented by a three-dimensional Gaussian distribution modified to reflect processes encountered in groundwater contaminant transport, such as dispersion, retardation and decay. The Gaussian plume model provides the same problem-solving capability provided by analytical solutions but with less mathematical complexity and computational requirements. In addition, the Gaussian plume model offers solutions not readily available through analytical solutions because the basic discrete components are independent of the temporal and spatial characteristics of the source to be modeled.

An Analysis of Perturbation Based Methods for the Treatment of Parameter Uncertainty in Numerical Groundwater Models
Connell, L. D.
Co-Operative Research Centre for Catchment Hydrology, Department of Civil Engineering, Monash University, Victoria, Australia
Transport in Porous Media Vol 21 No 3 1995 pp 225-240

Taylor series based procedures are an alternative to Monte Carlo methods for calculating prediction statistics in groundwater flow and transport modelling. Two such approaches, the first-order second moment (FOSM) and McLaughlin and Wood's perturbation method, are based on using a Taylor series to derive approximate expressions for the model predictions first and second statistical moments. The McLaughlin and Wood perturbation method was rederived using Vetter matrix notation. This was compared with the FOSM method and while the steady state expressions for these two approaches were shown to be equivalent, the transient forms were considerably different. A new form of FOSM was derived, which is simpler and has a lower computational burden. However, the McLaughlin and Wood expression had a significantly lower computational overhead than either of the FOSM methods presented. 15 ref.

Application of Uncertainty Analysis to Groundwater Pollution Modeling
Bobba, A.G.; Singh, V.P.; Bengtsson, L.
Natl. Water Res. Inst., Burlington, ON, Canada
Environmental Geology Vol 26 No 2 1995 pp 89-96

Prediction and evaluation of pollution of the subsurface environment and planning remedial actions at existing sites may be useful for siting and designing new land-based waste treatment or disposal facilities. Most models used to make such predictions assume that the system behaves deterministically. A variety of factors, however, introduce uncertainty into the model predictions. The factors include model and pollution transport parameters and geometric uncertainty. The Monte Carlo technique is applied to evaluate the uncertainty, as illustrated by applying three analytical groundwater pollution transport models. The uncertainty analysis provides estimates of statistical reliability in model outputs of pollution concentration and arrival time. Examples are provided that demonstrate: (a) confidence limits around predicted values of concentration and arrival time can be obtained, (b) the selection of probability distributions for input parameters affects the output variables, and © the probability distribution of the output variables can be different from that of the input variables, even when all input parameters have the same probability distribution.

Combined Regional and Local Modelling for Aquifer Remediation at a Uranium Mining Site in the Czech Republic

Zaadnoordijk, Willem J., IWACO Consultants for Water and Environment, Rotterdam, The Netherlands;
Tusveld, Marion C. L.; Slot, Antonio F. M.; Fiedler, Jiri, Int Assoc of Hydrol Sci
Proceedings: Groundwater Quality: Remediation and Protection GQ '95 Conference, Prague, Czech Republic
IAHS Publication 225 1995 pp 391-491
(Full text available from Congressional Information Service: 1-800-227-2477)

Uranium mining in the Straz pod Ralskem and Hamr regions of the Czech Republic, conducted since 1967, included chemical leaching that contaminated the groundwater in the adjacent area. Longterm contamination of the surrounding groundwater resources is also evident. Geological and hydrogeological data were used to develop a remediation study using a geographic information system (GIS). Two three-dimensional models were used to capture the entire area. Regional groundwater is addressed by the TRIWACO model, and local contamination by the METROPOL model. The integration of the two models completes the Contaminant Transport Information System (CTI). The combined model can address alternative remediation strategies at regional and local levels.

1994:

Optimal Parameter Estimation and Remediation Design for Contaminated Groundwater Systems

Xiang Yanyong. Waterloo Univ., ON, Canada, Dept. of Civil Engineering
Publisher: Waterloo, ON Univ. of Waterloo, 1994 (199 p)

Theoretical development and computer modelling are conducted in two related areas of study: optimal parameter estimation for groundwater modelling; and optimization of pumping schemes for contaminated groundwater cleanup. A composite L1 parameter is developed to solve the inverse problems in groundwater flow and solute transport modelling. The estimator is formulated using a weighted L1 norm as the error measure between the observed state variables and their model-computed counterparts. The gradients of the state variables with respect to the parameters are computed analytically using a formulation stemming from the finite element model for the state variables. Optimization models to determine the optimal pumping scheme for contaminated groundwater cleanup are developed. The objective function and groundwater quality constraints can incorporate a number of alternative formulations. The gradients associated with the injection and extraction components of the

pumping rates are computed separately using a state sensitivity equations method. The optimal pumping design for removing multiple contaminant species is also considered. Uncertainties in aquifer parameters described by the inverse modelling are incorporated in the optimization models by using probabilistic constraints, and the impacts of the quality of parameter estimation are studied. Numerical issues concerning the combination of optimization and simulation are examined. Remediation efficiency indicators and a cleanup ratio are proposed. Hypothetical examples are presented for the L1 parameter estimator and for the optimization formulations for contaminated groundwater cleanup. The analysis of remediation design is conducted for a groundwater contamination site in Elmira, Ontario. 125 refs., 57 figs., 10 tabs.

Rapid Assessment of Trichloroethylene in Ground Water
Hewitt, Alan D.; Shoop, Sally A.
U. S. Army, Cold Regions Research and Engineering Laboratory, Hanover, NH
Ground Water Monitoring & Remediation Vol 14 No 3 1994 pp 116-122
Abstract not available.

1993:

Simulation of Contaminant Migration under Conditions of Declining Ground Water Levels
Ng, Kit Yin; Findikakis, A.N., Bechtel Corp., San Francisco, CA;
Yang, Jing-Yea, Weston Institute, West Chester, PA
Proceedings: Engineering Hydrology Symposium on Engineering Hydrology, San Francisco, CA, 25-30 Jul 1993 pp 712-716
Publisher: New York, NY American Society of Civil Engineers 1993
Report Number(s): CONF-9307147
A ground water flow and transport model was developed to simulate the migration of contaminant originating from an industrial site. The development and calibration of the model were based on data collected from the field investigation and monitoring activities which were part of a restoration program for the site. Contaminant migration patterns at the site were complicated by the regional decline of the ground water table which led to dewatering of the uppermost aquifer zone. The model was used to simulate this condition, as well as to evaluate the hypothesis of potential interconnection and existence of pathways between different aquifer zones. The transport model was calibrated by simulating the historical migration of contaminants since the beginning of plant operations. The model was subsequently used to simulate and evaluate the effectiveness of alternative ground water extraction remedial schemes. The simulations were conducted with the Princeton Transport Code, a three-dimensional, ground water flow and transport model.

Behavior of Dense Volatile Organic Compounds in Bedrock
Foster, G.D.; Priore, S.
New York State Dept. of Environmental Conservation, Albany, NY
Proceedings: Association of Ground Water Scientists and Engineers (AGWSE) Educational Seminar on Chlorinated Volatile Organic Compounds in Ground Water, Kansas City, MO, 17-20 Oct 1993 Ground Water Vol 31 No 5 Sep-Oct 1993 p 838
Report Number(s): CONF-9310166

Data produced during a remedial investigation at a chemical plant in Niagara Falls, New York seemed contradictory. Dense chlorinated organic compounds traveled the farthest horizontally in bedrock in zones where it had been present for the shortest length of time. In reviewing this data the authors developed a theoretical concept to explain the observed behavior. This theory leads to a new insight concerning the behavior of dense nonaqueous phase liquids (DNAPLs) under confined bedrock conditions. This insight can be summarized in a statement of principle: when a dense nonaqueous phase liquid migrates through confined pathways such as bedrock fractures, its migration is controlled primarily such as bedrock fractures, its migration is controlled primarily such as bedrock fractures, its migration is controlled primarily by gravity and pressure head differences. This suggests that DNAPL migration does not rely on dispersion, advection, or any transport mechanism other than the one just described. This principle holds the key to a new strategy for the remediation of hazardous waste sites where large quantities of DNAPLs pose a significant threat to public health and/or the environment. This paper describes the hydrogeological setting for the initial case, discusses the field evidence, sets forth a mathematical analysis of the behavior, and presents the strategy for innovative remedial technique(s) based on the principles involved.

Case Study: Hydrogeology, Contaminant Transport, and Remediation in an Anisotropic, Fractured Bedrock Ground-Water System

Roach, L.F.; Robertson, C.G.
Groundwater Sciences Corp., Harrisburg, PA

Proceedings: Association of Ground Water Scientists and Engineers (AGWSE) Educational Seminar on Chlorinated Volatile Organic Compounds in Ground Water, Kansas City, MO, 17-20 Oct 1993 Journal of Environmental Health Vol 56 No 3 Oct 1993 pp 848-849
Report Number(s): CONF-9310166

The site has a 30-year history of low-volume halogenated solvent ge and is located in an area of New York underlain by mica schist bedrock which is covered by glacial deposits. Dilute waste-water releases resulted in a 2,000-foot long plume of dissolved volatile organic compounds, the shape of which reflects the control of bedrock fractures on ground-water flow conditions. The site has a large number of bedrock monitoring points with 34 bedrock monitoring wells located in or near the plume, including nine bedrock monitoring well clusters. Constant rate aquifer tests of at least 36-hour duration were conducted at five bedrock wells at various positions within the plume. Remediation to date consists of three years of bedrock ground-water withdrawal at near-source and downgradient locations for hydraulic control and areal reduction of the plume. The combined drawdown produced by these two pumping centers conforms to the drawdown predicted by the additive drawdowns observed in individual aquifer tests. VOC concentrations within the plume are decreasing rapidly with some wells experiencing a reduction in VOC concentrations of greater than 90%. The plume area has been reduced by approximately 50%.

Results of a Ground-Water and DNAPL Recovery and Containment Strategy

Mazierski, P.F.; Connor, J.M.
DuPont Environmental Remediation Services, Niagara Falls, NY

Proceedings: Association of Ground Water Scientists and Engineers (AGWSE) Educational Seminar on Chlorinated Volatile Organic Compounds in Ground Water, Kansas City, MO, 17-20 Oct 1993 Journal of Environmental Health Vol 56 No 3 Oct 1993 pp 843
Report Number(s): CONF-9310166

Ground-water contamination and dense nonaqueous phase liquids (DNAPL) were discovered at the DuPont Necco Park Landfill in Niagara Falls, New York, shortly after the facility was closed in the late 1970s. The facility received a variety of solid and liquid process wastes, including chlorinated volatile and semivolatile organic compounds. A number of proactive response activities--including the operation of a ground-water recovery system, installation of a grout curtain, and DNAPL recovery--were implemented by DuPont concurrent with site characterization. These efforts minimized off-site contaminant migration and removed most of the recoverable free-phase DNAPL prior to completion of the full site characterization. Site investigations to characterize hydrogeologic controls over occurrence and migration of ground water and DNAPL revealed with distinct water-bearing zones beneath the site. A DNAPL recovery program, using gas-driven pump assemblies, was initiated in early 1989 at a small group of wells where DNAPL was frequently observed. The volume of recovered DNAPL declined over the next four years from a peak of 397 gallons per month in 1989 to little or no recovery in recent months.

Method for Evaluating Dense Nonaqueous Phase Liquid (DNAPL) Presence from VOC Concentrations in Soil Gas

Cudzilo, T.F.; Rainger, L.E.
Radian Corp., Sacramento, CA

Proceedings: Association of Ground Water Scientists and Engineers (AGWSE) Educational Seminar on Chlorinated Volatile Organic Compounds in Ground Water, Kansas City, MO, 17-20 Oct 1993
Ground Water Vol 31 No 5 Sep-Oct 1993 pp 834-835
Report Number(s): CONF-9310166

Because DNAPLs pose significant problems in remedial alternative selection, a method for identifying DNAPLs in soils with VOC concentrations in soil gas was developed for an NPL site with a 100-foot-thick, VOC-contaminated vadose zone. Calculations based on VOC concentrations in soil and soil liquids indicated that DNAPL presence could not be determined consistently, and the path of DNAPL migration could not be determined consistently, and the path of DNAPL migration could not be tracked without additional sampling. Concentrations of 1,000 to 6,900 parts per million by volume (ppmv) of two halogenated VOCs suggested that the DNAPL mass was greater than indicated by soil analyses. The remedial investigation of a 5.5 acre area within the NPL site consisted of soil, ground water, and discrete-interval soil gas sampling and analysis. The area includes a number of potential discharge points, the most important of which is a degreaser waste collection sump for a metal plating shop. During the investigation, analyses of soil gas samples collected from four to five depth intervals between 20 and 100 feet below surface, in 81 soil borings, indicated that TCE and PCE were most highly concentrated, most frequently detected, and mixed throughout the vadose zone. Neither soil nor ground-water concentrations were great enough to indicate DNAPLs, assuming equilibrium conditions. To identify volumes of soil or ground water where DNAPLs would affect remedial actions, a method was derived for using the available soil gas sample data instead of additional, costly drilling and sampling to identify DNAPLs in the soil volume.

Development of a Numerical Simulator for In-Situ Remediation by Alcohol Flooding

Brame, S.E.; Falta, R.W.
Clemson Univ., SC. Earth Sciences

Proceedings: 42nd Annual Geological Society of America (GSA) Southeastern Section meeting, Tallahassee, FL, 1-2 Apr 1993
Geological Society of America, Abstracts with Programs Vol 25 No 4 Mar 1993 p 5

Report Number(s): CONF-9304188

At many sites in the US, volatile organic compounds (VOCs) have been allowed to contaminate groundwater supplies. Of particular concern are the VOCs which exist as a separate phase and have a higher density than water. These liquids are known as Dense Non-Aqueous Phase Liquids (DNAPLs). During the migration of these liquids below the water table, a certain amount of the DNAPL will become trapped as globules in the pore spaces between the soil grains. This trapped fraction is known as the residual saturation. The remediation of sites contaminated with DNAPLs using traditional pump and treat methods has been shown to be ineffective and inefficient at removing the residual contamination. The mobilization of the trapped DNAPL globules using alcohol flooding is a promising new technology that is currently in the experimental stage. Injecting alcohol solutions into contaminated soils reduces the interfacial tension between the aqueous and NAPL phases, allowing the trapped globules to move between the pore constrictions and to be recovered downgradient. The process of applying this technology to field applications demands an ability to predict, and thus model, the complex flow and interactions of an alcohol/water/DNAPL system moving through porous media. A compositional, multiphase Integral Finite Difference numerical simulator is presently being developed to model this process. The model will use a digitized version of the ternary diagram that represents the particular alcohol/water/DNAPL system being investigated. While the current code is being developed to simulate one-dimensional column experiments, the code will contain the capabilities for predicting multidimensional, field scale behavior given the appropriate parameters and measurements.

Evaluation of the Existing and Potential Future Ground-Water Remediation Systems at a Hazardous Waste Disposal Site in Southern New Jersey Using Ground-Water Modeling

DeCillis, Michael A.

Roux Associates, Islandia, NY

Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Burlington, VT Sept 27-29 1993

Publisher: Water Well Journal Pub. Co., Dublin, OH

Ground Water Management Vol 16 Sept 1993 pp 185-202

Abstract not available.

1992:

Organic Substances in the Subsurface: Delineation, Migration, and Remediation.

Murarka, Ishwar; Neuhauser, Edward; Sherman, Michael; Taylor, Barbara B.; Mauro, David M.; Ripp, John; Taylor, Terry

Electric Power Research Inst, Palo Alto, CA

Journal of Hazardous Materials Vol 32 No 2-3 Dec 1992 pp 245-261

The Electric Power Research Institute (EPRI) and Niagara Mohawk Power Corporation are sponsoring a research program concerning the release, transformation, and migration of organic compounds at a site where coal tar from former manufactured gas plant (MGP) operations was disposed nearly thirty years ago. Work at this site, referred to as EBOS Site 24, has included: determination of the location and chemical content of the tarry source material, delineation of the groundwater contaminant plume, evaluation and implementation of innovative methods for sampling and analysis, and the remediation and restoration of the site. The results of the initial phase of research provided several important insights into the mechanisms of contaminant release and migration. For example, the shape of the groundwater contaminant plume at EBOS Site 24 was dominated by longitudinal advection with

little contribution from transverse or vertical dispersion. A long-term monitoring program at EBOS Site 24 was initiated prior to the removal of the source material. The results of the baseline groundwater monitoring along the plume centerline were similar to the values predicted using EPRI's MYGRT™ model for migration of contaminants. After the baseline monitoring was completed, all of the tarry source material was removed in 1991 and used in the production of asphalt and portland cement. The groundwater monitoring program will continue for several years and the field results generated during this time will be used to evaluate and/or calibrate the MYGRT™ model. (Author abstract) 12 Refs.

Least Squares Approach for Solving Remediation Problems of Contaminated Aquifers

Zeitoun, D. G.; Pinder, G. F.
Hydrologic Service, Jerusalem, Israel

Proceedings: The 9th International Conference on Computational Methods in Water Resources Denver, CO Conference Date: June, 1992
Finite Elements in Water Resources, Proceedings of the International Conference Vol 1
Publisher: Computational Mechanics Publ, Southampton, Engl. p 329-336
1992

The minimization of the cost of remediation of a contaminated groundwater site may be analysed with the aid of the computer. This paper presents a new methodology for groundwater management, in which the simulation of groundwater flow and transport and the optimal remedial design are treated as one large minimization problem. The numerical solution of the flow-transport system as well as the management problem are solved using an optimal-control least squares formulation. An augmented lagrangian method associated with a Quasi-Newton algorithm is proposed for the global solution of the management problem. 2 Refs.

Use of Ion Mobility Spectrometry in Determining Organic Pollutants in Water

Poziomek, E.J., Univ. of Nevada, Las Vegas;
Eiceman, G.A. New Mexico State Univ., Las Cruces

Proceedings: 1992 Hazardous Materials Control Research Institute Federal Environmental Restoration Conference And Exhibition, Vienna, VA 15-17 April 1992 pp 252-254
Publisher: Greenbelt, MD, Hazardous Materials Control Resources Institute 1992

There is increasing interest in simple and inexpensive techniques that can be used for rapid on-site determinations of contaminants at hazardous waste sites. Such interest is motivated by costs and delays of sophisticated analytical methods and the need for multiple measurements during site characterizations and in remediations. Screening of samples on-site with portable, capable and simple technologies constitutes a compromise that may yield quantitative or semiquantitative results at acceptable speed and cost. Ion mobility spectrometry IMS is an instrumental technique for the detection and characterization of organic compounds as vapors in air. In IMS, analyte vapors are ionized in a reaction region, and resultant ions are injected into a drift region where determinations occur through gaseous ionic mobilities. Results from a recent US EPA Superfund Innovative Technology Evaluation SITE laboratory trial suggested that available IMS instruments are not field ready for environmental monitoring and measurement applications. Solutions to several technology barriers, such as sampling strategies for sod and water, are needed. This paper summarizes experiments on the use of solid-phase enrichment of organic compounds from aqueous solution as a means for overcoming the lack of water sampling methods that can be used in conjunction with IMS. On the basis of the initial results, it is judged that IMS holds much promise for field screening in the near term and as a diagnostic tool in the longer term.

Evaluation of Groundwater Flow Regime at a Landfill With Liner System
Maslia, Morris, L.; Aral, Mustafa, M.; Houlihan, Michael, F.
GeoSyntec Consultants, Norcross, GA
Journal of Environmental Science and Health, Part A: Environmental Science and Engineering Vol 27 No 7 Oct 1992 pp 1793-1816

The High Acres landfill is a 166-acre 67-ha sanitary waste disposal site located southeast of Rochester, New York. The site consists of an existing 92-acre 37-ha unlined landfill and a proposed 74-acre 30-ha landfill expansion. To contain the leachate that may be produced at the new site, the construction of a liner system is proposed. According to regulations, the base of the landfill liner system is required to be above the seasonal high water-table at the site. A multilayer aquifer model was used, therefore, 1 to simulate the mechanism by which groundwater moves through the High Acres site; and 2 to evaluate the average and seasonal high water-table conditions at the site with and without the liner system. Based on these simulations, critical design aspects of the landfill liner system and its effect on the local groundwater flow regime is evaluated throughout the entire site. Author abstract 14 Refs.

3-D Modeling Useful Tool for Planning
Calmbacher, C.W.
Safe Environmental Alternatives Group Inc., Lawrenceville, GA
Environmental Protection Vol 3 No 10 Dec 1992 pp 17-18

Visualizing and delineating subsurface geological features, groundwater contaminant plumes, soil contamination, geological faults, shears and other features can prove invaluable to environmental consultants, engineers, geologists and hydrogeologists. Three-dimensional modeling is useful for a variety of applications from planning remediation to site planning design. The problem often is figuring out how to convert drilling logs, map lists or contaminant levels from soil and groundwater into a 3-D model. Three-dimensional subsurface modeling is not a new requirement, but a flexible, easily applied method of developing such models has not always been readily available. LYNX Geosystems Inc. has developed the Geoscience Modeling System GMS in answer to the needs of those regularly having to do three-dimensional geostatistical modeling. The GMS program has been designed to allow analysis, interpretation and visualization of complex geological features and soil and groundwater contamination. This is a powerful program driven by a 30 volume modeling technology engine. Data can be entered, stored, manipulated and analyzed in ways that will present very few limitations to the user. The program has selections for Geoscience Data Management, Geoscience Data Analysis, Geological Modeling interpretation and analysis, Geostatistical Modeling and an optional engineering component.

The Use Of Small Diameter Probing Equipment For Contaminated Site Investigation
Christy, T.M.; Spradlin, S.C.
Geoprobe Systems, Salina, KS
Proceedings: Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, Las Vegas, NV, 11-13 May 1992 pp 87-101
Publisher: Dublin, OH Ground Water Management 1992

The past decade has witnessed a dramatic increase in the number of contaminated sites being investigated in the United States. This increase in subsurface investigation has spurred a corresponding increase in the development of subsurface sampling tools and methods. This development has placed heretofore unavailable tools at the disposal of site investigators. Mechanized, vehicle mounted soil probe systems apply both static force and hydraulically powered percussion hammers for tool

placement. Static down forces up to 3,000 lbs combined with percussion hammers of eight 8 horsepower continuous output are typical on equipment available to the field investigator. Using these energies, probing tools have been used for sampling a variety of media at depths exceeding 70 feet. Advantages of probing equipment which have contributed to its increasing usage in recent years include: ease of mobilization, absence of borehole cuttings, minimization of surface disturbance, and speed of sample collection. This paper focuses on the field application of hydraulic probing equipment including: the suitability of probing operations with respect to various Boil types and lithologies to probing operations; sampler types and recovery quantities for various media, and innovative probing applications presently being tested.

Alternative Groundwater Remediation Techniques Using Numerical Simulation and The Outer Approximation Method
Karatzas, G. P.; Pinder, G. F.
University of Vermont, College of Engineering and Mathematics, Burlington, VT
Proceedings: American Geophysical Union 1992 Fall Meeting, San Francisco, CA, Dec 7-11 1992
Publisher: American Geophysical Union, Washington, DC
American Geophysical Union Vol 73 No 43 Supplement; p 240
Abstract not available.

1991:

Selection of a Preferred Remedial Well Configuration Using Groundwater Modeling Techniques
Dove, H.; Spangler, R.; Myers, D.; Kroutch, B.
Proceedings: Environmental Remediation 1991: Cleaning up the Environment for the 21st Century, Pasco, WA, 8-11 Sept 1991 pp 789-792
Published: 1991
The alternative screening process of a Remedial Investigation/Feasibility Study RI/FS at a California location was assisted through the use of numerical modeling techniques to evaluate several groundwater pumping and injection schemes. Computer modeling was used to window the alternatives down to a recommended well configuration. The final scheme was a further refinement based on operational considerations. The remedial pumping rate was 200 gallons per minute gpm, and the initial concentration of trichloroethylene TCE was estimated to be less than 300 parts per billion ppb. The pumped groundwater was projected to reach a TCE concentration of 5 ppb after approximately 8 years of operation. When the 95 percent upper confidence limit on the arithmetic mean chemical TCE concentration of 15 monitoring wells is used to indicate compliance with the Applicable or Relevant and Appropriate Requirements ARARs, the TCE plume may be cleaned-up after 6 years of operation. Aquifer tests at the site have reduced the uncertainty in aquifer hydraulic parameters. However, uncertainties in TCE plume definition, natural TCE degradation, and TCE retardation with groundwater movement dominate the concentration estimates and the projected clean-up times.

Efficiency-Based Groundwater Monitoring Design Using the Monitoring Efficiency Model MEMO
Wilson, C.R.; Einberger, C.M., Golder Associates, Redmond, WA;
Jackson, R.L.; Mercer, R.B., Westinghouse Hanford Company, Richland, WA
Proceedings: Environmental Remediation 1991: Cleaning up the Environment for the 21st Century,

Pasco, WA, 8-11 Sept 1991 pp 915-917
Published: 1991

An analytical Monitoring Efficiency Model MEMO has been developed to assist in the design of monitoring well networks at hazardous waste sites. The method simulates the migration of hypothetical contaminant plumes from a site and quantifies the efficiency of alternative well network designs in detecting the plumes. The computed efficiency provides a quantified basis for optimizing the design. Maps of the site showing areas where releases would or would not be detected by a given well network are produced, providing insight into the benefits of adding, deleting, or moving specific wells. MEMO is applied using a menu-driven computer program.

Monte Carlo Simulation of Groundwater Remediation at a Nebraska Contamination Site
Elmore, A.C. Arizona Univ., Tucson, AZ
1991 199 p

Characterization of the effectiveness of ground water contamination remediation alternatives is complex due to uncertainties associated with the ground water system. This dissertation presents a Monte Carlo simulation model for stochastic characterization of the maximum concentration of contaminant remaining in an aquifer after the application of pump and treat remedial alternatives. The model is written in FORTRAN 77 for the Convex 240. The model uses a publicly available finite difference code for flow analysis and a commercially available method of characteristics transport code. Hydraulic conductivity fields are randomly generated using the turning bands method; initial concentration fields are conditionally simulated on measured and estimated concentration values; and retardation coefficient fields are negatively correlated to hydraulic conductivity using partition coefficients sampled from a log normal distribution. The model was applied to three pump and treat alternatives selected for consideration at a Nebraska contamination site. Two dimensional analysis of flow and transport was performed. Special treatment of flow boundary conditions was necessary due to site conditions and model restrictions. The probabilistic analyses of the resulting maximum concentration ensembles were used to demonstrate decision analysis at the site. Beta probability distributions were fitted to the maximum output ensembles. The decision tree model incorporated monetary values, human health considerations, and regulatory issues as well as probabilistic considerations. Illustration of the decision analysis procedure showed that the choice of the optimal remedial alternative was dependent on the monetary value assigned to noncarcinogenic and carcinogenic adverse human health risks.

Optimal Groundwater Quality Control and Monitoring With Incomplete Information
Lee, Sangil.
Stanford Univ., CA
1991 170 p

This research develops a new method for optimal groundwater quality management and monitoring in aquifer remediation when aquifer information is limited. The objective is to find the most cost-effective aquifer management policy for collecting site measurements, pumping, and treating contaminated aquifers. Subject to constraints on decision variables and on the reliability of meeting water quality standards, this method minimizes the expected value of the cost in the remaining periods. The optimal aquifer management policy is expressed as the sum of a deterministic and a stochastic control term. The former is obtained by solving a deterministic optimization problem and the latter by a perturbation approximation to the stochastic optimal control problem. Extended Kalman filtering is incorporated into the proposed optimization method to improve the accuracy of the estimated state and

parametric variables using available measurements. A hypothetical contamination case of a two-dimensional unsteady flow and transport for a persistent solute is studied to illustrate the applicability of the methodology. The effectiveness of the proposed method is studied under various conditions, and then compared with the cost and reliability of the deterministic feedback control method through Monte Carlo simulations. Finally, this research develops a method to determine the location of an additional monitoring well while the aquifer is being cleaned up. The candidate monitoring well sites are ranked based on the evaluation of the cost-to-go function, an index of costs expected until the goals of remediation are met.

A Critical Review of Site Assessment Methodologies
Selby, D.A.
Las Vegas Valley Water District, Las Vegas, NV
Proceedings: 1st Annual West Coast Conference on Hydrocarbon Contaminated Soils and Groundwater, Newport Beach, CA, Feb 1990 pp 149-160
Published: 1991

The ability to rapidly and accurately assess the nature and extent of petroleum hydrocarbon contamination in soil and groundwater is of significant importance to property owners, regulatory agencies, consultants, and others involved in site investigations. As state and federal underground storage tank regulations have been enacted, the need for assessment has increased dramatically. This demand has resulted in development of some accepted standard site assessment techniques and a number of innovative assessment methods which have yet to be proven. The site assessment normally forms the basis upon which subsequent actions are taken that may result in long-term liability and/or major expenditures for site remediation. As a result, it is extremely important that site assessment methods provide the most accurate and reliable information attainable. This paper focuses on the methods available to assess the extent, magnitude, and nature of petroleum hydrocarbon contamination in soil and groundwater. It includes an examination of factors that influence the accuracy of the techniques to assist investigators in the determination of appropriate methods for specific sites.

Statistical Method Developed by The American Petroleum Institute to Evaluate the Technical Limits of a Groundwater Remediation Project
Hockman, B.
Amoco Corp., Tulsa, OK
Proceedings: First Annual Groundwater and Soil Remediation, Development and Demonstration Symposium, Ottawa, Canada, 30 Jan 1991 pp 1-6, Paper 17 vp.

In subsurface hydrocarbon remediations, pump-and-treat technology is often most effective. The common response of dissolved hydrocarbon concentrations during a pump-and-treat remediation is presented. When the concentration curve vs time reaches the asymptotic phase, several responses are possible, and the optimum response may not be one requiring a technology modification. In addition, data within an asymptotic phase can include significant variability from sampling and/or analytical error, seasonal effects, or system malfunction, thereby introducing an uncertainty as to whether the asymptotic phase has been reached. A statistical method was developed to evaluate the applicability of remediation, based on real data from pump-and-treat remediations. Based on the results from two alternative approaches linear regression analysis and first order exponential decay a remediation was considered in the asymptotic phase if the slope of the line of concentration vs time was not significantly different from zero. A software program was then compiled to determine whether remediation has

reached the asymptotic phase. In practice, 10 measurements spaced over a 6-9 month period are required to give accurate results. 4 refs., 3 tabs.

Application of a Numerical Groundwater Flow Model for Evaluating Remedial Alternatives at a Contaminated Landfill Site
Hall, Peter J.
ABB Environ. Serv., Portland, ME
Proceedings: FOCUS Conference on Eastern Regional Ground Water Issues, Portland, ME, Oct. 29-31, 1991
Ground Water Management Vol 7 1991 pp 91-104
Abstract not available.

Modeling Ground-Water Flow for Remedial Design Using the Analytic Element Method
Wuolo, Ray W.
Barr Eng. Co., Minneapolis, MN
Proceedings: Association of Ground Water Scientists and Engineers annual meeting on Innovative ground water technologies for the '90s, Washington, DC,, Oct. 21-23 1991
Ground Water Vol 29 No 5 Oct 1991 p 753
Abstract not available.

1990:

Quantitative Structure-Activity Relationships: New Tools for Remediation of Contaminated Groundwater
Zitomer, D. H.; Speece, R. E.,
Vanderbilt Univ, Nashville, TN
Proceedings: 22nd Mid-Atlantic Industrial Waste Conference, Philadelphia, PA, 1990 pp 626-644
Until recently, it was widely believed that the groundwater of the United States was essentially uncontaminated. Within the last decade, however, contamination has been found to be a significant problem. One new technique which would presently solve some problems is Quantitative Structure Activity Relationships QSARs. These mathematical relationships predict chemical behavior -such as toxicity, bioconcentration, solubility and biodegradability -using molecular structure information gleaned from the chemical's structural formula. Six QSARs which relate to groundwater remediation strategies are described. Edited author abstract 22 Refs.

New Method For In-Situ Remediation of Volatile Contaminants in Groundwater: Numerical Simulation of the Flow Regime
Herrling, B.; Buermann, W.
Univ of Karlsruhe, Karlsruhe, Germany
Proceedings: 8th International Conference on Computational Methods in Water Resources, Venice, Italy, June 11 1990 pp 299-304
A new hydraulic system for in-situ remediation of volatile contaminants e.g. chlorinated hydrocarbons in groundwater is presented. The contaminated groundwater is stripped by air in a below atmospheric pressure field in a special filtered well. The vertical well discharge initiates a circulation

flow in the region surrounding the well. Using simplifying assumptions the complex three-dimensional velocity field and the capture zone of a well or well field are computed. Author abstract 2 Refs.

High Resolution Seismic Reflection Applications in Ground Water Monitoring Design
Lewis, B.R.; Folger, P.F.; Arndt, M.B.
EG&G Rocky Flats, Inc., Golden, CO
Proceedings: Fourth National Outdoor Action Conference on Aquifer Restoration, Groundwater Monitoring, and Geophysical Methods, Las Vegas, NV, 14-17 May 1990 pp 1167-1177

The bedrock underlying the Rocky Flats Plant, Golden, Colorado is comprised of claystone, siltstone and sandstone that were deposited by a complex fluvial system. Because of the heterogeneities inherent in such a complex stratigraphic system, monitoring networks should be based on an accurate reconstruction of the depositional system. Lithologic data collected from boreholes drilled at the Rocky Flats Plant suggest that the coarser grained, and presumably more permeable sediments cannot be easily correlated without boreholes being placed in a tightly spaced grid pattern. The inherent costs for such a network prompted an evaluation of alternative methods to characterize the subsurface geology. Shallow high resolution seismic reflection was modeled and field tested in light of remedial investigation objectives to assess ground water contamination. Field tests showed that seismic reflection could identify reflectors from 25 to 250 feet below ground surface with a three foot vertical resolution. In addition, paleochannel morphologies, facies changes, and other stratigraphic and structural features not evident from borehole correlations were indicated. The current stratigraphic and depositional models are being re-evaluated to incorporate this preliminary seismic information. A conceptual three-dimensional geologic model, in addition to previously collected contaminant data, is being used to develop the monitoring networks at the Rocky Flats Plant.

How Flat Is Flat: Termination of Remedial Ground-Water Pumping
Spreizer, G M; Maxim, D; Valkenburg, N; Hauptmann, M
Geraghty and Miller, Inc., Andover, MA
Ground Water and Vadose Zone Monitoring. STP 1053. ASTM, Philadelphia 1990 pp 247-255

Remedial actions are being initiated at many Superfund sites, and the analyses of water quality data from these sites are being performed. While the start of remediation is obvious, the determination of when remediation is complete may not be clear. Concentrations of characteristic contaminants typically will decrease rapidly and then level off to some asymptotic concentration. This is because the efficiency of remediation is generally considerably greater at higher concentrations than at lower concentrations. Some form of an exponential model will describe the system's behavior, particularly when groundwater pumping is the remedial measure. With Superfund remediation schemes, cleanup or performance goals are set for key compounds. The cleanup is complete when these goals are attained. However, attainment of cleanup goals may be technically infeasible in certain cases and alternative criteria may be appropriate. A statistical methodology, based upon an anticipated exponential decrease in the contaminant concentration resulting from groundwater pumping remediation, can be used to initially predict when remedial measures can be terminated. As the remediation program continues and additional monitoring data become available, the methodology will determine whether and when preestablished concentration limits will be attained and when the equilibrium concentration can be estimated. See also W91-08986 Author's abstract

Game-Theoretic Parameter Configuration Technique for Aquifer Restoration Design

Valocchi, A J; Keith, S M; Rahman, M R; Eheart, J W
Illinois Univ. at Urbana-Champaign, Dept. of Civil Engineering
Journal of Contaminant Hydrology Vol 6 No 3 Oct. 1990 pp 205-226

The problem of designing an active hydraulic system for remediation of a polluted aquifer is addressed for the case when parameters are not known with certainty. The design problem is cast as a game in which the protagonist-designer is pitted against an antagonist which alters the values of the uncertain parameters, within prescribed limits, so as to render the engineered system most ineffective. A solution method for the antagonist 's problem, referred to as the parameter configuration technique was developed. This technique selects spatially dependent values of the distributed parameter, transmissivity, such that the pattern of variation represents a pessimistic but realistic set of design conditions. The task of finding the worst set of parameter values is cast as a constrained optimization problem whose objective function is to thwart the remedial action design to the greatest degree possible. A rudimentary objective function is arbitrarily specified by the researchers. Several types of feasibility constraints restrict the distribution of parameter values to those combinations that are realistic. One type limits the variogram, another type, the mean, and a third type, the trend, of the log transmissivity. The resulting optimization problem is ill-behaved difficulty was encountered obtaining a mathematically optimal solution. Two special heuristic techniques for obtaining a near-optimal solution are selective constraint abeyance and reverse formulation. The parameter configuration technique is applied to a hypothetical contaminated aquifer with a simple single-extraction well flushing system. The solution is compared to a Monte Carlo approach applied to the same aquifer. The required pumping rate for a pessimistic parameter set generated by the new technique is about the same as the second largest of 100 Monte Carlo realizations. Author's abstract

Innovative Use of Standard Computer Software to Efficiently Manage Groundwater Data Used in an Aquifer Restoration

Struttman, Todd;
Morris, Kirk, Metcalf & Eddy, Columbus, OH
Proceedings: FOCUS Conference on Eastern Regional Ground Water Issues, Springfield, MA, Oct. 17-19, 1990
Ground Water Management Vol 3 1990 pp 557-571

Abstract not available.

CASE STUDIES

1996:

Technology Implementation and Cleanup Progress at Savannah River Site
Papouchado, L. M.
Westinghouse Savannah River Co., Aiken, SC.
Proceedings: Waste Management '96: HLW, LLW, Mixed Wastes and Environmental Restoration - Working Towards a Cleaner Environment, Tucson, AZ, 25-29 Feb 1996
Report No.: WSRC-MS-96-0011; NTIS Number: DE96060034 Jan 96 10p

The integrated high level waste treatment system at Savannah River has started up and the process of converting 34 million gallons of liquid waste to glass and saltstone is in its initial phase. New waste disposal vaults and startup of several other facilities such as the Consolidated Incinerator Facility and a mixed waste vitrification facility will help completion of the integrated system to treat and dispose of SRS wastes. Technology was utilized from industry, other laboratories, or was developed at the Savannah River Technology Center if it was not available. Many SRTC developments involved academia and other labs. SRS also has over 400 waste sites (400 acres) in its characterization/remediation program. To date over 90 acres were remediated (23 percent) and by 1997 we plan to remediate 175 acres or 44 percent. Thirteen groundwater facility treatment sites will be in operation by 1997. SRS has provided and continues to provide unique test platforms for testing innovative remediation, characterization and monitoring technologies. We are currently testing DNAPL characterization and remediation and an in-situ inorganic remediation technique for ground water.

Remediation Efforts at DOE's Hanford Site
Abbott, John C.
Fed Facil Environ J Vol 7 No 1 Spring 1996 pp 27-37

Chemical and radioactive contamination of soils and groundwater at the DOE Hanford, WA, site is now being remedied. Limitations of pump-and-treat, excavation, and other baseline technologies applied to site decontamination are discussed, followed by an assessment of the promise offered by emerging technologies. In situ bioremediation is being evaluated for remediation of carbon tetrachloride plumes in groundwater, and in situ redox manipulation is under consideration for destruction or immobilization of diverse subsurface contaminants. Effective site remediation will rest on deployment of in-well vapor stripping and other innovative cleanup options.

A Site Specific Evaluation of Remedial Alternatives for DNAPL Contaminated Groundwater
Zamojski, L.D.; Connare, K.M., Acres International Corp., Amherst, NY;
Bergman, C.W., New Jersey Dept. of Environmental Protection, Trenton, NJ
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1368-1372
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

The groundwater in the shallow aquifer at this Superfund site has been identified as being contaminated with volatile organic compounds, specifically tetrachloroethylene (PCE) and trichloroethylene (TCE) and some metals. In the Record of Decision (ROD), the pump and treat technology with reinjection of the treated groundwater was selected as the preferred remedial action. Based upon review of analytical data, past activities and further investigation of the site, it appeared that

dense non aqueous phase liquid (DNAPL) was present at the site. Since the issuance of the ROD in 1992, scientific studies have indicated that groundwater pump and treat systems alone are effective in containing contaminant plumes but may need enhancement for remediating DNAPL. As a result of the investigated presence of a DNAPL at this site and the desire to effect a successful remedial program, an evaluation of remedial alternatives for DNAPL and contaminated groundwater was undertaken. The evaluation included other technological enhancements in addition to the pump and treat alternative.

1995:

A Field Study of Enhanced Recovery of DNAPL Pooled Below the Water Table
Michalski, A; Metlitz, M N; Whitman, I L
Whitman Cos. Inc., East Brunswick, NJ
Ground Water Monitoring & Remediation, Vol 15 No 1 1995 pp 90-100

A large subsurface pool of waste solvent product, consisting primarily of 1,1,1-trichloroethane and carbon tetrachloride, was encountered during investigations at an industrial site in northern New Jersey. In the 1950s the product was discharged through a settling chamber directly below the shallow water table. Eventually, the product accumulated within elongated depressions of erosional surface of varved clays at depths 10 to 15 feet below grade. The host sediment, fine to medium sand, was overlain by fine sand and silt. The delineated area of pooled DNAPLs covered 2750 feet super(2), and the maximum pool thickness exceeded 3 feet. The primary recovery involved pumping product from nine wells. Each recovery well was equipped with a sump extending into the clay, which enabled the system to keep the product pumping level below the bottom of the pool. A total of 3495 gallons of solvent product was recovered over two years. Nearly half of this volume was produced by two wells placed at the lowest points of the pools. Postpumping sampling of the former pools indicated that 93 to 94 percent of the pooled solvent mass was removed during the primary recovery. Average initial product saturation within the pool was estimated at 53.2 percent of the total porosity measured at 31 percent. Average residual saturation after the primary product recovery was 3.7 percent of the total pore volume. To test the feasibility of residual product recovery, an experimental secondary recovery was undertaken. Using sheet piling, a 506 feet super(2) test cell was constructed inside the former DNAPL pool. The cell featured a central recovery well, six peripheral wells, and monitoring probes. The selected sequence of secondary operations included partial dewatering, hot water injection, final dewatering, and thermally enhanced vapor extraction (TVE). During six weeks of the secondary recovery operations, 87.9 gallons of product were removed, of which 72 percent was from TVE, 25 percent from hydraulic mobilization effects, and 3 percent from dissolution of residuals. Confirmatory soil sampling showed an average reduction of residual contamination by 93.4 percent in comparison to the concentration of residuals prior to the secondary recovery. For the test cell, a combined total solvent recovery of 99.6 percent was achieved. This high recovery exceeded DNAPL recoveries expected or achieved in other field-scale attempts.

1994:

The Successful Evolution of a Remediation Strategy for a Disposal Site in Western New York
Price, B.K.; Sturdevant, M.N., IT Corp., Knoxville, TN;
Bradley, C.K., IT Corp., Irving, TX;
Miller, L.M., Olin Corp., Charleston, TN
Proceedings: Volume 2: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994
pp 962-969
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

In order to design an appropriate remediation for an old industrial waste disposal site (Industrial Welding Site) in western New York, a detailed site assessment was conducted. The soil and groundwater at the site were evaluated to determine the presence and extent of contaminants. In addition, a detailed hydrogeologic assessment was performed to determine the interactions between the various water bearing zones (WBZs), surface water bodies and man-made conduits. The key constituents in soils were mercury, hexachlorocyclohexane (BHC), and polycyclic aromatic hydrocarbons (PAHs). The risk assessment concluded that current potential exposures do not pose health threats but may lead to unacceptable future health effects based on a potential residential scenario which includes frequent ingestion of soils/dusts and ingestion of home grown vegetables. A conceptual hydrogeologic model was derived from extensive field work that included: installing 16 monitoring wells and 12 piezometers, conducting aquifer tests, monthly monitoring of wells and piezometers, simultaneously monitoring shallow groundwater and surface water elevations daily for three months, and measuring the invert elevations of man-made conduits. Data from the field monitoring are evaluated with respect to the three discrete WBZs, the creek elevation, and locations and elevations of man-made conduits. The conceptual hydrogeologic model defined the aquifer interactions and all groundwater flow pathways. This model was used, along with the facts that groundwater is not used as drinking water and there is a regional contaminant plume in the area, to develop a remediation strategy which was protective of groundwater and surface water.

Removal of Hydrocarbons from A Shallow Aquifer - A Case Study
Purtill, James; Douglas, Blair R.
Proceedings of Water Down Under 1994 Conference, Part 2-B (of 3)
Conference Location: Adelaide, Aust, Nov 21-25 1994
National Conference Publication - Institution of Engineers, Australia V 2(B) N 94/14 1994.
IE Aust, Crows Nest, NSW, Aust. pp 731-734, 1994.

This case study presents several groundwater and soil hydrocarbon remediation technologies employed together at an Australian site. An investigation into a release of unleaded motor spirit from a service station in northern New South Wales indicated hydrocarbon vapors were accumulating in a stormwater drain located approximately 150 meters from the site. During the investigation, it became apparent that hydrocarbons had heavily impacted soil and backfill surrounding the stormwater drain. Both adsorbed and dissolved phase hydrocarbons were also detected within shallow groundwater restricted to a permeable channel deposit aquifer. The removal of multiple phases of hydrocarbons at the site was undertaken to suppress vapors within the stormwater pipe. A combination of technologies was used to achieve this objective. SPH recovery using a Filter Scavenger, groundwater treatment using a LOPRO air stripper and soil vapor extraction were combined. The system has reduced vapor

concentrations in the pipe from greater than 2000 ppm to below 20 ppm during its operational life. (Author abstract)

Design and Implementation of Vapor Extraction to Remove TCE at a Fractured Bedrock Site
Marcus, D., EMCON Associates, Burbank, CA;
Linder, S., EPA, San Francisco, CA
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 p 855

The purpose of this paper is to document a case history of how practical remediation goals can be set, a cost-effective remedial system designed and implemented, and how a clean-up that is protective of human health and ground water can be verified by innovative methods. The site, a closed southern California aircraft parts manufacturing facility, is underlain by fractured volcanic rock aquifer with ground water occurring from 20 to 50 feet below ground surface. A plume of trichloroethane (TCE) impacted ground water extends downgradient of the site. On-site, TCE concentrations of up to 180 mg/L have been detected, and the potential for the local presence of dense non-aqueous phased liquids (DNAPLs) has been suggested. Consistent with the October 1993 US EPA guidance on the Technical Impracticability of the Restoration of Ground Water at DNAPL Sites, hydraulic containment and control of the aqueous plume was selected as a first phase of a site remedy. An active drinking water well located 1 mile downgradient from the site is protected by a ground water pump-and-treat system consisting of eight wells extracting about 2 million gallons of ground water containing approximately 30 pounds of TCE a month. The next phase of corrective action for this site is to conduct source control measures to minimize ongoing impacts to ground water posed by TCE residual exceeding a risk-based cleanup level of 0.12 mg/kg.

Ground Water Remediation Performance Evaluation at One of the First Superfund Sites
Ross, R.R., Environmental Protection Agency, Ada, OK. R.S. Kerr Environmental Research Lab.;
Beljin, M.S., Univ. of Cincinnati, OH. Dept. of Civil and Environmental Engineering
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 pp 837-838

The Gilson Road Superfund Site located in Nashua, New Hampshire, was the first cooperative agreement entered into by the United States Environmental Protection Agency and a state (New Hampshire) under the Comprehensive Environmental Response, Compensation, and Liability Act. The site was a sand and gravel mining operation in the early 1960s, during which time sands and gravels were excavated over approximately 6 acres. During the late 1960s and early 1970s the owner of the property accepted domestic wastes and demolition debris for disposal in the abandoned pit. The owner/operator of the quarry subsequently disposed of solvents, sludges, and other industrial wastes. An estimated 800,000 gallons of aqueous waste was discharged into a crude leach field extending into the sand and gravel borrow pit. In 1979 approximately 1,300 55-gallon drums of hazardous waste were disposed at the site. Preliminary remedial actions consisted of an emergency drum removal and installation of a ground water recirculation system to prevent the further migration of contaminants until a passive containment system could be installed. The containment system consists of a 3-foot-thick, 4,000-linear-foot soil, bentonite slurry wall and synthetic membrane. The majority of the contaminant plume is contained within the perimeter of the slurry wall which encompasses approximately 20 acres and extends 30 to 100 feet below land surface to the top of bedrock in certain areas.

1993:

Fast-Track Remediation Case Study: Southern California Refined Fuel Distributor
Bubier, T.W.; Felix, P.R.
Proceedings: Air Waste Management Association 86th Annual Meeting Exhibition, Denver, CO, 13-18 June 1993 pp 110-111
Publisher: Pittsburgh, PA Air Waste Management Association, 1993
Report Number(s): CONF-930647

Successful environmental remediation projects have three requirements in common: (1) an adequate data base that defines the extent and severity of the problem; (2) a detailed understanding of the actual performance of the remediation technologies being considered; and (3) good communication with the regulatory agencies to assure them that the health and safety of the community and workers will not be jeopardized. In a fast-track remediation project, these requirements are key issues in the critical path. The case study involves soil and groundwater remediation of a 16-acre bulk fuel storage and distribution facility. The facility was in operation for approximately 75 years and contained 20 large aboveground tanks with a total capacity in excess of 20 million gallons. Activities at the facility included receipt, storage, and distribution of refined fuel products, such as kerosene, gasoline, diesel, and bunker fuel. A harbor-widening project was undertaken to increase the level of safety for larger ships when passing through the port. Because of the critical need for harbor-widening, the environmental cleanup needed to be completed as quickly as possible. The following steps were taken during the fast-track remediation case study to meet the above-listed requirements: 1) New Data Quality Objectives (DQOs) were identified for the project; 2) Potentially applicable remedial technologies were evaluated and tested; and 3) An agency task force was developed to enhance communication with the regulatory agencies. This paper discusses these steps and presents examples of how each step was implemented during the case study.

Successful Remediation of a Municipal Wellfield Aquifer Contaminated with Chlorinated Hydrocarbons
Sanborn, Paul M.; Head, Charles L.
Sanborn, Head and Associates, Concord, NH
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Burlington, VT Sept 27-29 1993
Publisher: Water Well Journal Pub. Co., Dublin, OH
Ground Water Management Vol 16 Sept 1993 pp 309-322

Abstract not available.

Site Complexities and the Selection of a Remediation System for Petroleum Hydrocarbon Contaminated Site, Central New Jersey
Maroney, Katherine J.; Gorte, Lynda L.; Talkington, Raymond W.
Ransom Environmental Consultants
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Burlington, VT Sept 27-29 1993
Publisher: Water Well Journal Pub. Co., Dublin, OH
Ground Water Management Vol 16 Sept 1993 pp 299-308

Abstract not available.

Remedial Investigation of a Karst Groundwater System
Goldberg, Steven P.; Wagner, W. Philip; Mills, Randall C.
Wehran Envirotech, Middletown, NY
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Burlington, VT Sept 27-29 1993
Publisher: Water Well Journal Pub. Co., Dublin, OH
Ground Water Management Vol 16 Sept 1993 pp 63-89
Abstract not available.

Evaluation of Petroleum Hydrocarbon Contamination of a Fractured Bedrock Aquifer; a Case Study for Pump and Treat Remediation
Gaule, Christopher; Goldstein, Kenneth J.; Hobert, Linda A.; Hiss, David R.
Malcolm Pirnie, Albany, NY
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Burlington, VT Sept 27-29 1993
Publisher: Water Well Journal Pub. Co., Dublin, OH
Ground Water Management Vol 16 Sept 1993 pp 49-62
Abstract not available.

1992:

Remediation of a DNAPL-Contaminated Site
Rao, B.V.; Staehle, W.J.; Voss, T.
Dresdner Robin Environmental Management, Inc., Jersey City, NJ
Proceedings: 1992 Hazardous Materials Control Research Institute Federal Environmental Restoration Conference And Exhibition, Vienna, VA 15-17 April 1992 pp 118-125
Publisher: Greenbelt, MD, Hazardous Materials Control Resources Institute 1992
The occurrence and nature of Dense, Non-Aqueous Phase Liquid DNAPL contamination and the associated dissolved phase contamination in groundwater at a former chemical manufacturing site were investigated and the remedial alternatives were evaluated. The proposed alternative for the site remediation is discussed in this paper. The DNAPL-bearing zone, ranging in thickness from 10 to 15 feet, is restricted to 15-to 25-foot thick unconsolidated fine-to medium-grained saturated sands and silty sands of the upper permeable zone. The groundwater beneath the site is generally encountered at 8 to 10 feet below ground surface. The DNAPL occurs as dispersed globules and thin discontinuous layers. It has a density of 1.02 and is low to moderately viscous. Approximately 60% by weight of the site DNAPL is composed of acid extractable compounds consisting primarily of differing phenolic and triarylphosphate compounds including tricresylphosphate. The groundwater beneath the site was contaminated as a result of continuous dissolution of DNAPL constituents. The major components of the proposed remedial alternative for the site include: 1 a line of injection wells on the upgradient side to divert the regional groundwater flow; 2 a system of extraction wells to create a hydraulic barrier to prevent migration of dissolved phase contamination; 3 a combination of injection and extraction wells to recover DNAPL; and 4 a treatment system for discharged groundwater and collection/separation system for DNAPL. Proposed conceptual designs of each of the above components of the proposed remedial alternative are presented.

RMA Groundwater Remediation: Pilot Testing Results Applied to Full-Scale Design
Merrill, W.G.; Roebuck, S.J., Harding Lawson Associates, Denver, CO;
Cain, K.R.; Scharmann, C.T.; Rocky Mountain Arsenal, Commerce City, CO
Proceedings: 1992 Hazardous Materials Control Research Institute Federal Environmental Restoration Conference And Exhibition, Vienna, VA 15-17 April 1992 pp 101-106
Publisher: Greenbelt, MD, Hazardous Materials Control Resources Institute 1992

A groundwater cleanup program was designed to remediate contamination of alluvial groundwater in the off-post operable unit of the Rocky Mountain Arsenal RMA NPL site in Commerce City, Colorado. The program is an interim response action IRA being performed in advance of the Record of Decision ROD, as required by the terms of CERCLA as amended by SARA and the Federal Facility Agreement for RMA. The IRA was designed and will be implemented under an accelerated schedule in order to minimize the future risk of exposure to contaminated groundwater and begin mitigation of alluvial groundwater contamination on as soon as practicable. This IRA included assessing several potential remedial alternatives and selecting and designing a cost-effective alternative that could be implemented in advance of the ROD. The design of the selected alternative included the use of groundwater extraction and recharge facilities wells and trenches placed either transverse or parallel to the axes of groundwater contaminant plumes, depending on plume characteristics. The water treatment facility designed for the IRA has a maximum design capacity of more than 44 L/sec. The final design was based upon the results of focused field investigations and pilot-scale testing in the target cleanup area. The field investigations included the use of surface and borehole geophysical techniques and hydrogeologic and hydrochemical data collection. Pilot-scale testing included the combined use of groundwater extraction and recharge tests, recharging water treated with a mobile water treatment facility. Review of the final IRA system design by the US. Army Corps of Engineers COE and parties to the Federal Facility Agreement is complete. Construction of the system began in November 1991 under the direction of COE. Full-scale operation of the system is scheduled to begin in summer 1993.

Environmental Investigation of Ground Water Contamination at Wright-Patterson Air Force Base, Ohio
Pacific Northwest Lab., Richland, WA, Environmental Management Operations;
IT Corp., Cincinnati, OH
Mar 1992 203 p

The Phase I, Task 5, Focused Feasibility Study FFS has been prepared as part of the Environmental Investigation of Ground Water Contamination Project being conducted by Wright-Patterson Air Force Base WPAFB. The primary objective of this FFS was to select a cost-effective method of preventing migration of contaminated ground water across the southwestern boundary of Area C of the Base. The FFS presented in this document is a portion of a much larger effort being conducted at WPAFB. The detailed analysis of alternatives for the extraction, treatment, and discharge of contaminated ground water migrating across the southwest boundary of Area C at WPAFB led to the selection of a preferred removal action alternative. Specifically, this alternative is that ground water be extracted utilizing a three well array pumping at a total of 400 to 800 gpm, removed water be treated via air stripping to achieve appropriate effluent concentrations, and treated water be discharged to the Mad River in accordance with a National Pollution Discharge Elimination System NPDES permit and other relevant permits.

Environmental Restoration: Integrating Hydraulic Control of Groundwater, Innovative Contaminant Removal Technologies and Wetlands Restoration—A Case Study at SRS

Lewis, C.M.; Serkiz, S.M.; Adams, J.; Welty, M.
Westinghouse Savannah River Co., Aiken, SC
Proceedings: 1992 Annual Meeting of the Geological Society of America GSA, Cincinnati, OH 26-29 Oct 1992
Geological Society of America, Abstracts with Programs Vol 24 No 7 1992 p A34

The groundwater remediation program at the F and H Seepage Basins, Savannah River Sites SRS is a case study of the integration of various environmental restoration technologies at a single waste site. Hydraulic control measures are being designed to mitigate the discharge of groundwater plumes to surface water. One of the primary constituents of the plumes is tritium. An extraction and reinjection scenario is being designed to keep the tritium in circulation in the shallow groundwater, until it can naturally decay. This will be accomplished by extracting groundwater downgradient of the waste sites, treatment, and reinjection of the tritiated water into the water table upgradient of the basins. Innovative in-situ technologies, including electrolytic migration, are being field tested at the site to augment the pump-treat-reinject system. The in-situ technologies target removal of contaminants which are relatively immobile, yet represent long term risks to human health and the environment. Wetland restoration is an integral part of the F and H remediation program. Both in-situ treatment of the groundwater discharging the wetlands to adjust the pH, and replacement of water loss due to the groundwater extraction program ar being considered. Toxicity studies indicate that drought and the effects of low pH groundwater discharge have been factors in observed tree mortality in wetlands near the waste sites.

Remediation of a 115,000-Gallon Petroleum Pipeline Leak

Noel, M.R.; Ebbott, K.A.
Hydro-Search, Inc., Brookfield, WI
Proceedings: 5th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, Las Vegas, NV, 13-16 May 1991 pp 275-289
Publisher: Dublin, OH Ground Water Management 1992

A rupture in a buried petroleum pipeline in June, 1988 released 115,000 gallons of diesel fuel, contaminating soil and ground water at a site in Milwaukee, Wisconsin. Emergency and interim response actions resulted in the recovery of over 70,000 gallons of product from the ground surface, a nearby creek, and recovery trenches. Based on the results of a contamination assessment, the most cost effective and technically feasible remedial alternative included low temperature thermal desorption for treatment of the impacted soils, and recovery of impacted ground water with discharge to a sanitary sewer. The implementation of the thermal desorption process was the first application of its type in the State of Wisconsin. Approximately 10,000 cubic yards of soil, with a total petroleum hydrocarbon TPH concentration of up to 24,000 parts per million ppm, was treated at the site using the thermal desorption system. Using a feed rate of approximately 20 tons per hour, the impacted unconsolidated materials, varying in composition from gravelly sand to silty clay, were heated to 400 to 500°F in a propane-fired rotary kiln. In the process, petroleum was vaporized off the soils and then completely oxidized at 1450 degrees F in an afterburner. After processing, the soil was replaced in the excavation with a TPH concentration of less than 10 ppm. Impacted ground water is still being treated at the site using a 225-foot long interception trench. An automated pumping system recovers slightly impacted ground water which is subsequently discharged to the sanitary sewer. Residual free product is collected from the water surface manually using oil skimming devices. Dissolved volatile organic compounds VOCs total less than 5 ppm; therefore no treatment is required prior to discharge to the sewer. Pending approval of a permit application, discharge will be to a nearby stream.

A Case Study Investigation And Remediation at a New England Landfill Site Containing DNAPL
Moore, Michael B.; Krumhansl, Ruth A.; Wolf, Steven
ENSR Consulting and Engineering
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Newton, MA,, Oct 13-15 1992
Ground Water Management Vol 13 pp 845-851
Abstract not available.

Groundwater Contaminant Investigation of Former Paint Factory Landfill; Tactical Approach to Remediation
Zelley, Robert L.; Ellwood, R. Brian
Converse Consultants East, Parsippany, NJ
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Newton, MA,, Oct 13-15 1992
Ground Water Management Vol 13 pp 353-367
Abstract not available.

1991:

Evaluation of Remedial Alternatives for a DNAPL-Contaminated Site: A Case Study
Rao, B.V.; Staehle, W.J.; Voss, T.
Dresdner, Robin Associates Inc., Jersey City, NJ
Proceedings: Hazardous Materials Control/Superfund '91: 12th National Conference, Washington, DC 3-5 Dec 1991 pp 207-214
Published: 1991
Dense, Nonaqueous Phase Liquid DNAPL chemicals are characterized by a density higher than water and very low solubilities. Because of these characteristics, DNAPLs tend to sink in the groundwater zone and form lenses and pools. In such cases, DNAPLs act as long-term subsurface sources of dissolved phase contamination by continuously releasing DNAPL constituents into the groundwater and causing contamination plumes to develop. This paper describes the soil and groundwater contamination by DNAPLs at an abandoned industrial site and evaluates possible alternatives for remediation and source control by taking into account the site conditions. The site is underlain successively by a layer of 8-to 10-ft thick fill material, 10-to 15-ft thick unconsolidated sands and silts, 4-to 6-ft thick varved cohesive clay, 10-to 15-ft thick gravel and a thick sequence of plastic clays. DNAPL occurrence is restricted to sand and silt deposits which are saturated with water. The DNAPL-bearing zone varies in thickness from 10-25 ft. The varved clay bed below the DNAPL-bearing zone forms a trough-like structure and apparently forms a natural containment for the DNAPL migrating vertically downwards. The DNAPL at the site is primarily composed of various forms of phenolic compounds and phosphate compounds which are denser than water. The estimated volume of DNAPL in the DNAPL-bearing zone ranges from approximately 70,000-265,000 gal. Occurrence of DNAPL as a free product in the unsaturated zone is minimal. Groundwater contamination by DNAPL constituents is restricted primarily to the area underlain by the DNAPL-bearing zone. Several technology types and process options for remediation of soils and groundwater and the removal or control of DNAPL were considered. The selected remedial alternative for the site consists of two separate systems with combinations of injection/extraction wells, one for the prevention of plume migration and the other for the recovery of DNAPL.

Soil Treatment and Groundwater Control for No 6 Fuel Oil and PCB Contamination
Girioni, M.J., SAIC Engineering, Inc., Lakeville, MA;
St. Hilaire, W.J., United Retek Corp., Holliston, MA
Proceedings: HMC-Northeast '91: Hazardous Materials Control Research Institute HMCRI Northeast Conference and Exhibition on Hazardous Materials Control, Boston, MA, 10-12 Jul 1991 pp 286-291

This paper reports that as part of a Short-Term Measure ordered by the Massachusetts Department of Environmental Protection DEP, soil contaminated by No 6 fuel oil and low-level polychlorinated biphenyls PCBs was excavated, treated and recycled on-site as an asphalt base course for a parking lot at an industrial complex in New Bedford, Massachusetts. Approximately 300 cubic yards of contaminated soil were treated with an asphalt emulsion and utilized as a aggregate component for asphalt processed at ambient temperatures during the month of December 1990. In order to determine if the contaminated soils to be recycled would be classified as a hazardous waste as defined by the Massachusetts Hazardous Waste Regulations, 310 CMR 30.000, or if the soil to be recycled would pose a significant risk to health, safety or the environment, analytical testing of the contaminated soil was conducted prior, during and after treatment. Analytical testing included Toxicity Characteristics Leaching Procedure TCLP analyses of the untreated and treated soil. An alternative solution to the standard groundwater pump-and-treat method was designed and constructed to control and recover the highly viscous floating petroleum product. A series of precast leaching galleys oil collection chambers and a precast leach pit groundwater discharge structure were constructed to alter the local groundwater table to induce groundwater flow by gravity into the leaching chambers. Passive i.e., nonpumping groundwater flow to the leaching chambers was induced by placing of the groundwater discharge structure hydraulically downgradient of the leaching chambers. Collected oil, separated by gravity, will be periodically vacuumed, as necessary, for proper off-site disposal. Excess water discharges to the downgradient leach pit.

Aquifer Restoration and Remedial Actions at An Aircraft Maintenance and Repair Facility
Barbour, Richard; Sanford, Theodore
ERM-Northeast, Woodbury, NY
Proceedings: FOCUS conference on Eastern regional ground water issues, Portland, ME, Oct. 29-31, 1991
Ground Water Management Vol 7 1991 pp 3-23

Abstract not available.

1990:

Limitations on Contaminant Recovery Systems in the Brunswick Formation Aquifer
Hewitt, Marilyn A.
Proceedings: FOCUS Conference on Eastern Regional Ground Water Issues, Springfield, MA, Oct. 17-19, 1990
Ground Water Management Vol 3 1990 pp 115-129
Abstract not available.

BIOLOGICAL TREATMENT

IN SITU BIOREMEDIATION

1996:

In Situ Bioremediation of Chlorinated Solvent with Natural Gas
Rabold, D. E., Westinghouse Savannah River Co., Aiken, SC.
Sponsor: Department of Energy, Washington, DC.
Report No.: WSRC-MS-95-0303; NTIS Number: DE96002956 1996 15p
A bioremediation system for the removal of chlorinated solvents from ground water and sediments is described. The system involves the in-situ injection of natural gas (as a microbial nutrient) through an innovative configuration of horizontal wells.

In Situ Groundwater Treatment in a Trench Bio-Sparge System
Christodoulatos C; Korfiatis G P; Pal N; Koutsospyros A
Cent. Environ. Eng., Stevens Inst. Technol., Hoboken, NJ 07030
Hazardous Waste & Hazardous Materials Vol 13 No 2 1996 pp 223-236
Simultaneous plume control and subsurface treatment technologies are receiving increasing attention for site remediation. In this paper, computer modeling and laboratory pilot scale results are presented to demonstrate the effectiveness of the Trench Bio-Sparge (TBS) system for in-situ treatment of groundwater contaminated with organic compounds. The TBS technology achieves simultaneous hydraulic control and treatment by directing the contaminated plume through a subsurface reactor where groundwater treatment is accomplished by physical or biological means or combinations thereof. Plume capture is achieved by a set of diversion wing walls. Specifically it is demonstrated that velocity equalization is necessary to attain uniform residence time distribution in the reactor. The modeling studies showed that the geometry of the plume diversion system is very important in the design of an efficient reactor. Results of laboratory studies are presented which demonstrate that very high treatment efficiency of organics can be achieved in relatively short reactors having short residence times. Experiments performed with phenol and BTEX contaminated groundwater demonstrated overall removal efficiencies exceeding 99.0%.

Bioslurping LNAPL Contamination
Baker, Ralph S.,
ENSR, Acton, MA
Pollution Engineering Vol 28 No 3 Mar 1996 pp 38-40

Bioslurping is an innovative technology for the remediation of sites contaminated with petroleum hydrocarbons (LNAPLs). For certain sites, this technology promises to be a fast, less costly and effective cleanup solution. Pilot studies and field applications confirm potential benefits, including dramatic increases in LNAPL capture rates. This technology should only be selected based on a thorough understanding of characteristics of the site including geology and hydrogeology.

Glutathione Conjugation and Contaminant Transformation

Field J A; Thurman E M
Dept. Agricultural Chemistry, Oregon State Univ., Corvallis, OR
Environmental Science & Technology Vol 30 No 5 1996 pp 1413-1418

The recent identification of a novel sulfonated metabolite of alachlor in groundwater and metolachlor in soil is likely the result of glutathione conjugation. Glutathione conjugation is an important biochemical reaction that leads, in the case of alachlor, to the formation of a rather difficult to detect water-soluble, and therefore highly mobile, sulfonated metabolite. Research from weed science, toxicology, and biochemistry is discussed to support the hypothesis that glutathione conjugation is a potentially important detoxification pathway carried out by aquatic and terrestrial plants and soil microorganisms. A brief review of the biochemical basis for glutathione conjugation is presented. We recommend that multidisciplinary research focus on the occurrence and expression of glutathione and its attendant enzymes in plants and microorganisms, relationships between electrophilic substrate structure and enzyme activity, and the potential exploitation of plants and microorganisms that are competent in glutathione conjugation for phytoremediation and bioremediation.

Microcosms for Aquifer Research: Application to Colonization of Various Sized Particles by Ground-Water Microorganisms

Dodds, Walter K.; Randel, Clay A.; Edler, Christopher C.
Ground Water Vol 34 No 4 July-August 1996 pp 756-760

New techniques to assess the effects of continuous water exchange and influx of particulates and nutrients on groundwater ecology have been developed to aid the field of bioremediation. Of these, the use of microcosms to analyze aquifer organisms has shown the biggest potential for use in bioremediation. The application of microcosms for aquifer experiments at Konza Prairie Research Natural Area in Manhanttan, KS, is discussed.

Feasibility of Bioremediation of a Ground Water Polluted with Alkylpyridines

Ronen, Zeev; Bollag, Jean-Marc; Hsu, Cheng-Hsiung; Young, James C.
Ground Water Vol 34 No 2 March-April 1996 pp 194-200

The efficacy of using bioremediation to clean up alkylpyridine-polluted ground water was examined. Results revealed that biodegradation using aerobic bacteria took place only in the presence of oxygen. Simulations of in situ bioremediation resulted in alkylpyridine of 40%-80%, while simulations of above-ground bioremediation systems resulted in removal rates of 98%-100%. These indicate that combining both in situ and above-ground approaches is the best method for ground water bioremediation.

A Look at Degradation of CAHs: Chlorinated Aliphatic Hydrocarbons Degrade by Reductive Dehalogenation and Co-Metabolism

Schaffner, Richard, Jr.; Hawkins, Edward; G., C.; Wieck, James
GZA GeoEnvironmental, Manchester, NH
Soil Groundwater Cleanup May 1996 pp 20-31

Bioremediation has been used to transform chlorinated aliphatic hydrocarbons (CAHs) at a former wastewater treatment site in New Hampshire. Cometabolism and reductive dehalogenation transform some CAHs to carbon dioxide, water, chloride, and intermediate products. Cometabolism is prompted by the microbial use of a primary substrate or a source of organic carbon and energy. Microbes transfer electrons to CAHs and thus transform them in the process of reductive dehalogenation. This review of this treatment process looks at site characteristics, groundwater, sludges generated by the treatment process, and strategies to stimulate bioremediation.

Anaerobic Bioremediation: Destroying Chlorinated Hydrocarbons In Situ
Zanikos, Isidoros J.,
DuPont Environmental Remediation Services, Wilmington, DE
Natl Environ J Vol 6 No 1 Jan-Feb 1996 pp 52-55
(Full text available from Congressional Information Service at 1-800-227-2477.)

Many industrial areas are heavily contaminated with perchloroethylene and other types of chlorinated hydrocarbons. These compounds are considered some of the most difficult to remediate. A new anaerobic bioremediation technology is described that was tested via a two-year pilot study. The proposed technique is considered both thorough and cost effective. A case study is presented in which an environmental team at an intermediate chemicals plant in Texas detected perchloroethylene in groundwater beneath the site. The plant initially installed a pump-and-treat system to prevent the spread of contamination. However, in 1989, plant management decided to support research aimed at developing an in-situ bioremediation strategy for treating these contaminants.

1995:

In Situ Bioremediation Using Horizontal Wells: Innovative Technology Summary Report
Oak Ridge National Lab., TN
Report No.: DOE/EM-0270; NTIS Number: DE96003565 Apr 1995 30p

In Situ Bioremediation (ISB) is the term used in this report for Gaseous Nutrient Injection for In Situ Bioremediation. This process (ISB) involves injection of air and nutrients (sparging and biostimulation) into the ground water and vacuum extraction to remove Volatile Organic Compounds (VOCs) from the vadose zone concomitant with biodegradation of the VOCs. This process is effective for remediation of soils and ground water contaminated with VOCs both above and below the water table. A full-scale demonstration of ISB was conducted as part of the Savannah River Integrated Demonstration: VOCs in Soils and Ground Water at Nonarid Sites. This demonstration was performed at the Savannah River Site from February 1992 to April 1993.

In Situ Bioremediation: Cost Effectiveness of a Remediation Technology Field Tested at the Savannah River
Saaty, R. P. ; Showalter, W. E. ; Booth, S. R.
Los Alamos National Lab., NM.
Report No.: LA-UR-95-698; NTIS Number: DE95007849 1995 9p
Conference Proceedings: Waste Management '95, Tucson, AZ 26 Feb - 2 Mar 1995.

In Situ Bioremediation (ISBR) is an innovative new remediation technology for the removal of chlorinated solvents from contaminated soils and groundwater. The principal contaminant at the SRID is the volatile organic compound (VOC), trichloroetylene (TCE). A 384 day test run at Savannah River, sponsored by the US Department of Energy, Office of Technology Development (EM-50), furnished information about the performance and applications of ISBR. In Situ Bioremediation, as tested, is based on two distinct processes occurring simultaneously; the physical process of in situ air stripping and the biological process of bioremediation. Both processes have the potential to remediate some amount of contamination. A quantity of VOCs, directly measured from the extracted air stream, was removed from the test area by the physical process of air stripping. The biological process is difficult to examine. However, the results of several tests performed at the SRID and independent numerical modeling determined that the biological process remediated an additional 40% above the physical process. Given this data, the cost effectiveness of this new technology can be evaluated.

A Treatment Train Approach to In Situ Bioremediation

Leavitt, M.E.
IT Corp., Knoxville, TN

Proceedings of HAZMACON '95: Hazardous Materials Management Conference and Exhibition, San Jose, CA 4-6 Apr 1995 pp 354-357
Publisher: Oakland, CA: Association of Bay Area Governments 1995
Report Number(s): CONF-9504134

Bioremediation technology has developed into a viable and often cost-effective alternative for environmental restoration. However, there has been a propensity for the “overselling” of bioremediation to the extent that users can be disappointed in bioremediation's limitations. IT's approach to bioremediation often utilizes additional treatment technologies so that a swift, effective system is used to achieve treatment goals. This paper will present a case history describing a site remedy that utilized soil vapor extraction, in situ aquifer bioremediation, and air stripping to address gasoline/diesel contamination in saturated and unsaturated soil at a service station.

A Method for Passive Release of Solutes from an Unpumped Well

Wilson, R.D.; Mackay, D.M.
Univ. of Waterloo, Ontario, Waterloo Centre for Groundwater Research

Ground Water Vol 33 No 6 Nov-Dec 1995 pp 936-945

A new method was developed for releasing dissolved solutes into ground water which has application in both academic studies and practical efforts to stimulate in situ bioremediation, introduce chemical reactants, or understand flow and transport properties. The method involves the diffusion of solutes out of inexpensive, simple emitter devices which are installed in large diameter wells. In laboratory experiments, benzene was released at or near 1.3 mg/l for a total of 31 days, TCE for 17 days at approximately 4.5 mg/l, and bromide for 23 days at 667 mg/l. The emitted concentration of a wide range of solutes can be stabilized for much longer periods of time once the mass flux in the flow-through system reaches steady-state, provided the concentration gradient is maintained. A simple computer model was written to aid in the design of source emitters. The model was used to match diffusion coefficients to data for three solute-tubing combinations. Once the diffusion coefficient of a given solute in a given type of tubing is determined from experimental data by curve-matching, the model can be used in a predictive capacity. A second TCE release test showed that the diffusion coefficient calibrated form the model can be used to predict the steady-state release concentration of TCE under different conditions. Simple two-dimensional transport modeling suggests that a relatively

uniform plume of solutes may be generated by emitters placed in wells spaced close together. The uniform introduction of nutrients and oxygen by this passive method may encourage more efficient in situ remediation, and in some situations, save time and money.

Groundwater Decontamination Using Sequencing Batch Processes
Wang L K; Ping Wang;
Univ. Illinois Urbana-Champaign, Dep. Agricultural Eng., Urbana Champaign IL
Water Treatment Vol 10 No 2 1995 pp 121-134

A newly developed batch bioremediation system involving the use of biological oxidation, air pressurization, and dissolved air flotation clarification for treatment of a phenol contaminated groundwater is described. Specifically the new bioremediation system which is known as sequencing batch flotation (SBF) accomplishes the unit processes and operations of filling, biological oxidation reaction, powdered activated carbon adsorption, dissolved air flotation, decanting, sludge wasting, and idling, within the confines of a single batch reactor. The new batch system is compact, simple and thereby cost-effective. A treatment effectiveness comparison between the innovative SBF system and a conventional sequencing batch reactor (SBR) system has been based upon experimental results. Other innovative and modified sequencing batch systems, which utilize dissolved air flotation, activated carbon addition, or chemical addition in various combinations, were examined.

Enhancement of Bioremediation Using Aeration Device
Anon
Hazardous Waste Consultant Vol 13 No 1 1995 pp 1.27-2.0

In situ bioremediation, relying on natural processes and indigenous materials to degrade contaminants, is becoming a popular method of treating contaminated soil and ground water under the right set of conditions it is effective and inexpensive. However, the technology can be limited by three factors: 1) the ability of microbes to degrade specific contaminants 2) the availability of inorganic nutrients in the surrounding soil or ground water and 3) the availability of an electron acceptor, such as oxygen, in the subsurface. An innovative membrane technology has recently been developed by Membran Corporation (Minneapolis, Minnesota) that increases the rate of oxygenation in water. An increased concentration of oxygen enhances the rate at which aerobic, in situ biological treatment can remediate an aquifer contaminated with petroleum hydrocarbons. Membran's design consists of a bubbleless hollow-fiber membrane aerator capable of dissolving oxygen directly in water.

Use of Groundwater Circulation (UVB) Technology and Integrated Bioreactors for Chemical Containment and In-Situ Bioremediation of Subsurface Environments Contaminated by Coal Tar Creosote: Full-Scale Field Validation
Mueller, J.G.; Lakhwala, F.; Lantz, S.E.; et al
SBP Technologies, Gulf Breeze, FL
Proceedings: International Symposium and Trade Fair on the Cleanup of Manufactured Gas Plants, Prague (Czech Republic) 19-21 Sep 1995
Land Contamination and Reclamation Vol 3 No 4 1995 p 6/11-6/16
Report Number(s): CONF-950977

Polycyclic aromatic hydrocarbons are present in many fossil fuels, they are also among the most widespread environmental contaminants. They are however very difficult to remove from contaminated sites, particularly those with impacted subsurface environments. Despite this, PAH biodegradation is

frequently recommended, especially where no other methods present themselves. Thus, safe in-situ bioremediation requires cost-efficient strategies with good monitoring of contaminants. With these goals, the authors completed the full-scale installation of a microbiologically-enhanced groundwater circulation (UVB) system coupled with an in-situ bioreactor (Patent pending) at an operating wood preserving site in the southeast United States, near (Gainesville, Florida) where constituents of coal tar creosote are present in soils and groundwater. Data collected from a continuing sampling and analysis plan include conventional measurements of bioremediation performance (PAH analysis of soil and water, in-situ respiration measurements, and nutrient utilization profiles) along with more innovative measurements of in-situ biodegradative activity including: bacterial productivity measurements: gene frequency responses; biosurfactant production; and stable isotopic C13 analyses of the fate and effect of organic compounds. The validity of using C13 and CO2 measurements in monitoring the in-situ bioremediation of environments impacted by creosote and related chemicals is simultaneously demonstrated.

Biological Fluidized-Bed Treatment of Groundwater from a Manufactured Gas Plant Site
Grey, Gary M., HydroQual Inc, Mahwah, NJ;
Scheible, O. Karl; Maiello, Joy A.; Guarini, William J.; Sutton, Paul M.
Biological Unit Processes for Hazardous Waste Treatment Vol 9 1995 pp 13-19
(Full text available from Congressional Information Service: 1-800-227-2477)

Fluidized-bed biological treatment was evaluated for treating groundwater at a manufactured gas plant in New Jersey. The primary soluble contaminants were PAHs and VOCs, and biological treatment, air stripping, and carbon adsorption were evaluated for their capacity to remove these constituents. Results are presented from bench- and pilot-scale studies of fluidized-bed biological treatment. The data indicated that C-based fluidized-bed biological treatment was effective in treating dissolved-air flotation subnatant generated from high- and moderate-strength groundwaters and for direct application to low-strength groundwaters. Substantial COD and complete removals were found for benzene, toluene, ethylbenzene, xylenes, and PAHs. Residual PAHs present in the effluent were adsorbed to effluent suspended particles and removed by subsequent filtration.

Sulfate-Enhanced Extraction and Bioaugmentation Provide New Possibilities for Chromium Remediation Et Al.
Hazard. Waste Consult Vol 13 No 1 1995 pp 1.1-1.3

Because it is a known carcinogen, chromium often receives priority for remediation. Unfortunately, the toxic hexavalent form of chromium, Cr(VI), is difficult to remove from the subsurface. Conventional pump-and-treat techniques frequently result in long cleanup times, as the rate of Cr(VI) removal may decrease sharply over time. Two studies have been conducted recently to offer remedial alternatives to the commonly used pump-and-treat method. In one study, the addition of sulfate to extraction water decreased by almost two orders of magnitude the number of pore volumes required to achieve a certain level of Cr(VI) reduction. The other study isolated Cr(VI)-resistant microbes and studied their growth and ability to reduce Cr(VI) concentrations under both aerobic and anaerobic conditions. The results of this testing suggest that reduction of Cr(VI) in soils may be bioaugmented.

Phytoremediation of TNT Contaminated Soil and Groundwater in Aquatic-Plant Systems
Saunders, F.M.; Jacobson, M.; Pavlostathis, S.G., et al
Georgia Institute of Technology, Atlanta, GA

Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 p 1251
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

Aquatic plants have been shown to rapidly transform trinitrotoluene and effectively remove by-products to trace levels. Aquatic Plant Lagoon (APL) systems are being used to test uni- and multi-species assemblages of submergent and emergent aquatic vegetation for remediation of explosives contaminated soils and waters. Test lagoons are contained in a field environment and have independent inflow control, temperature control, and are monitored for pH, nutrient content of plants and water, photosynthetic potential of plants, and sunlight irradiation. Previous and current laboratory experiments have been used to predict kinetics of the reactions, hydraulic residence times, by-product formation, species survivorship, acceptable plant densities, nutrient affects, and association of enzyme kinetics with TNT transformations. Results will be presented from both bench and pilot studies to demonstrate the potential for this innovative phytotechnology.

1994:

Phytoremediation: A New Technology for the Environmental Cleanup of Toxic Metals
Salt, D.E.; Kumar, P.B.A. Nanda; Dushenkov, S.; Raskin, I.
Rutgers Univ, New Brunswick, NJ
Proceedings: International Symposium on Resource Conservation and Environmental Technologies in Metallurgical Industries, Toronto, Ont, Can, August 20-25, 1994 pp 381-384
Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Canada 1994

Toxic metal-contaminated soils, aqueous waste streams and ground waters pose a major environmental and human health problem. The use of plants to remove these pollutants would provide an efficient, low cost, in situ cleanup technology able to remove toxic metals from the site leaving it intact for normal ecosystem redevelopment. We have demonstrated that the Indian mustard plant Brassica juncea can efficiently accumulate Pd, Zn, Cd, Cr(VI), Ni and Cu from soils or water into both roots and shoots. These uptake characteristics coupled with B. juncea high biomass and good agronomic practices make this an ideal plant for phytoremediation. (Author abstract) 7 Refs.

Assessment of the Potential for In Situ Bioremediation of Cyanide and Nitrate Contamination at a Heap Leach Mine in Central New Mexico
White, Carleton S.; Markwiese, James T.
Univ of New Mexico, Albuquerque, NM
Journal of Soil Contamination Vol 3 No 3 1994 pp 271-283

The potential for in situ bioremediation of cyanide (CN) and nitrate (NO//3) contamination within the extracted ore (residue pile) and downgradient groundwater at a CN heap leach mine in New Mexico was assessed through the following steps: (1) identification of the relative abundance of CN-degrading microorganisms in the contaminated residue pile, (2) identification of amendments to enhance aerobic CN degradation and assimilatory NO//3 reduction and determination of the optimal carbon-to-nitrogen concentration for degradation, (3) assessment of optimum amendment's influence on biodegradation of CN and NO//3 by experiments with large-scale columns filled with residue pile material, and (4) evaluation of the potential for other adverse environmental effects, specifically acid rock drainage, due to application of the amendment. These investigations determined that application of a reduced carbon

source (sucrose) significantly increased the rate of CN degradation and NO//3 immobilization without increasing the probability of acid rock drainage. (Author abstract) Refs.

Bioremediation of Contaminated Groundwater: A Turnkey Approach
Shivjiani, D.M.; Rudy, R.J.; Burns, B.; Heuler, G.
Proceedings: Volume 1: Federal Environmental Restoration and Waste Minimization Conference and Exhibition, New Orleans, LA, 25-29 Apr 1994 pp 44-50
Publisher: Rockville, MD Hazardous Materials Control Resources Institute, 1994
Report Number(s): CONF-940499

The Silvex Corporation Site is a Florida state funded remedial action site in St. Augustine, Florida, that, prior to 1980, was a silver smelting facility that accepted waste materials from the Naval Air Station-Jacksonville. Fuels, reportedly consisting of waste paint, cold carbon removers, and solvent degreasers that were stored in a 25,000-gallon tank, spilled onto the property. The assessment concluded that the surficial aquifer in the spill area and the area hydrologically down-gradient of the spill were contaminated by elevated levels of ketones (acetone, methyl-ethyl ketone, and methyl-isobutyl ketone), phenols, and toluene. Subsequently, a risk assessment/feasibility study and groundwater bench-scale and pilot-scale studies were performed to determine the technical feasibility/cost-effectiveness of the recommended alternative, submerged fixed-film bioremediation. The on-site pilot study, which was conducted at three flow rates (0.5, 1, and 2 gallons per minute), demonstrated a greater than 99% contaminant removal efficiency from the three-stage bioreactor. Due to the impact of site contamination on a nearby creek that flows into the St. Johns River, an interim remedial deign was developed and implemented to reduce the potential for migration of contaminated groundwater into the creek.

Stimulated Anoxic Biodegradation of Aromatic Hydrocarbons Using Fe(III) Ligands
Lovley, Derek R.; Woodward, Joan C.; Chapelle, Francis H.
US Geological Survey, Reston, VA
Nature Vol 370 No 6485 July 14 1994 pp 128-131

Contamination of ground waters with water-soluble aromatic hydrocarbons, common components of petroleum pollution, often produces anoxic conditions under which microbial degradation of the aromatics is slow. Oxygen is often added to contaminated ground water to stimulate biodegradation, but this can be technically difficult and expensive. Insoluble Fe(III) oxides, which are generally abundant in shallow aquifers, are alternative potential oxidants, but are difficult for microorganisms to access. Here we report that adding organic ligands that bind to Fe(III) dramatically increases its bioavailability, and that in the presence of these ligands, rates of degradation of aromatic hydrocarbons in anoxic aquifer sediments are comparable to those in oxic sediments. We find that even benzene, which is notoriously refractory in the absence of oxygen, can be rapidly degraded. Our results suggest that increasing the bioavailability of Fe(III) by adding suitable ligands provides a potential alternative to oxygen addition for the bioremediation of petroleum-contaminated aquifers. (Author abstract) 133 Refs.

Polymer Pendant Ligand Chemistry: A Biomimetic Chemistry Approach to Metals Removal and Recovery from Aqueous Environmental Solutions
Fish, R.H.; Huang, S.; Li, W., Univ. of California, Berkeley, CA;
Albright, R.L.; Fries, W., Rohm and Haas Co. Research Labs., Spring House, PA
Proceedings: 207th Spring National Meeting of the American Chemical Society (ACS), San Diego, CA, 13-18 Mar 1994 p 778

Publisher: Washington, DC American Chemical Society 1994
Report Number(s): CONF-940301

The use of polymer pendant ligands to selectively remove and recover metal ions from aqueous solutions will be an important remediation technique for the Department of Energy's (DOE) Environmental Management and Restoration program goals. The authors have initiated studies that will develop new polymer pendant ligands that are biomimics of known biological ligands that selectively complex metal ions. The authors present results on the synthesis of polymer pendant sulfonated catechol (CATS) and sulfonated 3,3 and 3,4-linear catechol amide (3,3 and 3,4-LICAMS) ligands and their selective reactions with Fe3+, Cu2+, Zn2+, Ni2+, Hg2+ etc. ions at various pH values. Kinetic studies for rates of metal ion removal as a function of pH and the rates of regeneration of the polymer pendant ligand site for the recovery of these metal ions is also presented.

1993:

Entrapment of Mixed Microbial Cells for Water and Wastewater Treatment

Yang, P.Y.; Nitisoravut, S.; See, T.S.
Univ of Hawaii at Manoa, Honolulu, HI

Water Science and Technology Vol 28 No 7 1993 pp 165-170

An entrapment of mixed microbial cells process was used to remove the pesticide Ethylene Dibromide (EDB), Trichlopropane (TCP) and nitrate in groundwater. The mixed microbes were entrapped into a polymeric cellulose triacetate. The system is able to remove (aerobically) more than 90% of EDB (influent concentration of 300 mu g/l) at more than 30 minutes of hydraulic retention time (HRT). TCP (influent concentration of 2.81 mu g/l) could not be detected in the effluent at the same HRT. The system is also able to remove (anaerobically) more than 99% of nitrate influent concentration of NO//3-N ranging from 50 to 850 mg/l) at an HRT of more than 2 hours. The system has shown very promising results in respect of the removal of trace pesticide and nitrate contaminated groundwater. It can also be considered as an alternative for direct treatment of nitrate-rich water or in a combination with an ion exchange process with an intermittent to eliminate the high nitrate concentration from the spent regenerant. The system could easily develop a package plant for removal of trace organics and inorganics from the groundwater. (Author abstract) 12 Refs.

1992:

Bioventing: a Successful Soil Vapor Remediation Technique for the Vadose Zone and Shallow Groundwater

Yancheski, T.B.; McFarland, M.A.
Tetra Tech Richardson, Christiana, DE

Hazardous Materials Control/Superfund 92: 13th Annual Conference and Exhibition, Washington, DC, 1-3 Dec 1992 pp 631-636
Publisher: Greenbelt, MD Hazardous Materials Control Resources Institute 1992
Report Number(s): CONF-921235

Bioventing, which is a combination of soil vapor remediation and bioremediation techniques, is an innovative, cost-effective, and efficient remedial technology for addressing petroleum contamination in the vadose zone and shallow groundwater. The objective of bioventing is to transfer petroleum compounds from the soil and groundwater into soil vapor using soil vapor extraction and injection technology and to promote the migration of the soil vapor upward to the turf root zone for degradation

by active near-surface microbiological activity. Promoting and maintaining optimum microbiological activity in the turf root rhizosphere is a key component of the bioventing technique. A bioventing system was installed at a site in southern Delaware with multiple leaking underground tanks during the Summer of 1992 to remediate the vadose zone and shallow groundwater contaminated by petroleum compounds. The system, a combination of soil vapor extraction and injection points, has very successfully reduced concentrations of petroleum compounds in the soil and has reduced the amount of free product and petroleum concentrations in the shallow groundwater to the extent that nearby residential wells are no longer threatened. Soil and groundwater cleanup goals for the site are expected to be reached within 1 to 2 years of operation. Total remediation costs to date have been less than $35,000. The bioventing system is a promising low cost and effective alternative for the cleanup of petroleum related soil and groundwater contamination and has application at hundreds of similar sites where there is little money available for remediation.

Use of Biologically Active Barriers For In Situ Treatment of Contaminated Groundwater
Kao, C. M.; Borden, R. C.
North Carolina State Univ, Raleigh, NC
Proceedings: 16th Biennial Conference of the International Association on Water Pollution Research and Control: Water Quality International '92, Washington, DC May 24 1992
Water Science and Technology Vol 26 No 9-11 1992 p 2325
1992

Aerobic biodegradation has been shown to be effective for many fuel spills. However, success is often limited by the inability to provide sufficient oxygen to the contaminated intervals due to the low solubility of oxygen. Nitrate can serve as an electron acceptor in place of oxygen and results in anaerobic biodegradation of organics via denitrification. Since nitrate is less expensive and more soluble than oxygen, it may be more economical to restore fuel-contaminated aquifers using nitrate rather than oxygen. The aim of this study is to design a two layer trench system to offer an alternative of treating groundwater contaminated with low levels of organics which will be less expensive than the biological and physical processes currently in use. Edited author abstract Refs.

Pilot Plant Design For a 3.5 MGD Biological Groundwater Treatment System
Rorech, G.J.; Nyer, E.K.
Geraghty Miller, Inc., Tampa, FL
Proceedings: 5th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, Las Vegas, NV, 13-16 May 1991 pp 487-498
Publisher: Dublin, OH Ground Water Management 1992

An industrial landfill along a major river will require a groundwater pumping rate of 3.5 million gallons per day in order to control plume movement toward the river. The groundwater will contain relatively high concentrations of organic contaminants, 30 to 50 mg/l of total specific organics. The main contaminants are substituted benzene and phenol compounds. An economic analysis showed that physical/chemical treatment air stripping with vapor phase control followed by carbon adsorption would have a capital cost of 3 to 4 times that of a biological treatment system. In addition, the operating cost would be 10 to 20 times that of biological treatment. Accordingly, it was decided to use biological treatment for this groundwater. There are several unique design criteria for this system. First, the concentration will decrease over time. Second, even the initial concentration is too low for standard biological designs. A new design technique, Growth/Decay, will be used to satisfy these design requirements. Because of the unique aspects of this treatment system, it was decided to perform a pilot

study before full scale design and installation. This paper will review the economic comparison between physical/chemical treatment and biological treatment; the Growth/Decay design for this groundwater, and the pilot plant design and study that will be required to confirm the design criteria for the full scale treatment system.

Removal of Nitrate and Pesticide From Contaminated Groundwater Using Entrapped Microbial Cell Process

Yang, P.Y.; See, T.; Nitisoravut, S.; Chen, H.
Univ. of Hawaii, Honolulu, HI

Proceedings: Research and Development 92: National Research and Development Conference on the Control of Hazardous Materials, San Francisco, CA, 4-6 Feb 1992 pp 62-65
Published: 1992

An entrapment of mixed microbial cells process was used to remove the pesticides ethylene dibromide EDB, trichloropropane TCP and nitrate from groundwater. The mixed microbes were entrapped into a polymeric cellulose triacetate. The system was able to remove aerobically more than 90% of EDB at more than 30 minutes of hydraulic retention time HRT. TCP could not be detected in the effluent at the same HRT. The system was also able to remove anaerobically more than 99% of nitrate influent concentration of NO{sub 3}-N ranging from 10 to 850 mg/L at an HRT of more than 2 hours. The system has showed very promising results with respect to the removal of trace pesticide and nitrate contaminated groundwater. It can also be considered as an alternative for direct treatment of nitrate rich water or in a combination with an ion exchange process with an intermittent to eliminate the high nitrate concentration from the spent regenerant. The system can easily develop a package plant for removal of trace organics and inorganics from the groundwater.

1991:

Cold-Climate Bioremediation: Composting and Treatment Near the Arctic Circle at a Coke Works Groundwater

Berg, J.D.; Eikum, A.S., Aquateam-Norwegian Water Technology Centre A/S, Oslo Norway;
Eggen, T.; Selfors, H., Terrateam-Norwegian Environmental Technology Centre A/S, Mo i Rana Norway

Proceedings: Hazardous Materials Control/Superfund '91: 12th National Conference, Washington, DC 3-5 Dec 1991 pp 321-325
Published: 1991

Bioremediation was evaluated as an alternative treatment method for a coke works site in northern Norway near the Arctic circle, which was characterized in 1989 as having significant contamination by polycyclic aromatic hydrocarbons PAHs, arsenic and cyanide. Approximately 20,000 tons of soil containing PAHs 500 mg/kg were excavated. Groundwater at the site contained approximately 2-3 mg/L and 0.4-1.6 mg/L naphthalene and benzene. A pilot study was conducted in 1990, in which 1000 M3 of soil were treated in an enhanced composting system and 7000 L of groundwater were treated in a biofilm reactor. The variables tested in the composting study were: N and P, bark matrix and dispersant addition, temperature 4-16 degrees C, moisture 10-35% and aeration by blowers, H2O2 addition or pile turning. The treatment objective was as a 10 mg/kg total PAHS. Results showed that the PAH content was reduced to below the objective within 8 weeks at 12-16 degrees C. The treatment efficiency ranged from 96-99% depending on test variables. Optimal results were obtained by: 1 addition of tree bark as a matrix, 2 supplemental forced aeration, 3 soil moisture maintained at 25-30% for this soil type, 4 N and

P additives and 5 dispersant additives. Groundwater was pumped from a pilot well and treated in a rotating biological contacter RBC, covered to control emissions of volatile compounds. The early migration of arsenic into the area also necessitated development of a two-stage precipitation process using lime and ferric chloride in series to remove arsenic. Nitrogen was added after pretreatment. Once the biofilms were acclimated to the water, chemical oxygen demand, total PAHs and toxicity Microtox were reduced 97, > 99 and 93 %, respectively.

1990:

In Situ Bioremediation of TCE and Other Solvents
Nelson, M J K; Cioffi, J A; Borow, H S
Proceedings: Superfund '90: 11th National Conference, November 26-28 1990 pp 800-806

In situ bioremediation of industrial solvents, hydrocarbons, and pesticides has been demonstrated as an effective alternative to aboveground treatment using physical processes such as air stripping and carbon adsorption. Biological degradation was demonstrated in a continuous-flow bioreactor with influent TCE concentrations of 1 to 5 mg/L being degraded to below detectable levels. The results indicate the utility of the system for field application using surface bioreactors in pump-and-treat processes. Subsequent laboratory studies identified conditions that would maintain trichloroethylene TCE and thus be suitable to use in situ. Utilizing these conditions, a pilot system was tested in the field for developing and maintaining TCE-degradative activity within an aquifer. Initial concentrations ranged from 2500 to 3500 microg/L TCE. After 24 hr of treatment, a downgradient monitor well had < 500 microg/L TCE the concentration decreased < 100 microg/L TCE after 7 days of operation. The test results indicate that in situ biological removal of TCE can be achieved in subsurface aquifers. Prior to the design and installation of the bioremediation system, geohydrological and microbiological evaluations were conducted to determine if in situ bioremediation was a viable treatment technology for the contaminated groundwater. The microbiological evaluation demonstrated that the groundwater contained a high existing 4-chloro-2-methyl-phenol 4C2MP biodegradation potential. Under laboratory conditions, the existing microorganisms in groundwater samples removed from the site generally reduced the 4C2MP concentration by more than 90% after 7 days of incubation. The geohydrological evaluation demonstrated that aquifer permeability and subsurface mass transport parameters were amenable to in situ bioremediation. In the initial 3 mo of operation, the total contaminated plume exhibited a 25% to 35% reduction in size after 6 mo, a 50% reduction was observed. See also W93-01098 Lantz-PTT

In Situ Biodegradation of TCE Contaminated Groundwater
Montoya, T; Kinsella, J V; Nelson, M J
ECOVA Corp
Environmental Progress Vol 9 No 3 August 1990 pp 190-196

Trichloroethylene TCE-contaminated groundwater is presently treated by transferring the solvent either to a solid carbon adsorption or to the atmosphere via air stripping. Biological treatment of the contaminated water is an alternative that causes complete destruction of the solvent. When performed within the aquifer it is termed in situ biotreatment. A specific strain of bacteria G4 has been isolated that degrades TCE enzymatically. The process has been extensively tested in the laboratory and confirmed in a field pilot test. The pilot test involved the injection of a clean, oxygenated water stream directly into the TCE plume. Nutrients and G4 were added to the injection stream and TCE and TCE concentrations were measured up-and downgradient of the injection well. A decline in TCE levels was observed eight

hr after injection and continued for the following ten days. TCE concentrations were reduced from a high of 3,000 parts per billion to a mean value of 78 parts per billion during a 20 day period.

In Situ Biological Treatment of Ethylene Glycol-Contaminated Ground Water, and Soil at Naval Air Engineering Center, Lakehurst, New Jersey

Jerger, D.E.; Flathman, P.E.
O.H. Materials Corp., Findlay, OH

Proceedings: International IGT Symposium on Gas, Oil, Coal, and Environmental Biotechnology, New Orleans, LA, 11-13 Dec 1989 pp 67-81

At the Naval Air Engineering Center in Lakehurst, New Jersey, biodegradation techniques successfully treated ethylene glycol-contaminated ground water and soil following the loss of an estimated 4,000 gallons of cooling water from a lined surface storage lagoon. The cooling water was estimated to contain 25% vol/vol ethylene glycol. The problem developed following a liner break. A subsequent investigative program confirmed soil contamination around the lagoon and identified a 180 foot long by 45 foot wide contaminant plume extending to the east. At the start of the project, mean ethylene glycol concentration in the ground water was 1,440 ppm. The biofeasibility study assessed the biodegradation potential of ethylene glycol in the spill site matrix as well as the presence of a toxic or inhibitory environment to microbial growth. Approximately 85 to 93% of the ethylene glycol was removed from the ground water within the first 26 days of biological treatment. By the completion of the project, ethylene glycol was reduced to below the limits of detection LOD = 50 ppm in all production wells at the site. Biological techniques effectively removed ethylene glycol from the ground water environment at a relatively rapid rate. The flexibility of the injection/recovery system in maintaining an environment conducive to biodegradation while flushing ethylene glycol from the ground water environment was a key factor in the removal of scattered pockets of contamination.

Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site

Wilson, B H; Wilson, J T; Kampbell, D H; Bledsoe, B E; Armstrong, J M
Dynamac Corporation; US EPA, RS Kerr Environmental Research Lab, Ada, OK

Geomicrobiology Journal Vol 8 No 3/4 Jul/Dec 1990 pp 225-240

A shallow water table aquifer under the US Coast Guard Air Station at Traverse City, MI, has acclimated to the aerobic and anaerobic transformation of monoaromatic hydrocarbons BTX released from an aviation gasoline spill. The aquifer also exhibits reductive dechlorination of a chlorinated solvent spill adjacent to the aviation gasoline spill. The groundwater is buffered near neutrality. The aviation gasoline plume is methanogenic and the aquifer contains enough iron minerals to support significant iron solubilization. The results of the laboratory study confirm field evidence of both aerobic and anaerobic transformation of alkylbenzenes and suggest that natural aerobic and anaerobic in situ biorestoration of groundwaters contaminated with petroleum products can occur. The anaerobic transformations seen at this site and confirmed by the laboratory study provide an attractive alternative to aerobic restoration. The removal of the alkylbenzenes in the anaerobic material was quite rapid and compared favorably to removals seen in the aerobic zone of treatment. Comparison of first-order rates of disappearance in anaerobic microcosms with those calculated from field data show acceptable agreement. Anaerobic processes in the subsurface are probably limited by in situ reaction rates rather than by mass transport limitations for nutrients. Potentially, anaerobic microcosm studies could be useful in the evaluation of natural bioremediation of petroleum-contaminated subsurface materials. Because oxygen is frequently depleted in heavily contaminated groundwater and spills due to excessive

oxygen demand, anaerobic biotransformation can enhance in situ biorestoration in oxygen-depleted regions of a plume. Lantz-PTT

Stimulation of Biologically Active Zones BAZ's in Porous Media by Electron-Acceptor Injection
Rittmann, B E; Valocchi, A J; Bae, W; Odencrantz, J E
Illinois Univ. at Urbana-Champaign, Dept. of Civil Engineering
Journal of Contaminant Hydrology Vol 6 No 1 July 1990 pp 37-52

In situ bioreclamation is a promising new technique for enhancing the cleanup rate of aquifers contaminated with organic pollutants, and involves injecting the materials necessary to increase the microbiological activity in the subsurface. A methodology involving laboratory-column experiments and computer modeling was utilized to investigate the formation of denitrifying biologically active zones BAZs in a porous medium , when a limiting electron acceptor NO3(- is injected along the flow path. Laboratory experiments conducted in a unique one-dimensional porous-medium column demonstrated the relationship between lateral injection of NO3(- and the location and extent of BAZs when acetate was present as the sole carbon source. The phenomena of BAZ formation and the utilization of limiting and non-limiting substrates were expressed quantitatively in a computer model that coupled principles of one-dimensional solute transport and steady-state biofilm kinetics. A new, highly efficient solution algorithm was developed to solve directly for the steady-state profiles of the limiting substrate and biofilm mass, as well as for the non-limiting substrate. The predictive ability of the model was verified by successful simulation of particular laboratory experiments using independently determined kinetic parameters for acetate. Research results indicate that injection of limiting substrate along the groundwater flow path is a viable means of establishing spatially distributed BAZs for enhanced in situ bioreclamation. Author's abstract

In-Situ Groundwater Treatment Method Holds High Promise
Nichols, A.B.
Water Environment Technology Vol 2 No 11 Nov 1990 p 13

A multidisciplinary team of scientists at the Lawrence Livermore National Laboratory LLNL in California is developing a new subsurface method to clean up ground water. The approach will use natural microbes to degrade hazardous chemicals, like trichloroethylene TCE, into harmless compounds such as water, carbon dioxide, and natural salts. The project started in 1989 with funding of $1.5 million, including 250,000 from the Department of Energy.

Biostimulation of Methanotrophic Bacteria to Transform Halogenated Alkenes for Aquifer Restoration
Roberts, P.; Semprini, L.; Hopkins, G.; McCarty, P.; Grbic-Galic, D.
Stanford Univ., CA
Proceedings: Environmental Research Conference on Groundwater Quality and Waste Disposal, Washington, DC, 2-4 May 1989 pp 28.1-28.19

The in-situ remediation of aquifers contaminated with halogenated aliphatic compounds is a promising alternative in efforts to restore groundwater quality. Approaches for the restoration of aquifers based on pumping the contaminated groundwater and subsequently treating it above ground have proven effective, but often entail great expense as well as a risk of transferring the contaminants to another medium during such treatments, e.g. the atmosphere. To overcome these difficulties, in-situ treatment of the contaminated groundwater is becoming a potentially favorable alternative, with the

innovative efforts now centering on promoting biotransformation of the halogenated alkanes. Our group at Stanford University has assessed, under field conditions, the capacity of native microorganisms i.e., bacteria indigenous to the groundwater zone to degrade halogenated organic contaminants when appropriate conditions are created to enhance bacterial growth. This paper summarizes the results of both the laboratory and field work. Readers are referred to the final report for more details.

EX SITU BIOREACTORS

1996:

Cleaning Up Hydrocarbon Contaminated Groundwater
Lei, Jiyu; Drouin, M C ; Sansregret, J L
World Water Environ. Eng. Vol 19 No 1 1996 pp 11-12

Accidental release of hydrocarbons into the subsurface represents a serious environmental problem. For example, the hydrocarbon leakage from underground storage tanks has been identified as one of the most common causes of groundwater pollution. Currently, the most commonly used methods for the treatment of hydrocarbon contaminated water are activated carbon adsorption or air stripping. These methods, though efficient, are based on the transfer of contaminants from one medium to another. Consequently, they generate a second waste requiring further treatment or disposal. An alternative is provided by biological treatment which involves the use of microorganisms to degrade and ultimately mineralize the pollutants. Biogenie has developed a fixed biomass reactor for the treatment of hydrocarbon contaminated groundwater.

1994:

Innovative Bioreactor Offers Cleanup Option for Petroleum-Contaminated Wastes
Hickey, R., Michigan Biotechnology Institute Lansing, MI;
Hayes, T., Gas Research Institute Chicago, IL;
Mazewski, G., Envirex Inc., Waukesha, WI
Environmental Solutions Vol 7 No 6 Jun 1994 pp 73-74

An innovative treatment technology that can remove more than 99 percent total benzene, toluene, ethyl benzene and xylene (BTEX) from groundwater is in commercial use at about 25 US sites. Work performed by the Michigan Biotechnology Institute (MBI) in cooperation with Envirex Inc. and the Gas Research Institute has shown that the granular activated-carbon, fluidized-bed reactor (GAC-FBR) is effective in treating groundwater, produced-water brines and tank bottom wastes contaminated with BTEX, aliphatic hydrocarbons and polynuclear aromatic hydrocarbons. The system offers significant cost-savings over conventional pump-and-treat methods, such as carbon adsorption or air stripping coupled with vapor-phase control of volatile organic compound (VOC) emissions.

1990:

Removing Toxic Organics from Groundwater: Biological Conversion of PCE and TCE
Jewell, W J
Engineering: Cornell Quarterly Vol 25 No 1 Autumn 1990 pp 25-29

The United States has been producing of 10 million tons of chlorinated solvents since the early 1970s, with tetrachloroethylene PCE and trichloroethylene TCE making up about 5% of this total. Recently, microorganisms have been discovered that can degrade PCE and TCE. Although the sequences of reactions in the anaerobic, methanogenic and the aerobic, methanotrophic pathways for treating PCE and TCE are not well understood, in both cases an energy source and an electron or an electron-donor source appear to be necessary to start the process. A nationwide effort is currently seeking to identify a new cost-effective technology for the biological treatment of contaminated groundwater. Since 1987 a project has been under way to develop a methanotrophic attached-film expanded-bed MAFEB reactor. Studies of the kinetics of reactions in attached-film expanded beds using both aerobic, methanotrophic bacteria and anaerobic, methanogenic bacteria indicate that chlorinated solvents could be treated successfully with a hybrid above-ground reactor. The possibility of using a pilot model is currently under review.

NATURAL ATTENUATION

1995:

Intrinsic Bioattenuation for Subsurface Restoration (Book chapter)
Wilson, J.; Rifai, H.; Ward, C.; Borden, R.
National Risk Management Research Lab., Ada, OK. Subsurfaces Protection and Remediation Div.
Report No.: EPA/600/A-95/112; NTIS Number: PB95-274213 1995 42p

Intrinsic bioattenuation has recently evolved as a viable remediation alternative at a number of sites where the risk of exposure to contaminants is within acceptable standards. Important mechanisms controlling the instrinsic bioattenuation include advection, dispersion, sorption, dissolution from a residual source, and abiotic and biological transformations. Since intrinsic bioattenuation is a plume management strategy, it requires characterizing and monitoring these processes. Intrinsic bioattenuation involves an assessment of risks to public health and the environment, and consequently requires prediction of the fate and transport of contaminants at the candidate sites. This paper reviews the processes controlling intrinsic bioremediation and summarizes case histories where intrinsic bioattenuation has been observed at sites contaminated with petroleum hydrocarbons and chlorinated solvents. The key steps in evaluation natural attenuation as a remedial alternative are summarized.

Review of Intrinsic Bioremediation of TCE in Groundwater at Picatinny Arsenal, New Jersey and St. Joseph, Michigan (Book chapter)
Wilson, J.; Kampbell, D.; Weaver, J.; Wilson, B.; Imbrigiotta, T.
National Risk Management Research Lab., Ada, OK. Subsurfaces Protection and Remediation Div
Report No.: EPA/600/A-95/096; NTIS Number: PB95-252995 1995 13p

Reductive dechlorination occurs frequently in large trichloroethylene (TCE) plumes. TCE is transformed largely to cis-dichloroethylene (cis-DCE), then to vinyl chloride, and finally to compounds that do not contain organic chlorine. This abstract evaluates the rate and extent of natural reductive dechlorination of TCE in two large plumes with similar properties. The half life for attenuation of TCE and its dechlorination products was approximately six months in both plumes. The rates of attenuation in the two plumes are slow as humans experience time. In particular, they are slow compared to the time usually devoted to site characterization. However, in plumes with a long residence time, on the order of decades, they have significance for protection of waters that receive the plumes.

Intrinsic Bioattenuation for Subsurface Restoration
Rifai, Hanadi S.; Borden, Robert C.; Wilson, John T.; Ward, C. Herb Rice University, Houston, TX
Intrinsic Bioremediation Vol 1 1995 pp 1-29
(Full text available from Congressional Information Service: 1-800-227-2477)

Intrinsic bioattenuation is a contaminant-plume management strategy by which natural assimilation processes are monitored and used to limit adverse impacts of groundwater contamination. Successful implementation requires adequate site hydrogeological, chemical, and biological characterization, as well as detailed data analysis, modeling of the fate and transport of the dissolved plume, and long-term monitoring. The physical, abiotic, and biologically mediated transformation processes controlling the steady-state contaminant distribution in the subsurface are described, and several case studies are presented that illustrate the technology. Overall, three indicators of natural attenuation can be developed from the initial site characterization: compound disappearance, loss of electron donors, and the presence of degradation products. Intrinsic bioremediation will be the preferred alternative when the costs of conventional remediation are high, the problem compounds are easily biodegradable, aquifer conditions are appropriate, there are no nearby groundwater receptors, and there is a well-defined surface-water discharge.

1994:

A Practical Approach to Evaluating Natural Attenuation of Contaminants in Groundwater
McAllister, P.M.; Chiang, C.Y.
Shell Development Co., Houston, TX
Accelerating underground storage tank corrective action -- II. Proceedings of the international specialty conference, St. Louis, MO, 10-12 Mar 1994 pp 91-110
Publisher: Pittsburgh, PA: Air and Waste Management Association 1994
Report Number(s): CONF-940333

The extent of natural attenuation is an important consideration in determining the appropriate corrective action at sites where groundwater quality has been impacted by releases of petroleum hydrocarbons. The objective of this study was to develop a practical approach for evaluating natural attenuation based on easily obtained field data and proven indicators of natural attenuation. The approach recommended here includes: (1) Consider natural attenuation during the initial site assessment and obtain the data needed to evaluate natural attenuation, (2) Apply primary indicators of natural attenuation to demonstrate that natural attenuation is an appropriate alternative, (3) Implement a monitoring plan to verify natural attenuation, (4) Reevaluate the site as additional data becomes available. For petroleum hydrocarbons, the primary indicators include plume characteristics and dissolved oxygen levels in groundwater. Other secondary indicators such as geochemical data, and more intensive methods such as contaminant mass balances, laboratory microcosm studies, and detailed groundwater modeling can be applied to demonstrate natural attenuation as well. Previous literature reports and data from several field locations were analyzed to support the indicators and evaluation methods in order to develop a practical approach.

Attenuation and Biodegradation of Chlorophenols in Ground Water at a Former Wood Treating Facility
Davis, Andy; Campbell, Jim; Gilbert, Craig; Ruby, Michael V.; Bennett, Meridan; Tobin, Susan
PTI Environmental Services, Boulder, CO
Ground Water Vol 32 No 2 Mar-Apr 1994 pp 248-257

This communication describes novel methods to measure site-specific sorption data, and to determine if biodegradation of pentachlorophenol (PCP) in complex technical-grade formulations occurs at industrial facilities. Ground-water slurry samples containing between 0.012 and 230 mg/l PCP were collected from a former wood treating site, the liquid and solid fractions separated, and both fractions analyzed for PCP using selective ion monitoring to determine sorption coefficients. The results imply that, at the plume periphery, PCP in the subsurface will be attenuated and degrade, while at higher concentrations (i.e., at the source), PCP is mobile, and more recalcitrant to degradation. (Edited author abstract) Refs.

The Role of Bioattenuation in the Management of Aromatic Hydrocarbon Plumes in Aquifers
Salanitro, Joseph P.
Shell Development Co., Westholow Research Center, Houston, TX,
Ground Water Monitoring & Remediation Vol 13 No 4 1994 pp 150-161

Abstract not available.

1992:

Natural Remediation as an Alternative to Conventional Pumping and Treatment
Pisciotta, Thomas R.; Trione, Charles W.; Chang, Virginia K.
Woodward-Clyde Consultants, Wayne, NJ
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Newton, MA,, Oct 13-15 1992
Ground Water Management Vol 13 pp 187-199

Abstract not available.

PHYSICAL/CHEMICAL TREATMENT

IN SITU TECHNOLOGIES

AIR SPARGING

1996:

Monitoring Air Sparging Using Resistivity Tomography
Schima, S ; LaBrecque, D J ; Lundegard, P D
Ground Water Monitoring & Remediation Vol 16 No 2 1996 pp 131-138

Air sparging is a relatively new technique for the remediation of ground water contaminated with petroleum hydrocarbons. In this technique, air is injected below the water table, beneath the contaminated soil. Remediation occurs by a combination of contaminant partitioning into the vapor phase and enhanced biodegradation. The air is usually removed by vacuum extraction in the vadose zone. The efficiency of remediation from air sparging is a function of the air flow pattern, although the distribution of the injected air is still poorly understood. Cross-borehole resistivity surveys were performed at a former service station in Florence, Oregon, to address this unknown. The resistivity measurements were made using six wells, one of which was the sparge well. Data were collected over a two-week period during and after several air injections, or sparge events. Resistivity images were calculated between wells using an algorithm that assumes axially symmetric structures. The movement of the injected air through time was defined by regions of large increases in resistivity, greater than 100 percent from the background. During early sparge times, air moved outward and upward from the injection point as it ascended to the unsaturated zone. At later sparge times, the air flow reached a somewhat stable cone-shaped pattern radiating out and up from the injection point. Two days after sparging was discontinued, a residue of entrained air remained in the saturated zone, as indicated by a zone of 60 to 80 percent water saturation.

Laboratory Testing of the In-Well Vapor-Stripping System
Gilmore, T. J.; Francois, O.
Battelle Pacific Northwest Labs., Richland, WA.;
Report No.: PNNL-10977; NTIS Number: DE96008811 Mar 96 26p

The Volatile Organic Compounds-Arid Integrated Demonstration (VOC-Arid ID) was implemented by the US Department of Energy's (DOE's) Office of Technology Development to develop and test new technologies for the remediation of organic chemicals in the subsurface. One of the technologies being tested under the VOC-Arid ID is the in-well vapor-stripping system. The project to demonstrate the in-well vapor-stripping technology is divided into three phases: (1) conceptual model and computer simulation, (2) laboratory testing, and (3) field demonstration. This report provides the methods and results of the laboratory testing in which a full-scale replica was constructed and tested above ground in a test facility located at DOE's Hanford Site, Washington. The system is a remediation technology designed to preferentially extract volatile organic compounds (VOCs) from contaminated groundwater by converting them to a vapor phase.

1995:

Expedited Design and Installation of an Innovative Ground Water Remediation System

Saucier, K.C.; Hughes, D.; Burgess, J.A.
RMT, Inc., Greenville, SC, Southeast Region
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1524-1531
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

A rural site in US EPA Region 4 was used for a disposal of organic wastes. The materials were placed in four 10-foot deep trenches in the early 1970s. The materials and affected soil were removed from the site as part of a US EPA Removal Action in 1990. Following removal activities, shallow ground water monitoring conducted as part of the RI/FS revealed at the presence of low concentrations of trichloroethene (TCE), manganese, and bis(2-ethylhexyl)phthalate (BEHP) in the shallow zone of the underlying aquifer. The preferred remedial alternative for the site involved the remediation of ground water through an innovative in-situ air sparging system. In-situ air sparging was designed to address the constituents in ground water through distribution of air into the aquifer at strategically-located trenches. Air sparging trenches were chosen over air injection wells to overcome the limited zones of influence observed with injection wells in saprolite soils. A pilot scale evaluation was conducted in the pre-final design phase to define the air distribution patterns and a evaluate ground water circulation flow. Dye tests were performed during the pilot-scale evaluation to confirm the symmetrical air circulation pattern. During the construction phase, two vertical-walled air sparging trenches were installed downgradient of the former disposal area. Given that the vertical-walled trenches were installed 20 feet below the water table, a biopolymer slurry method was used for trench installation. Excavated slurry-filled trenches were backfilled with continuous air distribution piping and gravel. The biopolymer slurry was enzymatically degraded and removed during trench development. Following start-up, air sparging is expected to promote volatilization of the TCE, enhance naturally-occurring biological degradation of BEHP, and encourage the reoxidation of the aquifer resulting in the precipitation of manganese.

In Situ Air Stripping Using Horizontal Wells: Innovative Technology Summary Report
Stone and Webster Environmental Technology and Services, Boston, MA.
Report No.: DOE/EM-0269; NTIS Number: DE96003564 Apr 1995 31p

In-situ air stripping employs horizontal wells to inject or sparge air into the ground water and vacuum extract VOC'S from vadose zone soils. The horizontal wells provide better access to the subsurface contamination, and the air sparging eliminates the need for surface ground water treatment systems and treats the subsurface in-situ. A full-scale demonstration was conducted at the Savannah River Plant in an area polluted with trichloroethylene and tetrachloroethylene. Results are described.

Use of Combined Air Sparging and Soil Vacuum Extraction (AS/SVE) and Groundwater Recovery and Treatment as Remedial Alternatives for Dissolved DNAPL Recovery
Sturdivant, R. Jr.; Fulton, G.A. Jr., C-K Associates, Inc., Baton Rouge, LA;
Bains, F.E., Paxon Polymer Co., Baton Rouge, LA
Proceedings: American Association of Petroleum Geologists (AAGS) Gulf Coast Section meeting Baton Rouge, LA 25-27 Oct 1995
AAPG Bulletin Vol 79 No 10 Oct 1995 p 1567d

Corrective action has been implemented to address a dissolved dense non-aqueous phase liquid (DNAPL) plume in the vicinity of a former waste impoundment at the Paxon Polymer Company facility, located north of Baton Rouge, Louisiana. Assessment activities focused on the characterization of the geologic and hydrologic properties of the sediments underlying the area of investigation and the

impact of the dissolved DNAPL plume to the soils and groundwater. Geologic characterization revealed that the facility is underlain by Quaternary age sediments consisting of mixtures of fine-grained sands, silt, and clay. Two hydrologic units were identified within the shallow sediments which are referred to as the Upper Permeable Zone and Second Permeable Zone. The investigation focused on the impacted soils and groundwater of the Upper and Second Permeable Zones. The Upper and Second Permeable Zones were characterized hydrologically to determine the most applicable remedial alternative for addressing the dissolved DNAPL plume. Pilot tests consisting of soil vacuum extraction (SVE), combined air sparging with SVE (AS/SVE), and groundwater recovery were performed. Evaluation of these remedial technology alternatives resulted in the selection of the combined AS/SVE system alternative for the Upper Permeable Zone and the groundwater recovery alternative for the Second Permeable Zone. Recovered off-gas from the combined AS/SVE treatment system from the Upper Permeable Zone is treated through use of a granular activated carbon unit, while recovered groundwater form the Second Permeable Zone is treated by use of a low-profile air stripper.

A Full-Scale Pilot Study to Investigate the Remediation Potential of Air Sparging Through a Horizontal Well Oriented Perpendicular to a Contaminant Plume: Preliminary Results
Wade, A.; Wallace, G.W.; Seigwald, S.F.
Woodward-Clyde Consultants, Overland Park, KS
Ground Water Vol 33 No 5 Sep-Oct 1995 pp 856-857

A full-scale, one-year pilot study of a new design of air sparging system is being conducted at a site in the Midwest where plumes of TCE-contaminated ground water have been identified in an unconfined sand and gravel aquifer in which ground water flows at approximately 0.5 feet/day. TCE concentrations in the ground water range up to several thousand ug/L. A horizontal sparging well and associated soil vapor extraction (SVE) system have been constructed perpendicular to a contaminant plume immediately downgradient from its source. In addition, a vertical sparging well and SVE system have been constructed at the source to accelerate volatilization of TCE from the soil and ground water in the area of greatest contamination. All 24 SVE wells installed for the study are vertical. Although sparging from horizontal wells has been shown to be effective at other sites, this pilot study represents the first time to the authors knowledge that a horizontal sparging well has been oriented perpendicular to the ground water flow direction in order to intercept a contaminant plume. In this design, the horizontal air sparging well takes advantage of the natural ground water flow to maximize its zone of influence. Preliminary data from a network of 24 ground water monitoring wells and 15 vadose zone monitoring wells show that for a given air sparing flow rate, the radius of influence (lateral distance air travels through the aquifer) of the horizontal well is significantly greater than the radius of influence of the vertical well, although both wells are screened in similar sediments at the same depth below the water table.

Unterdruck-Verdampfer-Brunnen (UVB): An In Situ System for Remediation of Contaminated Aquifers
Simon, M.A., Environmental Protection Agency, Cincinnati, OH;
Argus, R.R.; Hough, B.L., PRC Environmental Management, Inc., San Diego, CA
Proceedings: 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium, Cincinnati, OH 4-6 Apr 1995 pp 120-124
Publisher: Environmental Protection Agency 1995
Report Number(s): CONF-9504110

Traditionally, contaminated groundwater is pumped to a surface facility for treatment, often by air stripping. An innovative technology, the Unterdruck-Verdampfer-Brunnen (UVB), German for Vacuum Vaporizing Well, is an in situ groundwater remediation technology that combines air-lift pumping and air stripping to clean aquifers contaminated with volatile compounds. Additionally, the developer claims that in some cases the technology is capable of simultaneous recovery of soil gas from the vadose zone. An evaluation of this process is discussed in this abstract. The UVB technology is a process patented by IEG mbH in Reutlingen, Germany. IEG Technologies, Inc., located in Charlotte, NC, markets the technology in North America. IEG teamed with Roy F. Weston, Inc. to demonstrate the UVB technology at March Air Force Base (AFB), CA. March AFB allowed the US EPA Superfund Innovative Technology Evaluation (SITE) program to evaluate the technology. The SITE program retained PRC Environmental, Inc. to evaluate the performance of the UVB system at March.

Air Sparging in a Sandy Aquifer (Florence, Oregon, U.S.A.): Actual and Apparent Radius of Influence

Lundegard, P.D.; LaBrecque, D.
Unocal Corp., Environ. Technol. Group, Brea, CA
J. Contam. Hydrol Vol 19 No 1 1995 pp 1-27

Injection of air into the saturated zone of a contaminated aquifer, air sparging, is a currently popular remediation alternative to the conventional approach of groundwater extraction followed by surface treatment. The air flow behavior around a single air sparging well was investigated under natural field conditions in a relatively homogenous aquifer consisting of well-sorted dune sand. The response of conventional monitoring data (including water table mounding, soil gas pressure, soil gas composition and tracer gas response) was compared with the results of cross-borehole electrical resistance tomography (ERT), which provides a sensitive indication of the pattern of air flow in the saturated zone. Compared with the region of air flow imaged by ERT, conventional monitoring data provided an ambiguous indication of the region of air flow in the saturated zone, possibly leading to an overestimation of the radius of influence by a factor of two to eight. Critical evaluation of the conventional monitoring data indicates that the shortcomings are a function of various factors which include the transient aspects of pressure and water table changes, and differences in the controls on air flow within the saturated and unsaturated zones.

Air Sparging for In Situ Bioremediation of Toluene

Brown, Richard A.; Leonard, Wendy C.; Leahy, Maureen C.
Groundwater Technology Inc, Trenton, NJ
In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes Vol 2 1995 pp 185-191
(Full text available from Congressional Information Service: 1-800-227-2477)

At a manufacturing site in New York State, groundwater contaminated with toluene and other VOCs has been treated using in situ air sparging. A combined air sparging and soil-vapor extraction system was selected as the technology of choice based on the presence of the majority of the mass below the water table and the nature of the contaminants. The design of the system is described. Over a 2-yr period of operation, approximately 2372 kg of toluene have been biodegraded, as calculated from the carbon dioxide production. In addition, approximately 91 kg of VOCs have been removed by volatilization. Over the same period, groundwater concentrations of total VOCs in monitoring wells have decreased 95-99%.

1994:

In Situ Groundwater Remediation Using Air Sparging and Soil Vapor Extraction: Development and Calibration of a VOC Extraction Rate Model
Roth, R.J.; Land, C.A.
Terra Vac, West Trenton, NJ
Proceedings: Volume 1: Federal Environmental Restoration and Waste Minimization Conference and Exhibition, New Orleans, LA, 25-29 Apr 1994 pp 185-193
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-940499

Air sparging is an innovative technology in which air is injected into the saturated zone so that the VOCs in the liquid phase are partitioned to the vapor phase and the VOC-laden air migrates upward into the unsaturated zone where it is extracted using conventional SVE. To estimate the length of time necessary to remediate contaminated groundwater in a source area, the design engineer must be able to estimate the VOC extraction rate from air sparging. This information can also be used to size the vacuum blower for the SVE system, and estimate the VOC loading of the vapor treatment system. This paper develops and evaluates a proposed and simple mathematical model for the removal of VOCs from groundwater that is being remediated by air sparging. Two case studies will be presented to illustrate the application of the technologies. The first case involves the removal of solvents from soil and ground water in Michigan. The second case involves the removal of gasoline from soil and ground water in New Jersey.

Air Sparging of Organic Compounds in Groundwater
Hicks, P.M.
Groundwater Technology, Inc., Tampa, FL
Proceedings: Volume 1: Federal Environmental Restoration and Waste Minimization Conference and Exhibition, New Orleans, LA, 25-29 Apr 1994 pp 96-100
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-940499

Soils and aquifers containing organic compounds have been traditionally treated by excavation and disposal of the soil and/or pumping and treating the groundwater. These remedial options are often not practical or cost effective solutions. A more favorable alternative for removal of the adsorbed/dissolved organic compounds would be an in situ technology. Air sparging will remove volatile organic compounds from both the adsorbed and dissolved phases in the saturated zone. This technology effectively creates a crude air stripper below the aquifer where the soil acts as the packing. The air stream that contacts dissolved/adsorbed phase organics in the aquifer induces volatilization. A case history illustrates the effectiveness of air sparging as a remedial technology for addressing organic compounds in soil and groundwater. The site is an operating heavy equipment manufacturing facility in central Florida. The soil and groundwater below a large building at the facility was found to contain primarily diesel type petroleum hydrocarbons during removal of underground storage tanks. The organic compounds identified in the groundwater were Benzene, Xylenes, Ethylbenzene and Toluenes (BTEX), Methyl tert-Butyl Ether (MTBE) and naphthalenes in concentrations related to diesel fuel.

The State-of-the-Art in Air Sparging Technology
Marley, M.C.
Envirogen, Inc., Canton, MA

Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 241-249
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

Air Sparging is the injection of a gaseous medium (commonly air) into the saturated zone for the purpose of directly treating (volatilization) or indirectly treating (bioenhancement) soils and groundwater contaminated with volatile organic compounds. Due to its relative conceptual simplicity, the number of application of the technology across the United States has been rapidly growing. In addition, innovative derivatives of the core process are being developed to expand the scope of application of the technology. Further, both academic and industry research on the process if beginning to shed a light on number of aspects of the technology that are critical to its understanding and proper application. This paper will outline the state of the art in air sparging technology. Innovative variations on the core process of the technology will be presented. Examples of the innovative applications include; sparging trenches, bio-walls and various in well sparging/ground water circulation approaches. Further, preliminary findings from the author's experience at a number of field research sites and more than twenty commercial applications of the technology will be explored.

Air Sparging and Vapor Extraction as a Means of Removing Chlorinated and BTEX Compounds in Complex Groundwater Conditions

Barrera, J.A.
Proceedings: Volume 1 Superfund 14: Conference and Exhibition, Washington, DC, 30 Nov - 2 Dec 1993 pp 499-508
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-9311122

Typical groundwater treatment systems consist of recovery wells, product separators and water treatment completed by discharge to sewer or recharge basins. Air sparging or enhanced groundwater aeration is an innovative in-situ technique to restore groundwater conditions. Site candidates are usually limited to include permeable sediments impacted with highly volatile aromatic and aliphatic compounds. Sparging involves stripping dissolved volatile organic compounds (VOCs) in shallow or perched aquifers. Typical sparging systems consist of pressurized air injection wells advanced into an aquifer. Controlled air injection encourages aqueous phase VOCs to mobilize upward into the unsaturated soil. Soil vapor extraction (SVE) wells or trenches are employed to recover VOCs transferred into the unsaturated soils. Vapor extraction is typically used in combination with air sparging to recover VOCs and to prevent vapor phase transport off-site. This paper presents full scale air sparging and vapor extraction applications in difficult and atypical conditions.

Air Sparging: Practical Lessons from the Field and the Lab

Lundegard, P.D.
Unocal Corp., Brea, CA
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 pp 854-855

In this study, computer simulations of multiphase fluid flow surrounding sparge wells, as well as innovative field geophysical methods, have been employed to investigate the physical behavior of air sparging systems and the significance of conventional monitoring data. Field tests and simulations

demonstrate the initial air injection is followed by transient system behavior during which the region of air flow first expands and then collapses partially once air breaks through to the unsaturated zone. These transient phases can last from hours to months or longer. For pilot testing it is important to realize that the radius of influence during transient behavioral phases may differ considerably from the radius at steady state. Furthermore, some monitoring parameters, such as water table mounding and other pressure measurements, will respond beyond the actual limits of air flow. The field and simulation studies demonstrate that the ambiguity of conventional monitoring data is a function of various factors which include their indirect relationship to air flow in the saturated zone, the transient aspects of pressure and water table changes, and differences in the controls on air flow within the saturated and unsaturated zones. It is also shown that water table mounding is generally a transient phenomenon that dissipates in time. As a result, the potential for water table mounding to cause undesired contaminant displacement is much less than commonly thought.

Performance Monitoring and Pilot Testing of In Situ Air Sparging Systems
Johnson, P.C., Shell Development Co., Houston, TX;
Johnson, R.L., Oregon Graduate Institute Beaverton, OR. Dept. of Environmental Science and Engineering;
Neaville, C., Hart Crowser Inc., Lake Oswego, OR;
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 p 843

In this presentation the authors briefly review the current practice of air sparging and then summarize arguments put forward by proponents and critics of the process. The remainder of the presentation will focus on performance monitoring of in situ air sparging pilot tests, and the extrapolation of short-term pilot test data to the design and predicted long-term effectiveness of air sparging systems. Data will be presented from the study of an air sparging application at a former service station site where site performance monitoring was assessed by sampling traditional ground water monitoring and vapor extraction wells, as well as discrete piezometers placed in both the saturated and vadose zones. In addition, He and SF6 tracer gas tests were used to better understand air distributions, vapor flow paths, and vapor recovery efficiency. Samples were analyzed for changes in oxygen, contaminant, and tracer gas concentrations with time. The data illustrate that conclusions regarding the performance and applicability of air sparging at any given site can vary significantly depending on the sampling approach used, and that some combination of the traditional and innovative methods may be necessary to gain a more realistic assessment of air distributions, vapor capture, and aquifer remediation effectiveness.

There Are No In-Situ Methods
Nyer, E.K.
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 pp 845-846

Man will never understand the strengths and limitations of the new innovative technologies unless one comprehends how they accomplish the remediation goals. The first step to reach this understanding is to realize how the technology works. The two hottest in situ technologies being applied in the field today are soil vapor extraction (SVE; also known as vapor extraction systems, VES) and air sparging. Neither of these techniques are, in fact, in situ methods. Both of these technologies rely on air

movement to remove the contaminants from the ground aquifer. This does not constitute an in place treatment; it is a simple change of carrier. Pump-and-treat techniques use water as a carrier to remove the contaminants from the aquifer. SVE and air sparging use air as the carrier to remove contaminants from the ground and aquifer. Air provides several advantages over water, but still has some of the weaknesses of water. The only true in situ processes still rely on carriers. Biological reactions in the unsaturated zone and the aquifer are mainly limited by the lack of oxygen and nutrients. Water and air are used to deliver these compounds to the contaminated area of the aquifer. Water or air carry the oxygen and nutrients to the bacteria so that they can use the contaminants as a food source and destroy them below ground. The mass transfer advantage of air and the diffusion limitations of both still have an effect on the design of an in situ biological remediation.

A Cost-Effectiveness Analysis of the In Situ Air Stripping Technology at the Savannah River Integrated Demonstration Site

Brill, T.C.; Brookshire, D.S.; McKee, M.

New Mexico Univ., Albuquerque, NM. Dept. of Economics

Jan 1994

Report Number(s): LA-SUB-94-88; Order Number: DE94015419

This study reports on an evaluation of a proposed new technology for remediating existing groundwater contamination. Two tasks are undertaken in this report. The first is a conventional cost-effectiveness analysis of the new technology versus existing technologies. In this evaluation several issues are addressed such as the choice of the metric used in the cost-effectiveness analysis, the time period of the evaluation, the appropriate discount rate, and the assumptions used for extrapolation of the field data. The second task is the extension of the conventional cost-effectiveness analysis to incorporate a decision analysis framework. This extension revolves many issues raised in conducting cost-effectiveness analysis of complex technologies. It allows inclusion of physical modeling, in this case groundwater modeling, to augment the limited field data and to analyzed different implementations of the technology. This study evaluates the performance of the new technology, in situ air stripping (ISAS), as compared with a conventional technology that involves the joint use of pump and treat with soil vapor extraction (PT-SVE) using vertical wells.

An Overview of In Situ Air Sparging

Johnson, R. L.; Johnson, P. C.; McWhorter, D. B.; Hinchee, R. E.; Goodman, I.

Oregon Graduate Institute, Department of Environmental Science and Engineering, Portland, OR,; Shell Development, Colorado State University; Batelle Memorial Institute; U. S. Environmental Protection Agency

Ground Water Monitoring & Remediation Vol 13 No 4 1994 pp 127-135

Abstract not available.

Air Sparging; Savior of Ground Water Remediations or Just Blowing Bubbles in the Bath Tub?

Nyer, Evan K.; Suthersan, Suthan S.

Geraghty & Miller, Denver, CO

Ground Water Monitoring & Remediation Vol 13 No 4 1994 pp 87-91

Abstract not available.

1993:

Air Sparging and Ground-Water Flow: Optimizing the Remediation Potential of Air Sparging Through a Horizontal Well
Wallace, G. Wade, A.; Holland, B.;
Woodward Clyde Consultants, Overland Park, KS;
Proceedings: Association of Ground Water Scientists and Engineers (AGWSE) Educational Seminar on Chlorinated Volatile Organic Compounds in Ground Water, Kansas City, MO, 17-20 Oct 1993 Journal of Environmental Health Vol 56 No 3 Oct 1993 p 852
Report Number(s): CONF-9310166

Soil Vapor Extraction (SVE) systems are effective in volatilizing and extracting TCE from the soil in the vadose zone. When used in combination with air sparging systems, SVE systems can also be effective in volatizing TCE from soil and ground water in the saturated zone. At a site in the Midwest, several plumes of TCE-contaminated ground water, with concentrations ranging from several hundred to several thousand mug/1, have been identified in an unconfined sand and gravel aquifer in which the ground water flows at approximately 0.5 feet/day. TCE concentrations of several thousand mug/1 have been detected in the vadose zone. A pilot study will be conducted of a new design of air sparging system at the above described site. A horizontal sparging well and associated SVE system will be located perpendicular to a plume down gradient from its source but within the associated area of vadose-zone contamination. In addition, a vertical air sparging well and SVE system will be located at the source to accelerate volatilization of VOCs from the soil and ground water in the area of greatest contamination.

Laboratory Study of Air Sparging: Air Flow Visualization
Wei Ji; Dahmani, A.; Ahlfeld, D.P.; Jia Ding Lin; Hill, E. III
Ground Water Monitoring and Remediation Vol 13 No 4 Fall 1993 pp 115-126

Laboratory flow visualization experiments, using glass beads as the porous medium, were conducted to study air sparging, an innovative technology for subsurface contaminant remediation. The purpose of these experiments was to observe how air flows through saturated porous media and to obtain a basic understanding of air plume formation and medium heterogeneity effects. The experiments indicate that air flow occurring in discrete, stable channels is the most probable flow behavior in medium to fine grained water saturated porous media and that medium heterogeneity plays an important role in the development of air channels. Several simulated scales of heterogeneities, from pore to field, have been studied. The results suggest that air channel formation is sensitive to the various scales of heterogeneities. Site-specific hydrogeologic settings have to be carefully reviewed before air sparging is applied to remediate sites contaminated by volatile organic compounds.

Limitations of Pump and Treat Remediation in a Common New England Hydrogeologic Environment
Maclean, D.A.; Marin, P.A.
Ground Water, Inc., Higganum, CT
Proceedings: 28th Annual Geological Society of America (GSA) Northeastern Section meeting, Burlington, VT, 22-24 Mar 1993; Abstracts with Programs Vol 25 No 2 Mar 1993 pp 35-36
Publisher: Geological Society of America
Report Number(s): CONF-9303211

A common hydrogeologic setting in New England consists of a thin layer of permeable glacial outwash (0--20 ft.) which overlays dense contact till deposited directly by glacial ice. These settings provide quite a challenge for hydrogeologists attempting to contain and remediate ground water contamination. Average linear migration velocities are often high because of the high permeability of the outwash (ranging from 1 to 100 ft/day or more). Spills in these environments can quickly create contaminated ground water plumes of large size threatening drinking water wells and other sensitive receptors. Pump and treat" systems (consisting of a pumped recovery well with a treatment system to clean pumped water prior to discharge) are commonly installed in these environments, but they often fail to contain and remediate ground water contamination. Data from several case studies and from analytical models used to evaluate pump and treat options demonstrate that pumping rates are limited by the available drawdown in the shallow outwash unit and by the low hydraulic conductivity of the lower till unit. Therefore, pump and treat systems often fail to develop effective capture zones in these environments even though highly permeable outwash sands are present. Combined air sparging and soil venting techniques (AS/SV) may provide an effective alternative to pump and treat remediation systems in these environments. Data from cases studies show that AS/SV can remove more contaminant mass than pump and treat while treating soil and ground water in place.

1992:

Air Sparging Technology Evaluation
Loden, M.E., Camp Dresser and McKee Inc., Cambridge, MA;
Chiyuan, Fan, Environmental Protection Agency, Edison, NJ
Proceedings: Research and Development 92: National Research and Development Conference on the Control of Hazardous Materials, San Francisco, CA, 4-6 Feb 1992 pp 328-334
Published: 1992

Air sparging, which is also referred to as in situ air stripping and in situ volatilization,' involves the injection of air into the saturated zone to strip VOCs dissolved in groundwater and adsorbed to soils from the saturated zone. The vapor phase contaminants transferred to the unsaturated zone are then captured using soil vapor extraction SVE. In addition to contaminant removal via mass transfer, the introduction of oxygen by injection of air also enhances subsurface biodegradation of contaminants. The air sparging system design requires consideration of system component compatibility and operation to ensure optimization of blower selection, well configuration design and air emissions treatment. The technology is applicable to gasoline, solvents and other volatile contaminants. Air sparging systems are almost always coupled with soil vapor extraction to control the subsurface air flow. Proper hydraulic control is key to preventing migration of contaminants to uncontaminated areas. Air sparging is a relatively new treatment technology. Research efforts to date have not fully elucidated the scientific bases of the system, and the associated engineering aspects are not completely defined. However, a substantial amount of information is available describing the effectiveness and characteristics of air sparging systems. This paper summarizes the available literature and case studies regarding the use of air sparging technology as it has been implemented to date and identifies research needs.

Innovative Groundwater and Soil Remediation: In Situ Air Stripping Using Horizontal Wells
Kaback, D.S.; Looney, B.B.; Eddy, C.A.; Hazen, T.C.
Westinghouse Savannah River Co., Aiken, SC
Proceedings: 5th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, Las Vegas, NV, 13-16 May 1991 pp 47-58

Publisher: Dublin, OH Ground Water Management 1992

An innovative environmental restoration technology, in situ air stripping, has been demonstrated at the US Department of Energy's DOE Savannah River Site SRS in South Carolina. This process, using horizontal wells, is designed to concurrently remediate unsaturated-zone soils and ground water containing volatile organic compounds VOCs. In situ technologies have the potential to substantially reduce costs and time required for remediation as well as improve effectiveness of remediation. Horizontal wells were selected to deliver and extract fluids from the subsurface because their geometry can maximize the efficiency of a remediation system and they have great potential for remediating contaminant sources under existing facilities. The in situ air stripping concept utilizes two parallel horizontal wells: one below the water table and one in the unsaturated zone. The deeper well is used as a delivery system for the air injection. VOCs are stripped from the ground water into the injected vapor phase and are removed from the subsurface by drawing a vacuum on the shallower well in the vadose zone. The first demonstration of this new technology was conducted for a period of twenty weeks. A vacuum was first drawn on the vadose zone well until a steady-state removal of VOCs was obtained. Air was then injected at three different rates and at two different temperatures. An extensive characterization program was conducted at the site and an extensive monitoring network was installed prior to initiation of the test. Significant quantities of VOCs have been removed from the subsurface equivalent to an eleven-well 500 gpm pump-and-treat system at the same site. Concentrations of VOCs in the ground water have been significantly reduced in a number of the monitoring wells. In addition, the activity of indigenous microorganisms was increased as much as two orders of magnitude during the air injection.

1991:

Pilot-Scale Evaluation of a Multistage Diffused Bubble Aeration System for Removal of VOCs From Groundwater: Case Study

Pradhan, M.K.; Kaiser, K.J.; Raman, K.K.
Malcolm Pirnie, Inc., Paramus, NJ
Proceedings: National Research and Development Conference on the Control of Hazardous Materials, Anaheim, CA 20-22 Feb 1991 pp 365-367
Published: 1991

A pilot study was conducted to evaluate the treatment efficacy of a multistage diffused bubble aeration system to remove Volatile Organic Compounds VOCs from groundwater at a machinery manufacturing facility in New Jersey. The test showed that the system could achieve more than 99% removal of 1,1,1-trichloroethane from the contaminated water. Additionally, the low cost, ease of installation and maintenance and its low profile made this innovative treatment technique the most attractive treatment alternative for this site. 2 figs., 5 tabs.

Remediation of Petroleum Hydrocarbon-Contaminated Ground Water and Soil Using In-Situ Air Sparging and Active Soil Vapor Extraction at LUST Sites in New Mexico

Wild, Steve; Billings, Jeffrey F.; Brown, William J.; Ardito, Cynthia P.
New Mexico Environment Department, Santa Fe, NM;
Billings and Associates, Albuquerque Environmental Health Department, Intera
Proceedings: Geological Society of America, 1991 Annual Meeting, San Diego, CA,, Oct. 21-24, 1991
Abstracts with Programs -Geological Society of America Vol 23 No 6 1991 p 245

Abstract not available.

DIRECTIONAL WELLS

1996:

New Direction in Remediation
Parmentier, Paul P.; Klemovich, Ronald M.
Corporate Groundwater Technology, Inc, Norwood, MA
Civil Engineering (New York) Vol 66 No 4 Apr 1996 pp 55-57

Horizontal well drilling has become one of the most popular methods for soil and groundwater remediation. The technology was adapted from oil recovery and utility installation industries and has made it possible for a single well to contact a much larger contaminated area. Although horizontal wells cost more per drilled foot than vertical wells, the advantages can mean significantly lower total project costs, especially in the savings from decreased surface disruption. A single horizontal well can replace up to 10 vertical wells since they are able to follow the contaminated hydrocarbon plumes laterally.

Using Horizontal Wells as a Remediation Tool
Russell, D.L.
Environmental Protection Vol 7 No 1 1996 pp 36-43

The practice of drilling horizontal wells is a relatively old technology from the oil drilling community that is gaining acceptance in the remediation community. New developments in drilling motors and instrumentation technology have reduced the cost of drilling horizontal wells and permit the wells to be used in a number of new applications for remediating pollution-contaminated sites.

1995:

Synopsis of Environmental Horizontal Wells at the Savannah River Site
Denham, M. E. ; Lombard, K. H.
Westinghouse Savannah River Co., Aiken, SC.
Report No.: WSRC-TR-94-0239; NTIS Number: DE95014720 1995 17p

Seven horizontal wells for environmental remediation were installed at the Savannah River Site as part of an Integrated Demonstration Project sponsored by the Department of Energy's Office of Technology Development. The wells were used to demonstrate innovative remediation systems for the clean up of chlorinated organic solvent contamination in groundwater and the vadose zone. The wells were installed in four demonstrations of different horizontal drilling technologies. A short-radius petroleum industry technology, a modified petroleum industry technology (using a down-hole motor), a utility industry technology, and a river crossing technology were demonstrated. The goals of the demonstrations were to show the utility of horizontal wells in environmental remediation and further development of the technology required to install these wells. From the first demonstration in 1988 to the latest in 1991, there was significant evolution in horizontal drilling technology. The main technical challenges in the first demonstration were directional control during drilling and borehole instability. Through advancement of the technology these problems were overcome and did not affect the last demonstration.

Innovative Horizontal Wells Enhance Groundwater Remediation
Wyatt, K.W.; Reid, V.M.

Black and Veatch Waste Science, Inc., Kansas City, MO
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1542-1549
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

A Record of Decision (August 1990) required pump-and-treat remediation of the contaminated groundwater plume extending beneath Building 3001 at Tinker Air Force Base (AFB), OK. Operations inside Building 3001 (a 62-acre aircraft overhaul facility) had, in past decades, contaminated the underlying shallow aquifer zones with industrial solvents--primarily trichloroethylene (TCE) and chromium. The discussion will detail how horizontal extraction wells have greatly enhanced contaminant removal, thereby reducing the duration and cost of the remediation effort. The Environmental Protection Agency (EPA) required that contaminated groundwater be extracted from both the perimeter and the heart of the plume. This required placing extraction well screens beneath the center of Building 3001. Because installation of conventional vertical wells inside Building 3001 would have disrupted critical aircraft overhaul operations, five horizontal wells were drilled from outside the building using slant drill rigs and steerable down-hole drilling motors. Each horizontal well is more than 900 feet long, and each places 200 feet of extraction screen in the areas of highest contaminant concentration. The upper aquifer zone is a thin perched aquifer. A conventional vertical well would allow only about 15-feet of productive well screen, thus restricting flow to 2 or 3 gallons per minute (gpm) per well. The longer horizontal well screens have allowed extraction rates of 8 to 18 gpm per well. The increased flow rate has significantly improved plume control and capture and has accelerated contaminant mass removal, reducing ultimate duration and cost of remediation.

Horizontal Environmental Well Cost Evaluation Methods
Wilson, D.D., Independent Environmental Consultants, Arvada, CO;
Losonsky, G., IT Corp., Lake Charles, LA
Proceedings: 1995 American Society of Mechanical Engineers (ASME) Energy Sources Technology Conference and Exhibition, Houston, TX, 29 Jan - 1 Feb 1995 pp 43-50
Publisher: New York, NY: American Society of Mechanical Engineers 1995
Report Number(s): CONF-950116

Horizontal environmental well installation is an innovative technology and therefore there is little information regarding engineering cost estimates for its use in feasibility studies. This paper investigates three methods of assessing the costs of installing a horizontal well: (1) comparing the cost of installing horizontal wells with the cost of installing vertical wells; (2) examining the costs of previous horizontal well installations; and (3) comparing the costs of different drilling methods and well materials for horizontal wells. Two case studies are presented that illustrate the diversity of horizontal well installations and their associated costs.

1994:

Viability of Horizontal Directional Drilling Utilization for Soil and Groundwater Remediation
Lowe, George A. II; Watkins, Wesley S.
A&L Underground, Inc, Olathe, KS
Proceedings of the Energy-Sources Technology Conference, New Orleans, LA, January 23-26, 1994 Drilling Technology American Society of Mechanical Engineers, Petroleum Division V 56 1994 pp 215-219

Publisher: ASME, New York, NY 1994

Horizontal directional drilling (HDD) has now become the preferred method of installation for the majority of the pipeline and cable crossings installed in the United States. The advantages of installation are widely accepted and include better economics, shorter installation times and substantially reduced environmental impact compared to conventional dredging construction. The techniques for installation have been continually improved and downhole survey accuracy has become extremely accurate allowing for closer tolerance installations. In short, an industry that had its roots in the early 1970s has now grown to be an accepted standard for the construction industry. The utilization of horizontal wells for soil and groundwater remediation was a natural evolution from the original crossing applications utilizing HDD. Horizontal wells utilized in the proper locations could offer significant advantages over conventional vertical well applications. As technical personnel in the remediation field are increasingly exposed to the installation advantages, you will see many new applications being undertaken. The following are areas where HDD well installation are most cost effective and offer significant advantages to conventional vertical well installation and operation. (Author abstract)

Results of a Survey of Horizontal Environmental Well Installations

Wilson, D.D., CDM Federal Programs, Golden, CO;
Kaback, D.S., Colorado Center for Environmental Management, Golden, CO
Drilling technology -- 1994: PD-Volume 56
Vizniak, J.P. (ed.) (Maurer Engineering, Inc., Houston, TX)
Proceedings of 17th American Society of Mechanical Engineers (ASME) Energy-Sources Technology Conference and Exhibition (ETCE), New Orleans, LA, 23-26 Jan 1994 pp 193-197
Publisher: New York, NY American Society of Mechanical Engineers 1994
Report Number(s): CONF-940113

Horizontal environmental wells have been installed at various hazardous waste sites for the purpose of remediating contaminated soils and ground water. Horizontal wells provide the means to access a greater surface area of the contaminated zone and to access zones that are inaccessible by traditional remediation technologies. A survey of the horizontal environmental well industry was performed during June 1993 to determine the extent that the environmental industry has applied the new technology. The study is, in essence, an inventory of the horizontal environmental wells that have been installed. The initial results of the survey indicate that over 100 horizontal wells have been installed. Approximately 26 ground water pump and treat wells have been installed, 25 soil vapor extraction wells, and 55 other types of wells (including product recovery, air sparging, in situ stripping wells, and drains). The majority of the wells have been installed at depths of less than or equal to 8-m. vertical depth. The cost of the horizontal wells is directly related to the vertical depth of the installation, site geology, well materials, and the length of the well.

Horizontal Well for Extraction and Containment of PCB/VOC Contaminated Groundwater

Hicks, E.C., Kemron Environmental Services, Inc., Atlanta, GA;
Smith, C.L., Cooper Industries, Houston, TX
Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 215-221
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

As an alternative to a traditional vertical extraction well array, the horizontal directional well is a cost-effective technology for plume containment and free-phase product recovery and allows for the future addition of a vapor enhanced groundwater recovery option in low yield environments. A further advantage is to be able to exactly place the well 4 under, or through otherwise inaccessible areas. Kemron Environmental Services has successfully installed a 750 ft. well with 450 ft. screened interval within a contaminated aquifer at an industrial site in Pennsylvania. This site presented numerous engineering difficulties including sizeable subsurface boundary which made the use of conventional remedial design technology such as vertical extraction wells, recovery trenches, or the installation of slurry walls difficult.

A Horizontal Well Recovery System to Capture LNAPL and Affected Ground Water
Angle, D.G.
ERM-Southwest Inc., Houston, TX
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 pp 847-848

The use of a horizontal well recovery system and the existing subsurface hydraulic regime can be a very effective remedial alternative for capturing LNAPL and ground water affected by a release. The discovery of a leak in the floor of a 1-million-gallon aboveground tank prompted an investigation of the shallow soils in the immediate vicinity of the tank. Elevated levels of volatile organic compounds detected in soils around and underneath the tank led to the demolition of the tank and the removal of approximately 3,500 CYS of the most affected soil. The horizontal recovery system consists of 140 feet of well screen that is wrapped in geofilter fabric and placed in a bed of filter sand covering the bottom of the excavation to enhance fluid migration. The screen was laid in two fluid draining runs extending from a vertical standpipe. To enhance future vertical fluid migration to the filter sand, a geofilter fabric was laid along the sides of the excavation. A one-piece polyethylene liner was placed on top of the filter fabric and the filter sand in the base of the excavation and filled with clay. A pneumatic, low flow submersible pump installed in the standpipe is used to extract up to 720 gallons of LNAPL and affected ground water per day. Concentrations of the volatile organic compounds initially detected in the liquid collected from the standpipe were reduced from 4.23 percent to 0.1 percent over a 16-month time period.

1993:

Horizontal Wells Can Lower Costs of Remediating Soil, Groundwater
Oil and Gas Journal Vol 91 No 48 29 Nov 1993 p 65

Conventional approaches to soil and groundwater remediation make extensive use of vertical wells that penetrate the various contamination phases--liquid, adsorbed, dissolved, and vapor. But advances in horizontal drilling have added a new dimension to the remediation of hazardous soils and groundwater. Whereas conventionally drilled wells are perpendicular to the central axis of hazardous waste, horizontal wells can travel parallel to the axis. Dual wells can flank entire plumes for aggressive treatment, and sparge points can become sparge barriers--boundaries against migration of the contaminants. Under the right conditions, a single horizontal well can treat areas that previously required as many as 10 vertical wells. This not only reduces drilling costs, but also eliminates redundant hardware for groundwater pumping or soil vapor extraction. The paper briefly describes five applications and discusses limitations to the use of the technology.

Horizontal Wells Improve Access for VOC Remediation: Stretching the Limit for the Utility Industry
Wilson, D.D., CDM Federal Programs Corp., Golden, CO;
Kaback, D.S., Univ. of Colorado, Stony Brook, CO
Proceedings: Association of Ground Water Scientists and Engineers (AGWSE) Educational Seminar on Chlorinated Volatile Organic Compounds in Ground Water, Kansas City, MO, 17-20 Oct 1993 Journal of Environmental Health Vol 56 No 3 Oct 1993 pp 853-854
Report Number(s): CONF-9310166

Horizontal wells can be utilized to improve access to the subsurface for environmental restoration applications such as characterization, monitoring, and remediation. Increased remediation efficiency of approximately 5:1 has been documented using horizontal wells for environmental restoration and petroleum recovery applications. Existing directional drilling technologies have been modified for environmental applications. A provider of utility industry equipment modified an existing system for environmental applications and demonstrated the new system at a site in South Carolina. The demonstrated utility industry technology is based on a patented compaction drilling method that has the advantage minimizing drilling fluids, thus reducing costs associated with handling of investigative derived wastes. The technology was modified to promote greater depth capability, thereby broadening the number of environmental application sites. The horizontal well was proposed to be screened within a 40-foot deep clay stratum where two thermally enhanced vapor extraction technologies would be demonstrated. The low permeability clay has retained a large portion of VOCs released from a process sewer line near the surface and now acts as a secondary source of contamination. Due to the linear geometry of the original source of contamination and the concentration of contaminants within a thin zone, a horizontal well was selected to maximize the surface area of the screened zone during the vapor extraction remediation demonstration.

1990:

New Horizontal Wellbore System for Monitor and Remedial Wells
Karlsson, H; Bitto, R
Eastman Christensen (A Baker Hughes Company) Houston, Texas
Proceedings: Superfund '90: 11th National Conference, November 26-28 1990 pp 357-362

The development and field testing of an innovative drilling system for installing horizontal wells for groundwater monitoring and remediation is described. Detailed technical specifications and planning and operating considerations are provided with suggestions for specific applications for the system. A prototype system was successfully field tested and has been refined and introduced for commercial use. These uses include: recovery of contaminated groundwater or leachate from beneath lagoons, landfills, buildings, storage tanks, refineries and chemical plants soil gas extraction and in situ remediation.

DUAL PHASE EXTRACTION

1996:

Dual-Phase Treatment Reduces Cleanup Time and Cost
Safrin, Ted
Corporate Siemens Vacuum Pumps, Norwood, OH
National Environmental Journal Vol 6 No 3 May-Jun 1996

A process that simultaneously treats groundwater and extracts soil vapor, while cutting cleanup time in half, is reportedly gaining favor as an alternative to pump-and-treat tactics. In this scheme, the right choice of a vacuum pump or compressor depends on the demands and complexity of the project. Presented is a brief discussion of the various devices available and their relative merits and approximate costs.

In Situ Remediation of Jet Fuel in Soil and Ground Water by High Vacuum, Dual Phase Extraction
Kirshner, Marvin; Pressly, Nicholas C.; Roth, Robert J.
Ground Water Monitoring & Remediation Vol 16 No 1 Winter 1996 pp 73-79

This report summarizes the initial results of subsurface remediation at Terminal 1, Kennedy International Airport, to remediate soil and ground water contaminated with Jet fuel. The project was driven and constrained by the construction schedule of a major new terminal at the facility. The remediation system used a combination of ground water pumping, air injection, and soil vapor extraction. In the first five months of operation, the combined processes of dewatering, volatilization, and biodegradation removed a total of 36,689 pounds of total volatile and semivolatile organic jet fuel hydrocarbons from subsurface soil and ground water. The results of this case study have shown that 62 percent of the removal resulted from biodegradation, 27 percent occurred as a result of liquid removal, and 11 percent resulted from the extraction of volatile organic compounds (VOCs). (Author abstract) 2 Refs.

1995:

Soil and Groundwater Remediation Using Dual-Phase Extraction Technology
Miller, A.W., Eder Associates, Inc., Madison, WI;
Gan, D.R., Eder Associates, Inc., Jacksonville, FL
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1191-1200
Publisher: Bethesda, MD E.J. Krause and Associates 1995
Report Number(s): CONF-951139

A gasoline underground storage tank (UST) was formerly used to fuel vehicles for a hospital in Madison, Wisconsin. Elevated concentrations of gasoline range organics (GRO) were observed in soils and groundwater at the site during the tank removal and a subsequent site investigation. Based on the extent of soil and groundwater contamination, a dual-phase extraction technology was selected as the most cost effective alternative to remediate the site. The dual-phase extraction system includes one extraction well functioning both as a soil vapor extraction (SVE) and groundwater recovery well. After six months of operation, samples collected from the groundwater monitoring wells indicated that the groundwater has been cleaned up to levels below the Wisconsin preventative action limits. The dual-phase extraction system effectively remediated the site in a short period of time, saving both operation and maintenance costs and overall project cost.

Site Remediation Via Simultaneous Dual Extraction
Phillips, J.B.
Engineering Development Inst., Milwaukee, WI
Proceedings: Innovative Technologies For Site Remediation and Hazardous Waste Management: The National Conference, Pittsburgh, PA 23-26 Jul 1995 pp 30-37
Publisher: New York, NY: American Society of Civil Engineers 1995
Report Number(s): CONF-9507173

A method to remediate sites contaminated with volatile hazardous organic substances is developed. The method employs concurrent application of in situ groundwater extraction and soil vapor extraction to remove volatile substances, such as low molecular weight solvents, from contaminated soils. The method has the potential to decontaminate soils beyond the locus of the treatment equipment. Advantages and limitations of the technology are presented. This process was developed for two contaminated sites in Wisconsin. One is contaminated with vinyl chloride, and the other is contaminated with a mixture of oligo-chlorinated ethylene and ethane species. Field application of the method is discussed briefly.

Remediation in Clay Using Two-Phase Vacuum Extraction
Lindhult, Eric C.; Tarsavage, Joseph M.; Foukaris, Kimberly A.
Dames & Moore
Proceedings of the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management Pittsburgh, PA, 1995 pp 13-20

Soil and groundwater contamination in a tight clay usually requires costly and/or time consuming remediation, due to the inherently low hydraulic conductivity of the soil. However, Dames & Moore is successfully using an innovative, cost-effective two-phase vacuum extraction (VE) technology at a former gasoline service station. Dramatic decreases in BTEX concentrations in onsite and downgradient monitoring wells are apparent. (Author abstract)

2-Phase Groundwater and Soil Vapor Extraction Site Test at McClellan AFB
Koerner, C.; Kingsley, G.B.; Lawrence J.
Radian Corp., Sacramento, CA
Proceedings of HAZMACON '95: Hazardous Materials Management Conference and Exhibition, San Jose, CA 4-6 Apr 1995 pp 244-256
Publisher: Oakland, CA: Association of Bay Area Governments 1995
Report Number(s): CONF-9504134

The innovative 2-phase extraction technique is a method recently patented by Xerox Corporation for simultaneously extracting contaminated groundwater and soil vapor from the subsurface. The 2-phase technique is primarily applicable to those sites with semipermeable soils containing volatile organic compound (VOC) contamination in both soils and groundwater. This technique has several distinct advantages over either conventional soil vapor extraction or groundwater extraction, because it can: cut the dollar per-contaminant-pound cleanup costs by an order of magnitude; simplify the extraction and treatment of both contaminated water and vapor; and shorten remediation times. The U.S. EPA and the Air Force elected to conduct an EPA Site test of the 2-phase Extraction technology at McClellan results indicate: The groundwater flow rate is twice that of the pump-and-treat system. The mass of contaminants from a single well removed increased from 130 lbs/year to more than 5,000 lbs/year, over 30 times more than the pump-and treat rate, with potential for even higher removal rates: 5,000 to 8,000 pounds of contaminants per year. Up to 95% of the contamination was extracted in the vapor phase, where it could be treated more easily and efficiently.

Phase 1 Remediation of Jet Fuel Contaminated Soil and Groundwater at JFK International Airport Using Dual Phase Extraction and Bioventing

Roth, R.; Bianco, P. Rizzo, M., Terra Vac, West Trenton, NJ . Midatlantic Division;
Pressly, N.; Frumer, B., Port Authority of New York and New Jersey, New York, NY
Proceedings: Superfund 16, Volume 2: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste Washington, DC 6-8 Nov 1995 pp 1070-1079
Publisher: Bethesda, MD: E.J. Krause and Associates 1995
Report Number(s): CONF-951139

Soil and groundwater contaminated with jet fuel at Terminal One of the JFK International Airport in New York have been remediated using dual phase extraction (DPE) and bioventing. Two areas were remediated using 51 DPE wells and 20 air sparging/air injection wells. The total area remediated by the DPE wells is estimated to be 4.8 acres. Groundwater was extracted to recover nonaqueous phase and aqueous phase jet fuel from the shallow aquifer and treated above ground by the following processes; oil/water separation, iron-oxidation, flocculation, sedimentation, filtration, air stripping and liquid-phase granular activated carbon (LPGAC) adsorption. The extracted vapors were treated by vapor-phase granular activated carbon (VPGAC) adsorption in one area, and catalytic oxidation and VPGAC adsorption in another area. After 6 months of remediation, approximately 5,490 lbs. of volatile organic compounds (VOCs) were removed by soil vapor extraction (SVE), 109,650 lbs. of petroleum hydrocarbons were removed from the extracted groundwater, and 60,550 lbs. of petroleum hydrocarbons were biologically oxidized by subsurface microorganisms. Of these three mechanisms, the rate of petroleum hydrocarbon removal was the highest for biological oxidation in one area and by groundwater extraction in another area.

1994:

Innovative 2-Phase Extraction Method Provides Low Permeability Site Remediation Alternative
Tornature, P.M.
Proceedings: Volume 1: Federal Environmental Restoration and Waste Minimization Conference and Exhibition, New Orleans, LA, 25-29 Apr 1994 pp 727-732
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-940499

2-Phase Extraction is an innovative remedial process developed and patented by Xerox Corporation that combines the attributes of soil vapor extraction and groundwater recovery under high vacuum (>25 inches Hg at the source) in a way that synergistically increases the performance of the collective remedy. The process application uses simple, skid mounted equipment which eliminates the need for pump installations in recovery wells and reduces the total number of recovery locations. Extraction can be successfully accomplished from 2 inch diameter monitoring wells as an interim measure and for pilot evaluation of the technology. In many instances, additional extraction points can be minimized, reducing the cost of the installed remedy. The extraction process strips groundwater with soil vapors during recovery, and pretreats both recovered phases, reducing the cost for treatment equipment installation and operation. The extraction unit is modular and can be used with a wide variety of vapor and liquid treatment processes based on site economics. Haley and Aldrich has applied 2-Phase Extraction on a number of low permeability sites with a wide range of geologic conditions. Their paper focuses on an overview of results achieved at 4 of the sites under pilot and full scale operations. Soil permeabilities have ranged as low as 10-7 cm/sec, with shallow to moderate overburden overlying fractured bedrock, or fine grained silts, sands and clays. Contaminant plume characteristics varied from Non Aqueous Phase Liquids (NAPL) to dissolved phase plumes transported in low permeability fractured bedrock aquifers. Contaminants successfully extracted have ranged from petroleum products to blends of chlorinated solvents and mineral oils.

1993:

Integrated Remediation Technology Provides Rapid Site Remediation
Keegan, J.; Bosshard, B.; Ott, D.
Terra Vac, Costa Mesa, CA
Proceedings: Seventh National Outdoor Action Conference and Exposition, Las Vegas, NV, 25-27 May 1993 pp 3-13
Publisher: Dublin, OH Ground Water Management 1993
Report Number(s): CONF-9305192

An innovative process is being applied to the remediation of both groundwater and soil simultaneously. This process combines vacuum extraction, groundwater recovery, and enhanced bioremediation for an effective site remediation process. Dual Extraction, developed by Terra Vac, is an in situ process which recovers liquid, vaporous, dissolved and adsorbed contaminants from the subsurface while enhancing the biodegradation of contaminants in the subsurface. Dual Extraction has successfully been utilized at a number of sites contaminated with Volatile Organic Compounds (VOC's). Some of these sites presented a low soil permeability which limited traditional recovery and bioremediation methods. Dual Extraction has been successful in remediating such sites with increased recovery rates, increased radius of influence and decreased remediation times. Several case studies are presented demonstrating the effectiveness of the Dual Extraction technology in each of the following areas: 1. Enhanced bioactivity due to the application of dual extraction. 2. Increased groundwater

recovery rates. 3. Recovery of VOCs above and below the static water level. 4. Increased recovery rates of VOCs compared to conventional remediation techniques. A technology that demonstrates the above improvements will result in shorter remediation times frames and yield significant cost savings for a number of site cleanups.2 refs., 7 figs., 1 tab.

1991:

Innovative Technology for Simultaneous In Situ Remediation of Soil and Groundwater
Malot, J.J.; Piniewski, R.
Proceedings: HMC-South 91: Hazardous Waste, Hazardous Materials/Hazardous Materials Control HWHM/HMC Conference, Houston, TX, 24-26 Apr 1991 pp 191-195

An innovative process is being utilized to simultaneously remediate soils and groundwater contaminated with volatile organic compounds. The patented recovery process, dual vacuum extraction, has been developed by Terra Vac. Dual vacuum extraction is a physical, in situ process which combines vacuum extraction of unsaturated soils with groundwater recovery from a single extraction well. The process recovers liquid, vaporous, dissolved and adsorbed contaminants from the subsurface. Since both aquifer and source contamination are addressed simultaneously, the individual processes combine synergistically to increase the effectiveness of subsurface remediation, reducing the time and costs for total site remediation. The process has been successfully applied at many sites over a wide range of geologic and hydrogeologic settings, remediating volatile and semivolatile organic compounds VOCs. Dual vacuum extraction is utilized at hazardous waste sites with VOCs in soils and groundwater, sites where fluctuating ground water levels may redistribute contamination, sites with shallow groundwater and sites where a low permeability hydrogeologic setting limits traditional recovery methods. A process description and a case study documenting results of a dual vacuum extraction project are presented. Results demonstrate that the process is able to: 1 recover VOCs from soils above and below the static water level, 2 recover VOCs from soils and groundwater at an increased rate when compared with conventional technologies, 3 increase groundwater recovery rates in most hydrologic settings, 4 increase the radius of influence of extraction wells and 5 reduce the number of extraction wells required at a site. The process will recover a greater mass of VOCs in a shorter time period than pump-and-treat methods, yielding significant cost savings and reducing the time frame for site cleanup.

1990:

In-Situ Remediation of a Chlorinated Solvent Contaminant Plume Using Vacuum Extraction Technology
Hayes, C.A.; Duncan, J.; Johnson, T.M., Dunn Geoscience Corp., Parsippany, NJ;
Martin, J.P.; Cheng, S.C.; Susavidge, M.A., Drexel University, Philadelphia, PA
Proceedings: Mid-Atlantic Industrial Waste Conference, Philadelphia, PA, 24-27 Jul 1990 pp 269-289

A pilot-scale test of the Terra Vac Vacuum Extraction System VES was carried out at an actual hazardous waste site located in New York State. The site is slated for redevelopment and has previously been used for a number of different purposes. These include a salvage area for scrap metal, a concrete batch plant, and an oil storage tank farm. An environmental investigation determined that a small portion of the site contained soil and groundwater contaminated with volatile organic compounds VOC's. This paper shows the contaminated portion of the property. The ability of the VES to remove VOC's from soil pores, soils, and groundwater at the site was investigated during the Pilot Study. As a result of the fact that groundwater was only 3-4 feet below the surface, while contamination was

believed to exist at depths of up to 20 feet below the surface, a dual extraction system was used at the site. This involved pumping groundwater to depress the water table at the site and create an artificial vadose zone. Water and vapor were therefore both being withdrawn: hence the term dual extraction.

DYNAMIC UNDERGROUND STRIPPING

1995:

Dynamic Underground Stripping: Innovative Technology Summary Report
Stone and Webster Environmental Technology and Services, Boston, MA.
Report No.: DOE/EM-0271; NTIS Number: DE96003566 Apr 1995 38p

Dynamic Underground Stripping (DUS) is a combination of technologies targeted to remediate soil and ground water contaminated with organic compounds. The main technologies comprising DUS are steam injection at the periphery of a contaminated area to heat permeable subsurface areas, vaporize volatile compounds bound to the soil, and drive contaminants to centrally located vacuum extraction wells; electrical heating of less permeable sediments to vaporize contaminants and drive them into the steam zone; and underground imaging such as Electrical Resistance Tomography to delineate heated areas to ensure total cleanup and process control. A full-scale demonstration was conducted on a gasoline spill site at Lawrence Livermore National Laboratory in Livermore, California from November 1992 through December 1993.

1992:

Dynamic Underground Stripping Demonstration Project
Newmark, R.L. ed.
Lawrence Livermore National Lab., CA
April 1992 464 p

LLNL is collaborating with the UC Berkeley College of Engineering to develop and demonstrate a system of thermal remediation techniques for rapid cleanup of localized underground spills. Called dynamic stripping to reflect the rapid and controllable nature of the process, it will combine steam injection, direct electrical heating, and tomographic geophysical imaging in a cleanup of the LLNL gasoline spill. In the first eight months of the project, a Clean Site engineering test was conducted to prove the field application of the techniques. Tests then began on the contaminated site in FY 1992. This report describes the work at the Clean Site, including design and performance criteria, test results, interpretations, and conclusions. We fielded 'a wide range of new designs and techniques, some successful and some not. In this document, we focus on results and performance, lessons learned, and design and operational changes recommended for work at the contaminated site. Each section focuses on a different aspect of the work and can be considered a self-contained contribution.

STEAM STRIPPING

1992:

Efficacy of Steam Stripping in Removal of Dichloromethane from Groundwater
Ladanowski, C.; Punt, M.; Kerr, P.; Adams, C.
Marshall Macklin Monaghan Ltd., Thornhill, ON, Canada
Proceedings: Environment Canada Ninth Technical Seminar on Chemical Spills, Ottawa, ON, Canada 8-9 Jun 1992 pp 27-38

The applicability of steam stripping as a remedial technology to remove dichloromethane from contaminated groundwater was evaluated in laboratory and pilot-scale field studies. Laboratory evaluation using contaminated groundwater containing up to 5,200 ppM dichloromethane demonstrated that greater than 99% removal efficiencies could be achieved using a two-pass system. Based on the laboratory evaluation, a 6-month pilot-scale field trial was conducted at a contaminated groundwater site. Groundwater containing up to 9,700 ppM dichloromethane was fed to a 2,000 l/h mobile steam stripping unit at an average rate of 900 l/h. Under optimum conditions, greater than 99.99% removal efficiencies were achieved on a single pass through the unit. Slightly lower efficiencies were obtained under continuous operating conditions. Greater than 99.99% removal efficiencies have been routinely achieved in the field using a 2-pass treatment process. Under these operating conditions, the treated groundwater contains less than 1 ppM dichloromethane. Relative to other remedial technologies for the treatment of contaminated groundwater, steam stripping has been shown to be an economically viable and environmentally sound alternative for the removal of dichloromethane from groundwater. 5 refs., 3 figs., 3 tabs.

1991:

SITE Demonstration of AWD Technologie's Integrated AquaDetox/SVE Treatment System
Evans, G., EPA, Cincinnati, OH;
Behtash, B., PRC Environmental Management Inc., San Francisco, CA
Proceedings: Hazardous Materials Control/Superfund '91: 12th National Conference, Washington, DC 3-5 Dec 1991 pp 691-699
Published: 1991

Under the Superfund Innovative Technology Evaluation SITE Program, a technology developed by AWD Technologies, Inc., was demonstrated at the Lockheed site in Burbank, California, in September 1990. This paper presents the major results of the SITE demonstration of AWD Technologies integrated AquaDetox/SVE treatment system designed for simultaneous on-site treatment of contaminated groundwater and soil-gas. The AWD technology uses an AquaDetox moderate vacuum steam stripping system to treat contaminated groundwater and a soil vapor extraction SVE system that uses granular activated carbon GAC beds to treat soil-gas. The two systems are integrated into a closed-loop system that simultaneously treats groundwater and soil-gas with no air emissions. The groundwater and soil at the Lockheed site are contaminated with VOCs, primarily trichloroethylene TCE and tetrachloroethylene PCE. Results of extensive sampling and analyses of the groundwater and soil-gas before and after treatment by the system were used to calculate removal efficiencies. The AWD technology was evaluated based on the removal efficiencies of TCE and PCE from the contaminated groundwater and soil-gas. The technology was also evaluated based on compliance of the effluent groundwater with regulatory discharge requirements at the site. The conclusions drawn from these evaluations are: 1 the system effectively treated VOC-contaminated groundwater and soil-gas achieving

removal efficiencies as high as 99.99% for groundwater and 99.9% for soil-gas; 2 the effluent groundwater was in compliance with the regulatory discharge requirements of 5 [mu]g/L each for TCE and PCE for all test runs; 3 the system operated more efficiently at lower stripping tower pressures; and 4 the 1,000-gallon per minute system at Lockheed has an estimated capital cost of $4.3 million and annual operating and maintenance costs of approximately $820,000.

US EPA SITE Demonstration of AWD Technologies' AquaDetox/SVE System
Evans, G.M.
Environmental Protection Agency, Cincinnati, OH
Journal of the Air and Waste Management Association Vol 41 No 11 Nov 1991 pp 1519-1523

Under the Superfund Innovative Technology Evaluation SITE Program, a technology developed by AWD Technologies, Inc. was demonstrated in September 1990. This paper presents the major results of the SITE demonstration of AWD Technologies' AquaDetox/SVE treatment system designed for simultaneous on-site treatment of contaminated groundwater and soil-gas. The groundwater and soil at the demonstration site were contaminated with trichloroethylene TCE and tetrachloroethylene PCE. The AWD technology was evaluated on the basis of the removal efficiencies of TCE and PCE from the contaminated groundwater and soil-gas. The conclusions drawn from these evaluations are 1 the system achieved removal efficiencies as high as 99.99 percent for groundwater and 99.9 percent for soil-gas; 2 the effluent groundwater was in compliance with the regulatory discharge requirements of 5 {mu}g/L each for TCE and PCE for all test runs; 3 the demonstrated 1,000 gpm system has an estimated capital cost of $4.3 million and annual operating and maintenance cost of approximately $820,000.

FRACTURING

1996:

Hydraulic and Pneumatic Fracturing for In Situ Remediation of Groundwater and Soil
Industrial Health & Hazards Update Jan 1, 1996 p. N/A

This EPA document describes the research and development of hydraulic and pneumatic fracturing technologies to remove contaminants from soil and ground water at waste disposal and spill sites. The activities include research, demonstrations, and field application of these technologies. The pneumatic fracturing process involves the injection of highly pressurized air into consolidated sediments that are contaminated, in order to extend existing fractures and create a secondary network of fissures and channels. This enhanced fracture network increases the permeability of the soil to liquids and vapors and accelerates the removal of contaminants, particularly by vapor extraction, biodegradation, and thermal treatment. The new passageways increase the effectiveness of many in situ processes and enhance extraction efficiencies by increasing contact between contaminants adsorbed onto soil particles and the extraction medium.

1995:

Using Pneumatic Fracturing for In-Situ Remediation of Contaminated Sites
Schuring, J.R.; Chan, P.C.; Boland, T.M.
Civ. Eng., New Jersey Inst. Technol., NJ
Remediation Vol 5 No 2 1995 pp 77-90

Pneumatic fracturing is an innovative technology enhancing the removal and treatment of contaminants in moderate-to-low permeability formations. The main advantages are a reduction in treatment time and the extension of available in-situ technologies to more difficult geologic conditions. Pneumatic fracturing has been successfully demonstrated in the field at a number of contaminated sites and in a variety of geologic formations. The technology is now commercially available and is being incorporated into site cleanups. This article provides an overview of the pneumatic fracturing technology, beginning with a general description of the concept and apparatus. Next, key technological considerations will be discussed including fracture initiation, fracture orientation, fracture flow, and treatable soils and contaminants. Three case studies are presented describing different applications of pneumatic fracturing. The article concludes with a discussion of cost benefits of the technology.

1994:

U. S. Environmental Protection Agency's Superfund Innovative Technology Evaluation of Pneumatic Fracturing Extraction
Frank, Uwe
U. S. Environmental Protection Agency, Edison, NJ
United States Air & Waste Vol 44 No 10 Oct 1994 pp 1219-1223

Abstract not available.

1992:

Removal of Contaminants From the Vadose Zone By Pneumatic Fracturing. Final Report
Schuring, J.R.; Chan, P.C.
New Jersey Institute of Tech., Newark, NJ, Dept. of Civil and Environmental Engineering
Jan 1992 184 p

Pneumatic fracturing is a new process which enhances the removal and treatment of hazardous organic contaminants from the vadose zone. It consists of injecting high pressure air or other gas into contaminated geologic formations at controlled flow rates and pressures. Initial studies performed at a bench scale consistently demonstrated that fractured soils displayed 100% to 360% higher removal rates than unfractured soils. A full-scale prototype system was subsequently fabricated and field tested at two uncontaminated sites, including an unconsolidated clayey silt deposit and a sandstone/siltstone formation. At both sites, pneumatic fracturing caused significant increases in subsurface air flow typically ranging from one to two orders of magnitude. Measurement of ground surface heave confirmed fractures propagated up to 16 feet from the point of injection. Complementary theoretical studies have resulted in the development of models for: 1 pneumatic fracture initiation; and 2 dual porosity flow and mass transport in pneumatically fractured media. The study concludes that pneumatic fracturing is an effective emerging technology which can reduce treatment time of contaminated formations, and extend available technologies to more difficult geologic conditions.

1991:

Capture of a Groundwater Contamination Plume in Fractured Bedrock by an Artificially Produced Fracture Zone Created Through Controlled Blasting
Begor, K.F.; Sutch, R.W., Dunn Geoscience Corp., Albany, NY;
Nothnagle, R.J. Nothnagle Enterprises, Scottsville, NY
Proceedings: Fourteenth Conference on Explosives and Blasting Techniques, Anaheim, CA, 31 Jan -5 Feb 1988 pp 111-122
Published: 1991

A manufacturing facility in Upstate New York operated a series of surface impoundments used to treat wastewater from plating operations and various other metal finishing processes. A comprehensive groundwater quality assessment program conducted at the facility identified contamination of the groundwater by volatile organic compounds VOCs within both the overburden and bedrock aquifers. A corrective action program was implemented upon completion of the groundwater assessment program. Using a carefully controlled single line pattern blasting technique, a 6-foot wide, 300-foot long fracture zone was created in the upper 25-feet of the bedrock aquifer perpendicular to the centerline of the plume. Following fracturing, a second 72-hour aquifer test was conducted at the same location and under conditions similar to the first test. The second test indicated that the single recovery well located in the newly created fracture zone should be fully capable of recovering contaminated groundwater and preventing further migration of the plume. The recovery well produced a substantially higher yield of 18.5 gpm with only 11.2 feet of drawdown. Furthermore, all of the nearby observation wells showed significant response to pumping. Success at this site is promising and the approach may prove useful at other sites involving contaminated bedrock aquifers.

PASSIVE TREATMENT AND SLURRY WALLS

1996:

Treatment Walls for In Situ Remediation of Soils and Groundwater
Industrial Health & Hazards Update Jan 1, 1996 p. N/A

This EPA document describes demonstrations, field applications, and research on treatment walls for remediating contaminated ground water at waste disposal and spill sites. Water permeable treatment walls are installed as permanent, semi-permanent, or replaceable units across the flow-path of a contaminant plume, which allows the plume to move passively through them while precipitating, sorbing, or degrading the contaminants. These mechanically simple barriers may contain: metal-based catalysts for degrading volatile organics; chelators for immobilizing metals; nutrients and oxygen for microorganisms to enhance bioremediation; or other agents. Degradation reactions break down the contaminants in the plume into harmless byproducts. Precipitation barriers react with contaminants to form insoluble products that are left in the barrier as water continues to flow through. Sorption barriers adsorb or chelate contaminants to the barrier surface. The reactions that take place in barriers are dependent on parameters such as pH, oxidation/reduction potential, concentrations, and kinetics. Thus, successful application of the technology requires characterization of the contaminant, ground-water flux, and subsurface geology. Although most barriers are designed to operate in situ for years with minimal maintenance and without an external energy source, the stability of aging barriers has not been established.

1995:

In Situ Remediation Technology Status Report: Treatment Walls
Environmental Protection Agency, Washington, DC. Technology Innovation Office.
Report No.: EPA/542/K-94/004; NTIS Number: PB95-252383 Apr 1995 34p

The purpose of the document is to describe demonstrations, field applications, and research on treatment walls for remediating contaminated ground water at waste disposal and spill sites. Information for this report came from computerized databases such as the Dialog Information Services and the Environmental Protection Agency's (EPA) Vendor Information System for Innovative Treatment Technologies (VISITT) and Alternative Treatment Technologies Information Center (ATTIC). Additional materials were obtained from publications such as the Hazardous Substance Research Center Annual Reports, Superfund Innovative Technology Evaluation Technology Profiles and Department of Energy's Office of Technology Development Program Summary as well as conference summaries, proceedings and compendiums.

Design and Evaluation of an In-Situ Ground Water Treatment Wall Composed of Zero-Valent Iron
Gallinatti, J.D.; Warner, S.D.; Yamane, C.L.; Szerdy, F.S., Geomatrix Consultants Inc., San Francisco, CA;
Hankins, D.A., Intersil Inc., San Francisco, CA;
Major, D.W., Beak Technologies Inc., Guelph, Ontario, Canada
Ground Water Vol 33 No 5 Sep-Oct 1995 pp 834-835

An in-situ permeable treatment wall using zero-valent iron for the remediation of ground water affected by chlorinated volatile organic compounds (VOCs) was recently constructed in Sunnyvale, California. Because this site was the first full-scale application of this technology as a final remedy of VOC-affected ground water, it provides a framework for assessing the factors that must be considered when moving from laboratory studies of this treatment technology to design and construction of a full-scale treatment system. Experience from this case study is valuable for both practical design considerations and as incentives for future research. The patented treatment process, licensed by Environmental Technologies Inc., utilizes granular zero-valent iron as a porous medium to enhance the degradation of VOCs dissolved in ground water. The dissolved VOCs, such as 1,1,1-trichloroethylene (TCE), that pass through the granular iron matrix are transformed through the oxidation of the iron and reductive dechlorination of the organic compound to a final end product consisting chiefly of chloride and ethylene. The degradation process appears to be abiotic and half-lifes of the transformations are several orders of magnitude faster in the presence of zero-valent granular iron than observed in the ambient environment.

Zero-Valent Metals Provide Possible Solution to Groundwater Problems
Wilson, Elizabeth K.
Chemical & Engineering News Vol 73 No 27 Jul 3 1995 pp 19-23

Contaminated groundwater can now be efficiently treated using a new technology involving the use of permeable underground barrier containing iron. Such method exploits zero-valent metals. This technology does not require electricity or maintenance as well as there are no parts to be broken. Thus, this technology is a more promising technique.

Combine Palladium with Iron for Enhanced Dechlorination
Environmental Engineering World Vol 1 No 4 Jul-Aug 1995 p 39

Research Corporation Technologies (RCT; Tucson, Arizona) is completing bench-scale testing of a new groundwater-treatment process that uses particles of palladium-coated iron to dechlorinate organic compounds. The palladized-iron process, developed by a research team at the University of Arizona, dechlorinates low-molecular-weight hydrocarbons by converting the chlorinated organics to chloride ions and either methane or ethane gas. A three-month test of an above-ground treatment unit is scheduled to begin in September. The key to the new process is the palladium. When elemental iron is immersed in water, it oxidizes and releases electrons, which create a reducing environment. This reducing environment breaks down chlorinated and fluorinated organic compounds. Unfortunately, a layer of metal oxide (rust) forms on the iron surface. This layer ultimately impedes the flow of electrons into the water and makes the reduction process slow and inefficient. To overcome this, RCT deposits a small amount (0.05 wt%) of palladium as discrete islands on the iron particles. This palladium prevents rust from coating the iron but does not impede the steady flow of the electrons needed to sustain a reducing environment.

Reductive Dechlorination of Chlorinated Ethenes by Iron Metal
Sivavec, T.M.; Horney, D.P.
GE Corp. Research and Development, Schenectady, NY
Proceedings: 209th American Chemical Society (ACS) National Meeting, Anaheim, CA 2-6 Apr 1995 p 665
Publisher: Washington, DC: American Chemical Society 1995
Report Number(s): CONF-950402

Reduction of chlorinated ethenes in aqueous solution by iron metal was studied in batch and column systems under anaerobic and mildly aerobic conditions. The goal of this work was to gain a fundamental mechanistic understanding of the reaction chemistry and to determine the factors that affect dechlorination rate and long-term performance in groundwater treatment. Pseudo-first-order TCE, DCE and VC dechlorination rates and product mass balances (chloride ion and C2-C6 hydrocarbons) were measured for greater than twenty-five commercial iron metals. All experimental evidence was found to support a direct reduction mechanism in which electron transfer from Fe-o to the adsorbed chloroethene occurs at the metal/water interface. XPS depth profile analysis was used to correlate Fe-o surface concentration with observed dechlorination rates. A linear dependence of dechlorination rate on iron specific surface area was determined. Other factors that influence dechlorination rates will be discussed, including proton- and anion-promoted dissolution processes that remove surface iron oxides and yield new Fe-o surfaces.

In Situ Remediation of Chromium Contaminated Groundwater Using Zero Valent Iron
Blowes, D.W.; Ptacek, C.J.; Hanton-Fong, C.J.; Jambor, J.L.
Univ. of Waterloo, Ontario, Canada
Proceedings: 209th American Chemical Society (ACS) National Meeting, Anaheim, CA 2-6 Apr 1995 p 699
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-950402

In situ porous reactive walls, using zero-valent iron as a reductant, are an alternative technology for the treatment of groundwater contaminated with electroactive elements, such as Cr(VI). Laboratory column and batch experiments were conducted to assess the treatment of Cr(VI) using zero-valent iron

in the form of iron filings. Batch tests were conducted with and without calcite addition. Batch test results indicate that removal using iron filings is rapid, with initial Cr(VI) concentrations reduced from approximately 20 mg/L to < 0.05 mg/L within 3 hours. Iron filings retained from the batch tests were examined mineralogically. The results indicate that the most abundant secondary minerals are goethite, lepidocrocite, maghemite and hematite. Of these minerals, the most abundant was goethite. No discrete chromium-bearing phases were detected, but chromium-rich zones, containing up to 27.3 wt.% Cr as Cr(OH)3, were detected within the iron oxyhydroxides, most notably within the goethite. A flow-through column experiment, conducted at a flow rate of 10 m/a indicated continuing treatment of Cr(VI) at concentrations of approximately 20 mg/L to <0.05 mg/L for more than 130 pore volumes.

Phenomena Affecting Remediation of Organic Groundwater Contaminants with Iron Metal at Solid-Water Interface

Agrawal, A.; Liang, L., Oak Ridge National Lab., TN;
Tratnyek, P.G., Oregon Graduate Institute, Portland, OR
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 p 54
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

A great deal of interest has developed in the groundwater remediation community in the last couple of years over the prospects of new treatment strategies for some priority pollutants (e.g. chlorinated solvents, other polyhalogenated organics, and nitro aromatic compounds) based on their rapid degradation by granular iron metal. These developments have created a need for process-level insight into the geochemistry of these systems in order to explain, predict, and/or enhance their performance. To this end, we are investigating various aspects of the reduction of some common organic contaminants at the iron particle-water interface. Recent results demonstrate that metal corrosion, condition of iron oxide/carbonate passivating surface films, and mass transport processes determine the overall reactivity of iron surface towards organic contaminants. Evidence for such processes is found through the experimental variables that influence the kinetics of environmentally-relevant, reduction of aromatic nitro groups as well as the metal surface reactivity through scanning electron microscopic analysis of the iron metal. The role of precipitation on the metal surface in determining contaminant reduction kinetics will also be discussed.

Iron Enhanced Abiotic Degradation of Chlorinated Hydrocarbons

Chen, C.T.
Environmental Protection Agency, Cincinnati, OH
Proceedings: 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium, Cincinnati, OH 4-6 Apr 1995 pp 74-78
Publisher: Environmental Protection Agency 1995
Report Number(s): CONF-9504110

Since the 1970s, several researchers have investigated the ability of certain zero-valent metals or alloys to enhance the degradation of halogenated organic compounds in contaminated water. Iron, zinc, aluminum, brass, copper, and stainless steel have been studied at various times with varying degrees of success. Gillham and O'Hannesin have recently made a literature review and conducted tests on 14 halogenated aliphatic compounds using zero-valent iron as an enhancing agent. The results showed that rapid dehalogenation occurred on all of the compounds tested except dichloromethane. Based on these test results, EnviroMetal Technologies, Inc. proposed to remediate groundwater contaminated with

chlorinated organic compounds using this technology. The EPA Superfund Innovative Technology Evaluation (SITE) program has accepted this technology for demonstration. This demonstration project will include two processes, above ground reactor and in situ permeable wall. The demonstration on the above ground reactor is being conducted at a site in Wayne, New Jersey. The main contaminants at this site are tetrachloroethene (PCE) and trichloroethene (TCE). The in situ permeable wall process will be conducted at a site in upstate New York. This site is a shallow sand aquifer containing TCE, dichloroethenes, and 1,1,1-trichloroethane.

Building a Wall Against Toxic Waste (Iron Filings to Protect Groundwater from Contamination by Toxic Military-Base Waste)
Rousk, Wade
Science Vol 269 No 5223 July 28 1995 p 473

A new decontamination technology will be tested in attempt to stop toxic wastes from Massachusetts Military Reservation from reaching four Cape Cod, MA, towns through groundwater. A steel wall in the ground will channel the water through iron-filing filters aimed at breaking down toxic molecules.

Enhanced Slurry Walls as Treatment Zones for Inorganic Contaminants
Evans, J.C.; Adams, T.L.; Dudiak, K.A.
Bucknell Univ., Lewisburg, PA
Proceedings: Hazardous and Industrial Wastes: The Twenty-Seventh Mid-Atlantic Industrial Waste Conference, Bethlehem, PA, 9-12 Jul 1995 pp 712-721
Publisher: Technomic Publishing Co., Inc. 1995
Report Number(s): CONF-9507204

At present, slurry walls are widely used as passive vertical barriers to control the horizontal flow of contaminated ground water. The most commonly employed slurry wall is known as a soil-bentonite cutoff wall and is composed of a backfill mixture of soil, bentonite, and water. To date, slurry walls have not been used as a medium to treat contaminated ground water which passes through the wall. This paper describes the modification of the present mix design through the addition of alternative clay minerals such as those which act as molecular sieves and have superior adsorption capabilities. In this way the enhanced slurry wall will serve to both impede the rate of ground water flow and remove contaminants from the ground water as it passes through the wall. Geochemical attenuation of lead was studied in an effort to investigate the use of enhanced soil-bentonite slurry walls as active treatment zones for heavy metal ions in solution in the ground water. Distribution coefficients were determined from adsorption isotherms for conventional sand-bentonite and enhanced sand-bentonite-chabazite backfills. These results were 23 ml/g and 144 ml/g, respectively. Using these laboratory data, theoretical breakthrough curves were generated to predict and compare breakthrough time between the conventional barrier and the enhanced barrier. Adsorption test and analytical modeling results demonstrate that adding chabazite to slurry wall backfill does enhance the conventional passive barrier performance.

Treat Groundwater in Place
Smyth, David; Cherry, John; Jowett, Robin
University of Waterloo, ON, Canada
Soil Groundwater Cleanup Dec 95 pp 36-44

Pump-and-treat remediation methodologies are commonly quite expensive and often fail to deliver the promised results. As a result, a number of innovative, alternative remediation methods are being developed to cope with contaminated sites. The design and development of a sealable joint steel sheet piling system developed by researchers at the University of Waterloo (ON, Canada) are detailed. As part of the treatment regime, contaminated groundwater is funneled through a series of gates for in-situ treatment. The funnel-and-gate system can be used for a wide range of remediation activities, including plume containment, partial aquifer restoration, and complete aquifer restoration. Case studies of several remediation scenarios are included.

1994:

Hydraulic Design Considerations for Permeable In Situ Ground Water Treatment Walls
Gallinatti, J.D.; Warner, S.D.
Geomatrix Consultants Inc., San Francisco, CA
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 p 851

Permeable subsurface walls have been proposed as a means for implementing various in situ ground water treatment technologies such as metal-enhanced reductive dehalogenation, enhanced biodegradation, and air sparging. In addition to the technical considerations associated with a specific treatment technology, hydraulic design considerations exist which should be addressed to assure that the success of the technology is not compromised by lack of hydraulic control. Specifically, the permeable treatment wall must be designed to generate a residence time of ground water passing through the treatment material (as dictated by the particular treatment technology employed and the site-specific chemical concentrations) that allows the treatment process to reduce the concentration of the dissolved target chemicals to clean-up goals. Nonuniform flow conditions may significantly affect the residence time of ground water within a treatment wall and reduce the effectiveness of the treatment technology. Therefore, the wall should be designed to minimize nonuniform flow conditions. Geomatrix has recently applied these considerations in designing a permeable in situ treatment wall for a site in northern California where regulatory approval for the treatment wall was granted as the final remedy for the site.

Removal of Chromium From Groundwater Using Permeable Barriers: An Aquifer Simulation Study
Schmidt, Mark D.; Shelton, Stephen P.
Univ of New Mexico, Albuquerque, NM
Proceedings of the 1994 National Conference on Environmental Engineering: Critical Issues in Water and Wastewater, Boulder, CO, July 11-13, 1994 pp 792-803
Publisher: ASCE, New York, NY 1994

Previous efforts to remediate groundwater contaminated by chromium-bearing industrial wastes have involved post-extraction methods, whereby groundwater is pumped to the surface treated and returned to the aquifer. This practice has proven effective for removing soluble pollutants. However, it is often costly and labor intensive and requires treating large volumes of water. Also, institutional obstacles such as ground and surface water discharge permits and groundwater rights must be considered. An alternative to conventional remediation methods is the in situ permeable barrier process, which intercepts soluble contaminants from solution but allows groundwater to flow through.

Trench-based barriers, backfilled with reactive media, result in the direct adsorption of chemical species or the oxidation or reduction of chemical species followed by precipitation. Laboratory studies were conducted to determine the technical feasibility of using trench-based media to remove chromium from groundwater. In batch tests various doses of candidate media and 10g of silica sand were added to glass vials containing a chromium solution. Candidate media included powder-activated carbon, ferric oxide and agricultural limestone. Adsorption isotherms were plotted from batch test results. In aquifer simulation tests a chromium-containing solution was passed through an aquifer simulation model containing silica sand and a vertical barrier of candidate media. Removal of soluble hexavalent chromium (Cr(VI)) to concentrations less than the maximum contaminant level (MCL) for total chromium in drinking water (0.05 mg/l) was demonstrated with all candidate media in the aquifer simulation model. Adsorption appeared to be the principle mechanism of removal for all candidate media considered. Information gained from experience with the physical model was used in developing a computer generated, 1-D solute transport model to predict the movement of hexavalent chromium in an aquifer system. (Author abstract) 16 Refs.

Funnel-and-Gate for In Situ Groundwater Plume Containment

Smyth, D.J.A.; Cherry, J.A., Univ. of Waterloo, Ontario, Canada, Waterloo Centre for Groundwater Research;
Jowett, R.J., Waterloo Groundwater Control Technologies Inc., Rockwood, Ontario, Canada

Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994
pp 312-318
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

At most CERCLA and RCRA sites and numerous other sites, plumes of groundwater contamination emanate from subsurface source zones, commonly DNAPL or LNAPL source zones, where considerable volumes of immiscible organic liquids persist below the water table. Pump-and-treat can provide an effective means of containing hydraulically the dissolved contaminants emanating from these sources; however, at many sites pump-and-treat will have to continue for many decades or longer because the source zones dissipate slowly. Projected long term costs of operation, maintenance, and water disposal or reinjection are therefore large. A new approach for source zone containment or plume control that is more passive than pump-and-treat and that offers considerable potential for long term cost savings has been developed at the University of Waterloo (UW) and is referred to as the fuel-and-gate system (patent pending). In this system low permeability vertical barriers are placed across plumes. Gaps in the barrier allow passage of the plume through the barrier. In the gaps, referred to as gates, a reactive medium is positioned or released so that the plume water is treated while passing through the gates. The reactive medium can be solid phase particles and/or liquid from a controlled release system. The goal is to cause the plume to meet water quality standards on the down gradient side of the funnel-and-gate system and to avoid pumping plume water to surface for treatment.

1992:

Permeable Reaction Wall for In Situ Degradation of Halogenated Organic Compounds
O'Hannesin, Stephanie F.; Gillham, Robert W.
Univ of Waterloo, Waterloo, Ont, Canada
Proceedings: 45th Canadian Geotechnical Conference, Toronto, Ont, Canada October 26-28 1992 pp 73/1-73/9

This paper describes a new remediation technology for removing aqueous-phase halogenated organic compounds from groundwater. A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the plume to passively move through the wall. The halogenated organic compounds are degraded by reactions with a mixture of porous media and a metal catalyst, emerging on the opposite side with the halogenated organic compounds removed. This passive method of remediation could be a cost effective alternative to conventional pump-and-treat systems and the halogenated organic compounds actually degrade rather than simply being transferred to a different medium. (Author abstract) 4 Refs.

1990:

Sheet Pile Barrier Walls as an Alternative to Slurry Walls for Temporary Containment Actions at Hazardous Waste Sites
Grachek, R W; Johnson, G
U.S. Army Corps of Engineers, Omaha District, Omaha, Nebraska
Proceedings: Superfund '90: 11th National Conference, November 26-28 1990 pp 484-488

A common technology for temporary waste containment and groundwater flow diversion at Superfund and other hazardous waste sites is the subsurface barrier wall. In most cases, the wall is constructed from a soil-bentonite-concentrate slurry. The walls are effective for most conditions, but sometimes are subject to construction, cost and compatibility problems. The use of an interlocking 'Z' section steel sheet pile barrier wall was found to be an effective approach to containment of contaminated soil and groundwater at the Southern Maryland Wood Treatment SMWT Superfund site. Factors that may influence selection of a sealed sheet pile barrier wall over a slurry wall include: structural integrity, chemical compatibility, constructability, property access constraints, cost and compatibility with the final remedy. Based upon experience at the SMWT Superfund site, the sheet pile barrier wall offers a constructible, cost-effective and technically sound option to the traditional slurry wall for temporary containment at hazardous waste sites.

SURFACTANT ENHANCEMENT

1994:

Solubilization and Microemulsification of Chlorinated Solvents Using Direct Food Additive (Edible) Surfactants
Shiau, Bor-Jier; Sabatini, David A.; Harwell, Jeffrey H.
Univ of Oklahoma, Norman, OK
Ground Water Vol 32 No 4 Jul-Aug 1994 pp 561-569

Surfactant enhanced subsurface remediation is being evaluated as an innovative technology to expedite contaminant extraction from the subsurface. Regulatory approval of this technology will likely

be enhanced by use of surfactants with FDA direct food additive status ('edible' surfactants). This research establishes edible surfactant systems capable of solubilizing (via micellar partitioning) and microemulsifying (via middle phase microemulsions) chlorinated solvents (PCE, TCE, and trans 1,2-DCE). Micellar partition coefficients with edible surfactants are observed to be comparable to values previously reported for other surfactants, with solubilization increasing aqueous concentrations by one to two orders of magnitude for the chlorinated organics. Middle phase microemulsion formation is dependent on surfactant structure and cosurfactant concentration. Solubility enhancement in the middle phase systems (microemulsification) is at least one to two orders of magnitude higher than solubilization for the same surfactant concentration, but is much more sensitive to the surfactant system and the contaminant. In addition, successful microemulsion formation is seen to be a function of ground-water temperature and hardness, indicating the need to consider these and additional factors for successful design and implementation of surfactant enhanced subsurface remediation. This research thus establishes a variety of edible surfactant systems that can significantly expedite subsurface remediation of chlorinated solvents, and illustrates the importance of proper selection and design of surfactant systems. (Author abstract) 42.

1992:

Evaluation of Innovative Approaches to Stimulate Degradation of Jet Fuels in Subsoils and Ground Water. Final report, Jun 88-Aug 89
Arthur, M.F.; O'Brien, G.K.; Marsh, S.S.; Zwick, T.C.
Battelle Columbus Labs., OH
June 1992 35 p

The objective of this study was to evaluate the feasibility of surfactant-enhanced biodegradation of JP-5 in soil from Patuxent Naval Air Test Center NATC under simulated conditions of soil venting. Surfactants and emulsifiers were screened for microbial toxicity and for their capacity to solubilize jet fuel from soil. Three surfactants were subsequently evaluated in 60-day flask aerobic biodegradation experiments. One surfactant was tested in soil columns under simulated soil venting conditions for 47 days. The results of the soil column study showed that the surfactant plus soil venting failed to enhance biodegradation of JP-5 compared to soil venting alone. Soil venting appears to overcome oxygen limitations in unsaturated soil and should be considered for enhanced biodegradation and soil bioremediation at NATC.

IN SITU VACUUM EXTRACTION

1996:

Assessing UST Corrective Action Technologies: Diagnostic Evaluation of In Situ SVE-Based System Performance (Rept. for Feb 94-Mar 96)
Johnson, R. L.; Dupont, R. R.; Graves, D. A.
Oregon Graduate Inst. of Science and Technology, Portland.
Sponsors: IT Corp., Knoxville, TN.; National Risk Management Research Lab., Cincinnati, OH.
Report No.: EPA/600/R-96/041; NTIS Number: PB96-163597 Apr 96 164p

The objective of the report summarized here is to present the data, methods, and tools required for evaluating the performance of in situ systems for cleaning up leaking underground storage tanks sites. The five test procedures presented herein can be used as diagnostic tools to evaluate in situ remediation

performance. Three of the procedures are tracer tests that can be used to evaluate air flow in the subsurface (SVE air flow, IAS air recovery, and IAS air distribution). The tracer tests are new procedures that have been tested at a small number of sites and can be expected to undergo revision to improve their diagnostic capabilities. The other two procedures are designed to evaluate biodegradation in the subsurface (bioventing and natural attenuation).

1995:

Demonstration Shows UVB Effective on VOC Contaminated Ground Water
Environmental Remediation Technology Sep 6, 1995 p N/A

An 18-month demonstration of a vacuum vaporizing well found the system effectively can tackle volatile organic compound (VOC)-contaminated aquifers with a mix of chemical, physical and biological processes. A demonstration project conducted by Roy F. Weston Inc. at March Air Force Base showed the Unterdruck-Verdampfer Brunnen (UVB) system, developed and patented by Reutlingen, Germany-based IEG mbH, resulted in removal of more than 95 percent of trichloroethene during normal operating conditions. The West Chester, Pa.-based company conducted the demonstration program at the Riverside, Calif., base in conjunction with IEG and under a subcontract to Black & Veatch Waste Science Inc. While the system must be tailored to site-specific conditions for each project, potential benefits include minimal permitting, no surface water discharge, no water quality treatment, below-ground installation and minimal operating requirements, said Weston's Jeff Bannon. "They add up in most cases to a cost-benefit," he said, adding actual savings vary from site to site. The in-situ system links a ground water treatment well, a negative pressure stripping reactor, an above-ground vacuum extraction blower and, if necessary, an off-gas treatment system. The technology is designed to extract soil gas during ground water treatment, according to EPA's Superfund Innovative Technology Evaluation report of the demonstration. The system was demonstrated for March AFB, EPA's Office of Research and Development and the U.S. Army Corps of Engineers, Omaha District. The treatment well consists of two screened zones. One section is located at the bottom of the treatment interval, straddling the ground water interface, according to a paper presented by Bannon and three co-authors at a recent Air & Waste Management Association conference. A centrifugal blower keeps the upper, closed section below atmospheric pressure, according to the paper by Bannon, Weston's Mark Dominick and John Sontag, and March AFB's John Sabol. A fresh air pipe draws in air for in-situ stripping. "Soil air is also drawn into the treatment well from the vadose zone through the upper well screen," the paper says. "The negative pressure within the upper part of the well also causes a water level rise within the treatment well." A packer installed in the treatment well between the two screened zones ensures directional flow of ground water through the well, the researchers note in the paper.

Remediating TCE-Contaminated Soils: A Case Study of a Focused RI/FS and Vacuum Extraction Treatability Study
Westervelt, W.W.; Hundt, T.R. Gannett Fleming, Inc., Baltimore, MD; Marley, M.C. Vapex Environmental Technologies, Inc., Canton, MA
Proceedings: 5th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, Las Vegas, NV, 13-16 May 1991 pp 431-451
Publisher: Dublin, OH Ground Water Management 1992

A focused remedial investigation/feasibility study RI/FS was conducted for EPA Region III to determine the extent of trichloroethene TCE contamination in soils at a former sanitary landfill site and to evaluate alternatives for soil remediation. The investigation revealed high concentrations of TCE up

to 330,000 [mu]g/kg trapped in a 50-foot-deep vadose zone, and high concentrations of TCE and acetone up to 840,000 [mu]g/kg in the saturated soils above bedrock. The overburden soils in the vicinity of the spill areas are between 40 to more than 100 feet deep and were classified as predominately silt. Due to the depth of contamination and potential problems of controlling volatile organic compound VOC emissions, a combination of capping and in-situ vacuum extraction was considered to be the most promising alternative for this site. To evaluate the effectiveness, implementability, and cost of vacuum extraction, a pilot-scale treatability study was performed at the site. Physical and chemical data were collected over a two-week period that allowed for a determination of the radius of influence of vacuum pressure in various soil units, an evaluation of the effects of key operating parameters and system designs on performance, and an estimation of the time required to remediate the contaminated soils. Subsurface air flow and contaminant removal models were calibrated to the pilot-scale data and used to predict the performance of various full-scale system configurations that included nested vacuum extraction wells, surface capping, and air injection wells. Preliminary costs and designs for full-scale remediation systems were developed.

1993:

Advances in the Vacuum Extraction Technology for Effective Subsurface Remediation
Pezzullo, J.A.; Trowbridge, B.E.; Bosshard, B.
Terra Vac, West Trenton, NJ
Proceedings: Ninth Annual Environmental Management and Technology Conference, West: HazMat West '93, Long Beach, CA, 16-18 Nov 1993 pp 61-73 Publisher: Glen Ellyn, IL Advanstar Expositions 1993
Report Number(s): CONF-9311169

The vacuum extraction technology has become one of the most widely acclaimed methods for remediating soils contaminated by petroleum hydrocarbons and volatile organic compounds (VOCs). The removal of the source of contamination in the soil is often the first step in the effective control of groundwater contamination. Though originally thought to be effective only for vadose zone contamination by light end hydrocarbons in higher permeable soils, vacuum extraction can now be adapted to address situations of high water table, low permeability soils and heavier end compounds. This paper reviews these innovative modifications to the vacuum extraction process and how they solve a wide variety of subsurface contamination problems.

EX SITU TECHNOLOGIES

AIR STRIPPING

1996:

Ceramic Gas Diffusers for VOC Stripping at Groundwater Remediation Sites Now Offered by Diffused Gas Technologies, Inc.
News Release March 6, 1996 p. N/A

Diffused Gas Technologies, Inc. a Cincinnati, Ohio manufacturer of gas diffusers has recently made available a new line of ceramic gas diffusers for use in air stripping of volatile organic compounds (VOC). These diffusers have been used successfully in the aeration of wastewater and water treatment applications for many years and have been modified to meet the special needs required at ground water

remediation sites. The relatively small bubble produced by these diffusers provides an extremely high ratio of gas/liquid interface per CFM of gas supplied. This ratio coupled with an increase in contact time due to the slower rise rate of the fine bubble accounts for the high transfer efficiency of these devices which converts to high removal rates of volatile organic compounds. This higher efficiency means more gas interface per energy dollar expended. As with any diffuser, the efficiency of the device is directly related to tank depth and gas flow per diffuser. The ceramic diffusers are offered in two configurations. The Model FBP/FBS series diffusers are constructed of corrosion resistant materials and designed for years of trouble free operation. The FBP diffuser features an ABS plastic base, while the FBS diffuser features a heavy duty, #316 stainless steel base. These ceramic diffusers utilize a dome shaped ceramic diffusion device constructed of a porous aluminum oxide material. This duty efficient material provides uniform permeability for bubble formation as well as strength and resistance to wear for a long service life. The FBT Series is a tubular diffuser which comes with a standard tube length of 2', but is available in shorter lengths also. Both diffusers utilize a 3/4" NPT fitting to connect the piping manifold and have optional gasket materials to meet the chemical resistance and thermal needs of the customers application. For additional information contact Steve Deiters, Diffused Gas Technologies, Inc. tel: 513-5314426

1994:

Air Stripper VOC Treatment Using Specialized Adsorbents
Craven, C.N.; Blystone, P.G.; Grant, A.
Purus, Inc., San Jose, CA
Proceedings: Volume 2: Federal Environmental Restoration III and Waste Minimization II Conference and Exhibition, New Orleans, LA, 25-29 Apr 1994 pp 1198-1205
Publisher: Rockville, MD Hazardous Materials Control Resources Institute
Report Number(s): CONF-940499

Abatement of volatile organic compound (VOC) emissions is required by federal, state and local regulatory agencies. Sources of VOC emissions include air stripping processes at groundwater remediation and industrial wastewater operations. The Purus A2000 system is an innovative emission control system that utilizes specialized adsorbent resins, on-site regeneration and solvent recovery for abatement of VOCs. This paper describes two applications in which air stripper off-gas is treated by the Purus A2000 Adsorption System. The first is a groundwater remediation pump-and-treat operation in which the air stripper off-gas contains chlorinated solvents. At the second site, benzene and styrene emissions from an industrial wastewater air stripper operation were successfully treated. At both sites the recovered solvent was recycled. Capital and operating costs will be compared to other treatment methods.

Crossflow Air Stripping With Catalytic Oxidation. Final Report, 1 October 1990-30 September 1994
Kim, B.C.; Gavaskar, A.R.; Ong, S.K., et al
Battelle Columbus Labs., OH
Report Number(s): AD-A-294410/6 1994

A novel air stripping technique was tested on a pilot scale at Dover Air Force Base. Groundwater contaminated with 1,2-dichloroethane was subjected to air stripping in two towers: the novel crossflow tower and the conventional countercurrent tower. The crossflow tower was found to require higher airflow rates but much lower pressure drops to effect the same removal efficiency. The airstream from

the towers was directed into bench-scale and pilot-scale commercial catalytic units. An innovative photocatalytic unit also was tested. Five of the six catalysts tested performed well. Air stripping in conjunction with catalytic oxidation was found to be a good technique for remediation of groundwater containing low levels of organics. However the crossflow air stripper did not offer any cost advantages over conventional counterflow air stripping.

Removal of Volatile Substances From Water
Vasak, Frantisek; Broz, Zdenek
Inst of Chemical Process Fundamentals AS CR, Prague, Czech
Proceedings: Symposium on Hazardous Waste Treatment, Prague, Czech Repub, August 29-Sept 03 1993
Journal of Hazardous Materials Vol 37 No 1 Apr 1994 pp 153-164

In this paper the rotating disk stripper (RDS) for removal of volatile contaminants from water has been modeled mathematically. For experimental verification two model systems have been used, namely desorption of CO2 from water and desorption of radon from ground water. As a result of the performed study the new apparatus suitable for volatile organic contaminants (VOC) removal has been designed. (Author abstract) 3 Refs.

1993:

A Comparison of Steam Stripping and Air Stripping for the Removal of Volatile Organic Compounds from Water
Punt, M.; Whittaker, H
Collection of papers related to treatment of contaminated soil and water
Environment Canada, Ottawa, ON, Canada, River Road Environmental Technology Centre, Jan 1993 pp 1-16
Report Number(s): EE-145 MICROLOG--93-07135

Air stripping has been used for many years to remove volatile organic compounds (VOCs) from water, but concerns have been raised over the potential problem with air pollution when using this method. Environment Canada's Emergencies Engineering Division examined alternative methods for VOC removal from water and conducted a test comparing air stripping with steam stripping for removal of VOCs at a contaminated site. The theory of air stripping and steam stripping are explained, and the mobile equipment used in the tests is described. Results of the tests are presented and discussed. Both stripping methods are effective in removing VOCs from water. Air stripping is considerably less expensive, but the addition of off-gas treatment to resolve air pollution concerns increases the cost of air stripping substantially to the point where steam stripping is competitive. However, advancement in new destruction methods for off-gas treatment may increase the favorability of air stripping for VOC removal. When comparing operating and capital costs, it must be kept in mind that steam stripping is a more flexible technology since it is capable of removing a much wider range of compounds than air stripping. 13 refs., 4 figs., 5 tabs.

1992:

Combined Air Stripper/Membrane Vapor Separation System For The Removal of Volatile Organic Compounds From Contaminated Water
Wijmans, J.G.; Kamaruddin, H.D.; Kaschemekat, J.; Baker, R.W.,
Membrane Technology and Research, Inc., Menlo Park, CA;
Tedder, D.W., School of Chemical Engineering, Georgia Institute of Technology, Atlanta, GA
Proceedings: American Chemical Society ACS Special Symposium on Emerging Technologies in Hazardous Waste Management, Atlanta, GA, 21-23 Sept 1992 pp 103-105
Published: 1992

Groundwater and soil contamination are problems at many government and private industrial sites throughout the United States. The two most common organic contaminants are trichloroethylene TCE and carbon tetrachloride. Perchloroethylene and other chlorinated hydrocarbons, solvents, and fuel hydrocarbons have also been identified in groundwater and soil samples. This paper reports on air stripping which is the least expensive method of removing these volatile organic compounds VOCs from polluted groundwater. With the support of the Office of Environmental Restoration and Waste Management of the Department of Energy, MTR has developed a combined air stripper/membrane vapor separation system in which the membrane system removes the VOCs from the air stripper vent stream and recirculates the air to the stripper. The combined system is smaller than a carbon adsorption system, and has none of the problems associated with spent carbon regeneration. The economic benefits of the new system are compelling.

Removal of Volatile Organic Compounds From Groundwater Using a Rotary Air Stripper
Singh, Surinder P.; Wilson, James H.; Counce, Robert M.; Villiers-Fisher, John F. et al
Oak Ridge Natl Lab, Oak Ridge, TN
Industrial & Engineering Chemistry Research Vol 31 No 2 Feb 1992 pp 574-580

The performance of a centrifugal vapor-liquid contactor was evaluated for air stripping of jet fuel components from groundwater. Hydraulic test data indicated that the Sherwood flooding correlation, which has been proposed for use in designing centrifugal vapor-liquid contactors, overestimates the rotational speeds at which flooding occurs. A concept of the area of a transfer unit ATU was introduced in the mass-transfer tests to account for the change in fluid loading with the radius of the packing torus. A new correlation based on the specific surface area of the packing for predicting ATU described the experimental data with a fair degree of accuracy. The power consumed in rotating the packing torus was found to depend mainly on the liquid flow, outer rotor radius, and rotational speed. Previous claims in the literature that the centrifugal vapor-liquid contactor is resistant to fouling because of high shear forces were not found to be valid for groundwater with high iron content. Author abstract 14 Refs.

1990:

Air/Superfund National Technical Guidance Study Series: Comparisons of Air-Stripper Simulations and Field-Performance Data. Final Report
Saunders, G.L.
PEI Associates, Inc., Cincinnati, OH
Feb 1990 112p

One of the more common problems noted at Superfund sites is the contamination of ground water by volatile organic compounds VOCs. One remedial alternative that is used to reduce or remove the

VOC contamination from water is air stripping in a tower that uses either packing media or trays. The ability to strip a compound from the water depends on several factors, including the air/water ratio, the packing or tray type, and the Henry's Law value for the compounds of interest. The objective is to remove the VOCs from the water. When being considered for remediation purposes, the air stripper design should be evaluated for removal efficiency and cost of operation. The purpose of the project was to collect available design and operating data on operating air strippers and to input the design and operating parameters into the ASPEN simulator through a user interface program. The results from the ASPEN simulator were compared to the operating data gathered for the sites to determine the relative accuracy of the ASPEN model results when compared with the actual performance data.

Novel Closed-Loop Air-Stripping Process for VOC Removal from Contaminated Water
Bhowmick, M.; Sontag, T.K.; Semmens, M.J.
Dept. of Civil and Mineral Engineering, Minnesota Univ., Minneapolis, MN
5 Dec 1990 133p

The study presents an approach for the treatment of contaminated groundwater, which includes Volatile Organic Compounds VOCs stripped from the water using hollow fiber membranes or using conventional air stripping technology and then the VOCs are oxidized in the gas phase using UV oxidation or a combination of photooxidation and photo-catalysis with Titanium Dioxide TiO2. The work on the photooxidation of VOCs is applicable to both water and soil treatment techniques, such as air stripping and in-situ vacuum extraction. The study is divided into five major segments: Each segment includes relevant sections on the experimental methods employed, the results from the tests conducted, the development of models, and the conclusions which were drawn from the work.

Cascade Air-Stripping - A New Technology for Cost Effective Removal of Semi and Low Volatile Organics From Groundwater
Nirmalakhandan, N., New Mexico State Univ., Las Cruces, NM;
Jang, W., Seoul National Univ. Korea
Speece, R.E. Vanderbilt Univ., Nashville, TN
Proceedings: Fourth National Outdoor Action Conference on Aquifer Restoration, Groundwater Monitoring, and Geophysical Methods, Las Vegas, NV, 14-17 May 1990 pp 515-524

A novel modification of the conventional counter-current air-stripping process, introduced as cascade air-stripping is proposed for cost-effective removal of semi-and low volatile organic contaminants from water. A pilot scale demonstration study was undertaken to demonstrate the concept of cascade air-stripping under a grant from the AWWA RF. The pilot scale study served to validate the process model, and to compare the performance of the cascade system against that of the conventional system under equal energy inputs. The advantages of the proposed process over the conventional process are in accommodating 35 to 50% more air flow and in achieving comparable removals at 40 to 50% of the packing depth and considerably lower effluent concentrations under equal energy.

FILTRATION/ADSORPTION

1996:

Removing Chromium from Groundwater and Process Wastewater
Frank, Wayne L.; McMullen, Michael D.
Geraghty & Miller, Denver, CO
Natl Environ J Vol 6 No 2 Mar-Apr 1996 pp 36-40
(Full text available from Congressional Information Service at 1-800-227-2477.)

A new technology is being used to remove chromium from groundwater and wastewater. Granular activated carbon (GAC) filtration at prescribed pH levels is being utilized to adsorb chromium in its trivalent and hexavalent states. Experiments were conducted to determine whether inorganic compounds might interfere with chromium removal by carbon. Spent GAC may be regenerable, depending on the final concentration of chromium in the carbon. Chromium adsorption as a function of contact time and pH is examined. Scale-up from an experimental facility to a full-scale system is discussed.

1995:

Colloid-Enhanced Ultrafiltration in Remediating Wastewater and Groundwater
Sherril D. Christian; Edwin E. Tucker; John F. Scammer
Speciality Chemicals May 1995 p 148

A water-soluble colloid added to contaminated water during filtration caused target impurities to become concentrated in the retentate stream, thus providing high purity permeate. Ultrafiltration (UF) is a useful separation process for removing and recovering solute species having molecular weights of 1,000 daltons or more. Because large fluxes can be obtained at relatively low pressures, UF is particularly attractive as a low-energy industrial method for separating relatively large molecules from water. Unfortunately, traditional UF is not effective in removing solutes having molecular weights less than about 500 daltons. During several research projects beginning about 1982, we developed a new class of UF techniques called colloid-enhanced ultrafiltration methods 1-27. All of these processes require adding a soluble colloid to an aqueous feed stream, followed by ultrafiltration to produce a stream having much-reduced concentrations of the target molecules or ions. In the so-called direct methods (including micellar enhanced ultrafiltration (MEUF) and polyelectrolyte enhanced ultrafiltration (PEUF)), the added colloid binds or solubilises target solutes or impurities present in the feed, so that the subsequent ultrafiltration step produces a permeate stream passing through the membrane nearly free from solutes and the added colloid behind the UF membrane. Table 1 shows comparison of permeate concentrations of organic and metal pollutants in MEUF.

Removal of Explosives Using Standard and Innovative Adsorption Technologies
Fleming, B.C., Eastern Waterways Experiment Station, Vicksburg, MS;
Christiansen, K., US Army Omaha District, NB;
Cerar, R., US Environmental Center, Edgewood Arsenal, MD
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management
Atlanta, GA 17-20 Sep 1995 pp 602-605
Publisher: Washington, DC: American Chemical Society 1995
Report Number(s): CONF-9509139

The main objective of this study was to determine the most effective adsorption process for removal of explosive compounds from ground water at the Cornhusker Army Ammunition Plant. Preliminary evaluations of carbon, carbonaceous resin, polymer, and organophilic clay adsorbents were made; three carbons (Calgon F-400, American Norit ROW 0.8, and Westates CC-601) were selected for further evaluation in isotherm studies. Four adsorbent dosages were evaluated for the isotherm studies. Contaminants tested were cyclotrimethylenetrinitramine (RDX), trinitrobenzene (TNB), trinitrotoluene (TNT), and cyclotetramethylenetrinitramine (HMX). Westates CC-601 was the most effective adsorbent for removal of RDX, TNB, and HMX. American Norit ROW 0.8 was the most effective for removal of TNT.

Biofiltration - An Innovative Approach to Vapor Phase Treatment at the Silvex Hazardous Waste Site in Florida

Hartsfield, B.
Florida Dept. of Environmental Protection, Tallahassee, FL
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 p 1066
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

Biofiltration is an emerging technology that is being used for vapor phase treatment at the Silvex hazardous waste site. Biofiltration works by directing the off-gas from the groundwater treatment system through a bed of soil, compost or other medium that supports the growth of bacteria. Contaminants are absorbed into the water present in the medium, and are subsequently degraded by the microorganisms. The biofiltration system at the Silvex hazardous waste site has been effective in removing contaminants from the off-gas. The biofiltration system has also been effective in minimizing the odor problem resulting from mercaptans in the off-gas. Biofiltration has been used for many years at wastewater and industrial plants to control odor and remove organic contaminants. This technology has only recently been used for hazardous waste site cleanups. The hazardous waste literature is now listing biofiltration as a vapor phase treatment technology, along with carbon, thermal oxidation and others.

Biofiltration of the Silvex Hazardous Waste Site

Hartsfield, B.D., Florida Dept. of Environmental Protection, Tallahassee, FL;
Marsenison, P.R.; Latona, J.D., Ecology and Environment, Inc., Tallahassee, FL
Proceedings: Innovative Technologies For Site Remediation and Hazardous Waste Management: The National Conference, Pittsburgh, PA 23-26 Jul 1995 pp 497-503
Publisher: New York, NY: American Society of Civil Engineers 1995
Report Number(s): CONF-9507173

Biofiltration is an innovative technology that is being used for vapor phase treatment at the Silvex hazardous waste site located in northeastern Florida. A silver smelting recovery facility once operated at the site. Various waste liquids were used as fuel for the furnace. A major spill in 1981 contaminated soil and groundwater. The Surficial Aquifer System beneath the site is highly contaminated with acetone, methyl ethyl ketone, methyl isobutyl ketone, and phenols (all at concentrations ranging from 1 to 50 parts per million). Contaminated groundwater is discharging into Ward's Creek west of the site. In October 1993, the State of Florida implemented a pump-and-treat system to recover contaminated groundwater and minimize discharge into Ward's Creek. Groundwater is recovered from four wells at a total flow rate of 15 gallons per minute. The effluent is discharged to infiltration galleries. The

groundwater treatment system includes an equalization tank, a fixed film aerobic bioreactor, a clarifier, and carbon polishing vessels. The system also includes vapor-phase treatment for the bioreactor off-gas.

Using Specialized Adsorbents for Remediation
Hochmuth, D.P., Harding Lawson Associates, Novato, CA;
Grant, A., Purus Inc., San Jose, CA
Proceedings: Innovative Technologies For Site Remediation and Hazardous Waste Management: The National Conference, Pittsburgh, PA 23-26 Jul 1995 pp 441-448
Publisher: New York, NY: American Society of Civil Engineers 1995
Report Number(s): CONF-9507173

This paper describes two remediation case studies in which specialized adsorbents were used. In one case, the adsorbents were used to treat effluent from a soil vapor extraction system. In the other case, the adsorbents were used to treat air from a groundwater air stripper. The specialized adsorbents effectively removed volatile organic compounds from each air stream.

Application of Ambersorb 563 Adsorbent Technology for Treatment of Chlorinated Organics in Groundwater
Frye, R.W.; Martino, J.F.; Turner, R.E.
Roy F. Weston, Inc., West Chester, PA
Proceedings: 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium, Cincinnati, OH 4-6 Apr 1995 pp 108-112
Publisher: Environmental Protection Agency 1995
Report Number(s): CONF-9504110

Roy F. Weston, Inc., in conjunction with Rohm and Haas Company, conducted a field pilot study to demonstrate the technical feasibility and cost-effectiveness of Ambersorb 563 (A-563) carbonaceous adsorbent for the remediation of groundwater contaminated with volatile organic compounds (VOCs). The project was conducted under the Emerging Technology Program of the EPA Superfund innovative Technology Evaluation (SITE) program. Ambersorb adsorbents are a family of patented, synthetic, tailorable carbonaceous adsorbents that were developed by Rohm and Haas in the 1970's for the treatment of contaminated water. In specific applications, Ambersorb adsorbent technology may offer a cost-effective alternative to air stripping or granular activated carbon (GAC), which are typically used in pump and treat systems for remediating groundwater contaminated with organic compounds. Ambersorb adsorbents have been found to be effective in the removal of low levels of VOCs and other synthetic organic compounds from contaminated water. Previous applications using Ambersorb adsorbents have demonstrated several key performance benefits over GAC. Ambersorb 563 adsorbent can be regenerated onsite using steam, solvents, or other techniques, permitting the recovery of a concentrated organic stream which can be disposed of or reclaimed. Ambersorb 563 adsorbent has a significantly greater adsorption capacity than GAC for chlorinated hydrocarbons when the contaminants are present at low concentrations. Ambersorb 563 adsorbent systems can operate at higher flow rates than GAC systems, white maintaining effluent water quality below drinking water standards.

Use of Activated Carbon for the Treatment of Explosives-Contaminated Groundwater at the Picatinny Arsenal (Final Rept)
Bricka, R. M. ; Fleming, E. C.
Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab.

Report No.: WES/TR/EL-95-31; NTIS Number: AD-A304 160/5/ Nov 95 158p

Past military operations have resulted in the contamination of soils by munitions such as Research Department Explosive (RDX), High Melting Explosive (HMX), and TNT. This report details the removal of low levels of RDX and HMX from drinking water sources located at Picatinny Arsenal near Dover, NJ. This report details the use of carbon as a treatment alternative. This study was initiated to investigate the removal of RDX and HMX using carbon adsorption technologies. Five carbons were evaluated using batch isotherm tests. (MM).

Development of Humasorb™, a Lignite Derived Humic Acid for Removal of Metals and Organic Contaminants from Groundwater

Sanjay, H. G.; Ivastava, K. C.; Walia, D. S.

ARCTECH, Inc., Chantilly, VA

Proceedings: Environmental Technology Development Through Industry Partnership, Morgantown, WV 3-5 Oct 1995

Report No.: DOE/MC/32114-96/CO625; NTIS Number: DE96003741 1995 14p

Heavy metal and organic contamination of surface and groundwater systems is a major environmental concern. The contamination is primarily due to improperly disposed industrial wastes. Decontamination of surface and groundwater can be achieved using a broad spectrum of treatment options such as precipitation, ion-exchange, microbial digestion, membrane separation, activated carbon adsorption, etc. The groundwater contamination at different Department of Energy (DOE) sites (e.g., Hanford) is due to the presence of both VOCs and heavy metals. A two-step approach increases the cost of remediation. To overcome the sequential treatment of contaminated streams to remove both organics and metals, a novel material having properties to remove both classes of contaminants in one step is being developed as part of this project.

Emerging Technology Report: Demonstration of Ambersorb (Trade Name) 563 Adsorbent Technology (Research rept. 1 Oct 94-28 Feb 95)

Weston (Roy F.), Inc., West Chester, PA

Report No.: EPA/540/R-95/516; NTIS Number: PB95-264164 Aug 95 116p

The Ambersorb (Rohm and Haas) Adsorbent Technology Demonstration was conducted over a 12-week period during the spring/summer of 1994 at Site 32/26 of the former Pease Air Force Base, Newington, N.H. The ground water in this area is contaminated with a number of chlorinated organics, including vinyl chloride, 1,1-dichloroethene, cis-1,2-dichloroethene, trans-1,2,-dichloroethene, and trichloroethene. The demonstration showed that Ambersorb Adsorbent is effective for this ground water. The effluent consistently met drinking water standards.

1994:

Groundwater Heavy Metals Removal With the Gore Backpulse/Dupont Oberlin (SITE) Technology

Mayer, E.
E.I. du Pont de Nemours, Inc., Newark, DE

Proceedings: Volume 2: Superfund 14: Conference and Exhibition, Washington, DC, 30 Nov - 2 Dec 1993 pp 1162-1170
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-9311122

The novel DuPont/Oberlin Microfiltration Technology has recently been demonstrated in EPA's Superfund Innovative Technology Evaluation (SITE) program. Its key features are fine microfiltration at low cost using DuPont's new Tyvek* T-980 spunbonded olefin filter media coupled with Oberlin's reliable automatic pressure filter (APF). This new microfiltration technology is best suited for contaminated heavy metal wastewaters and groundwaters. The SITE demonstration actually removed Zn, Cu, Se, Cd and Pb from contaminated groundwater from the Palmerton, PA Superfund site. However, this new microfiltration technology is limited to low flows, generally less than about 150 gpm. As a consequence, Gore backpulse filters have been used to concentrate the flow by 25-50X prior to DuPont/Oberlin microfiltration. The Gore backpulse filter assures the ppb metals removal and is much simpler than the conventional Lamella/sand filter combination traditionally used. This paper will describe these two new technologies in detail and will present some typical application results.

A Novel Passive Sorptive Method for Site Screening of VOCs and SVOCs in Soil and Groundwater

Stutman, M.
W.L. Gore and Associates, Inc., Elkton, MD, Environmental Products Group

Proceedings: Volume 2 Superfund 14: Conference and Exhibition, Washington, DC, 30 Nov - 2 Dec 1993 pp 1111-1120
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-9311122

A preliminary site screening is an established means of lowering the overall cost and time required before remediation can commence. Currently available soil-gas methods work best for simple volatile compounds in dry soils. This paper describes field results from a new site screening service, under development for several years. This service features patented, passive sorbent collection devices, constructed from GORE-TEX microporous polytetrafluoroethylene (similar to Teflon. These devices are inserted directly into the soil or ground water. All Gore-Sorber™ Screening Modules contain replicates of specially selected adsorbent materials i.e. Tenax-TA. No elaborate field tools are required for installation or retrieval. Installation rates, including selection of sample locations, can exceed five per hour. After retrieval, sorbers are thermally extracted, then analyzed via GC/MS, and the results mapped. Case studies from gasoline stations, chemical and asphalt plants are described, and comparisons are made to available soil, ground water and soil-gas data. These devices have been demonstrated effective in detecting both volatile and semivolatile compounds in difficult applications such as clay and saturated soils.

1991:

SITE Demonstration of Microfiltration Technology for Groundwater Contaminated With Metals
Martin, J.F., Environmental Protection Agency, Cincinnati, OH;
Topudurti, K.; Labunski, S., PRC Environmental Management, Inc., Chicago, IL
Proceedings: 17th Annual Hazardous Waste Research Symposium, Cincinnati, OH, 9-11 Apr 1991 pp 1-4

The Superfund Innovative Technology Evaluation SITE Program has as its major thrust the documentation of reliable performance and cost information for innovative alternative technologies so that they are developed, demonstrated, and made commercially available for the permanent cleanup of Superfund sites. Demonstration projects identify limitations of the technology, applicable wastes and waste media, potential operating problems, and the approximate cost of applying the technology. A demonstration project was conducted with E.I. DuPont de Nemours and Company, Inc. and the Oberlin Filter Company to evaluate a microfiltration technology for removal of suspended solids from wastewater. The microfiltration system utilized DuPont's Tyvek T-980 membrane filter media in conjunction with the Oberlin automatic pressure filter. The project was undertaken at the Palmerton Zinc Superfund site in April 1990 to evaluate the ability of the technology to remove zinc from the site's shallow groundwater. Pretreatment of the groundwater to precipitate dissolved zinc and other metals was included as part of the demonstration program. The treated filtrate indicated that the system removed precipitated zinc and other suspended solids at greater than 99.9%, and the filter cake produced during the study passed both the EP Toxicity test and the TCLP.

Immobilized Biomass for Remediation of Metal-Contaminated Water
Darnall, D.W., New Mexico State Univ.;
Las Cruces Bio-Recovery Systems, Inc., Las Cruces, NM
Proceedings: 201st American Chemical Society ACS National Meeting, Atlanta, GA, 14-19 Apr 1991 p 5, Paper ENVR 14 52 p

A biosorption process has been developed for removing heavy metal ions from aqueous solutions. The process is based upon the natural, very high affinity of the cell walls of plants and microorganisms for heavy metal ions. Non-living bio-mass materials, primarily algae, have been immobilized in a polymeric matrix to produce a biological ion exchange resin. The material, which has a very high affinity for metal ions, can be packed into columns through which waters containing heavy metal ions are flushed. Metal ions are adsorbed by the biomass, and once saturated with metal ions, metal ions can be stripped from the material in a highly concentrated form. The efficacy of biosorption process has been tested for remediation of mercury-contaminated groundwaters in conjunction with the US Environmental Protection Agency's Superfund Innovative Technology Evaluation SITE program. Specific applications will be discussed.

1990:

Field Evaluation of a Microfiltration Technology to Treat Groundwater Contaminated with Metals
Topudurti, K; Labunski, S; Martin, J
Proceedings: Superfund '90: 11th National Conference, November 26-28 1990 pp 425-432

Field evaluations were conducted of a newly developed microfiltration technology in April and May 1990 at the Palmerton Zinc Superfund PZS site in Palmerton, Pennsylvania, under the US EPA's

Superfund Innovative Technology Evaluation program. The microfiltration system uses an automatic pressure filter and Tyvek T-980 membrane filter media to remove solids > 0.1 micron in diameter from liquid wastes. At the PZS site, the microfiltration technology was evaluated for treating groundwater contaminated with metals primarily zinc. Under optimum operating conditions for the microfiltration system, the zinc and total suspended solids TSS removal efficiencies were approximately 99.95% the filter cake was approximately 41% solids by weight. At the 95% confidence level, the filtrate met the applicable metals and TSS limits for discharge into a local waterway. However, the filtrate did not meet the pH discharge standard. The filter cake passed: 1 the paint filter liquids tests 2 the extraction procedure toxicity test and 3 the toxicity characteristics leaching procedure test. See also W93-01098 Author's abstract

Design Modifications to Improve Granular Activated Carbon Treatment System Performance
Ball, B R; Synder, M G; Michael, J I
B and V Waste Science and Technology Corp., Tacoma, Washington
Proceedings: Superfund '90: 11th National Conference, November 26-28 1990 pp 686-691

The treatment system was implemented to assist with remedial cleanup activities at the South Tacoma Channel Groundwater Treatment System, an NPL site in Tacoma, Washington. The existing treatment system utilizes liquid-phase, granular activated carbon GAC treating 150 gpm of groundwater to remove volatile chlorinated hydrocarbons. Current GAC performance for contaminant breakthrough and competitive adsorption was accurately simulated with a plug-flow pore and surface diffusion model for multicomponent fixed-bed mixtures. The model was also used to estimate GAC performance at higher influent loading rates, which would occur if a new proposed groundwater extraction well were added to the system in the future. The recommended design improvements included the addition of an air stripping process at the end of the GAC system to remove vinyl chloride. The air stripping tower was designed to remove only vinyl chloride, which is weakly adsorbed and quickly displaced from the GAC by other competing organics, resulting in high overall carbon usage rates. An analysis of air stripping design was performed with a computer model based on a two-resistance approach using Onda correlations. The modified treatment system configuration of GAC combined with air stripping, as simulated by computer models, was shown to be capable of surpassing performance requirements for air and water discharge. An economic evaluation showed that the modification could pay for themselves in approximately two years based on savings associated with carbon replacement if more stringent vinyl chloride discharge standards were adopted in the future. See also W93-01098 Author's abstract

ION EXCHANGE

1994:

In Situ Treatment of Chromium VI With an Iron Reduction Process
Brown, R.A., Groundwater Technology, Inc., Trenton, NJ;
Crosbie, J., Red Hawk Environmental, Chadds Ford, PA;
O'Neil, S., Pennsylvania Department of Environmental Resources, Norristown, PA
Proceedings: Volume 1: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 266-274
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

Chromium VI is a fairly soluble compound and a known human carcinogen. Consequently, groundwater contamination with Chromium VI often represents a sensitive environmental issue. Removal of Chromium VI from groundwater has most often required long term and expensive pump and treat systems. Chromium III, on the other hand, is an essential nutrient and is, in most forms, highly insoluble. The conversion of Chromium VI, the soluble carcinogenic form, to the non-hazardous, insoluble Chromium III is the basis of many of the commercial water treatment processes such as the Andco process or the Unocal, Unipure process. Both processes are based on the reaction of Chromium VI with ferrous iron (Fe+2) to give Chromium III and Iron III, both of which are highly insoluble. This same technology -- iron reduction and precipitation of Chromium VI -- was successfully applied in situ to treat a perched aquifer contaminated with Chromium VI at a former industrial facility. The site was located on the Delaware River in an ecologically sensitive area. Groundwater concentrations of approximately 85 ppm Chromium VI were successfully reduced to below 50 ppb across most of the site and discharge of Chromium VI into the Delaware River was stopped by the injection of a ferrous sulfate solution. This paper will discuss the selection, laboratory testing, regulatory approval, design and implementation of this in situ iron reduction process. The alternative to this in situ approach is a multi-year pump and treat operation involving high capital expenditure.

Dehalogenation of Chlorinated Solvents in Groundwater Under Reductive Conditions

McCullough, M.L.; Hill, J.; Mills, S.; Dagdigian, J.V.
McLaren/Hart Environmental Engineering, Irvine, CA

Proceedings: Volume 2: Superfund 14: Conference and Exhibition, Washington, DC, 30 Nov - 2 Dec 1993 pp 1156-1161
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-9311122

This study was performed in order to determine the potential of reductive dehalogenation as an alternative method of treating groundwater contaminated with chlorinated solvents. The reducing potential of various compounds as applied to dehalogenation has been well documented by traditional organic chemists. Previous research demonstrates the positive effect of reducing agents on chlorinated solvents in groundwater under certain conditions. The sought reaction is a dehalogenation. This may be a successful way of treating ground water contaminated with solvents in that the reaction leaves salts and aliphatics. This particular study analyzes the effect of reduced iron on groundwater contaminated with 1,1,1-trichloroethane, trichloroethene, tetrachloroethene, and 1,2-dichloroethane under abiotic, anoxic conditions. The study demonstrated positive results in that an overall reduction of chlorinated solvents was witnessed in the treated samples versus the control. Furthermore, an initial increase in the lower substituted aliphatics was observed as expected. Future work will involve investigation of alternative reducing agents and the advantages of a biotic environment.

Photocatalytic Decomposition of Aromatic and Nonaromatic Substituted-Nitrogen Compounds Using TiO2

Moore, E.S.; Rechsteiner, G.; Green, D.B.; Hutchinson, B.
Pepperdine Univ., Malibu, CA

Proceedings: 207th Spring National Meeting of the American Chemical Society (ACS), San Diego, CA, 13-18 Mar 1994 p 353
Publisher: Washington, DC American Chemical Society 1994
Report Number(s): CONF-940301

The use of illuminated TiO2 to photocatalytically decompose organic compounds has been studied in the lab as an alternative method for polluted groundwater remediation. The authors have observed that the presence of a heteroatom in the molecule decreases the rate of oxidation and extent of mineralization in solutions of illuminated TiO2 suspensions. Solutions of aromatic and nonaromatic substituted-nitrogen compounds, structurally similar to many common herbicides and pesticides, were prepared in 0.1% suspensions of Degussa P25 TiO2. Solutions were illuminated by a 1000-watt high-pressure Xe lamp in a system designed to recirculate solution from a reservoir through a glass reactor cell. Decomposition progress was monitored with UV-visible spectroscopy, HPLC, and on-line CO2 analysis. The data suggests that the rate of oxidation decreases with decreasing distances between, and increasing numbers of, nitrogen atoms.

1992:

Groundwater Remediation Using Ion Exchange: a Case Study

Hosea, J.M.; McPherson, R., Bio-Recovery Systems Inc., Las Cruces, NM;
Evans, W.D., Systems Integration Inc., Richland, MI

Hazardous Materials Control/Superfund 92: 13th Annual Conference and Exhibition, Washington, DC, 1-3 Dec 1992 pp 698-704
Publisher: Greenbelt, MD Hazardous Materials Control Resources Institute 1992
Report Number(s): CONF-921235

Despite a number of proposed strategies for the protection of groundwater, contamination continues to be a growing problem. This paper describes the evaluation, implementation and first year of operation of an ion exchange system which is currently recovering hexavalent chromium and nickel from a contaminated aquifer in the midwestern United States. The source of the contamination was a plating facility which was no longer in operation. Even though a conventional wastewater treatment system was already in place, high operating costs and the liability associated with the landfilling of hazardous metal hydroxide sludge had driven the parties responsible for remediation in search of a more economical and environmentally acceptable alternative. Ion exchange (IX) was selected as the best treatment technology because: IX had already been successfully used to recover heavy metals from industrial wastewaters. IX systems can quickly pay for themselves through savings in operating costs. IX systems can eliminate long-term liability by recovering metals in reusable form. IX treatability of the contaminated aquifer was verified by treating samples of the groundwater in bench-scale experiments using small columns of various ion exchange resins. The results of this study indicated that a two-stage IX system would effectively and economically remove chromium and nickel ions and produce segregated metal concentrates which could be reused in the manufacture of stainless steel. Based on data generated in the treatability study, an IX treatment system was designed, built and installed. During its first 365 days of operation, the system produced an average of 114 gpm of decontaminated water, operating 24 hours/day without a single shutdown. Based on its first year of operation, the system is expected to pay for itself

within 2.5 years. It is believed that remediation of the aquifer will require 25 years of continuous treatment.

Diphonix - A New Ion-Exchange Resin for the Treatment of Industrial Waste Streams, Contaminated Groundwaters, and Mixed Wastes

Horwitz, E.P.; Gatrone, R.C.; Chiarizia, R.; Alexandratos, S.

In: Surveys of Research in the Chemistry Division, Argonne National Laboratory
Grazis, B.M. ed. pp 164-166
Publisher: Argonne National Lab., IL 1992

Interest in the removal and recovery of heavy toxic metal ions from contaminated groundwater, mixed wastes, industrial waste streams, and contaminated drinking water continues to increase as environmental laws become more stringent and permissible discharge limits are lowered. Treatment of contaminated water or industrial waste streams has frequently utilized precipitation and ion-exchange technologies. However, precipitation will not meet the lower limits and requires excessive quantities of chemicals, and commercially available ion-exchange resins do not have high affinities for many of the toxic metals relative to Ca and Mg. The authors have synthesized and characterized a new ion-exchange resin that shows considerable potential for environmental restoration, for the treatment of industrial waste streams, and for the treatment of alpha-active mixed waste. The new resin contains geminally substituted diphosphonic acid functional groups. The resin is called Diphonix for diphosphonic ion exchange. Alkyl-1,1-diphosphonic acids are among the most powerful complexing agents for polyvalent metal ions in aqueous solution, particularly at pH < 2. But heretofore, it has not been possible to synthesize resins containing diphosphonic acid groups because of the difficulty of introducing this group into a preformed polymer matrix. The synthesis of Diphonix was accomplished by the copolymerization of tetraalkylvinylidene diphosphonate with styrene, divinyl-benzene, and acrylonitrile followed by deesterification of the resultant resin by refluxing with concentrated HCl. 3 figs., 2 tabs.

1991:

Reductive Dechlorination of Trichloroethylene in Anoxic Aquifer Material From Picatinny Arsenal, New Jersey. Water Resources Investigation
Wilson, B.H.; Ehlke, T.A.; Imbrigiotta, T.E.; Wilson, J.T.
Rice Univ., Houston, TX
1991 7 p

Ground water at Picatinny Arsenal, New Jersey, has been contaminated with chlorinated solvents released from the waste water-treatment system of a metal-plating shop and from overflow from a degreasing vat. Trichloroethylene is the major contaminant, but 1,1,1-trichloroethane and tetrachloroethylene are also present. Cis-1,2-dichloroethylene and vinyl chloride were not original contaminants, but their accumulation in the ground water indicates reductive dechlorination of the trichloroethylene and tetrachloroethylene released to the aquifer. Laboratory microcosms were used to estimate the kinetics of reductive dechlorination at field scale. The microcosms were constructed with aquifer material collected from locations along the longitudinal extent of the plume and from outside the area of contamination. To determine whether supplementary electron donors would enhance reductive dechlorination, three suites of electron donors were added to aquifer material: 1 butyrate, propionate, toluene, and p-cresol; 2 butyrate, propionate, formate, methanol, toluene, and p-cresol; or 3 formate and methanol.

UV/OXIDATION

1995:

Greening of Ground Water
Dulle, Kevin J.; Streckfuss, Ted H.
Sverdrup Environmental, Inc, St. Louis, MO
Civil Engineering Vol 65 No 4 Apr 1995 pp 62-65

At the heavily contaminated Bofors-Nobel Superfund site in Michigan, engineers built a $12.4 million, 1.1 mgd continuous-flow plant that establishes an unusual model for the much-maligned pump-and-treat remedial approach. Designed by the US Army Corps of Engineers' Omaha District and built by Sverdrup Corp., St. Louis, the facility is one of the largest government-built ground-water pump-and-treat systems in the US. The plant's novel treatment system combines UV oxidation with ammonia stripping as well as other processes such as metals precipitation and carbon adsorption. An unconventional system was necessary due to extremely varied and toxic contaminants, although these are present in relatively low concentrations.

Evaluation of Ultraviolet Oxidation Methods for the Remediation of Explosives-Contaminated Groundwater
Wujcik, W.J.; Young, C.T.; Hammell, J.O.
Roy F. Weston, Inc., West Chester, PA
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 pp 1016-1019
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

An evaluation of commercially available ultraviolet oxidation (UV/Ox) processes for remediation of explosives-contaminated groundwater was performed by conducting a pilot-scale demonstration at Savannah Army Depot Activity (SADA) of four vendor processes. This demonstration was performed to assess whether UV/Ox methods offer a technically feasible and cost-effective alternative to granular activated carbon (GAC) for the treatment of explosives compounds including trinitrotoluene (2,4,6-TNT), trinitrobenzene (1,3,5-TNB), and other nitroaromatics found in groundwaters at Army installations nationwide. The adequacy of bench-scale testing data for predicting full-scale equipment requirements was also evaluated. Daily average effluent concentrations of nitroaromatic compounds were calculated and compared with daily average treatment criteria. There was considerable variation in the consistency with which the processes met the criteria; only the Ultrox process achieved the criteria for all 14 days of the demonstration. Initial and revised cost estimates were prepared by each vendor. The full-scale system configurations and cost estimated made after bench-scale testing and after pilot-scale testing were significantly different, indicating that pilot-scale testing provides data necessary for the accurate sizing of full-scale systems. Based on this demonstration, routine bench-scale testing is inadequate for providing sufficient data for full-scale UV/Ox systems.

Vacuum-UV-Oxidation of Chloroorganic Compounds in an Excimer Flow Through Photoreactor
Baum, G.; Oppenlaender, T.
Fachhochsch. Furtwangen, Dep. Chem. Biochem. Eng. Villingen-Schwenningen, FRG
Chemosphere Vol 30 No 9 1995 pp 1781-1790

The application of a novel vacuum-UV excimer flow through photoreactor (lambda = 172 nm) to the degradation of chloroorganic compounds in water is presented. A sample of ground water, contaminated with trichloroethene (Tri), 1,2-dichloroethene (1,2-DCE) and tetrachloroethene (Per), was purified successfully without the addition of oxidizing agents like H sub(2)O sub(2) or O sub(3). During the VUV-oxidation the intermediary formation of 1,1,2-trichloroethane (1,1,2-Tri) was established by GC-MS analysis. Over 93% of the organically bound chlorine atoms were transformed to inorganic chlorine ions (Cl super(-)). The photomineralization of 2,4-dichlorophenol (2,4-DCP) is presented on the basis of 2,4-DCP, Cl super(-) and TOC analyses. In few of technical applications the volume-corrected energy efficiencies Phi sub(-s) of the degradation of 2,4-DCP were determined for different intensities of irradiation and different flow rates (e.g. Phi sub(-s)(142 W, 48 l/min) = 16200 mg/kWh).

1994:

Advanced Oxidation Technologies for the Treatment of Contaminated Groundwater (Book Chapter)
Lewis, N.M.; Topudurti, K.
Environmental Protection Agency, Cincinnati, OH, Risk Reduction Engineering Lab.
1994 (14 p)
Report Number(s): PB-94-137353; EPA 600/A-94/005

The paper presents information on two pilot-field applications of advanced oxidation technologies for contaminated groundwater with organics. The Ultrox technology was demonstrated in 1989 with the U.S. Environmental Protection Agency's Superfund Innovative Technology Evaluation (SITE) program at the Lorentz Barrel and Drum (LB D) site in San Jose, California. Peroxidation Systems technology was applied at the Old O-Field site located within the Aberdeen Proving Ground, in Maryland. The

information presented includes a description of the technologies, factors affecting the technologies, and results from the two pilot-scale studies of the UV/oxidation treatment system applications.

Removal of Methyl Tertiary-Butyl Ether From a Model Ground Water Using UV/Peroxide Oxidation

Wagler, Jennifer L.; Malley, James P. Jr.
GEI Consultants, Inc, Winchester, MA

Journal of the New England Water Works Association Vol 108 No 3 Sept 1994 pp 236-260

The widespread use of underground storage tanks (USTs) to store petroleum products has made many ground waters susceptible to volatile organic chemical contamination. Methyl tertiary-butyl ether (MTBE), a gasoline additive, has been detected in municipal and private drinking water wells. Ethers tend to be more soluble in water than other volatile organic chemicals, so MTBE is difficult to remove from ground waters using the conventional remediation alternatives: air stripping and/or carbon adsorption. This paper explores the alternative oxidation processes of UV photolysis, hydrogen peroxide (H2O2), and the combination of UV H2O2 to remove MTBE from model ground water. (Author abstract) Refs.

Advanced Oxidation of Munitions in Water

Himebaugh, W.S.
Zimpro Environmental, Inc., Santa Ana, CA. Ultrox Div.

Proceedings: Volume 2: Federal Environmental Restoration III and Waste Minimization II Conference and Exhibition, New Orleans, LA, 25-29 Apr 1994 pp 1233-1241
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-940499

This paper discusses on-site destruction of explosives in groundwater and waste water by the application of Advanced Oxidation Process (AOP). AOP utilizes ultraviolet (UV) light, ozone and hydrogen peroxide in various combinations to destroy explosive compounds on site. Many US military facilities currently involved in the production of munitions, or with a history of munitions production or storage, are faced with the task of cleaning up residual explosives in groundwater and in process waste waters. With the closing of many military installations and the associated environmental compliance requirements, this has become of prime interest. The US Army has been actively evaluating AOP as an alternative to adsorption or combined with GAC as a method of reducing GACge, which ultimately results in lower life cycle treatment costs. Three case studies, including treatment of groundwater from two sites on the National Priority List (NPL), will be presented. Treatment studies conducted on site at military facilities located in three geographical regions will be discussed. While each study involves the destruction of explosives in water, each water is unique in its characteristics and optimized treatment approach. Explosive compounds treated in these studies include RDX, HMX, Nitrobenzene, 1,3-Dinitrobenzene, 2,4-Dinitrotoluene, 1,3,5-Trinitrobenzene and 2,4,6-Trinitrotoluene.

On-Site Application of Photochemical Oxidation to Unforeseen Groundwater Remediation Problems in the United States and Europe

Cothren, J.E.; Giggy, C.L.; Schmidt, F.; Winkler, H.E.

Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994

Ground Water Vol 32 No 5 Sep-Oct 1994 p 850

On-site photochemical oxidation was recently applied at two unusual ground water remediation sites. At one site, located at Waukegan Harbor near Chicago, PCBs had accumulated in the basin of a harbor boat slip over a substantial period of time. An on-site treatment study was initiated using an electrolytic soil washing process to remove the organic contaminants from the harbor bottoms. The perox-pure photochemical oxidation system was then evaluated to determine the destruction efficiency and economics for the treatment of several hundred milligrams per liter of phenolic break-down products from the soil washing operation. Upon startup of the system, phenolic concentrations detected were 10 times greater than expected and the water quality was poor. Via an innovative application, the perox-pure photochemical oxidation process was applied to achieve destruction of the phenolic compounds to below analytical detection limits. At a second site, an unused pump manufacturing facility near Berlin, Germany, photochemical oxidation was to be used for ground water treatment during excavation for construction activities. The ground water was expected to be contaminated with sub-mg/L levels of aromatic hydrocarbons. Through innovative application of the photochemical oxidation system, all of the contaminants were destroyed to low levels.

Field Demonstration of Perox-Pure™ Chemical Oxidation Technology

Lewis, N., Environmental Protection Agency, Cincinnati, OH Risk Reduction Engineering Lab; Topudurti, K.; Keefe, M.; Wooliever, P., PRC Environmental Management, Inc., Chicago, IL

Proceedings: Volume 1 Superfund 14: Conference and Exhibition, Washington, DC, 30 Nov - 2 Dec 1993 pp 323-329

Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994

Report Number(s): CONF-9311122

This paper presents the field evaluation results for an advanced chemical oxidation technology developed by Peroxidation Systems, Inc., of Tucson, Arizona. The Technology, known as the Perox-Pure™ technology, was evaluated under the US Environmental Protection Agency Superfund Innovative Technology Evaluation program at Lawrence Livermore National Laboratory (LLNL), Site 300 in Tracy, California, in September 1992. The Perox-Pure™ technology uses ultraviolet radiation and hydrogen peroxide to oxidize dissolved organic compounds in water. At the LLNL site, this technology was evaluated in treating groundwater contaminated with volatile organic compounds (VOC) including trichloroethene (TCE); tetrachloroethene (PCE); 1,1,1-trichloroethane (TCA); 1,1-dichloroethane (DCA); and chloroform. The system generally produced an effluent that contained TCE, PCE, and DCA at levels below detection limits, and TCA and chloroform at levels slightly above detection limits. The system achieved maximum removal efficiencies of greater than 99.9, 98.7, and 95.8 percent for TCE, PCE, and DCA, respectively. The system also achieved removal efficiencies of up to 92.9 and 93.6 percent for TCA and chloroform, respectively. The treatment system effluent met California drinking water action levels and federal drinking water maximum contaminant levels for all VOCs at the 95 percent confidence level. Cost analysis indicated that the groundwater remediation cost for a 50-gallon per minute system would range from $7 to $11 per 1,000 gallons, depending on contaminated groundwater characteristics. Of this total cost, the Perox-Pure™ system direct treatment cost would range from $3 to $5 per 1,000 gallons.

1993:

An Innovative Approach to Aquifer Restoration Using UV/Oxidation to Treat Groundwater Contaminated with Tetrahydrofuran
Van Doren, Edward P.; Johnson, Russell A.; Nelson, Eric G.
ABB Environmental Services, Wakefield, MA
Proceedings: Focus Conference on Eastern Regional Ground Water Issues, Burlington, VT Sept 27-29 1993
Publisher: Water Well Journal Pub. Co., Dublin, OH
Ground Water Management Vol 16 Sept 1993 pp 331-345
Abstract not available.

H202/VIS-UV Process for Treatment of Leachates and Contaminated Groundwater
Shimoda, Steven; Prengle, H.William Jr.; Symons, James M.
Univ of Houston, Houston, TX
Proceedings: Gulf Coast Hazardous Substance Research Center's 1993 Symposium on Emerging Technologies: Metals, Oxidation, and Separation, Belmont, TX, Feb 25-26 1993
Waste Management Vol 13 No 5-7 1993
Leachate from hazardous waste sites and improper disposal of waste have caused the national problem of organic contamination of groundwaters. The level of contamination exists in both mg/L concentrations and g/L concentrations. Currently, the two common treatment techniques, air stripping and granular activated carbon absorption, have problems, particularly for remote sites and small drinking water utilities. Thus, a simple alternative treatment technique for organic contaminant control was sought. The H202/Vis-UV process uses hydroxyl radicals to oxidize the organic contaminants. Because complete oxidation is a multi-step process, both parent compound (A) and total organic carbon (TOC) conversion are measured to characterize the rates of reaction because a given level of conversion is determined by measuring the disappearance of H202. Parameters of the study include photon intensity, molar space velocity, and oxidant to reactant ratio. The process was studied in both a CSTR and a tubular flow reactor (TFR). The compounds investigated included benzene (BEN); 1,4-dichloroebenzene (DCB; trichloroethylene (TCE); and trichloroethane (TCA). It has been found that the CSTR is more effective than the TFR and that conventional kinetics do not apply. The rate controlling variable is the photon flux (phi). The reaction rate constants for the compounds are k(BEN) equals 0.40, k(DCB) equals 0.00082, k(TCER) equals 11.0, k(TCA) equals 0.73 mu mol A/min, lr, phi . The organic carbon reaction rate constants are koc(BEN) equals 0.023, koc(DCB) equals 0.0000020, koc(TCE) equals 2.2, koc(TCA) equals 0.31 mu mol/min, lr, phi . (Author abstract)

Catalytic Oxidation of Organics in Vapor Streams at Remediation Sites: Remedial Action Tech Data Sheet
Naval Energy and Environmental Support Activity, Port Hueneme, CA, Jan 1993 (10 p)
Report Number(s): PB-93-182962; NEESA--20.2-051.5
Leaks from underground fuel storage tanks and associated piping have resulted in contamination of soil and ground water. Navy-wide, more than 350 sites are in need of remediation to remove fuel contamination from soil and ground water. These sites are located at about 80 different Navy activities (including Marine Corps installations). As a result of remedial activities to clean these contaminated soils and ground water, contaminated air streams are often generated. Available alternatives for the

treatment of these air streams include carbon adsorption and incineration. The Tech Data Sheet describes catalytic oxidation, a third alternative that has the potential to be effective at a lower cost.

1992:

Treatment of Contaminated Groundwater Using Chemical Oxidation
Zappi, Mark E.; Fleming, Beth C.; Cullinane, M. John, Jr.
U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS; Illinois State Water Supply
Proceedings: Hydraulic Engineering; Saving a Theoretical Resource, In Search of Solutions, Baltimore, MD, Aug 2-6 1992 pp 1184-1189
Publisher: Am. Soc. Civ. Eng., New York, NY

Abstract not available.

1991:

UV/Oxidation Technology Demonstration to Treat Groundwater Contaminated with VOCs
Topudurti, K.
PRC Environmental Management Inc, Chicago, IL
Proceedings: 1st IAWPRC International Symposium on Hazard Assessment and Control of Environmental Contaminants in Water, Otsu City, Japan, Nov 25 1991
Water Science and Technology Vol 25 No 11 1992 pp 347-354

This paper presents the field demonstration results of the ultraviolet radiation (UV)/oxidation technology developed by Ultrox International, Santa Ana, California. The technology was demonstrated at the Lorentz Barrel and Drum (LB&D) site in San Jose, California, under the United States Environmental Protection Agency's Superfund Innovative Technology Evaluation program. The UV/oxidation technology uses UV radiation, ozone, and hydrogen peroxide to oxidize organic contaminants present in water. At the LB&D site, this technology was evaluated in treating groundwater contaminated with volatile organic compounds (VOCs). The Ultrox system achieved VOC removals greater than 90 percent. The majority of VOCs were removed through chemical oxidation. However, for a few VOCs, such as 1,1,1-trichloroethane (1,1,1-TCA) and 1,1-dichloroethane (1,1-DCA) stripping also contributed toward removal. The treated groundwater met the applicable discharge standards for disposal into a local waterway at 95 percent confidence level. There were no harmful air emissions from the Ultrox system into the atmosphere. (Author abstract) 2 Refs.

Remediation of VOCs in Water Using UV/Oxidation.
Bhumgara, Rayomand R.; Yen, Chen-yu; Grubbs, D. Randolph; Bircher, Keith
Gannett Fleming, Inc, Baltimore, MD
Proceedings: National Conference on Environmental Engineering - Water Forum '92, Baltimore, MD August 02 1992 pp 98-103
Publisher: ASCE, New York, NY 1992

Recent regulatory developments such as Air Quality Regulations and Land Disposal Restrictions have initiated the United States Environmental Protection Agency (USEPA) to investigate treatment technologies which carry no secondary pollution or disposal requirements. HALLIBURTON NUS (NUS) and Gannett Fleming, Inc. (GF) were contracted by USEPA under the Alternative Remedial Contracting Strategy (ARCS) Program to conduct a pilot-scale treatability study at a Superfund site to

evaluate the effectiveness of ultraviolet (UV) light enhanced oxidation technology in removing volatile organic compounds (VOCs) from the groundwater and lagoon surface water. Solarchem Environmental Systems was then subcontracted by NUS/GF to provide and operate their pilot-scale Rayox™ UV/oxidation system. (Author abstract) 2 Refs.

Treatment of Contaminated Water, Air And Soil With UV Flashlamps
Wekhof, A.
Ultraviolet Energy Generators, Inc., Oakland, CA
Environmental Progress Vol 10 No 4 Nov 1991 pp 241-247

A new and effective method has been developed for the treatment of VOC's, PCB's and other toxic organics. Direct UV photolysis of organics is achieved with this new method with the use of high intensity ultraviolet light of a broad UV spectrum. Standard and novel UV flashlamps can be used for generation of this broad UV spectrum. The pulsing nature of such spectrum helps to increase the efficiency of destruction of toxics. The final products of this destruction process are non-toxic simple compounds. The energy efficiency of this new process exceeds that the traditional UV aided processes with medium pressure mercury lamps. This article reviews the Direct UV Photolysis Process, gives experimental results, and provides recommendations for applications in the treatment of groundwater, wastewater, contaminated air and soil.

1990:

On Site Destruction of Water Phase PCBs Utilizing Ultrox Ultraviolet Oxidation Technology
Zeff, J.D.
Ultrox International, Santa Ana, CA
Proceedings: International Conference for the Remediation of PCB Contamination, Houston, TX, 2-3 Apr 1990 pp 161-174

While PCBs are no longer manufactured or used in any manufacturing, the possibility of PCBs reaching waterways and groundwaters from residuals present in manufacturing facilities which formerly used PCBs necessitates the use of water treatment systems capable PCB destruction to acceptable concentration levels in industrial effluents, groundwaters, surface waters, and leachates. The first major PCB treatability work involved the setting up on site a small UV-ozone pilot plant at a General Electric Plant at Hudson Falls, New York. Other treatability studies in both bench reactors and pilot plants followed in the ensuing years on a wide variety of waters and types of PCBs. However, at the present time no full scale PCB systems have been installed as far as we know. UV/oxidation equipment, which is being manufactured for destroying other toxic organic compounds is readily adaptable and available for cleaning up PCBs in water. We foresee the need of UV/oxidation arising in the near future at several sites, and hope to be able to start installing PCB equipment within the next two years. The pilot work has shown that the UV/oxidation process is practical and cost effective for destroying the PCBs to less than one part per billion. An example pilot plant study is included in this paper.

Oxidation Technologies for Groundwater Treatment
Heeks, R. E.; Smith, L. P.; Perry, P. M.
Xerox Corp, Webster, NY
Proceedings: ACS Symposium 468 Emerging Technologies in Hazardous Waste Management II, Atlantic City, NJ, Jun 4-7, 1990 p 110

Xerox has been aggressively investigating innovative technologies for treatment of contaminated groundwater. As a result, chemical oxidation technologies involving combinations of UV radiation, hydrogen peroxide, and ozone were evaluated as methods for groundwater treatment. Three UV/ oxidation processes were pilot tested on contaminated groundwater containing chlorinated and nonchlorinated organic solvents. These technologies include the ULTROX system developed by ULTROX Intl, the perox-pure process of Peroxidation Systems, and the Rayox process by Solarchem Environ Systems. Data gathered during pilot testing demonstrated that these processes are effective in the destruction of organic contaminants in groundwater. Based on the results of these trials, Xerox leased a Peroxidation, LV60 unit for its Blauvelt, NY, facility.

Groundwater Treatment with Zero Air Emissions

Swett, G H; Loven, C G; Giggy, C L; Cheuvront, D A
Peroxidation Systems, Inc

Environmental Progress Vol 9 No 3 August 1990 pp 143-148

Air emissions from the treatment of volatile organic compound VOC-contaminated groundwater are a growing problem in the United States. When air stripping is used to remove VOCs from contaminated groundwater, contaminants are released into the air causing air pollution problems. Several treatment processes with zero air emissions are available for the decontamination of groundwater. In the liquid phase carbon process, organic contaminated water is percolated through beds of granular activated carbon. The carbon is later regenerated in a fired furnace or is disposed of in a hazardous waste landfill. In air stripping/vapor phase carbon, the organic pollutants are scavenged in the vapor phase usually onto activated carbon which is regenerated either on-site by steam stripping or off-site by furnace. In ultraviolet UV chemical oxidation, hydrogen peroxide is used in conjunction with UV light to catalyze the chemical oxidation of organic contaminants in water. This system requires little operator attention and does not produce air emissions. Five case studies relate how the air pollution regulation factors affected the decision for groundwater remediation programs. A southern California aerospace manufacturer chose UV/peroxidation for emissions control in its air stripping operations because of the economic attractiveness of this process and the waiver of permit requirements for UV/peroxidation units. For similar reasons, a northern California fleet refueling facility chose UV peroxidation to cleanup a subsurface spill of leaded gasoline. A northern California industrial facility chose a UV/ peroxidation system to handle air stripping discharge from the cleanup of a trichloroethylene plume that was migrating towards a residential area. A New York industry chose UV/peroxidation to help cleanup efforts for a a_env.pfgroundwater contaminated with trichloroethylene, vinyl chloride and numerous other industrial solvents. A California industrial facility selected UV peroxidation to comply with regulations to reduce toxicity, mobility and volume of hazardous chemicals at Superfund sites.

OTHER TREATMENT TECHNOLOGIES

1996:

A Geochemical Way to Keep Metals at Bay
Rouse, J.V., Fluor Daniel GTI, Englewood, CO;
Leahy, M.C., Fluor Daniel GTI, Windsor, CT;
Brown, R.A., Fluor Daniel GTI, Trenton, NJ
Environmental Engineering World Vol 2 No 3 May-Jun 1996 pp 6-11

Metals contamination is ubiquitous at many industrial facilities and most Superfund sites. Nonetheless, few technologies exist that can effectively address subsurface metals contamination within a reasonable cost or time frame. A new method--in situ geochemical fixation--is now available to minimize the threat posed by metals in soil and groundwater. An improvement over the conventional pump-and-treat approach, in situ fixation mixes chemical reagents with a smaller volume of pumped groundwater, and reinjects the treated water around the perimeter of a contaminated plume. As the treated plug of groundwater moves through the plume, it promotes subsurface reactions that cause free metals to bind or fix onto soil particles, rendering them inert and immobile. This reduces the risk of environmental damage and human exposure by metals left in place, and substantially reduces the total volume of groundwater that must be pumped--typically calling for pumping just 10% of the total volume of groundwater otherwise extracted using conventional pump-and-treat methods. For cation-mobile metals, such as zinc, cadmium and copper, suitable reagents for pH adjustment may be lime or caustic. For anion-mobile metals, such as hexavalent chromium, arsenic and selenium, the reagent of choice may be ferrous sulfate. Fluor Daniel GTI has also developed proprietary, patent-pending reagents for in situ metals fixation.

Injecting a New Remedial Technology
ECON Vol 11 No 1 Jan 1996 pp 17-19
(Full text available from Congressional Information Service at 1-800-227-2477.)

A new remedial technology for treating groundwater contaminated with organic substances is presented. Standard technologies rely on pump-and-treat methods that are expensive, time consuming, and often inadequate. The new patent-pending technology tries to destroy the contamination where it exists. The technology is based on the "Fenton Reaction Chemistry" process, and uses specifically designed equipment and injectors to diffuse or disperse a solution of oxidizers, catalysts, and other non-hazardous compounds. The process increases soil permeability, then chemically destroys the contaminants. The new process has been used successfully in several states. DOE and DOD currently are evaluating the process for full-scale remediation projects.

1995:

Dynaphore, Inc. Forager (Trade Name) Sponge Technology: Innovative Technology Evaluation Report
Vaccaro, G. F. ; Kitaplioglu, O.
Science Applications International Corp., Hackensack, NJ
Report No.: EPA/540/R-95/522; NTIS Number: PB95-268041 Jun 1995 85p

The Forager Sponge is a volume reduction technology in which heavy metal contaminants from an aqueous medium are selectively concentrated into a smaller volume for facilitated disposal. The

technology treats contaminated groundwater, surface waters and porous waters by absorbing dissolved ionic species onto a sponge matrix. The sponge matrix can be directly disposed or regenerated with chemical solutions. The Sponge can remove toxic heavy metals from waters in the presence of high concentrations of innocuous, naturally occurring dissolved inorganic species. The Forager Sponge technology was demonstrated under the SITE Program at the NL Industries, Inc. Superfund site in Pedricktown, N.J. The mobile, pump and treat system treated groundwater contaminated with heavy metals.

SITE Demonstration of the Dynaphore/Forager Sponge Technology to Remove Dissolved Metals from Contaminated Groundwater

Esposito, C.R., Environmental Protection Agency, Edison, NJ;
Vaccaro, G., Science Applications International Corp., Hackensack, NJ

Proceedings: 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium, Cincinnati, OH 4-6 Apr 1995 pp 177-180
Publisher: Environmental Protection Agency 1995
Report Number(s): CONF-9504110

A Superfund Innovative Technology Evaluation (SITE) demonstration was conducted of the Dynaphore/Forager Sponge technology during the week of April 3, 1994 at the N.L. Industries Superfund Site in Pedricktown, New Jersey. The Forager Sponge is an open-celled cellulose sponge incorporating an amine-containing chelating polymer that selectively absorbs dissolved heavy metals in both cationic and anionic states. This technology is a volume reduction technology in which heavy metal contaminants from an aqueous medium are concentrated into a smaller volume for facilitated disposal. The developer states that the technology can be used to remove heavy metals from a wide variety of aqueous media, such as groundwater, surface waters and process waters. The sponge matrix can be directly disposed, or regenerated with chemical solutions. For this demonstration the sponge was set up as a mobile pump-and-treat system which treated groundwater contaminated with heavy metals. The demonstration focused on the system's ability to remove lead, cadmium, chromium and copper from the contaminated groundwater over a continuous 72-hour test. The removal of heavy metals proceeded in the presence of significantly higher concentrations of innocuous cations such as calcium, magnesium, sodium, potassium and aluminum.

Electrical Resistance Tomography During In-Situ Trichloroethylene Remediation at the Savannah River Site

Daily, W.; Ramirez, A.
Lawrence Livermore National Laboratory, Livermore, CA

Journal of Applied Geophysics Vol 33 No 4 April 1995 pp 239-249

Electrical resistance tomography was used to monitor in-situ remediation processes for removal of volatile organic compounds from subsurface water and soil at the Savannah River Site near Aiken, South Carolina. This work was designed to test the feasibility of injecting a weak mixture of methane in air as a metabolic carbon source for natural microbial populations which are capable of trichloroethylene degradation. Electrical resistance tomograms were constructed of the subsurface during the test to provide detailed images of the process. These images were made using an iterative reconstruction algorithm based on a finite element forward model and Newton-type least-squares minimization. Changes in the subsurface resistivity distribution were imaged by a pixel-by-pixel subtraction of images taken before and during the process. This differential tomography removed all static features of formation resistivity but clearly delineated dynamic features induced by remediation

processes. The air-methane mixture was injected into the saturated zone and the intrained air migration paths were tomographically imaged by the increased resistivity of the path as air displaced formation water. We found the flow paths to be confined to a complex three-dimensional network of channels, some of which extended as far as 30 m from the injection well. These channels were not entirely stable over a period of months since new channels appeared to form with time. Also, the resistivity of the air injection paths increased with time. In another series of tests, resistivity images of water infiltration from the surface support similar conclusions about the preferential permeability paths in the vadose zone. In this case, the water infiltration front is confined to narrow channels which have a three-dimensional structure. Here, similar to air injection in the saturated zone, the water flow is controlled by local variations in formation permeability. However, temporal changes in these channels are minor, indicating that the permeable paths do not seem to be modified by continued infiltration.

1994:

Applications of Electrical Resistance Tomography to Subsurface Environmental Restoration
Ramirez, A.L.; Daily, W.D.
Lawrence Livermore National Lab., CA
Imaging Sciences Workshop, Livermore, CA, 15-16 Nov 1994 pp 73-74
Report Number(s): CONF-9411140-Absts.; Order Number: DE95017252

We are developing a new imaging technique, Electrical Resistance Tomography (ERT), to map subsurface liquids as flow occurs during natural or clean-up processes and to map geologic structure. Natural processes (such as surface water infiltrating the vadose zone) and man-induced processes (such as tank leaks and clean-up processes such as steam injection), can create changes in a soil's electrical properties that are readily measured. We have conducted laboratory and a variety of field experiments to investigate the capabilities and limitations of ERT for imaging underground structures and processes. In the last four years we have used ERT to successfully monitor several field processes including: a subsurface steam injection process (for VOC removal), an air injection process (below the water table) for VOC removal, water infiltration through the vadose zone, radio-frequency heating, ohmic heating, and tank and pond leaks. The information derived from ERT can be used by remediation projects to: detect and locate leaks, determine the effectiveness of clean-up processes, select appropriate clean-up alternatives, and to verify the installation and performance of subsurface barriers.

Contaminated Groundwater Control Using Electron Beam Treatment Systems
Kurucz, C.N.; Waite, T.D.; Cooper, W.J.; Nickelsen, M.G.
High Voltage Environmental Applications, Inc., Miami, FL
Proceedings: Volume 2: Superfund 14: Conference and Exhibition, Washington, DC, 30 Nov - 2 Dec 1993 pp 1121-1125
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-9311122

The contaminants discussed in this paper include solvents, aromatic hydrocarbons, explosives, and PCBs. These compounds typically originate from industrial process wastewater, spills, or disposal operations associated with various facilities both civilian and military. Electron beam irradiation has proven to be an effective technology for removing hazardous organic compounds in aqueous streams. The removal results from the action of highly reactive chemical species (OH, eaq-, H) generated when high energy electrons penetrate water. Since eaq- and H are reducing radicals and OH is an oxidizing radical, the process is effective against a wide range of individual organic compounds as well as mixture

of compounds found in industrial wastewater, landfill leachate, and contaminated surface and groundwater. This paper will present a brief overview of the technology, selected results from the simulated groundwater experiments, and results from bench scale experiments on waters containing NAPL contamination. The economics of full scale treatment systems will also be discussed as well as comparisons to selected alternative processes.

Passive Remediation of BTEX Compounds Using An Oxygen-Releasing Compound (ORC)
Bianchi-Mosquera, G.C., Geomatrix Consultants Inc., Newport Beach, CA;
Mackay, D.M., Univ. of Waterloo, Ontario, Canada, Centre for Groundwater Research
Proceedings: Ground Water Remediation: Existing Technology and Future Direction, Las Vegas, NV, 9-12 Oct 1994
Ground Water Vol 32 No 5 Sep-Oct 1994 pp 848-849

The use of an innovative, passive BTEX remediation technique is being investigated in a pilot study within an existing plume of petroleum hydrocarbons. Previous laboratory and field controlled studies have shown that a proprietary oxygen-releasing compound (ORC) can enhance the dissolved oxygen (D.O.) content of ground water. The field study also demonstrated that at least 4 mg/L each of benzene and toluene could be biodegraded due to the increased D.O. that resulted from the use of ORC. A pilot study undertaken in the summer of 1994. will evaluate the performance of ORC as a passive remediation technique at a plume associated with a retail gasoline outlet. The pilot study will compare several methods to contact the ORC with water and assess the optimal oxygen delivery system: (1) ORC-concrete briquettes, (2) ORC pencils, and (3) ORC trench. The author will discuss the effectiveness of the alternatives at promoting the in situ biodegradation of BTEX compounds and act as a barrier against further plume migration.

Using Air-lift Pumping as an In-Situ Aquifer Remediation Technique
Gvirtzman, H.; Gorelick, S.M.
Hebrew Univ of Jerusalem, Jerusalem, Israel
Proceedings: 5th International Conference on Environmental Quality and Ecosystem Stability, Jerusalem, Israel, June 1992
Water Science and Technology Vol 27 No 7-8 1993 pp 195-201

The global attempt to protect and restore the major water resources encouraged hydrologists to develop new, simple and effective aquifer remediation methods. A new in-situ remediation procedure is proposed to remove Volatile Organic Compounds (VOC) dissolved in groundwater. This is accomplished by injection of air into a well, using a combined technique of air-lift pumping with a form of vapor stripping. The feasibility of the proposed method was analyzed using concepts of mass transfer of VOCs from water to air-bubbles and transport of VOCs in porous media. (Author abstract) Refs.

1993:

Radiation-Induced Remediation of Groundwater
Gehringer, P.
Austrian Research Centre Seibersdorf
Proceedings: Meeting of the European Society for New Methods in Agricultural Research (ESNA), Halle, Germany, 5-9 Sept 1993 pp 166-170
Report Number(s): CONF-9309462

Because of nitrite and hydrogen peroxide formation irradiation treatment alone is not apt for groundwater remediation with regard to utilization as drinking water. Addition of ozone to the water before irradiation eliminates the nitrite and hydrogen peroxide as well and causes the reducing species of water radiolysis to be converted into OH radicals. The resulting advanced oxidation process is the only one which is based on two OH radical sources: water radiolysis and ozone decomposition. The basic chemistry and a 3 m3 prototype installation is described. (orig.)

New Treatability Tests
Roy, K.A.
Hazmat World Vol 6 No 1 Jan 1993 p 52

EPA, under its Superfund Innovative Technology Evaluation (SITE) program, recently announced results from treatability tests on Thorneco Inc.'s (Payson, Ariz.) Enzyme-Activated Cellulose Technology. The technology relies on cellulose coated with a proprietary enzyme to remove metals and organic compounds from aqueous solutions. Following enzyme treatment, cellulose is placed in one or more towers that operate in series. Contaminated water enters the towers from the bottom and flows upward through the enzyme-activated cellulose to a discharge pipe at the top. The technology can remove metals and organic compounds from aqueous solutions in the form of ions, particulates or colloidal compounds. The treatability study was conducted between Aug. 26 and Sept. 30, 1991, at the Engineering Science treatability lab in Atlanta. Contaminated groundwater came from Stream A at the Stringfellow Superfund site in Glen Avon, Calif. A bench-scale treatability study was performed because of a lack of complete background data and uncertainty concerning the technology's removal mechanisms.

Surface Modified Clays: An Innovative Technology
Healy, B.
Colloid Environmental Technologies Company, Arlington Heights, IL
Proceedings: Seventh National Outdoor Action Conference and Exposition, Las Vegas, NV, 25-27 May 1993 pp 61-69
Publisher: Dublin, OH Ground Water Management 1993
Report Number(s): CONF-9305192

A new treatment technology has been developed to remove low solubility organics from groundwater. The primary active ingredient in this granular absorption media is montmorillonite (bentonite) clay which has been chemically modified to be completely hydrophobic. The media is used in a contacter vessel in much the same way as granular activated carbon. Its unique absorption properties make the media ideal for many "hard to treat" waste streams. The bentonite based hydrophobic media has the capacity to absorb up to 60% of its weight in organic contaminants. The removal rate of any specific organic constituent is directly related to its solubility in water. In general, these surface modified clay medias will remove approximately 90% of organic constituents that are less

than 200 mg/l soluble in water. Depending on the waste stream, this hydrophobic media can be used for primary treatment, pretreatment or post-treatment. Primary treatment applications would include waste streams only containing oil and grease extractables (such as wood treating wastes). As a pretreatment, the media can remove the larger, less soluble organics that tend to blind carbon and are difficult to air strip. Dependent on the waste stream, carbon consumption can be reduced by as much as 10 times, drastically cutting treatment cost. In the post treatment mode, the hydrophobic media can be used downstream of oil/water separators, dissolved air flotation units, or bioreactors to assure discharge quality. 4 refs., 6 figs.

1991:

Ultrasonic Process For Detoxification of Groundwater
Wu, Jiann M.; Huang, H.S.; Livengood, C.D.
Argonne National Lab., IL
Proceedings: American Institute of Chemical Engineers AIChE Annual Meeting, Los Angeles, CA, 17-22 Nov 1991

In this paper, we present the results of an investigation of the ultrasonic irradiation of carbon tetrachloride at various pH values, temperatures, and power intensities. Kinetic data and selected chemical mechanism are discussed and proposed. To study oxidant efficiency, chemical oxidants, such as hydrogen peroxide, are also considered. This work is part of a project entitled Ultrasonic Process for Detoxification of Groundwater and Soil," sponsored by the US Department of Energy, Office of Technology Development, to develop an innovative process for the effective destruction of chlorinated organics in soil and groundwater.

Radial Flow Extraction to Remove Heavy Metals From Groundwater
Einolf, D.M.; Rajkovich, S.B., EIChroM Industries, Inc., Darien, IL;
Horwitz, E.P.; Dietz, M.L., Argonne National Lab., IL
Proceedings: Waste Stream Minimization and Utilization Innovative Concepts: An Experimental Technology Exchange, Washington, DC, 25-26 Apr 1991 pp 1.1-1.14

This system, using resin-based solvent extraction in a radial-flow column, promises to be highly selective and cost-effective. Radial flow extraction systems have been designed to integrate directly into ion-exchange resin-based pump-and-treat systems for waste treatment. Ion-exchange resins represent 40% to 70% of the operating costs of a resin-based treatment system. The remaining costs of such a system are represented by regenerants and chemical modifiers needed for ion-exchange resins to function. Because of the increased selectivity of the extraction chromatography system, specific materials can also be recovered for ultimate recycle. Bench-scale experiments examining uranium removal from groundwater have shown that extraction chromatography materials can obtain decontamination factors greater than 1 {times} 10{sup 4}, which both exceeds standards for groundwater contamination and represents allowable disposal limits for mixed wastes. Five areas need further study as a result of the preliminary experimentation: 1 determine the actual residual amount of uranium remaining in the groundwater, 2 explore the overall purity of the recovered uranium and, by extension, the opportunity for recovering and recycling commercially important metals from contaminated groundwater, 3 process a larger volume of material >10 liters through the radial column, 4 determine the long-term stability of the extraction chromatographic column, 5 perform multiple runs of the chromatographic columns to examine the completeness of column stripping and the possibility of performance degradation through multiple use. When stability and characterization experiments are

completed, enough data will have been generated to undertake engineering design and process implementation.

1990:

The Application of Multiple Stage Diffused Aeration in the Treatment of Petroleum Contaminated Groundwater

Cowdery, C.; Amram, P.
Delta Environmental Consultants, Inc., Tampa, FL

Proceedings: Fourth National Outdoor Action Conference on Aquifer Restoration, Groundwater Monitoring, and Geophysical Methods, Las Vegas, NV, 14-17 May 1990 pp 57-71

A practical alternative to air stripping with a packed column is the use of diffused aeration. The objective of this study was the evaluation of multiple stage aerators in low flow applications 0. 1 to 10 gpm particularly where the potential for plugging is high due to scaling or biological growth. Data was collected from six operating systems in the states of Florida and Alabama. The systems were evaluated in terms of contaminant removal efficiency, maintenance requirements, and reliability. All systems were used to treat gasoline and/or diesel contaminated groundwater at flow rates between 0.14 and 25 gallons per minute. The use of multiple tanks allowed for greater removal rates by limiting axial dispersion. This allowed multiple tank aerators to be implemented in place of a single tank with the same overall air flow and liquid residence time and approximately equivalent utility consumption and capital cost. Removal efficiencies of greater than 99% were achieved for volatile aromatic compounds, methyl tert-butyl ether MTBE, 1,2-dibromoethane EDB, and 1,2-dichloroethane with relatively low capital and maintenance costs. The results indicated that the tank-in-series design is highly effective in removing volatile aromatic compounds from ground water and that diffused aeration is a viable alternative to a packed tower air stripper for low flow applications. Furthermore , while precipitates and bacterial growth is significant in these systems, the open design allowed for normal operation with little impedance to flow or reduced removal efficiency.

Remediation of Gasoline-Contaminated Groundwater: Spray Aeration/Internal Combustion Oxidation

Rippberger, M L
Harding Lawson Associates, Newbury Park, California

Proceedings: Superfund '90: 11th National Conference, November 26-28 1990 pp 865-867

Vacuum enhanced spray aeration with thermal oxidation has been demonstrated to be an effective method of removing hydrocarbons from contaminated groundwater and oxidizing the contaminants so that they are no longer a significant health hazard. The vacuum to the well effectively increases the flow of free product to the well as it extracts vapors from the well for combustion. This system has been demonstrated to be an economical and practical alternative to carbon canisters and their associated costs. The vacuum spray aeration tank has been demonstrated to have an effectiveness equivalent to a packed-tower air stripper, without the problems of packing fouling or the expense of packing replacement costs. Savings are realized in both the initial cost of equipment and the operating costs of a conventional system using vacuum extraction, a packed-tower air stripper and carbon polishing. While optimization of operating parameters is being further defined, this system has been shown to be both practical and cost-effective for remediation of gasoline-contaminated groundwater and contaminated soil vapors.

Application of Combined Ozone/Hydrogen Peroxide for the Removal of Aromatic Compounds from Groundwater

Mallevialle, J; Mazounie, P; Anselme, C; Duguet, J P
Centre de Recherche Lyonnaise des Eaux -Degremont Ozone
Science and Engineering Vol 12 No 3 1990 pp 281-294

Nitro and chloro-benzene compounds, which are widely used in dye industries, have been associated recently with groundwater contamination. Because of their potential toxicity and for taste and odor considerations, three main actions were undertaken to solve the problem at a French site. First, to follow the advance of pollution toward the wells, samples were collected automatically and analyzed using gas chromatography/mass spectrometry. Results indicate that ortho-chloronitrobenzene was the main pollutant in concentrations ranging from 100 to 2000 micrograms/L. Second, to monitor drinking water quality, an on-line spectrophotometer was used to measure the optical density at 254 nm at the inlet and outlet of the water treatment plant. Third, the feasibility of using the ozone/hydrogen peroxide O3/H2O2 combination was determined at a 450 L/hour pilot plant. Reduction of concentrations of chloronitrobenzenes from 1900 micrograms/L to less than 20 micrograms/L could be reached by the application of 8 mg O3/L and 3 mg H2O2/L with a 20 minute contact time. To avoid an eventual bacterial regrowth in the network due to biodegradability of the oxidation by-products, sand and GAC filtration were tested after oxidation. An evaluation of the costs of these different treatments for the specific case studied showed that investment and operational costs were of the same order of magnitude as construction costs of new wells at another location and transportation of the water. Author's abstract

Use of Pervaporation for the Removal of Organic Contaminants from Water

Cote, P; Lipski, C
Zenon Environmental, Inc
Environmental Progress Vol 9 No 4 Nov 1990 pp 254-261

Pervaporation is a new membrane process for the removal and concentration of volatile organic compounds from contaminated water. It can be used to treat groundwater, leachate, and wastewater. A resistance-in-series model was formulated and validated using silicone rubber hollow fibers for the treatment of water containing trichloroethylene. This process model was coupled with a costing model to assist in the design of pervaporation systems. High fluxes and separation factors were obtained for the removal of trichloroethylene from water using a thick silicone rubber membrane. Two different membrane configurations were tested using the same hollow fibers. Pervaporation was described by a resistance-in-series model: a liquid film resistance and a membrane resistance. Estimation of the two resistances showed that, for the trichloroethylene, mass transfer was limited by the liquid film resistance from an inside flow module. Membrane resistance only became apparent for a transversal flow module. A pervaporation case study of trichloroethylene demonstrated that the flux of trichloroethylene was a function of both the membrane thickness and module hydrodynamic conditions. A case study found that the pervaporation unit treatment cost was $0.56/cu m for the transversal flow module, $1. 10/cubic m for the spiral-wound module, $1.41/cu m for the inside flow module wide bore fibers and $3.80/cu m for the inside flow module narrow bore fibers. For comparison, the cost of conventional technologies ranged from $0.10/cubic m, for air stripping alone, to $0. 80/cubic m, for treatment trains including stripping and/or granular activated carbon on the aqueous or off-gas streams. In addition to the fact that pervaporation has definite technical advantages over conventional processes, it appear pervaporation has a economic advantage as well.

In-Situ Cleaner Wick System for Removal of Groundwater Contaminants

Konon, Walter
New Jersey Inst of Technology, Newark
Adv Environ Technol Manag Vol 1 1990 pp 77-85

Plastic geotextile wicks have been increasingly used to serve as vertical water migration paths in poorly draining soils. This established drain wick technology, used for soil consolidation, was modified so that new cleaner wicks could be used to adsorb groundwater contaminants. The cleaner wick system is operated using an air lift principle to circulate the contaminated water up through sorbent material in the wick core. Laboratory tests conducted to date have been favorable and have demonstrated the basic operational effectiveness of this device. Typically, reductions of 70% in contaminant-concentrating levels were achieved using cleaner wicks for durations of under one week of system operation.

Butane Stripping of Organic Contaminants From Water, Phase II Report

Pan Canadian Consultants Ltd., Ottawa, ON, Canada
Report No EE-126 1990 168p

The study was conducted to develop a new technology for the removal of organic contaminants from water using steam stripping. Phase I of the program, completed in 1988, examined the concept in a small batch-type, laboratory bench-scale apparatus. Phase II involved the construction of a continuous, counter-current flow pilot plant capable of treating 5-10 litres/hour with butane, attaining good extraction efficiency, and recovering the butane solvent in a pure form for recycling. This report describes the results of Phase II.

Multi-Chamber Approach to VOA Volatilization

Wilson, J.M.; Ackart, R.T.; Gonzalez, C., Geraghty Miller, Inc., Tampa, FL;
Haeberle, R.A., Kerr-McGee Refining Corp., Oklahoma City, OK
Proceedings: Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration, Houston, TX, 31 Oct-2 Nov 1990 pp 463-475

The purpose of this paper is to report on the results of remediation of dissolved motor-fuel components mainly benzene, toluene, ethyl benzene, and xylenes in ground water by means of multi-chamber diffusion methods. Calculated volatile organic aromatic VOA reduction is compared to empirical data. Data have been generated at a variety of sites and under a wide variety of regulatory requirements across the eastern United States for a period of three years. Common technologies used today to remove dissolved hydrocarbons principally VOAs from water include carbon adsorption, bioremediation, packed-tower air stripper, and diffuser whether single-or multi-chamber. These methods and the field data requirements for design are briefly examined. Diffusers offer an alternative to packed-tower air strippers for relatively low flows of ground water containing volatile motor-fuel components. The results during the three year period indicate that diffusers may offer these advantages: Compactness and portability; Add-ons treatments are easier/less expensive i.e., off-gas treatment, bioremedial nutrient introduction, chlorination, iron filtration; Aesthetically acceptable; No packing to clean or replace; Stripping efficiency equal to packed towers; Costs equal to or better than towers in terms of: capital installation operation and maintenance winterization. A series of graphs show diffuser effectiveness and compare predicted effectiveness of various multiple diffuser tanks to actual empirical data collected at a variety of sites. The effects of varying air flow rates, depths of water flow, number of diffusers, or inflow VOA concentrations in diffuser tanks are discussed. Equipment spotlighted in this paper also features suspended iron and other particulate removal.

ELECTROKINETICS

1996:

A New Approach to Electrokinetic Remediation of Soils Polluted by Heavy Metals
Li Z; Yu J-W; Neretnieks I
Dep. Chem. Engineering Technol., Chem. Engineering, Royal Inst. Technol., Stockholm, Sweden
Journal of Contaminant Hydrology Vol 22 No 3-4 1996 pp 241-253

When the electrokinetic method is used to remove metals from soils, metals may precipitate as hydroxides in the region of the soil where pH is raised, which limits the remediation efficiency. The pH rise is caused by the generation of hydroxide ions as a result of electrolysis of water during the remediation. This paper proposes a new technique in which a conductive solution is inserted between the cathode and the soil to be treated. By this approach, the pH in the soil can be kept low so that no metal precipitation will occur. Thus metal ions may migrate out of the soil and precipitate in the inserted solution. Laboratory experiments have been carried out to remove copper and zinc from sand by the proposed technique. The experimental results show that metal removal efficiencies depend on the duration of the treatment and the content of electrolytes in the solution. Metal removal efficiencies of about 96% can be reached for both copper and zinc.

Electrokinetic Remediation of Mercury-Contaminated Soils Using Iodine-Iodide Lixiviant
Cox C D; Shoesmith M A; Ghosh M M
Dept. Civil Environmental Engineering, Center Environmental Biotechnol., Univ. Tennessee, Knoxville, TN
Environmental Science & Technology Vol 30 No 6 1996 pp 1933-1938

In-situ remediation of mercury-contaminated soils, by electrokinetic or other means, is difficult because of the low solubility of mercury and its compounds. In this research, enhanced electrokinetic remediation of HgS-contaminated soils using I-2/I- lixiviant was investigated using bench-scale electrokinetic cells. The thermodynamic conditions under which the lixiviant could be effective were determined by constructing a pE-pH diagram for the Hg-S-l system. Introduced near the cathode, the lixiviant migrated through the soil to the anode by electromigration. Mercury, released by the oxidation of HgS compounds by 12, was complexed as Hgl-4-2-. The negative complex continued to electromigrate toward the anode. Up to 99% of the Hg present in laboratory-contaminated soils could be removed. Electrokinetic treatment of a field-contaminated soil, containing more organic matter than the laboratory-contaminated soil, occurred much slower. The critical issues in determining the efficacy of the process are the oxidation of reduced Hg by 12 and I-3- and the transport of the resultant Hgl-4-2- complex.

Electronic (Ek) Remediation of a Contaminated Soil at Several Pb Concentrations and Applied Voltages
Reed B E; Carriere P C; Thompson J C; Hatfield J H
Dept. Civil Environ. Eng., West Virginia Univ., Morgantown, WV
Journal of Soil Contamination Vol 5 No 2 1996 pp 95-120

The in situ remediation of a lead-contaminated silt loam by electrokinetic (EK) soil flushing was studied. Two initial soil Pb concentrations (150 and 1000 mg/kg of Pb) and applied voltages (30 and 60 V) were investigated. The EK soil flushing process was less efficient for the 150 mg/kg of Pb soils despite these tests being operated for longer durations, having larger EO flows and energy inputs, and

lower soil pHs. The decrease in effectiveness was attributed to a larger average metal-soil binding energy for the lower contaminated soil. Increasing the voltage increased the EO flow, current, energy input (kW-hr/kg of soil), and provided a more evolved low pH front, resulting in more soil being remediated. There appeared to be a correlation between the amount of EO flow and the desorption and transport of soil-bound lead. Because complete soil remediation did not occur in any of the tests, the final energy input per kilogram of soil could not be calculated.

In Situ Electrokinetic Remediation of Contaminated Soils and Groundwater
Industrial Health & Hazards Update July 1, 1996 p. N/A

This EPA document presents a status report that describes demonstrations, field applications, and research, on electrokinetics for remediating contaminated soils and groundwater at waste disposal and spill sites. While clay and silt tend to sequester large quantities of organic and inorganic contaminants, they are resistant to remediation using traditional technologies because of their low hydraulic conductivities. Although electrokinetics has been used for decades in the oil-recovery industry and to remove water from soils, the in situ application of electrokinetics to remediate contaminated soil is very new.

Electrokinetic Flushing to Remove Contaminants from Fine-Grained Soils
Industrial Health & Hazards Update April 1, 1996 p. N/A

Electrokinetic (EK) soil flushing is a candidate technology for in situ remediation of low permeability soils. For most in situ techniques, hydraulic pressure is used to disperse the chemical additives and collect the contaminated groundwater. Many in situ treatment technologies have had success at sites containing sandy soils, but have not shown much promise for soils having large amounts of clay and silt, due primarily to the difficulty in transporting groundwater, contaminants, and chemical additives through the subsurface. Soils high in clay and silt are known to sequester large quantities of inorganic and organic contaminants; thus, soils having low hydraulic conductivities are generally efficient in sequestering pollutants but are resistant to standard in-situ remediation techniques because of the difficulty in transporting groundwater and contaminants. In EK soil flushing, groundwater and contaminants are transported under an applied voltage. The transport of groundwater, electroosmotically, does not depend directly on the soil's hydraulic conductivity; thus, soils that would otherwise require excavation and treatment can be remediated in situ if electrokinetics is used as the driving force for liquid and contaminant transport. This (National Research Center for Coal and Energy) report details the results of work conducted on the use of electrokinetic (EK) soil flushing to remediate a fine grained soil contaminated with lead. The experimental work entails soil collection and characterization, soil adsorption, desorption of lead, and EK reactor construction and testing. The study also investigates the efficacy of using EK soil flushing on an actual soil, using bench-scale EK reactors, including the affect of initial conditions on the efficiency of EK soil flushing. (Order this INDUSTRIAL HEALTH & HAZARDS UPDATE reviewed report from InfoTeam Inc., P.O. Box 15640, Plantation, FL 33318-5640; Phone (954)/or(305) 473-9560, Fax (954)/or(305) 473-0544: Report No HN941225; Oct. 1993, 102 pp. Price: $129.00, prepaid.)

In Situ Soil Remediation Using Electrokinetics
Industrial Health & Hazards Update Feb 1, 1996 p. N/A

Electrokinetics is emerging as a promising technology for in situ soil remediation. It is especially attractive for Superfund sites and government operations containing large volumes of contaminated soil. The approach uses an applied electric field to induce transport of both radioactive and hazardous waste ions in soil. The transport mechanisms include electroosmosis, electromigration, and electrophoresis. The feasibility of using electrokinetics to move radioactive 137Cs and 60Co at the Hanford Site in Richland, WA is discussed in this Battelle Pacific Northwest Laboratories paper. A closed cell is used to provide in situ measurements of 137Cs and 60Co movement in Hanford soil. Preliminary results of ionic movement, along with the corresponding current response, are presented and discussed. (Order this INDUSTRIAL HEALTH & HAZARDS UPDATE reviewed report from InfoTeam Inc., P.O. Box 15640, Plantation, FL 33318-5640; Phone (954)/or(305) 473-9560, Fax (954)/or(305) 473-0544: Report No H960230; Nov. 1994, 34 pp. Price: $79.00, prepaid.)

Electrokinetics for In Situ Remediation of Soil and Groundwater
Industrial Health & Hazards Update Jan 1, 1996 p. N/A

This EPA document describes demonstrations, field applications, and research on electrokinetics for remediating contaminated soils and groundwater at waste disposal and spill sites. Electrokinetics separates and extracts heavy metals, radionuclides, and organic contaminants from saturated or unsaturated soils, sludges, and sediments. A low intensity direct current is applied across electrode pairs that have been implanted in the ground on each side of the contaminated soil mass. The electrical current causes electroosmosis and ion migration, which move the aqueous phase contaminants in the subsurface from one electrode to the other. Contaminants in the aqueous phase or contaminants desorbed from the soil surface are transported towards respective electrodes depending on their charge. The contaminants may then be extracted to a recovery system or deposited at the electrode. Surfactants and complexing agents can be used to increase solubility and assist in the movement of the contaminant. Also, reagents may be introduced at the electrodes to enhance contaminant removal rates.

Electrokinetic Treatment of Contaminated Soils: Removal of Lead from Porous Kaolinite
Lu, I-Min; Yen, Shi-Chern; Chapman, Thomas W.
Natl Taiwan Univ, Taipei, Taiwan
Proceedings of the 1996 TMS Symposium on Emerging Separation Technologies for Metals II Kona, HI
Minerals, Metals & Materials Soc (TMS) 1996 pp 349-361

An electric field was applied to a metal-bearing kaolinite specimen to investigate the efficiency of electro-osmosis in removing heavy metals from contaminated soils. The electric field induces a flow of water through the porous medium, called electro-osmosis, which is superimposed on the hydraulic flow. Because the electro-osmotic flow is relatively stronger in smaller pores, it can enhance the displacement of contaminated solution by fluid convection. Furthermore, local changes in pH caused by the electrode reactions can affect adsorption equilibria and the distribution of solutes between the solution and the solid surfaces. The electro-osmosis experiments were conducted by applying either a constant current or a constant voltage across 8-cm inside diameter, 25 to 30-cm long specimens of kaolinite clay with graphite electrodes. Samples of the pore fluid and of the clay were analyzed to determine metal content, pH, and conductivity as functions of time and position. Results show that removal of heavy metals from soil can be accomplished effectively by electrokinetic treatment of sufficient duration. Approximately 95% of the lead was removed after 189 days. (Author abstract) Refs.

Electrokinetic Remediation. 2: Theoretical Model
Alshawabkeh, A.N., Electrokinetics, Inc., Baton Rouge, LA;
Acar, Y.B., Louisiana State Univ., Baton Rouge, LA, Civil & Environmental Eng Dept.
Journal of Geotechnical Engineering Vol 122 No 3 Mar 1996 pp 186-196

A mathematical model is presented for multicomponent species transport under coupled hydraulic, electric, and chemical potential differences. Mass balance of species and pore fluid together with charge balance across the medium result in a set of differential equations. Sorption, aqueous phase, and precipitation reactions are accounted by a set of algebraic equations. Instantaneous chemical equilibrium conditions are assumed. Transport of H+, OH-, Pb2+, NO3-, the associated chemical reactions, electric potential, and pore pressure distribution across the electrodes in electrokinetic remediation are modeled. Model predictions of acid transport, lead transport, and pore pressure distribution display very good agreement with the pilot-scale test results validating the formalisms offered for multicomponent transport of reactive species under an electric field. The model also bridges the gap between the electrochemistry and mechanics in electroosmotic consolidation of soils.

Electrokinetic Remediation. I: Pilot-Scale Tests with Lead-Spiked Kaolinite
Acar, Yalcin B.; Alshawabkeh, Akram N.
Journal of Geotechnical Engineering Vol 122 No 3 March 1996 pp 173-186

The feasibility and efficiency of transporting lead under electric fields are investigated at pilot scale in three Georgia kaolinite specimens spiked with lead nitrate solution and at an electrode spacing of 72 cm. Enhancement methods such as cathode depolarizatlon and/or catholyte neutralization techniques are not used in processing. A constant direct current density of 133umA/cm2 is applied. Two of the tests are conducted on specimens spiked with lead at concentrations of 856 mg/kg and 1,533 mg/kg. The third test is conducted on a 1:1 mixture of compacted kaolinite/sand spiked with lead at a concentration of 5,322 mg/kg. Lead was transported toward the cathode and precipitated at its hydroxide solubility value within the basic zone in direct contact with the cathode compartment. Subsequent to 2,950 h of processing and an energy expenditure of 700 kWh/(m.sup.3), 55% of the lead removed across the soil was found precipitated within the last 2 cm close to the cathode, 15% was left in the soil before reaching this zone, 20% was found precipitated on the fabric separating the soil from the cathode compartment, and 10% was unaccounted. Heavy metals and species that are solubilized in the anodic acid front can be efficiently transported by electromigration under an electrical field applied across electrodes placed in soils.

Electrokinetic Remediation of Soils, Sludges and Groundwater
Clarke, Robert L.; Kimmel, Stan; Lageman, R.; Smedley, Stuart
Geokinetics, Orinda, CA
Proceedings: The 58th American Power Conference, April 9-11 1996 Chicago, IL Vol 1 pp 347-352
Publisher: Illinois Inst of Technology, Chicago, IL,

Electrokinetic remediation techniques are now rapidly emerging as a favorable and commercially applicable ground and groundwater remediation technology. This approach is based on using the Pool Process to manage and maintain optimal soil and electrolyte conditions. The technique offers an in-situ and ex situ process in the following formats: in-situ removal of polar pollutants in the vadose and saturated zones; batch and lagoon systems; 'ring fences' to prevent migration of contaminated plumes in the saturated zones. In addition, the Pool Process is proving to be a versatile option for a variety of applications, which require the management of soil chemistry.

Electrokinetic Remediation of Soils Contaminated with Electroplating Wastes
Reddy, Krishna R.**;** Parupudi, Usha S.; Devulapalli, Srinivas
Univ of Illinois at Chicago, Chicago, IL
Proceedings: The 58th American Power Conference, April 9-11 1996 Chicago, IL Vol 1 pp 342-346
Publisher: Illinois Inst of Technology, Chicago, IL,

Electrokinetic remediation of soils simulated with electroplating waste contamination are studied in two soil, kaolin and glacial till. Soil samples are contaminated with nickel, cadmium and hexavalent chromium and subjected to an external electric field for four days. Results of these experiments reveal that the soil composition plays an important role in electrokinetic remediation. Due to induced electric potential, a distinct pH gradient is developed in kaolin; however, in glacial till alkaline conditions exist throughout the soil because of its high carbonate buffering capacity.

1995:

In Situ Remediation Technology Status Report: Electrokinetics
Environmental Protection Agency, Washington, DC. Office of Solid Waste and Emergency Response
Report No.: EPA/542/K-94/007; NTIS Number: PB95-236873/ Apr 95 27p

The purpose of this document is to describe demonstrations, field applications, and research on electrokinetics for remediating contaminated soils and ground water at waste disposal and spill sites. Although clay and silt tend to sequester large quantities of organic and inorganic contaminants, they are resistant to remediation with traditional technologies because of their low hydraulic conductivities. Although electrokinetics has been used for decades in the oil recovery industry and to remove water from soils, in situ applications of electrokinetics to remediate contaminated soil is new.

A Mathematical Model for the Electrokinetic Remediation of Contaminated Soil
Choi Y S; Lui R
Dept. Math., Univ. Conn., Storrs, CT 06268
Journal of Hazardous Materials Vol 44 No 1 1995 pp 61-75

We propose to develop a mathematical model for the electrokinetic remediation of contaminated soil. We assume that the contaminants are mostly heavy metals, water is in excess, the dissociation-association of water into hydrogen and hydroxyl ions is rapid, and that electroosmosis is insignificant when compared to electromigration as a transport mechanism. Steady-state solutions for the model are derived and results of the numerical simulations are given to show that heavy metals in the soil are removed by this method in the long run.

Installation of an Innovative Remedial Technology
Hines, B.
CDM Federal Programs Corp., Kevil, KY
Proceedings: Superfund 16, Volume 1: Hazardous Waste Conference and Exhibition: New Frontiers in Hazardous Waste, Washington, DC 6-8 Nov 1995 pp 228-234
Publisher: Bethesda, MD E.J. Krause and Associates 1995
Report Number(s): CONF-951139

The major goal of the LASAGNA project was to design, construct, install, and operate an in situ remediation system in low-permeability soil. A new technology--the Lasagna process--uses electro-osmosis to move contaminated groundwater through treatment zones. The treatment zones are installed in contaminated soils, thereby forming an integrated in situ remedial process. Electro-osmosis, well known for its effectiveness and extremely low power consumption, uses a direct current to cause Groundwater to travel through low-permeability soil. When a bench-scale version of the technology was 98 percent effective in removing contamination, an actual field test was the next step. The site chosen for this first field effort was the DOE-owned Paducah Gaseous Diffusion Plant located in Paducah, Kentucky. The target contaminant for this project was trichloroethylene (TCE) because it is found at many sites across the country and is present at approximately 60 percent of DOE's sites.

Electrokinetic Remediation. II. Amphoteric Metals and Enhancement with a Weak Acid
Wilson, David J.; Rodriguez-Maroto, Jose Miguel; Gomez-Lahoz, Cesar
Vanderbilt Univ, Nashville, TN
Separation Science and Technology Vol 30 No 16 Sep 1995 p 3111-3128

A one-dimensional model is developed for the electrokinetic treatment of aquifers contaminated with an ionic salt. Electrokinetic removal of amphoteric metals such as zinc and lead is simulated. The use of a weak acid (acetic acid) to neutralize a portion of the OH- generated electrolytically in the cathode compartment is explored in connection with the electrokinetic removal of nonamphoteric metals such as copper and cadmium. (Author abstract) 10 Refs.

Challenges Involved in Moving Electrokinetic Technology from Lab to Field
SenGupta, A.K.
ISOTRON Corporation, New Orleans, LA
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 pp 678-679
Publisher: Washington, DC: American Chemical Society 1995
Report Number(s): CONF-9509139

This paper summarizes problems likely to be encountered in electrokinetic remediation of soil. Issues identified are primarily engineering design difficulties involved in expanding applications from lab-scale to full-scale. Problems discussed include insolubility of contaminants, design of an electrode configuration that ensures a fairly uniform electric field, optimizing electrode spacing, counteracting electroosmotic water loss, electrode buffering, and structural integrity and ion conductivity of the electrode assembly.

Advances in Electro-Reclamation
Lageman, R.; Pool, W.
Geokinetics, Rhenen (Netherlands)
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management
Atlanta, GA 17-20 Sep 1995 p 650
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

Electro-Reclamation stands for a clean-up technology which can cope with most of today's soil and groundwater contamination problems. Electro-Reclamation encompasses a number of techniques. They are based on the use of electrical current, which enhances desorption and transport of contaminants in combination with soil vapour extraction, groundwater extraction and biodegradation. For in and ex situ removal of inorganic contaminants, a direct (DC) current is sent through the soil by means of alternating cathode and anode arrays. For the remediation of soils and groundwater contaminated with petroleum hydrocarbons and other organic compounds electro-reclamation can be combined with bio-reclamation or with soil vapour and groundwater extraction. An alternative which combines containment, remediation and prevention is electrokinetic fencing. With an electrokinetic fence it is possible to capture polar contaminants, influence pH and redox potential near the fence, increase temperature and introduce micro-organisms into the soil/groundwater.

The Capture and Destruction of Chlorinated Solvents via Electrokinetic Pumping: the LASAGNA Process
Salvo, J.J., GE Corporate Research and Development, Schenectady, NY;
Ho, S.V., Monsanto Company, St. Louis, MO;
Shoemaker, S.H., DuPont Engineering, Houston, TX
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management
Atlanta, GA 17-20 Sep 1995 p 469
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

Remediating soils and groundwater that have been contaminated with chlorinated solvents is a significant challenge for current environmental technology. Soils with a high proportion of fine silts and clays have been especially recalcitrant due to their low permeability. Recently, electrokinetics has shown great promise in gaining access to these contaminated zones that fail to yield with traditional pumping methods. An integrated approach using electrokinetics combined with in situ capture and destruction zones (LASAGNA (trademark)) is being developed and field tested by Monsanto, DuPont and GE under the auspices of the EPA's Remediation Technology Development Forum and with financial support from the Department of Energy. To speed implementation and encourage partnering, royalty-free cross-licensing of the developed technology is available to consortium members for use on their sites.

Electrokinetic Soil Remediation: Advances and Process Enhancement
Hodko, D.; Franaszczuk, K.; Rogers, T.D.
Lynntech, Inc., College Station, TX
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management
Atlanta, GA 17-20 Sep 1995 p 870
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

Electrokinetic remediation is an in situ emerging technology that offers potential cost and process benefits for contaminated soil treatment. The innovative approach under development at Lynntech, Inc. is based on the application of nonhomogeneous pulsed DC or AC electric fields with the objective to maximize rates of contaminant removal. The process combines several DC and AC electrokinetic phenomena occurring in soil when pulsed electric fields are applied across the electrodes positioned in the soil and utilize them for an enhanced contaminant removal from soil. Removal of contaminants is achieved by: (I) electroosmotic pore fluid flow; (ii) electromigration of anionic and cationic contaminants towards electrode wells, where they can be removed by electrodeposition, and, (iii) dielectrophoretically induced pore fluid flow and migration of charged and noncharged contaminants through the soil. Successful combination of DC and AC electrokinetic phenomena in soil presents a basis for an enhanced electrokinetic process for removal of both charged and noncharged contaminants from soil. The process utilizes an electrochemically produced acid in the anode well which propagates through the soil and solubilizes heavy metal ions in the pore fluid. A leachant appropriate for the type of soil and heavy metal contaminant, is electrokinetically delivered and distributed in soil to further enhance solubilization and mobilization of heavy metal contaminants through the soil. It can be efficiently combined with other existing in situ contaminated soil treatment processes, e.g. bioremediation, soil extraction and soil washing. A field scale study is initiated in 1995 and preliminary results will be described.

The Use of Electrokinetics, EDTA, and Flushing Solutions in the Removal of Lead from Kaolin Clay

Coletta, T.F.; Bruell, C.J.; Ryan, D.K.
Univ. of Massachusetts, Lowell, MA

Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management Atlanta, GA 17-20 Sep 1995 pp 462-465
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

The use of electrokinetics in conjunction with anodic and complexant-bearing cathodic flushing solutions was studied to determine its efficiency in removing lead from clay. Experiments were conducted in a horizontal soil column apparatus with Kaolin clay. Anodic flushing solutions were prepared by mixing water and clay in rations ranging from 2:1 to 40:1 by weight. To decrease the pH (and therefore lead buildup) at the cathode, the cathode was flush with an EDTA solution. A total organic carbon analysis was performed to determine if the EDTA was migrating back into the clay column. Results showed that lead removal efficiency increased with an increasing water to clay ratio to an optimum ratio of 7:1. In addition, increasing the time of cathode flushing to four days with EDTA at pH 4 increased lead removal at the cathode end. Lead removal at the cathode is higher than in columns flushed with sodium chloride and ionic solutions. Flushing the cathode for 10 days resulted in decreased overall lead removal efficiency. This is possibly due to precipitation of EDTA at the low final pH distribution. EDTA does migrate back into the column, and high concentrations are associated with significant lead removal at the cathode end. It appears that the optimization of the elemental constituents of the anodic flushing solution in conjunction with the proper conditioning of the cathode with complexants enhances lead removal from Kaolin clay.

Thermal Analysis of Electrokinetic Remediation
Shapiro, A.P., General Electric Corporate Research and Development, Schenectady, NY;
Schultz, D.S., Dupont Central Research and Development, Newark, DE
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management
Atlanta, GA 17-20 Sep 1995 pp 457-460
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

A mathematical model which predicts the thermal behavior of electrokinetic remediation is described. Three model simulations are summarized and compared to pilot test measurements. The model shows that constant applied current should lead to a relatively constant flow rate and decreasing power consumption, whereas constant voltage will lead to increasing electroosmotic flow and increasing power consumption. While steady-state thermal conditions were not reached in the 100-day pilot test, the constant current case simulations approach steady-state temperature distribution much sooner than constant voltage cases. Commonly used electric fields in laboratory experiments of about 100 V/m appear to cause excessive heating in field scale applications.

Electrokinetic Remediation of Anionic Contamination from Unsaturated Soil: Field Application
Lindgren, E.R.; Mattson, E.D.
Sandia National Labs., Albuquerque, NM
Proceedings: ACS Special Symposium: Emerging Technologies in Hazardous Waste Management
Atlanta, GA 17-20 Sep 1995 p 456a
Publisher: Washington, DC American Chemical Society 1995
Report Number(s): CONF-9509139

Electrokinetic remediation is an in situ technique under development at Sandia National Laboratories for removal of ionic contaminants from soil. While to date most other studies of this technique have focused on saturated soils, usually clays, the work at Sandia has been to extend the process to unsaturated sandy soils typical of arid regions. The impetus for this study is a chromate plume located beneath an old Sandia chemical waste landfill. Working in unsaturated soils is complicated by moisture control requirements, both to prevent undesired hydraulic transport of contamination outside the treatment zone and to optimize soil properties for efficient electrokinetic remediation. Two field tests will be discussed. First, a field test in clean soil is in progress to demonstrate moisture control with the Sandia electrode system. The second field demonstration, planned to begin the Fall of 1995, involves chromate removal from a in a chemical waste landfill.

Electrokinetic Remediation: I. Modeling of Simple Systems
Wilson, D.J., Vanderbilt Univ., Nashville, TN;
Rodriguez-Maroto, J.M.; Gomez-Lahoz, C., Universidad de Malaga (Spain)
Separation Science and Technology Vol 30 No 15 Sep 1995 pp 2937-2961

A one-dimensional model is developed for simulating the electrokinetic treatment of saturated porous media contaminated with an ionic salt. Simulations of simple, unenhanced electrokinetic treatment for the removal of a nonamphoteric salt such as cadmium sulfate exhibit a severe drop-off in electric current and in remediation rate after about 50-60% of the cation has been removed. Simulation of electrokinetic treatment in which the OH- generated in the cathode compartment is partially neutralized by the addition of acid show rapid and complete removal of the cation. Partial neutralization of H+ in the anode compartment by addition of base results in immobilization of the toxic metal as the solid hydroxide, although this should be a useful technique for the removal of arsenate and selenate.

Electrokinetic Remediation: Technology Status

Acar, Y.B., Louisiana State Univ., Baton Rouge, LA;
Alshawabkeh, A.; Gale, R.J., Electrokinetics, Inc., Baton Rouge, LA

Proceedings: 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium, Cincinnati, OH 4-6 Apr 1995 pp 129-133
Publisher: Environmental Protection Agency 1995
Report Number(s): CONF-9504110

The demand to develop innovative and cost-effective in-situ remediation technologies in waste management stimulated the effort to employ conduction phenomena in soils using an electric field to remove chemical species from soils. This technique variably named as electrokinetic remediation, electro-reclamation, electrokinetic soil processing, electrochemical decontamination, electrorestoration or electrochemical soil processing uses low-level DC in the order of mA/cm2 of cross sectional area between the electrodes or an electric potential difference in the order of a few volts per cm across electrodes placed in the ground in an open flow arrangement. The low-level DC results in physico-chemical and hydrological changes in the soil mass leading to species transport by coupled and uncoupled conduction phenomena in the porous media. Electrolysis reactions prevail at the electrodes. The species input into the system at the electrodes (either by the electrolysis reactions, or through the cycling processing fluid) and the species in the pore fluid will be transported across the porous media by conduction phenomena in soils under electric fields. This transport coupled with sorption, precipitation and dissolution reactions comprise the fundamental mechanisms affecting the electrokinetic remediation process. Electrokinetics Inc. of Baton Rouge has completed large-scale pilot studies using spiked and naturally contaminated soil deposits under the USEPA SITE program. In collaboration with the US Army Waterways Experiment Station, Electrokinetics Inc. is currently carrying out a field study of extracting lead from soils at a Firing Range that belongs to the US Army. This demonstration study will be independently evaluated by the USEPA under the SITE program. The purpose of this paper is to present some of the recent developments in this technique and to outline the ongoing activities.

Electrokinetic Soil Remediation: Impact of Aqueous Phase Properties on Soil Surface Charge and Electroosmotic Efficiency

Vane, L.M.; Zang, G.M.
Environmental Protection Agency, Cincinnati, OH

Proceedings: 21st Annual Risk Reduction Engineering Laboratory (RREL) Research Symposium, Cincinnati, OH 4-6 Apr 1995 pp 202-206
Publisher: Environmental Protection Agency 1995
Report Number(s): CONF-9504110

The electrokinetic remediation of soils is described. The effect of pore fluid properties on the surface charge of clays was examined. Zeta potential results indicate that the electro-osmotic efficiency (flow/voltage ratio) in bentonite should be relatively insensitive to pH and ionic strength variations. The zeta potential of kaolinite, however, was found to be quite sensitive to pH. The electro-osmotic efficiency for kaolinite was found to be equally sensitive to pH. Zeta potential results further indicate that the electro-osmotic efficiency as well as the direction of electroosmosis in kaolinite will be impacted dramatically by the presence of metal cations. These results suggest that zeta potential measurements could be used to study the impact on electro osmotic efficiency of initial site conditions as well as conditions expected during an electrokinetic remediation process.

Electrokinetic Treatment of Hazardous Wastes in Soil and Groundwater
Loo, W.W.
Environment Technology Services, San Francisco, CA
Proceedings of HAZMACON '95: Hazardous Materials Management Conference and Exhibition, San Jose, CA 4-6 Apr 1995 pp 147-158
Publisher: Oakland, CA: Association of Bay Area Governments 1995
Report Number(s): CONF-9504134

Electrokinetic (EK) treatment processes are recognized by the US department of Defense, US Department of Energy, and the US EPA as the most potentially cost effective treatment of hazardous wastes. Recently, EK has attracted the attention of Dupont, General Electric, and Monsanto for various aspects of hazardous waste treatment. Electrolysis and electro-osmosis are known electrokinetic processes. Electrolysis is one of the principal industrial process used in the production of aluminum, chlorine, metal plating, welding, corrosion protection, etc. Electro-osmosis is a very well established process used to dewater and stabilize the clayey foundations of buildings and structures. These processes are very effective in the treatment of hazardous metals and organic compounds in soil, sludge, and water. Electrolysis can be applied in both permeable and impermeable media. It can be used as a neutralization process for pH control. It can also be used for the isolation or capture of metallic ions, or positively charged ions, at and near the cathode electrode. and negatively charged ions at and near the anode electrode. Electrolyis will also oxidize petroleum hydrocarbons and benzene-based organic chemicals such as PCBs, pesticides, and PAHs. Electro-osmosis can be used in the treatment of hazardous chemicals in silty and clayey material. The electro-osmotic process causes and imbalance of charge bonds in clayey material that results in clay compaction and chemical desorption. The compaction and desorption processes will reduce the cleanup time and are particularly successful in the desorption of organic chemicals and metals from clayey materials. This accelerates and improves the performance of typically inefficient pump and treat projects. Electrokinetic processes can be applied both above ground (ex situ) or in the subsurface (in situ).

Utilization of Solubilizing and Stabilizing Agents in Electrokinetic Processing of Soils
Weeks, Antoinette; Pamukcu, Sibel
Lehigh University, Bethlehem, PA
Proceedings: Hazard and Industrial Wastes: 27th Mid-Altantic Ind Waste Conference, July 9-12, 1995 pp 824-935
Publisher: Bethlehem, PA: Technomic 1995
(Full text available from Congressional Information Service: 1-800-227-2477)

Electrokinetic treatment uses electroosmosis-electrophoresis and ion migration to enhance the transport in and removal of heavy metals from soil. Two applications are examined to enhance electrokinetic treatment: enhancement and control of the transport, and collection or in situ stabilization of the targeted contaminants. The solubilization agent examined was poly lactic acid (PLA), an agricultural by-product currently utilized in polymerization technologies. Results from batch tests indicated that PLA improved the extraction of lead, nickel, and zinc, with Zn being the most and consistently affected regardless of the soil matrix. In addition, electrokinetically injected bivalent iron into a soil matrix containing hexavalent chromium facilitated the reduction of Cr(V), since the electrokinetic process produced low pH conditions.

Electrokinetic (EK) Remediation of a Fine Sandy Loam: the Effect of Voltage and Reservoir Conditioning

Ramsey, Joel; Reed, Brian
West Virginia University, Morgantown
Proceedings: Hazard and Industrial Wastes: 27th Mid-Altantic Ind Waste Conference, July 9-12, 1995 pp 804-814
Publisher: Bethlehem, PA: Technomic 1995
(Full text available from Congressional Information Service: 1-800-227-2477)

The electrokinetic (EK) soil flushing process was used to remove lead from an artificially contaminated soil system. The effect of voltage and reservoir conditioning on energy expenditure and time required for Pb removal was investigated. The EK process involves the application of a DC current to the soil to promote water and contaminant movement: cations are attracted to the negatively charged cathode, and anions are attracted to the positively charged cathode. The soil used in the study was classified as a galen fine sandy loam, which was contaminated with Pb at a concentration of 1000 mg/kg of dry soil. Results indicated that the 60 v tests were more than 100% faster at removing 250 mg/kg of the initial 1000 mg/kg than 30 v. However, as the amount of Pb removed increased, the difference in time between the 30 and 60 v tests to achieve the specified removal decreased. The increase in energy expenditure from 30 to 60 v ranged from 63% at 500 mg/kg removal to 150% at 750 mg/kg removal. The addition of acid to the reservoirs had a significant effect on the extent and rate of Pb removal.

Electrokinetic Decontamination of Millpond Sludge
Khan, Lutful I.; Rahman, M.
Cleveland State University, OH
Proceedings: Hazard and Industrial Wastes: 27th Mid-Altantic Ind Waste Conference, July 9-12, 1995 pp 795-796
Publisher: Bethlehem, PA: Technomic 1995
(Full text available from Congressional Information Service: 1-800-227-2477)

The electrokinetic decontamination of high clay-containing soils, which has been designated by EPA as a viable in situ process, involves the inducement of a high water flow rate in soils by electroosmosis. The technology is primarily suitable for heavy-metal removal. Results are presented from a study that examined the electrokinetic decontamination of a soil with high organic-matter content. The foundry millpond sludge was contaminated with zinc, lead, and manganese. Decontamination was carried out for 5, 10, and 20 d. Within 20 d, about 90 and 35% of Pb and Zn, respectively, were extracted using tap water as influent. When 0.02 M sodium-EDTA solution was used as influent, the electroosmotic flow increased, but increased metal extraction was not observed. The high pH of the sample may have been the cause for the immobility of Zn and Mn.

1994:

Complicating Features of Electrokinetic Remediation of Soils and Slurries: Saturation Effects and the Role of the Cathode Electrolysis
Ugaz, A.; Puppala, S.; Gale, R.J.; Acar, Y.B.
Louisiana State Univ, Baton Rouge, LA
Chemical Engineering Communications Vol 129 1994 pp 183-200

Electrokinetic soil processing is an emerging technology for decontamination of certain radionuclides, heavy metals, or organic species from soils or slurries. Tests reveal that the process efficiencies in partially saturated kaolinite samples (without contaminants) are high, since water supplied at the anode eventually flushed across the specimens and saturated the deposits. Consolidation settlements are expected in the vicinity of anodes in fine-grained soils, even when both electrodes allow ingress or egress of the water. Uranylion at 1000 pCi/g could be effectively removed from kaolinite but the removal efficiency decreased close to the cathode due to the high pH in this region. A yellow uranium hydroxide precipitate was collected at the cathode. Thorium ion, even at 300 pCi/g, could not be efficiently removed throughout the cell because of its high adsorptive capacity, facile hydrolysis, and the precipitation of insoluble hydroxide. Methods are required to prevent hydroxide ion formation by the cathode reduction of water and thus enable extraction of these metal species in soluble forms. (Author abstract) 19 Refs.

Passive In-Situ Cometabolic Biotreatment of Gasoline and Diesel in Soil and Groundwater: An Electrokinetic Enhanced Bioremediation Case History
Loo, W.W.
Environment and Technology Services, San Francisco, CA
Proceedings: Volume 2: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 1558-1565
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

This paper presents the results of passive in-situ biotreatment of gasoline and diesel conducted at the subject facility in Hayward, California. Past spills of petroleum hydrocarbon fuels from an underground storage tank farm caused soil and shallow groundwater contamination in the clayey Bay Mud. The soil contamination was limited to a depth of about 10 feet with total petroleum hydrocarbons (TPH) concentration of 100 to 3,900 ppm. Due to the low permeability of the clayey Bay Mud, a passive in-situ biotreatment (PISB) system was designed and implemented for both soil and groundwater plumes. The PISB consisted of a system of electrokinetic, oxygen, nutrient and moisture enhancement units covering the soil and groundwater plumes. The electrokinetic system was installed to promote rapid migration of nutrient oxidant between electrodes to enhance the in-situ biodegradation processes. The gasoline and diesel in soil was remediated to less than 100 ppm of TPH. The TPH in groundwater was remediated to less than 10 ppm of TPH. The TPH in groundwater was remediated to less than 10 ppm. The groundwater remediation is in progress and the target cleanup levels were to be less than 10 ppm TPH and BTEX to less than 0.005, 1.0, 0.7 and 10.0 ppm respectively which are all below the MCL under the EPA primary drinking water standard. The total duration of this PISB was completed in less than 4 weeks.

Electrokinetic Enhanced Bioventing of Gasoline In Clayey Soil: A Case History
Loo, W.W.; Wang, I.S.; Fan, J.
Environment and Technology Services, San Francisco, CA
Proceedings: Volume 2: SUPERFUND XV: 15th Environmental Conference and Exhibition for the Hazardous Materials/Hazardous Waste Management Industry, Washington, DC, 29 Nov - 1 Dec 1994 pp 1566-1574
Publisher: Rockville, MD Hazardous Materials Control Resources Institute 1994
Report Number(s): CONF-941189

This paper presents a case history on the bioventing of gasoline in soil with electrokinetic enhancement. The gasoline in soil was related to a 10,000-gallon underground storage tank spill, San Diego, California. The gasoline soil plume covers an area of about 2,400 square feet and to a depth of about 30 feet. The upper 15 feet of the soil plume consists of highly conductive marine clay. The lower 15 feet of the soil plume consists of dense cemented conglomerate sandstone. The gasoline concentration in the soil plume range from 100 to 2,200 mg/Kg(ppm) and the target cleanup level is below 100 ppm. Total gasoline in soil plume is estimated at about 1,000 pounds of gasoline in about 3,500 tons of soil. The soil remediation effort was completed after about 90 days of treatment. The concentration of gasoline in soil after treatment was way below the proposed cleanup level of less than 100 mg/Kg(ppm). The cost of treatment is about $50 per ton for this advanced soil treatment process which provides a cost effective solution to this soil plume with minimum disruption to business operation at the facility.

Electrokinetic Removal of Coal Tar Constituents from Contaminated Soils
Pamukcu, S., Lehigh University, Bethlehem, PA. Dept. of Civil Engineering;
Electric Power Research Institute Palo Alto, CA
Mar 1994 (200 p)
Report Number(s): EPRI-TR-103320

Laboratory studies on soil cores collected from a former manufactured gas plant (MGP) site demonstrated that electrokinetic processes can facilitate the transport and removal of coal tar constituents from contaminated soils. Further development of the method is required to determine if electrokinetics can be used on a field scale to provide a reliable method for in situ remediation of MGP sites.

Electrokinetics; An Innovative Technology for In-Situ Remediation of Heavy Metals
Mattson, Earl D.; Lindgren, Eric R.
New Mexico Institute of Mining and Technology, Socorro, NM; Sandia National Laboratories
Proceedings: Eighth National Outdoor Action Conference and Exposition; Aquifer Remediation/Ground Water Monitoring/Geophysical Methods, Minneapolis, MN, May 23-25, 1994 Ground Water Management Vol 18 1994 pp 235-245

Abstract not available.

1993:

Lab-Scale Investigation of In-Situ Electrokinetics
Hatfield, Jarrod H.; Thompson, John C.; Reed, Brian E.; Berg, Mitchell T.
West Virginia Univ, Morgantown, WV
Proceedings: 25th Mid-Atlantic Industrial Waste Conference, College Park, MD, July 07-09, 1993 pp 55-64
Publ by Technomic Publ Co Inc, Lancaster, PA 1993

There is a need for cost effective and more efficient technologies that can be used to remediate low permeability soils in-situ. A candidate technology for the remediation of low permeability soils is electrokinetic (EK) flushing. Research conducted thus far has demonstrated that electrokinetic flushing is effective in solubilizing and transporting Pb retained on fine grained soils. Primarily, removal of Pb is due to the acid front generated at the anode migrating across the soil specimen. The electroosmotic flow carrier the Pb(II) toward the cathode until regions of high pH are encountered. These regions correspond to areas of the soil sample that have no been completely flushed by the acid front. In these areas, the Pb(II) removed by the acid front near the anode is precipitated and adsorbed to soil particles. Corresponding to work by Hamed et al, this research suggests that the efficiency of Pb removal is directly related to the extent of the acid front migration. 5 Refs.

1992:

Travel to The Netherlands and Russia to Assess Electrokinetic Technology As it is Being Applied to The Remedial Treatment of Metal-Contaminated Soils and Groundwater
Adams, R.E.
USDOE Oak Ridge Field Office, TN
January 1992 65 p
Report Number(s): DOE/FTR-93018609 Order Number: DE93018609

The purpose of this trip was to serve as a member of an evaluation team composed of the Department of Energy DOE and DOE contractor personnel to evaluate and assess the state of international electrokinetic technology as it is being applied to the remedial treatment of metal-contaminated soils and groundwater. This travel was requested by the DOE Office of Technology Development OTD to determine whether electrokinetic technology research, development, and field demonstrations on foreign soils and groundwater have applicability for the remediation of metal contamination at DOE sites.

Travel to Europe to Evaluate Electrokinetic Technology Applications to Remedial Treatment of Metal Contaminated Soils and Groundwater
Tyler, L.D.
Sandia National Labs., Albuquerque, NM
March 1992 8 p
Report Number(s): DOE/FTR-93015529 Order Number: DE93015529

The purpose of this trip was to serve as a member of an evaluation team composed of the Department of Energy DOE and DOE contractor personnel to evaluate and assess the state of international electrokinetic technology as it is being applied to the remedial treatment of metal contaminated soils and groundwater. This travel was requested by DOE Office of Technology Development OTD to determine whether electrokinetic technology research, development, and field

demonstrations on foreign soils and groundwater have applicability for the remediation of metal contamination at DOE sites.

A Trip to Russia to Study Field Applications of Electrokinetics For The Remediation of Both Uranium and Mercury Contamination of Soils
Adams, R.E.
Martin Marietta Energy Systems, Inc., Oak Ridge, TN
Sponsoring Organization: DOE USDOE, Washington, DC
October 1992 8 p
Report Number(s): DOE/FTR-93011659 Order Number: DE93011659

Purpose of this trip was to learn of latest results in projects being conducted in three states of the former Soviet Union on field applications of electrokinetics for the remediation of both uranium and mercury contamination of soils. Technologists from the states of Russia, Uzbekistan, and Kazakhstan are cooperating in these field applications. A new organization called Energopool has been formed within the Research and Development Institute of Power Engineering RDIPE in Moscow to coordinate electrokinetic activities.

1991:

Travel to The Netherlands and Russia to Assess International Electrokinetic Technology as Applied to Remedial Treatment of Metal-Contaminated Soils and Groundwater
Adams, R.E.
Martin Marietta Energy Systems, Inc., Oak Ridge, TN
1991 59 p

The purpose of this trip was to serve as a member of an evaluation team composed of the Department of Energy DOE and DOE contractor personnel to evaluate and assess the state of international electrokinetic technology as it is being applied to the remedial treatment of metal-contaminated soils and groundwater. This travel was requested by the DOE Office of Technology Development OTD to determine whether electrokinetic technology research, development, and field demonstrations on foreign soils and groundwater have applicability for the remediation of metal contamination at DOE sites.

Effect of Dissolved Mineral Species on the Electrokinetic Behaviour of Sulfides
Acar, S.; Somasundaran, P.
Columbia Univ, New York, NY
Minerals Engineering Vol 5 No 1 1991 pp 27-40

The effect of mineral species of selected sulphide minerals namely, synthetic covellite, millerite and pyrrhotite is investigated in this study using the electrokinetic technique. Tests in inorganic solutions showed that surface reactions and/or bulk precipitation could be responsible for the changes in the zeta potential of above mentioned minerals. Author abstract 9 Refs.

Electrokinetic Phenomena of the Second Kind and Their Applications

Dukhin, S. S.

Advances in Colloid and Interface Science Vol 35 Mar 1991 pp 173-196

The special features of the concentration polarization generated by an electric current passing through the boundary separating two conducting media are considered. When the electric current is strong a bulk charge is induced inside the concentration polarization zone. In the case of curved interfaces this charge is determined by the normal component of the external electric field. The tangential component of the external electric field exerts a force on this bulk charge, leading to liquid movement along the interface; this process is analogous to electro-osmotic slip. It is predicted that due to these charges conducting particles move in external electric fields. This phenomenon is called electrophoresis of the second kind. An approximate theory for this phenomenon is proposed and experimentally verified. Possible applications of electrokinetic phenomena of the second kind are discussed. Author abstract 18 Refs.