(1996b) Specification of Sediment Maintenance Flows for a Large Gravel-Bed River. *Water Resour. Res.,* **32,** 9, 2911.

Wilkin, R.T.; Barnes, H.L.; and Brantley, S.L. (1996) The Size Distribution of Framboidal Pyrite in Modern Sediments: An Indicator of Redox Conditions. *Geochim. Cosmochim. Acta* (G.B.), **60,** 3897.

Wilkins, A.L.; Davidson, J.A.C.; Langdon, A.G.; and Hendy, C.H. (1996a) Sodium, Calcium, and Resin Acid Levels in Ground Water and Sediments from Two Sites Adjacent to the Tarawera River, New Zealand. *Bull. Environ. Contam. Toxicol.,* **57,** 575.

Wilkins, A.L.; Thandi, M.S.; and Langdon, A.G. (1996b) Pulp Mill Sourced Organic Compounds and Sodium Levels in Water and Sediments from the Tarawera River, New Zealand. *Bull. Environ. Contam. Toxicol.,* **57,** 434.

Wilson, J.P., and Gallant, J.C. (1996) Eros: A Grid Based Program for Estimating Spatially-Distributed Erosion Indices. *Comput. Geosci.,* **22,** 707.

Wu, J., and Luther, G.W., III (1996) Spatial and Temporal Distribution of Iron in the Surface Water of the Northwestern Atlantic Ocean. *Geochim. Cosmochim. Acta* (G.B.), **60,** 2729.

Wu, J.S.; Holman, R.E.; and Dorney, J.R. (1996) Systematic Evaluation of Pollutant Removal by Urban Wet Detention Ponds. *J. Environ. Eng.,* **122,** 983.

Wu, Q.; Bedard, D.L.; and Wiegel, J. (1996) Influence of Incubation Temperature on the Microbial Reductive Dechlorination 2,3,4,6-Tetrachlorobiphenyl in Two Freshwater Sediments. *Appl. Environ. Microbiol.,* **62,** 4174.

Xiouzhu, Z.; Yunfei, W.; and Huaiyan, L. (1996) Authigenic Mineralogy, Depositional Environments and Evolution of Fault-Bounded Lakes of the Yunnan Plateau, South-Western China. *Sedimentology,* **43,** 367.

Yamazaki; Tsurusake; and Chung (1996) Geotechnical Properties of the Pacific Seamount Sediments Measured by a Gravity Corer. *Mar. Geosour. Geotechnol.,* **14,** 3.

Yu and Song (1996) Sedimentary Features of Shelf North of Taiwan Revealed by 3.5 kHz Echo Character. *Acta Oceanogr. Taiwan,* **35,** 2, 105.

Yu, K.-C.; Ho, S.-T.; Tsai, L.-J.; Chang, J.-S.; and Lee, S.-Z. (1996) Remobilization of Zinc from Ell-Ren River Sediment Fractions Affected by EDTA, DTPA and EGTA. *Water Sci. Technol.* (G.B.), **34,** 7-8, 125.

Zamora, J.V.M. (1996) Distribution of Hydrocarbons in Recent Marine Sediments off the Coast of Baja California. *Environ. Pollut.* (G.B.), **92,** 45.

Zelilidis, A., and Kontopoulos, N. (1996). Significance of Fan Deltas Without Toe-Sets Within Fift and Piggy-Back Basins: Examples From the Corinth Graben and the Mesohellenic Trough, Central Greece. *Sedimentology,* **43,** 253.

Zhang, D., and Neuman, S.P. (1996) Effect of Local Dispersion on Solute Transport in Randomly Heterogeneous Media. *Water Resour. Res.,* **32,** 2715.

Zhanh, H.; Chou, L.; and Wollast, R. (1996) Export of Dissolved Metals from the North Sea to the Channel: Additional Field Evidence. *Oceanol. Acta,* **19,** 183.

Zmudzinski (1996) The Effect of the Introduction of the American Species *Marenzelleria viridis* (Polychaeta: Spionidae) on the Benthic Ecosystem of Vistula Lagoon. *Mar. Ecol.,* **17,** 1-3, 221.

Zouhiri, S., and Dauvin, J.C. (1996) Diel Changes of the Benthic Boundary Layer Macrofauna over Coarse Sand Sediment in the Western English Channel. *Oceanol. Acta,* **19,** 141.

Zwolsman, J.J.G.; van Eck, G.T.M.; and Burger, G. (1996) Spatial and Temporal Distribution of Trace Metals in Sediments From the Scheldt Estuary, South-West Netherlands. *Estuarine Coastal Shelf Sci.,* **43,** 55.

Groundwater quality

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INTRODUCTION

In this review, papers considering fate and transport processes in groundwater systems are discussed first. The fate and transport process papers are divided among saturated systems, vadose zone systems, and systems containing nonaqueous-phase liquids (NAPLs). Within these categories, subdivisions are made between physical, chemical, or biological processes such as hydrodynamics, sorption-desorption, chemical reactions, and biodegradation. Next, papers concerning groundwater quality monitoring and groundwater remediation are divided among various techniques or specific phases. Papers that are concerned with general field studies of fate and transport are ordered by compound or source classifications. Finally, papers describing risk assessment and groundwater protection are discussed.

SINGLE-PHASE SYSTEMS

Hydrodynamics. *Dispersion Theory.* The permeability and dispersivities of solute and heat for a periodic medium were described by numerical solution of boundary value problems for unit cells (Lee, C.K., *et al.,* 1996). The cell problems were derived from the asymptotic theory of homogenization, which systematically accounts for the effects of pore-scale mechanics on the macroscale processes. Dilution of solute in two-dimensionally (2-D) periodic heterogeneous media was assessed by numerical simulation of advection-dispersion (AD) concentration fluctuations induced by advective heterogeneity (Kapoor and Kitanidis, 1996). The plumes became increasingly irregular with time, and at large times, the relative concentration fluctuations weakened.

Experimental models with two-, three-, and four-layer periodic heterogeneities were constructed to investigate the effect of heterogeneity size on the scale dependence of dispersion (Irwin *et al.,* 1996). Because the experimentally determined dispersion coefficients appeared to be scale dependent up to a distance of approximatley 20 to 30 times the size of the repeated heterogeneity group (hydraulic unit), it was concluded that a medium with periodic heterogeneity likely may be characterized by the scale of its hydraulic unit. A method based on piecewise bilinear functions was presented for upscaling of permeability in heterogeneous porous media (Nilsen and Espedal, 1996). Numerical results showed that this method conserves more of the heterogeneous fingering than classical block-based upscaling methods. It was shown that spatial upscaling may result in nonsymmetric large-scale permeability tensors, for which principal axes do not exist (Zijl, 1996). A symmetry approximation was introduced for the nonsymmetric permeability tensors that resulted in a difference between flux and transport direction.

Various non-Fickian transient dispersion relationships were discussed and rigorously derived from the equation of motion of a solute in a porous medium (Hassanizadeh, 1996). Under various simplifying assumptions, the generalized theory presented was found to agree with conventional Fickian theory as well as other non-Fickian relationships, and for nonconservative solutes, it was shown that the traditional dispersion tensor was affected by the rate of mass exchange of solute. Analytical solutions were obtained by the Fourier transform technique for the one-dimensional (1-D), 2-D, and three-dimensional (3-D) transport of a conservative solute injected instantaneously in a uniform groundwater flow (Zou *et al.,* 1996). These solutions account for dispersive nonlinearity caused by the heterogeneity of the hydraulic properties of aquifer systems and can be used as building blocks to construct solutions by convolution (principle of superposition) for source conditions other than slug injection.

The pore tree model of pore structure, originally developed to allow coupled reactions and diffusions into and out of nonpermeable porous media in the absence of convection, was extended to describe the permeable pore structure that characterizes the subsurface transport of gas and water in soil, the dispersion of contaminants, and *in situ* remediation (Simons, 1996). The extended pore tree model successfully explained measurement errors in permeability resulting from scale size and successfully predicted the bulk gaseous diffusivity in partially saturated soil. The dependence of the anisotropy factor for different diffusive and convective transport mechanisms on the direction-dependent connectivities and pore size distribution was investigated using a uniaxial, anisotropic simple cubic lattice (Friedman and Seaton, 1996). It was found that while connectivity-induced anisotropy significantly affects transport coefficients in both directions, anisotropy induced by pore size distribution mainly affects the perpendicular transport coefficients.

The lattice Boltzmann equation (LBE) was developed to solve large-scale fluid flow and reactive transport in porous media (Zhao and Sykes, 1996). Flow and dispersion relaxation parameters in the LBE were correlated to fluid viscosity, pore structure parameters, and dispersion coefficients on a representative elementary volume. An error was pointed out in a previous paper where an incorrect data point was used in the weighted least-squares fit for regression formulas relating dispersivity and field scale (Al-Suwaiyan, 1996). The authors' reply indicated that, because this data point was characterized by the lowest reliability, the error has little influence on the regression equations, and their stated conclusions remain unchanged (Xu and Eckstein, 1996).

An experimental investigation was performed to determine if the phenomena predicted by new theories of dispersion in 1-D heterogeneous porous media were observable (Sternberg *et al.,* 1996). Results showed a newly observed phenomenon that was interpreted as a nonlocal effect and verified the new predictive theories. A review of experimental diffusion measurements was carried out to provide estimates of apparent diffusion coefficients for a range of elements of importance in the French high-level radioactive waste management program (Stenhouse *et al.,* 1996). The type of information that would enhance an understanding and interpretation of diffusion measurements on site-specific media also was outlined.

Capillary tube experiments were performed on the miscible displacement of a viscous fluid by a less viscous one (Petitjeans and Maxworthy, 1996). A diagnostic measure of the amount of viscous fluid left on the wall of the tube was found as a function of the Peclet (*Pe*) and Atwood numbers, as well as a parameter that was a measure of the relative importance of viscous and gravitational effects. In conjunction with this experimental work, numerical simulations were presented that identified two distinct *Pe* regimens, separated by a transitional region (Chen and Meiburg, 1996). For large values of *Pe*, a quasisteady finger forms before it starts to decay, and in the small-*Pe* regime, the flow decays from the start, approaching Taylor dispersion asymptotically. The effect of exchangeable cation—Na^+ and Ca^{2+}—on the diffusive transport of I^-, Sr^{2+}, and ^3H (as HTO) in compacted bentonite was examined using a through-diffusion method (Choi and Oscarson, 1996). The uncertainty in deterministic groundwater models resulting from the assumption of macrodispersive mixing was quantified for the Cape Cod and Borden natural-gradient tracer tests (Fitts, 1996).

Density Effects. A 3- and a 1-D model were developed to simulate unstable flow and mixing of variable-density fluids in a vertical, nominally 1-D homogeneous system (Liu and Dane, 1996a). In the 3-D model, the fluid flow and solute transport equations were solved numerically with a fine spatial discretization, whereas the 1-D numerical model was derived from a theoretical model to simulate the flow and mixing of fluids with variable density and viscosity at the field scale. Results showed that the 1-D model provides a good prediction of breakthrough curves (BTCs) and that the 3-D model was able to qualitatively simulate BTCs for highly unstable flow and mixing. A 3-D hydrogeochemical transport model coupled with a density-dependent groundwater-flow model was developed by using an iterative sequential approach (König, 1996). The hydrogeochemical transport model yields densities at each node, making it possible to update the flow model using the changed densities.

Closed-form solutions were derived for steady-state density-dependent fluid flow and solute transport problems in a 1-D vertical soil column (Park, 1996). Characteristics of density-dependent solutions, including effects of variations in density and the thickness of transition zones, were investigated, and nonuniform concentration profiles with vanishing density effects also were identified. A new criterion was proposed to predict gravitational instabilities in the transverse mixing zones at the bottoms of dense plumes in porous media (Liu and Dane, 1996b). This criterion was based on the existing π_1 number and a modified *Pe*, and results show that the criterion was useful for prediction purposes.

Laboratory studies were conducted to investigate the gravity-induced convection of fertilizer salts from surface-applied fertilizer bands when the water table approaches within 30 to 45 cm of the soil surface (Bonczek and McNeal, 1996). Implications were discussed concerning early-season fertilizer management in vegetable production regions of the southeastern Coastal Plain.

Transport in Fractured Rock. A numerical study was used to investigate contaminant transport in aquifers comprising fractured permeable formations (Rubin *et al.,* 1996a). Consideration was given to the evaluation of dispersion from both mixing between the fracture flow and the permeable block flow as well as longitudinal dispersion in the discrete fractures. Particle-tracking numerical simulations were used to examine the influence of matrix diffusion on solute transport in fractures (Rajaram, 1996). The transverse motion of a solute particle was simulated based on approximate probability distributions obtained by solving the coupled boundary value problem for diffusive exchange between the fracture and the surrounding matrix.

The conceptual and mathematical basis of a model for transport of nuclides in the geosphere was presented. It considered the effects of 1-D matrix diffusion, advection, linear sorption in the fractures and rock matrix, and radioactive decay (Barten, 1996). A linear response concept was developed for solution of the balance equations on the scale of a channel network, in the individual channels, and in the rock matrix adjacent to the channels. A new finite element (FE) code, TRIPOLY, was introduced that combines a fracture network simulator with a method to account for the diffusive interaction between the fractures and the adjacent matrix blocks (Birkholzer and Karasaki, 1996). The fracture network simulator uses a mixed Lagrangian-Eulerian adaptive gridding technique for the transport in fractures, whereas the fracture-matrix interaction was calculated with a method that was used successfully in the past for dual-porosity models.

A semidiscrete upwind FE method was used for the numerical solution of the transport equation in a fractured subsurface (Barlag and Zielke, 1996). The porous rock matrix was discretized by 3-D volumes, the discrete fractures by 2-D planes, the main pathways inside of the fractures by 1-D bars, and an *hr*-adaptive method was used to refine the mesh in the area of the moving sharp concentration fronts. A numerical model was formulated and used to investigate chloride migration in a chalk aquifer (Little *et al.*, 1996). A Galerkin FE method was used to solve the equations of flow and transport in the fissure system, where lateral advection and hydrodynamic dispersion were dominant, and a truncated series approximation to the analytical solution for 1-D diffusion was used to couple the fissure model to the surrounding porous matrix, where molecular diffusion was dominant.

Methyl tertiary butyl ether (MTBE) transport in a fractured dolomite aquifer of low matrix permeability was studied by creating a deterministic-stochastic fracture network model using the FRACMAN code (Hardisty and Schroder, 1996). Results show that wells hydraulically connected to a given fracture set may exert a significant influence on contaminant behavior, even at significant distances, whereas wells completed very close by, but not connected to the same fractures may exert little or no influence. A stochastic model of a fractured medium conditioned on a specific set of field data was developed, in which the more conductive fractures and the less permeable matrix were generated within the framework of a single-continuum stochastic model based on nonparametric indicator geostatistics (Tsang *et al.*, 1996). Simulations were carried out for 3-D transport from point tracer sources at hundreds of locations in the medium.

In an attempt to integrate field experiments, laboratory investigations, and modeling at possible sites for nuclear waste repositories, tracer migration experiments were performed during several years at Nagra's Grimsel Test Site in the Swiss Alps (Hadermann and Heer, 1996). Evaluation of the experimental results for nonsorbing and sorbing tracers showed that a consistent picture of tracer transport, and specifically tracer sorption, was obtained when exploiting all available experimental information and using models that were not overly simplistic. U transport at the Nopal I deposit in Chihuahua, Mexico, was studied to investigate mechanisms by which high-level waste (HLW) components could be transported through silicic tuff over long periods of time (Pearcy *et al.*, 1995). The results of this analysis suggest a ranking for U retention: microfracture network retention $\gg$ mesofracture retention and individual microfracture retention $\gg$ matrix retention.

A petrophysical and geochemical study of the El Berrocal experimental site in Spain was conducted to quantify the extent of radioelement migration/retention in the granite (Montoto *et al.*, 1996). Data on preferential fissure zones and uranium microdistribution were obtained and could be used for evaluating the retardation capacity of the crystalline rock matrix around a high-level radioactive waste repository. A natural analog study was presented that demonstrated the concepts of matrix diffusion and redox front entrapment to potential sedimentary host formations for an HLW repository in Switzerland (Mazurek *et al.*, 1996).

The usefulness of chemical extractions in the study of uranium migration through fractured rock was considered in light of the results of a natural analog study at Palmottu in southern Finland (Suksi *et al.*, 1996). The study provides more specific information on the fixation of U on silicate material and its sorption in rock pores. Rock column experiments were performed to examine the effects of matrix diffusion and hydrodynamic dispersion on the migration of radionuclides at the laboratory scale (Hölttä *et al.*, 1996). The numerical compartment model for advection and dispersion, with and without matrix diffusion, was used to interpret the tracer transport, and matrix diffusion behavior was distinguished from dominating hydrodynamic dispersion at the slowest water flow rates.

A radionuclide migration experiment was performed over a distance of 1 m in a natural fracture in a quarried block of granite (Vandergraaf *et al.*, 1996). It was observed that α-emitting radionuclides and rare-earth elements showed limited mobility, while the mobilities of ^{137}Cs and ^{85}Sr were higher than those of the rare-earth elements, and when samples of fracture-coating material were separated into fractions with different specific gravity, there was a clear indication of radionuclide association with mineral groups. Concentrations of ^{222}Rn in groundwater may vary considerably within megascopically homogeneous rocks over relatively short distances (Folger *et al.*, 1996).

Calculations were made in fractured Pikes Peak granite, indicating that different hydraulic apertures of water-bearing fractures may account for variations in dissolved ^{222}Rn measured in domestic water wells, assuming all other factors influencing dissolved ^{222}Rn are constant. Basic transport processes were formulated for the migration of a tracer slug in a fractured permeable formation (Rubin *et al.*, 1996b). Dimensionless parameters governing transport phenomena were identified, and a simplified conceptual model was employed for the quantitative evaluation of the physical phenomena associated with tracer migration in the domain.

Alternate formulations of the analytical modeling for contaminant transport in nonisothermal fractured porous media were presented in which transient and steady heat flows were coupled with solute transport, either implicitly as natural convection or explicitly as a Soret effect (Bai *et al.*, 1996). Two different dual-porosity conceptualizations of fractured porous media were proposed based on alternative assumptions of matrix flow. Further development of the fracture-matrix transport (FMT) code was presented that couples saturated porous medium advection and diffusion with mechanistic chemical models for speciation and interphase reactions (Novak, 1996). The latest version of FMT now allows for aqueous density to vary with phase composition and void volume to change as minerals dissolve and precipitate.

A 3-D variable-aperture fracture network model for flow and transport in fractured crystalline rocks was used to study the effects of large variability in fracture transmissivity on nonsorbing and sorbing tracer transport and scale effects in transport distance (Nordqvist *et al.*, 1996). The variable-aperture character of the fractures was introduced into the model through a library of single-fracture permeabilities and associated particle transport residence time spectra. A new FE formulation was presented for the numerical simulation of solute transport in fractured porous media that was characterized by high advection in fractures and slow diffusion in the matrix (Wendland and Schmid, 1996). This method consists of a two-step approach that results in a symmetric coefficient matrix and introduces artificial diffusion which acts only in the direction of flow.

Other Physical Processes. A multiple pore-region model was developed to assess the effects of interaggregate advection and diffusion on mass transport in structured soils (Gwo *et al.*, 1996). Sensitivity analyses indicated that time-dependent interaggregate advection and diffusion were important processes controlling physical nonequilibrium. A mathematical model was developed for solute transport in saturated porous media after an abrupt pressure impact (Sorek, 1996). The model focuses on two time intervals after the impact, showing that the pressure was distributed uniformly within the affected domain during the first time period, and during the second interval, the momentum balance equation for the fluid conforms to a wave form.

A model was proposed for coupling the 1-D transport of solute with surface precipitation kinetics, which induces the clogging of an initially homogeneous porous medium (Magnico, 1996). By focusing on the nonlinear feedback effect between the transport and the chemical reaction through the permeability of the medium, results showed that the competition between microscopic and macroscopic scales controls the clogging mechanism, which differs depending on whether short or long times were considered. A recently developed stochastic model that incorporates transiency of the piezometric head gradient was applied to the Borden site (Bellin *et al.*, 1996). It was found that the impact of transients on spreading was significant in the transverse direction, and the definition of a Fickian transverse dispersion coefficient may not be a simple task for transport occurring under natural flow conditions.

A 3-D integral finite difference (FD) simulator was presented for single- and multiphase flow of non-Newtonian fluids in porous/fractured media (Wu and Pruess, 1996). The methodology, architecture, and numerical scheme of the model were based on a general multiphase, multicomponent fluid and heat flow simulator, the TOUGH2 code. Preliminary numerical results were presented concerning the coupled effects of free thermal convection and mineral dissolution and precipitation on permeability heterogeneities (Bernard and Gouze, 1996). This study was conducted on a tilted porous layer embedded in an impervious surrounding of finite thermal conductivity and showed the importance of free thermal convection in creating, sharpening, or smoothing permeability heterogeneities.

Improvements in the classical boundary layer approximation method were presented and termed the top specified boundary layer (TSBL) approach (Rubin and Buddemeier, 1996a). The TSBL modification involves the specification of the contaminant concentration at the top of the contaminated region of interest and significantly improves the ability of the boundary layer method to predict the development of concentration profiles through both space and time. Contaminant transport in a system of leaky aquifers in Taiyuan, Sanxi Province, was modeled, with results agreeing well with observed data (Xue *et al.*, 1996).

A study was conducted for a hypothetical repository site in Bedfordshire, U.K., to illustrate the contribution that geostatistical techniques can make to risk assessment for buried waste repositories (Mackay and Cooper, 1996). Multiple realizations of the hydraulic properties of the principal aquifers were constructed, and for each realization, a numerical model was used to predict a possible pattern of migration. It was shown how stream and pseudopotential surfaces provide natural platforms for process visualization of groundwater flow and transport processes (Matanga, 1996). This was demonstrated on the 3-D groundwater flow beneath the Borden landfill. Perceived errors in a previous paper on the AD equation under recharge and variable velocity and its analytical solution were discussed (Su, 1996a). A response to this discussion was presented (Serrano, 1996).

Tracers and Isotopes. A mathematical model was developed to estimate the effect of backward spreading of an initial plume after introduction into an injection borehole (Chen, J.S., *et al.*, 1996a). It was concluded that the presence of backward movement of the initial plume in a radially convergent flow field yields a decrease of peak concentration and spreading of BTCs, which were significant for small *Pe* and can be neglected for large *Pe*. An improved boundary condition formulation was presented for use with convergent radial tracer tests (Zlotnik and Logan, 1996). The formulation of the boundary conditions was based on a more detailed analysis of the kinematic flow structure and tracer mass balance in the neighborhood of the injection well and its finite mixing volume.

Advective transport in a heterogeneous 2-D aquifer was simulated and quantified by the statistical moments of tracer travel time and transverse displacement, which depend on the statistics of the Lagrangian velocity given as a function of space rather than time (Cvetkovic *et al.*, 1996). Two empirical relationships were identified that, in combination with first-order results for the flow, capture the main features of nonlinear transport and appear to be robust for log transmissivity variance at least up to 1. A correction was made regarding the injection well mixing factor defined in a previous paper (Moench, 1996). A nonintrusive fluorescence imaging technique was introduced and used to measure quantitatively the pore geometry, fluid velocity, and solute concentration within a saturated, 3-D porous medium (Rashidi *et al.*, 1996). The approach illustrated how microscopic information can be measured, averaged, and used to characterize medium-scale processes.

The potential ecotoxicity of fluorescent dyes used in tracing, and their possible effects on human health, were evaluated using available toxicological information, test data on analogous substances, and mathematical expressions for biological activity (Field *et al.*, 1995). Simplified injection, sampling, and analytical procedures using dissolved gases as groundwater tracers were presented for use in saturated conditions at both the laboratory and field scales (Sanford *et al.*, 1996). Examples of the use of these methods at both scales were presented.

In situ neutron activation of ^{36}Cl was used as a hydrogeologic tracer in geologic deposits that have elevated concentrations of uranium (Cornett *et al.*, 1996). Two small-scale forced gradient tracer tests were conducted at the Horkheimer Insel field site to investigate the effects of reactive transport processes within a heterogeneous porous aquifer (Ptak and Schmid, 1996). The tracer test results will serve in future work for the validation of numerical stochastic transport simulations taking into account the spatial variability of hydraulic conductivity and sorption-related aquifer properties.

A methodology was presented for the conjunctive use of environmental and injected tracers to estimate direct precipitation recharge to a confined aquifer undergoing large withdrawal stress (Sukhija *et al.,* 1996a). Tracer experiments were conducted to assess *in situ* reaction and transport of NO_3-N within an imposed constant-flowing shallow groundwater system (Starr, J.L., *et al.,* 1996). A constant-head, single-injection well technique was adapted for the study using multilevel soil-water samplers placed at 14 locations around the center injection well.

The distribution of characteristics with depth in a heterogeneous aquifer was obtained using improved geophysical logging, a constant-rate discharge test, and point-dilution tracer test techniques (Newcomer *et al.,* 1996). Data results from these techniques were used to develop a conceptual model of a heterogeneous aquifer. Chemical and isotopic tracing was used to estimate spatial and temporal variability of recharge fluxes to an alluvial aquifer in the Var valley in southern France (Guglielmi and Mudry, 1996). The application of dissolved SF_6 as an injected conservative, nonreactive tracer in saturated media was examined (Wilson and Mackay, 1996b). For sand possessing significant intragranular porosity, SF_6 did not show persistent tailing as a result of physical nonequilibrium transport to the same degree as bromide, and no evidence of retardation was seen in sand with high organic carbon (OC) content.

Tritium, nitrate, and chloride tracers were used to study groundwater flow and recharge in the shallow groundwater across two loess hill slopes (O'Brien *et al.,* 1996). A new method was presented for the determination of the isotope composition and chemistry of groundwater in aquitards, where the effective porosities for each component can be determined concurrently (van der Kamp *et al.,* 1996). The method was based on diffusive exchange of water and solutes between groundwater in a cylindrical core of aquitard material and water in a reservoir placed along the axis of the cylinder. From this method, a model was developed for interpreting diffusional transport in porous geological materials (Novakowski and van der Kamp, 1996). The model accounts for radial diffusion, mass balance in the reservoir, linear adsorption, decay or transformations, and periodic abstraction of samples. Stable isotope and ^{14}C measurements of surface and groundwater samples were used to identify recharge areas and evaluate residence times and flow paths in the cold springs of the Hat Creek Basin in northeastern California (Rose *et al.,* 1996).

Groundwater isotope data across the Sacramento Valley, California, establish two types of groundwater mining (Criss and Davisson, 1996). Vertical profiles of $\delta^{18}O$ were used to constrain hydraulic conductivity in a thick, unfractured aquifer (Remenda *et al.,* 1996). Results indicated that conventional permeability tests in a very tight media tend to overestimate conductivity where advective transport is negligible and transport can be simulated with diffusion only. $\delta^{18}O$ and salinity data were integrated for studying recharge conditions of phreatic aquifers and tracing the flow paths of groundwater mixing in the Delhi area (Datta *et al.,* 1996a). This type of investigation will be useful to protect the groundwater resources from depletion and salinization. Stable isotope (^{18}O) and fluoride signatures in groundwater were examined to characterize the sources and controlling processes of fluoride contamination in groundwater in the Delhi area (Datta *et al.,* 1996b). The study indicated that approximately 50% of the area was affected by fluoride contamination beyond the maximum permissible limit.

The use of ^4He for dating groundwater as young as 10 years old was postulated (Solomon *et al.,* 1996). Both observations and modeling suggested that ^4He may be useful as a groundwater dating tool during a range of tens to hundreds of years, which was important because no other groundwater dating techniques were accurate for waters ranging from 40 to approximatley 500 years old. Groundwater age dating with chlorofluorocarbons and $^3H/^3$ and groundwater flow path analysis were used to investigate groundwater travel times, flow patterns, and recharge rates of a homogeneous, shallow, unconfined aquifer system in the southern New Jersey coastal plain (Szabo *et al.,* 1996). The demonstrated validity of the combined tracer-dating techniques to determine the age of water in the aquifer system indicates that groundwater flow models can be refined when apparent ages based on $^3H/^3He$- and chlorofluorocarbon (CFC)-dating are used as calibration targets.

A new method was proposed to simulate groundwater age directly by the use of an AD transport equation with a distributed zero-order source of unit strength, corresponding to the rate of aging, where the dependent variable in the governing equation was a mass-weighted average age (Goode, 1996). Example simulations of age in two idealized regional aquifer systems demonstrate the agreement between the proposed method and traditional particle-tracking approaches. CFCs were used as tracers for age-dating groundwater where the initial concentrations were assumed to be known and the tracer was assumed to be stable (Oster *et al.,* 1996). It was shown that local CFC soil-air measurements can provide a valuable local correction factor for CFC dating and extend the applicability of CFC studies in specific environments.

The Pasco Basin in Washington state serves as a basis for evaluating the chloride mass-balance technique for estimating recharge (Murphy *et al.,* 1996). An extension of the conventional chloride mass-balance model was used to evaluate chloride profiles under transient annual precipitation conditions, and the model was inverted to determine the paleorecharge history for a given soil chloride profile. Concentrations of Cl^- and $^{36}Cl^-$ along the flow path in the Aquia aquifer in southern Maryland were studied, and the implications for flow velocities were discussed (Purdy *et al.,* 1996).

Advances in accelerator mass spectrometry permit ^{36}Cl measurement at the required sensitivity, and data show that in general the streams in the region have $^{36}Cl:Cl$ ratios similar to those expected in present-day atmospheric fallout, but terminal lakes into which the streams flow have much lower ratios. Large-scale dispersion in a sandy unconfined aquifer in Denmark was studied by simulating the transport of environmental tritium in a moderately deep unsaturated zone and in a relatively long cross section of the aquifer (Engesgaard *et al.,* 1996). Chlorofluorocarbon 12, ^3H, and ^3He were used to infer groundwater flow and solute transport in saprolite and fractured rock near Oak Ridge, Tennessee (Cook *et al.,* 1996). Conceptual models of shallow groundwater flow and solute transport in this system were difficult to evaluate using physical characterization or short-term tracer methods because of extreme spatial variability in hydraulic properties.

$^{87}Sr:^{86}Sr$ ratios served as tracers in groundwater and surface waters in Mono Basin, California (Neumann and Dreiss, 1995). A follow-up study was presented to remeasure and reevaluate the ^{36}Cl content at several previously studied sites in the Great Basin (Phillips *et al.*, 1995). Soil-water chemistry and isotopic data were presented from three deep vadose zone boreholes at the Nevada Test Site to quantify soil-water flux and its relationship to climate (Tyler *et al.*, 1996). Tracing techniques and core data were used to study the temporal and spatial variations of the soil-water flux and recharge during the last 120 000 years. Natural variations of stable isotopes were used to study infiltration in clay soils and groundwater recharge in the small drainage basin of Barogo in West Africa (Mathieu and Bariac, 1996). The isotope analyses led to the characterization of two separate infiltration processes as well as two recharge processes.

Stochastic Modeling and Analysis. The spatial-temporal averaging method was used for modeling transport in porous media with a nonhomogeneous distribution of elementary domains in the spatial-temporal space (He and Sykes, 1996). Several averaging theorems and corollaries about the averages of spatial and temporal derivatives were presented and rigorously proved. The real-space expressions for second-order mean velocity and velocity covariance in 3-D, statistically anisotropic media were derived, and the effect of higher-order flow correction terms on advective transport was examined (Zhang and Zhang, 1996).

First- and second-order reliability methods were applied as alternatives to Monte Carlo simulation in the probabilistic analysis of groundwater contaminant transport and remediation (Hamed *et al.*, 1996). A 2-D FE model was interfaced with a reliability analysis program that provided the probability that a contaminant exceeds a target level at a well. Covariances of velocity, head, and log (hydraulic conductivity) under quasi-steady flow were developed, and their effect on advective transport was examined (Zhang and Neuman, 1996a). Results showed that temporal fluctuations in the direction of the mean velocity cause longitudinal dispersion to decrease and transverse dispersion to increase.

Probability distributions of travel times were developed for 1-D (vertical) convective solute transport in field-scale soils under unsteady and nonuniform flows (Kavvas *et al.*, 1996). Approximate ensemble probability distribution functions of conservative solute travel time were derived directly from the convective transport stochastic partial differential equation. A higher-order theory was presented for steady-state, mean uniform saturated flow and nonreactive solute transport in randomly heterogeneous porous media (Hsu *et al.*, 1996). Results show significant improvements compared with lower-order theories.

Dagan's solution for transport in heterogeneous porous formations was extended to the case of finite *Pe* (Fiori, 1996). It was suggested that pore-scale dispersion matters only with reference to transverse spreading, and that Dagan's solution, valid for $Pe = \infty$, was an adequate approximation in a wide range of finite *Pe*. General equations for the first two moments of the particle trajectory were derived for the problem of transport of inert solutes in random nonstationary velocity fields (Indelman and Rubin, 1996). It was shown that the equations can be solved analytically for the case of quasi-unidirectional mean flows, and the theory was applied to the case of transport in media displaying a linear trend in the mean log (conductivity).

The general expressions for the time-dependent ensemble averages of the second spatial moments $\langle A \rangle$ and the effective dispersivities γ were evaluated to study the effect of initial plume size on $\langle A \rangle$ and γ in 3-D heterogeneous isotropic aquifers (Zhang, Y.K., *et al.*, 1996). Results confirm that $\langle A \rangle$ and γ approach their respective ergodic limits as the size of the source increases and that transverse lengths of a source were more important than longitudinal length for the ergodic condition to be met. The exact and approximate deterministic partial differential equations of the time-space evolution of mean, two-point moment, and *n*-point moment solute concentration for conservative solute transport by steady and unsteady groundwater flow in a heterogeneous aquifer were developed in the real space-time domain (Kavvas and Karakas, 1996). The derivations were performed by means of the cumulant expansion method, combined with the calculus for the time-ordered exponential and with the calculus for the Lie operator.

A fully nonlinear analysis of the integro-differential equation for the spatial second moments *X* of the ensemble mean concentration in a heterogeneous aquifer was carried out by solving the nonlinear integro-differential equation for *X* numerically and iteratively (Zhang and Chi, 1995). The effects of log (hydraulic conductivity) variance, *Pe*, and anisotropy then were investigated. A stochastic modeling approach and Monte Carlo simulation were used to characterize the uncertainty in migration pathways in geological media surrounding a hypothetical buried water repository in Bedfordshire, U.K. (Mackay, R., *et al.*, 1996).

The coupled effects of porous media heterogeneity and flow unsteadiness on transport were investigated using a stochastic-Lagrangian approach, where log(conductivity) was modeled as a space random function and flow unsteadiness was considered deterministic, affecting the magnitude and direction of mean head gradient (Dagan *et al.*, 1996a). By applying the model to the case of a periodic variation in the flow direction, it was shown that unsteadiness has an insignificant effect on the longitudinal spread, whereas it strongly affects the transverse spread. An experimental velocimetry technique based on particle image analysis was used to perform a Lagrangian description of nonreactive pollutant particle motion in a 3-D saturated porous medium (Cenedese and Viotti, 1996). Statistical analysis of the experimental data allowed for estimation of velocity and displacement probability density functions, velocity component correlation functions, Langrangian integral scales, and mechanical dispersion coefficient tensor components.

A recently developed exact Eulerian-Lagrangian theory of advective transport in space-time random velocity fields was extended to account for anisotropic local dispersion (Zhang and Neuman, 1996b). Results showed that the effect of local dispersion on first- and second-concentration moments varies monotonically with the magnitude of the local dispersion coefficient, and when this coefficient is small relative to macrodispersion, its effect on the prediction of nonreactive transport under uncertainty can be disregarded.

Analytical Modeling. The determination of solution criteria for RADT, a FORTRAN program based on a semianalytical approximation for solute transport during divergent radical tracer tests, was presented (Piggott and Novakowski, 1996). The principal of superposition was used to develop a semianalytical solution for 1-D AD solute transport under an arbitrary concentration boundary condition (Ge and Lu, 1996). A generalized 3-D analytical solute transport model for multiple rectangular first-type sources was presented (Batu, 1996). The solutions could be used for predicting solute concentrations from partially penetrating solute sources located at any place along a vertical plane perpendicular to the flow direction of groundwater, rivers, and canals.

A discussion was presented regarding a paper on inappropriate use of analytical fate and transport models to estimate the age and risk of petroleum product releases (Nolan, 1996). A reply to the preceding discussion also was presented (Alvarez, 1996). Comments were made on a previous paper on exact solutions of convection-diffusion and diffusion equations (Wang and Yeh, 1996). A reply to the preceding comments was also presented (Philip, 1996).

Numerical Modeling. A consistent FE approach for modeling solute transport through anisotropic, heterogeneous media was developed that does not require imaginary mathematical formulations and overcomes the limitations of both the conventional FD and FE methods (Rabbani, 1996). This method allows fluid flow and solute transport in radial directions, and the resulting matrices were field representative, diagonally dominant, and easily convergent. Various FE schemes of the Bubnov-Galerkin and Taylor-Galerkin types were analyzed to obtain expressions for the truncation errors for both the steady-state and transient forms of the AD equation (Comini *et al.,* 1995). Stability limits were determined for the transient equation, and the operational equivalence between Taylor-Galerkin and Petrov-Galerkin methods was illustrated.

A new algorithm was presented for the resolution of both interior and boundary layers present in the AD equation in laminar regimes, based on the formulation of a family of polynomial-exponential elements (Olmos *et al.,* 1996). The algorithm was an adaptation of the standard variational methods that supplies nonoscillatory and accurate solutions. Multidimensional residual distribution schemes for the AD equation were described (Paillère *et al.,* 1996). Compact cell vertex schemes were used for the convective term, whereas the FE Galerkin formulation and various residual-based approaches were compared for use on the diffusive term. An extension to the integrated FD method was developed that permits a more accurate approximation of the governing equations for 2-D groundwater flow and mass transport in heterogeneous anisotropic media (Ferraresi and Marinelli, 1996). A comparison was made between results obtained by applying this method and the FE method to various test problems.

An FE model was developed for longitudinal dispersion of a pollutant in porous media (Rao, 1996). Results obtained from the model were found to be in close agreement with analytical solutions. A Petrov-Galerkin formulation based on two different perturbations to the weighting functions was presented for the numerical solution of the transient AD equation in the vicinity of sharp gradients (Idelsohn *et al.,* 1996a). To accurately solve the 1-D convection-diffusion equation, a multilevel Petrov-Galerkin FE method was developed in which the weight functions were calculated from simple algebraic recursion relations (Ganesan and Salamon, 1996). This multilevel method was extended to cases of the nonhomogeneous problem with polynomial forcing functions.

A Fourier analysis of the linear and quadratic Petrov-Galerkin FE methods applied to the 1-D transient AD equation was performed, showing that although *a priori* optimization of the linear method was not possible, *a priori* optimization of the quadratic method can be accomplished without the addition of artificial dispersion (Carrano and Yeh, 1995). The spectrally weighted average phase error method was introduced for the optimization of the quadratic Petrov-Galerkin method, and optimal values predicted by the method were shown to be in excellent agreement with those suggested by numerical experimentation. A Lagrangian-Eulerian method consisting of advection-diffusion decoupling, backward particle tracking, forward particle tracking, adaptively local zooming, peak/valley capturing, and slave point utilization was presented to solve 2-D advection-diffusion transport problems (Cheng, J.R., *et al.,* 1996). This approach was developed to circumvent the difficulties associated with the EPCOF scheme when it was extended from a 1-D space to a multidimensional space.

A multidimensional particle tracking technique was presented for applying the Lagrangian-Eulerian FE method to solve transport equations in transient-state simulations (Cheng, H.P., *et al.,* 1996). An in-element particle-tracking technique was used for computing advection in the Lagrangian step, where fictitious particles in the real-world flow field were traced on an element-by-element basis. A generalized Eulerian-Lagrangian localized adjoint method (ELLAM) of cells was presented for solving advection-dominated contaminant migration problems (Garfiás *et al.,* 1996). In this method, piecewise constant test functions were advected with the transport velocity, with simultaneous use of optimal weighting and interpolating functions.

A formal statistical analysis of the random walk method and its relation to the classic AD equation was given (Hathhorn, 1996). It was shown that uniform or symmetric-triangular steps, as opposed to Gaussian distributed steps, can be employed without loss of generality in accuracy of the solution and may yield significant computational savings. The constant displacement (CD) scheme, which has been shown to be computationally efficient and accurate for dispersion-free particle tracking in highly heterogeneous fields, was extended and applied in the random walk method (Wen and Kung, 1996). Results show that the CD scheme may be 15 times faster than the traditional constant-time scheme for the calculations of contaminant transport in highly heterogeneous media.

The use of interpolation schemes that preserve discontinuities in velocity at material contacts could result in a solute transport random-walk model that does not locally conserve mass unless a correction has been applied at the contacts (LaBolle *et al.,* 1996). Techniques for resolving the problem, including interpolation schemes and a reflection principle, were reviewed and tested, and results from simulations show which methods satisfy continuity. An interpolation-corrected modified method of characteristics (ICMMOC) was proposed for solving AD equations (Liu and Dane, 1996c). The ICMMOC, an improved version of the modified method of characteristics, uses a high-order interpolation scheme to reduce numerical dispersion, an interpolation-corrected procedure to eliminate numerical oscillation, and a simple peak-capturing scheme to overcome the peak clipping problem.

A discussion was presented regarding a proposed numerical technique based on the method of characteristics for the solution of the advection and AD equations (Zoppou and Roberts, 1996). It was pointed out that there were alternative schemes in the literature that were conservative and provided better time-stepping than the proposed scheme. A closure to the preceding discussion was presented as well (Li and Yu, 1996). Derivation, stability, and error analysis for cell-centered finite volume approximations of convection-diffusion problems were presented (Lazarov *et al.,* 1996). Various upwind strategies were investigated, and theoretical results were illustrated by numerical examples. An overlapping control volume (OCV) approach was introduced to solve 2-D steady-state AD problems on structured nonorthogonal grids (Verma and Eswaran, 1996). Results of diffusion and convection modeling using OCV on rectangular and nonorthogonal grids were compared with results obtained using the QUICK method.

Two different moving-grid methods were applied to solve numerically AD equations in 1-D and 2-D (Zegeling, 1996). Both methods were based on the method of lines, with the first using moving FEs and the second using moving FDs. Large-time solutions were derived for the partial differential equations governing contaminant transport in porous media for initial data with bounded support (Dawson *et al.,* 1996). Results of a formal asymptotic analysis of the governing equations as $t \rightarrow \infty$ were compared with numerical solutions of the complete initial value problem, providing convincing confirmation of the derived analytic solutions.

Inversion/Sensitivity Analysis. To address the problem of parameter insensitivity and correlation in groundwater flow parameter estimation, advective-transport observations were added to the groundwater flow parameter-estimation model MODFLOWP using particle-tracking methods (Anderman *et al.,* 1996). The resulting model was used to investigate the importance of advective-transport observations relative to head-dependent flow observations and was found to improve the calibration of the model and the estimation of groundwater flow parameters. Physical and nonreactive flow and transport parameters for a contaminated aquifer were identified through an optimization approach that combines a flow and transport model with nonlinear least-squares multiple regression (Sonnenborg *et al.,* 1996). The sensitivity of the optimization approach to steady-state versus transient flow conditions and to the amount of hydraulic and solute data used also was investigated.

A methodology for solving the coupled linear flow and transport inverse problems was presented that allows the estimation of aquifer parameters using their prior estimates as well as head and concentration measurements as basic information (Medina and Carrera, 1996). The applicability of the method was shown by means of two real examples, which illustrated that the proposed approach can successfully address model selection, parameter uncertainty, and nontrivial identifiability problems. Direct and adjoint sensitivity methods were developed that could be used with time-continuous approaches to groundwater contaminant transport simulation, such as the Laplace transform Galerkin technique (Skaggs and Barry, 1996). The relative efficiency of the two methods depends on the number of model parameters, number of performance measures, and number of spatial discretization nodes, but in the model problems analyzed, the direct and adjoint methods were 9 to 156 times faster than the perturbation method.

It was shown that given prior information in terms of a lower and upper bound, a prior bias, and constraints in terms of measured data, minimum relative entropy (MRE) yields exact expressions for the posterior probability function and the expected value of the linear inverse problem (Woodbury and Ulrych, 1996). The MRE approach was used to recover the release and evolution histories of a plume in a 1-D, constant known velocity and dispersivity system in which, for noise-free data, the reconstructed plume evolution history was indistinguishable from the true history. The effects of concentration measurements of an existing plume on identification of log (conductivity) and flow transport variables were assessed (Dagan *et al.,* 1996b). A Lagrangian approach was used for conservative solute transport in a heterogeneous media, which improves the solution of the inverse problem and the prediction of transport of existing plumes.

A theoretical framework was presented that allows for conditioning of the moments of the concentration on measurements of conductivity and hydraulic head (Ezzedine and Rubin, 1996). Conditioning the concentration reduces the uncertainty associated with its estimation and alleviates difficulties with estimation of the extent of contamination. A field application and sensitivity analysis was demonstrated for the split inversion method, which combines seismic, hydraulic, and tracer data to estimate lithologic and transport properties in 3-D (Hyndman and Gorelick, 1996). The method was applied to the Kesterson aquifer in the San Joaquin Valley, California.

An automatic calibration technique, developed for the 2-D numerical solution of the groundwater flow and transport equations, used a mixed Picard/Newton-Raphson solution scheme for the nonlinear unconfined flow problem and a fluctuation splitting FE method for the transport equation (Siegel *et al.,* 1996). The calibration algorithm was based on the adjoint state method for the calculation of the gradients associated with a quasi-Newton minimization procedure, and a downscaling procedure was developed for the hydraulic conductivities and the storage coefficients. Two neural networks systems, called SCANN and PIANNO, were used to solve 2- and 3-D groundwater inverse problems (Rizzo and Dougherty, 1996a). SCANN was used as an alternative to conventional geostatistical methods to produce initial estimates of the desired discrete log-hydraulic conductivity field, and PIANNO interacts with the groundwater flow and transport simulator to solve the groundwater inverse problem.

Sorption-Desorption. *Organic Compounds.* Adsorption/desorption and mobility of a pesticide carbofuran in soil from Kenya were investigated (Lalah and Wandiga, 1996). Soil sorption coefficient of 12 heterocyclic nitrogen compounds based on the octanol-water partitioning coefficient (K_{ow}) and water solubility were determined (Liao *et al.,* 1996). Shake flask experiments were conducted to determine the K_{ow} and the water solubilities of phenylthio-carboxylates (Feng *et al.,* 1996b).

Adsorption studies of linear alkyl benzene sulfonate (LAS) on soil were carried out (Ou *et al.,* 1996). At low LAS concentrations, adsorption isotherms were linear but were observed to increase exponentially with an increase in LAS concentrations. The adsorption of the herbicide metamitron on various soils with a wide range of organic matter (OM) and clay content was examined (Cox, L., *et al.,* 1996a). Leaching indices of some major triazine metabolites were determined (Bottoni *et al.,* 1996). The sorption of the pesticides hexazinone, sulfometuron methyl, and tebuthiuron on six acidic, saturated sands was determined as a function of depth (Koskinen *et al.,* 1996). Changes in adsorption patterns of four pesticides on a sandy soil, induced by application of anionic, cationic, and nonionic surfactants, were determined using the batch equilibrium method (Iglesias-Jimenez *et al.,* 1996). The degree of hydrophobicity, type, and concentration of surfactants proved to be critical.

Quantitative structure property relationship technique was used to predict the soil partition coefficient of polychlorinated biphenyls (PCBs), chlorinated phenols, and benzenes (Sacan and Balcioglu, 1996). The effects of soil organic content and dissolved OM on the sorption of atrazine and isoproturon were investigated (Beck and Jones, 1996). Screening methods to estimate soil adsorption coefficients were compared (Muller and

Kordel, 1996). Spatial and temporal variation of isoproturon residues and their sorption/desorption coefficients in a clay soil were monitored in field scale, after pre- and postemergent isoproturon applications (Beck *et al.,* 1996a).

Adsorption of eight phenylthioacetates from water by natural soil was examined at varying concentrations (Feng *et al.,* 1996a). Sorption of ionizable dicamba at different concentrations and pH levels on organo-clays was studied (Zhao *et al.,* 1996). A nonlinear model for estimating K_{oc}, applicable to polar and nonpolar organics based on artificial neural networks using K_{ow} and water solubility, was developed (Gao *et al.,* 1996). Batch isotherms were determined for various organic compounds in aqueous suspensions of a sandy loam soil and a peat soil with a wide range of sorptive capacities (Xing and Pignatello, 1996).

Adsorption characteristics of the nonionic surfactant Tergitol 15-S-7 on clays were investigated (Ray *et al.,* 1995). The mobility of emamecetin benzoate in soil was investigated by a batch equilibrium technique and thin layer chromatography (Mushtaq *et al.,* 1996). The adsorption/desorption of atrazine and its three metabolites on Levy wetland soil was determined using the batch equilibrium technique (Mersie and Seybold, 1996). The sorption of acifluorfen on eight soil humic acids was determined at various pH values and concentrations (Celi *et al.,* 1996). Results indicated that the nature of humic acid influences the sorption in addition to pH.

The interactions between a smectite saturated with aluminum and rimsulfuron were examined (Pantani *et al.,* 1996). A mechanistic model of ion adsorption combined with an AD solute transport model was developed to predict multicomponent adsorption and transport of fluoride at variable pH in a Goethite-silica sand system (Meeussen *et al.,* 1996). Effect of temperature on sorption of naphthalene, phenanthrene, and pyrene onto low OC sediments was investigated (Piatt *et al.,* 1996). Adsorption of CO_2 and N_2 was used to examine the effect of surface area of soil OM and porosity on sorption of organic contaminants (de Jonge and Mittelmeijer-Hazeleger, 1996).

Effect of soil size fractionation and temperature on sorption of atrazine onto a mineral soil was studied (Li, J.H., *et al.,* 1996a). Soil size fraction had little effect and temperature had a significant effect on sorption of atrazine. A microfiltration-HPLC technique was used to study the labile and nonlabile processes of sorption of atrazine onto mineral soil (Li, J.H., *et al.,* 1996b). Sorption and mobility of two herbicides and two pesticides in an allophanic and nonallophonic soil were studied (Baskaran *et al.,* 1996). An empirical approach for description of multicomponent reactive transport in a porous media was presented (Borkovec *et al.,* 1996). The effects of pH, methanol, surfactants, and soil properties on desorptive behavior of chlorophenols in contaminated soils were investigated (You and Liu, 1996).

Sorption and mobility of bentazon in coastal plain soils were studied using soil solution and soil thin-layer chromatography, respectively (Grey *et al.,* 1996). Adsorption and degradation of primisulfuron and rimsulfuron, in soil and aqueous solution, respectively, were investigated (Vicari *et al.,* 1996). Sorption of bentazon and its degradation products in two Mississippi soils were studied (Gaston *et al.,* 1996a). Thermodynamics of the interaction of lindane with Indian silty loam soils were studied at different temperatures, and sorption studies were carried at various concentrations and contact times (Khan, Z.A., *et al.,* 1996).

The impact of two-phase desorption kinetics on human health risk assessment and hazardous waste clean-up was investigated (Gong *et al.,* 1996). Adsorption of nitroaromatic compounds onto clay minerals was studied (Haderlein *et al.,* 1996). Phenanthrene sorption rates onto four different soils were determined by studying the time dependence of solute-phase distribution relationships in completely mixed batch reactors (Weber and Huang, 1996a). Competitive sorption of simple organic acids and sulfate onto goethite was investigated (Ali and Dzombak, 1996). Reversible sorption and irreversible binding of naphthalene and α-naphthol onto sandy soils were evaluated (Burgos *et al.,* 1996).

The adsorption kinetics of toluene on Yolo loam and montmorillonite were obtained with a gravimetric method (Arocha *et al.,* 1996). Sorption was observed to occur in two stages: adsorption in macropores and in micropores. Binding of 4-monochlorophenols to OM in soils during humification processes in soil was studied (Bhandari *et al.,* 1996). A surface complexation model to describe the adsorption of metal–ethylenediamine tetraacetic acid (EDTA) complexes onto various oxides was described (Nowack *et al.,* 1996). Competitive sorption between atrazine and other cosolutes in water suspensions of natural and model sorbents was examined (Xing *et al.,* 1996).

Sorption of phenanthrene from water onto alumina coated with dianionic surfactants was examined as a function of the surfactant's loading rate and alkyl chain length (Sun and Jaffe, 1996). The influence of near-surface characteristics in mineral domains on sorption of phenanthrene onto various particulate mineral solids was studied (Huang *et al.,* 1996). Comments regarding an earlier article by Weber and Huang were presented (Pedit and Miller, 1996). Responses to these comments were presented to support conclusions drawn in the earlier article (Weber and Huang, 1996b).

A solid-state nuclear magnetic resonance method was presented for spectroscopic adsorption studies of organic pollutants on surfaces of powders (Ukrainczyk and Smith, 1996). Laboratory soil-column flushing experiments were carried out to study the removal of benzene, toluene, ethylbenzene, and xylene from the soil cores of unsaturated zone of a waste site (Mackay, A.A., *et al.,* 1996). An analytical model of effects of application frequency on pesticide concentration in a coupled saturated–unsaturated system was described (Beltman *et al.,* 1996). Instantaneous equilibrium and equilibrium-kinetic sorption models, which can be used to describe pesticide leaching and runoff, were compared (Ma *et al.,* 1996). Batch and continuous column sorption experiments were carried out to examine the effects of the ratio of different compounds or isomers and experimental conditions on sorption parameters (Soerens and Sabatini, 1996).

Batch studies at various concentrations of perchloroethylene were conducted to study the nonlinear sorption onto aquitards (Allen-King *et al.,* 1996c). The effect of tillage practices on sorption pattern and degradation of bentazon in conventional and no-till Dundee soil was investigated (Gaston *et al.,* 1996b). Incorporation of nonextractable atrazine residues into soil size fractions as a function of time was discussed (Barriuso and Koskinen, 1996). The use of supercritical fluid extraction with carbon dioxide as a method of extraction of pesticides from soils was described (Rochette and Koskinen, 1996).

Sorption of primisulfuron and sulfonylurea at various concentrations on six oxides, two clays, and 23 different soils was studied (Ukrainczyk and Ajwa, 1996). The interactions between the divalent cationic herbicides diquat and paraquat and montmorillonite were studied by different techniques (Rytwo *et al.*, 1996). Generalized models to predict sorption of pentachlorophenol onto natural soils were developed (Christodoulatos and Mohiuddin, 1996).

Inorganic Compounds. Radionuclide and heavy metal sorption around low- and high-pH waste disposal sites at Oak Ridge, Tennessee, was modeled using MINTEQA2 (Saunders and Toran, 1995). A comparative study was presented on the quantitative characterization procedures of soils and sediments in terms of specific radiocesium sorption potentials obtained during elaborate procedures (Wauters *et al.*, 1996b). A new procedure was developed for assessing the speciation of radiocesium and freshwater sediments (Wauters *et al.*, 1996c). An equation based on the value of the radiocesium interception potential was presented for predicting solid/liquid distribution coefficients of radiocesium on soils and sediments (Wauters *et al.*, 1996a). Flushing of a Pb(II) synthetically contaminated sandy loam using 0.1 N HCl, 0.01 M (EDTA), and 1 M $CaCl_2$ was investigated in the continuous-flow column mode (Reed *et al.*, 1996a).

Cesium sorption in six Welsh soils was modeled using Langmuir and Freundlich adsorption isotherms (Campbell and Davies, 1995). The capability of soil components to immobilize Cd and the effects of environmental factor changes on its retention *in vitro* and under soil conditions were studied (Kurek *et al.*, 1996). The influence of pH and chloride on the retention of cadmium, lead, mercury, and zinc by soil was studied (Lumsdon *et al.*, 1995). A natural zeolite additive was used to study the stabilization of Cd, Ni, and Pb in soil (Shanableh and Kharabsheh, 1996). Ion exchange between aqueous protons and surface Hg and Cu sites on cinnabar and chalcocite were examined by potentiometric titrations (Balsley *et al.*, 1996).

Soil-water partition coefficients for cadmium were determined on 15 New Jersey soils by characterizing soils in terms of surface properties and chemical composition (Lee, S.Z., *et al.*, 1996). The effect of fulvic acid on the sorption of actinides and fission products on granite and selected minerals was studied (Ticknor *et al.*, 1996). Mercury mobilization off of aquifer sediments by acid rain, road runoff, and fertilizer solutions was investigated using column and batch equilibria experiments (Macleod *et al.*, 1996). Distribution coefficients of platinum-group metals were measured by a batch technique for agricultural soils collected in Japan using a multitracer solution containing their radioisotopes (Yasuda *et al.*, 1996).

The migration of trace radiocalcium and radiostrontium in a clayey and calcareous sandy soil was studied (Lefevre *et al.*, 1996). A series of core flood experiments was performed to investigate the migration behavior of uranium under rigidly controlled conditions (Sims *et al.*, 1996). Based on potentiometric titration data, a uniform approach was used to develop a set of consistent parameters for three surface complexation models and nine simple hydroxides (Turner and Sassman, 1996). The geochemical properties of an aquifer sediment that control metal-ion adsorption were investigated to determine their potential use as indicators of the spatial variability of metal adsorption (Fuller *et al.*, 1996).

Experiments on the migration of ^{137}Cs through columns containing quartz sand were performed (Saiers and Hornberger, 1996a). Distribution coefficients were measured for cadmium and nickel in laboratory batch experiments for 18 sandy aquifer materials (Christensen *et al.*, 1996). Extractability of zinc, cadmium, and nickel in soils amended with EDTA was investigated (Li and Shuman, 1996a). The sorption and desorption of herbicides using dialysis membrane technique was studied (Govi *et al.*, 1996). Single and multiple metal ion reaction processes were studied on humic acids (Jin *et al.*, 1996).

Heavy metal movement in soil profiles was studied using three metal-contaminated soils from cropland (Li and Shuman, 1996b). The sorption characteristics of clayey calcareous sediments were studied using combined sequential extraction-sorption isotherm analysis (Salim *et al.*, 1996). The effects of pH and competitive anions on the adsorption of arsenate were investigated (Manning and Goldberg, 1996). The effect of subsoil liming and ionic strength on the movement of anion in highly weathered acid soil columns was studied (Bellini *et al.*, 1996). Four methods to determine the cation exchange of soils and clays were evaluated (Wang *et al.*, 1996). The competitive desorption/dissolution of kaolin-adsorbed heavy metal mixtures and mixtures of adsorbed Cd with Mg and/or Ca by four chelators was investigated (Hong and Pintauro, 1996).

The behavior of Pb in the A and B horizons of two soils was studied to determine the effects of shock loading (Howard and Sledzinski, 1996). Cadmium transport in an unsaturated stony subsoil monolith was investigated (Buchter *et al.*, 1996). An experimental analysis was presented on the influence of specific surface area on the transport of the sorbing solutes in fractures (Wels *et al.*, 1996). Sorption of cupric, dichromate, and arsenate ions by the surface and subsurface horizons of two free-draining New Zealand soils was examined (Carey, G.R., *et al.*, 1996). A surface complexation model coupled with a 1-D AD model was used to simulate phosphate transport and was compared with column experiment data (Stollenwerk, 1996). A slow rate of approach to complete breakthrough was attributed to non-equilibrium effects that were not included in the model.

Interactions with Other Processes. The effect of temperature on sorption equilibrium and sorption kinetics for organic pollutants was studied and presented (ten Hulscher and Cornelissen, 1996). The study indicated that some pollutants were affected and others were not affected by temperature. The extraction of RDX from soil using various anionic surfactants and cyclodextrin was investigated (Hawari *et al.*, 1996). The sorption and desorption kinetics of polycyclic aromatic hydrocarbons by soils in mixed-solvent systems were studied (Errett *et al.*, 1996).

The effect of soil additives on the adsorption characteristics and hydraulic conductivity of two soils, a glacial till and a marine clay, was investigated (Katz *et al.*, 1996). The additives enhanced the adsorption capacity but had little effect on hydraulic conductivity. The relative importance of molecular diffusion and advection and the effect of pollutant retardation on the advective and diffusive transport were discussed using a conceptual mathematical model (Lo, 1996). The effect of several water-miscible organic solvents, with a wide range of solvent properties, on sorption of benzoic acid by surface soils was examined (Lee and Rao, 1996). The sorptive characteristics of organoclays were studied and compared with those of natural soil OM in terms of magnitude and mechanism (Sheng *et al.*, 1996). The effects of high pH on arsenic mobility in a shallow sandy aquifer and on aquifer permeability along the adjacent shoreline were investigated (Mariner *et al.*, 1996). The results of a modeling study to determine the transport and the partitioning behavior of a certain cationic surfactant in porous media were presented (Hayworth and Burris, 1996). Batch and column studies were conducted to investigate the use of cationic surfactants to enhance the sorption of dissolved organic contaminants in an aquifer with low OC content (Brown and Burris, 1996).

Three sandy subsurface materials and a sandy surface soil were used to assess the influence of mineralogy and surface chemistry on the determination of physical transport parameters (Seaman *et al.,* 1996). Column tests were conducted to study the influence of boundary conditions and soil attributes on the transport of two commercial anionic surfactants (Allred and Brown, 1996a). The sorption of 2-methylnaphthalene by Rossburg soil in the absence and presence of a nonionic surfactant was studied and presented (Chin *et al.,* 1996). The effect of soil properties, OM, and pH and surfactants on sorption and desorption by soil was investigated (Werkheiser and Anderson, 1996). A simple approach to estimate the leachate concentration, residual contaminant levels in soil, and amounts of contaminants released into groundwater after certain years of infiltration was presented (Prakash, 1996). Chromium sorption and reduction on soil with implications to bioremediation were investigated (Cifuentes *et al.,* 1996).

Modeling. Solute transport and sorption or surface reactions in a single fracture were analyzed with a series of approximate analytical models (Berkowitz and Zhou, 1996). The conditions were determined where a local equilibrium assumption was appropriate and a retardation factor could be used to model the effects of surface reactions. An organic solute diffusion model was proposed based on solute pore diffusion, partitioning into OM, diffusion in OM, adsorption on mineral fractions, and surface diffusion along mineral surfaces (Yiacoumi and Rao, 1996). Model simulations were conducted to identify conditions where each of the processes was important. A model was developed to describe solute transport with sorption onto immobile aquifer materials and mobile, dissolved OC (Knabner *et al.,* 1996). Model simulations were compared with experimental results for a variety of solutes to explain the processes leading relative mobility of each solute. The model was analyzed further mathematically, and guidelines were developed for assessing the overall mobility of solutes in the presence of mobile and immobile sorbents (Totsche *et al.,* 1996).

Numerical solution approaches for solving two-domain, nonequilibrium solute transport models were compared (Gallo *et al.,* 1996). An algebraic substitution method appeared to be the most efficient approach for scalar computing platforms, whereas a FE Laplace transform method was most efficient for multiprocessor platforms. A stream tube model with equilibrium and nonequilibrium adsorption was used to analyze breakthrough characteristics as a function of correlations between random fields of transport parameters (Toride and Leij, 1996a). The model was used further to assess the effects of using boundary conditions or initial conditions to simulate solute introduction (Toride and Leij, 1996b). The model also was compared to 1-D and more detailed 2-D numerical modeling results.

Solutions for macroscopic sorption kinetics were developed to allow for comparisons of the relative importance of intragranular diffusion and field-scale physical and chemical heterogeneities (Miralles-Wilhelm and Gelhar, 1996). Macroscopic sorption kinetics calculated for the Borden aquifer indicated that larger-scale heterogeneities were more important than intragranular diffusion on controlling the transient behavior of a sorbing plume. Analytical solutions were developed for describing the transport of a nonlinearly sorbing in a heterogeneous aquifer (Berglund and Cvetkovic, 1996). Aquifer cleanup times were found to vary significantly depending on the isotherm equation. Analytical expressions for the limiting behavior of nonlinearly adsorbing solutes were derived for heterogeneous aquifers (Bosma *et al.,* 1996). The degree of nonlinearity was shown to have an effect on plume behavior that was more important than the effect of heterogeneity.

The asymptotic behavior of solute plumes undergoing nonlinear adsorption was found to decay asymptotically as a power-law function of the Freundlich exponent (Jaekel *et al.,* 1996). The analysis was useful for estimating Freundlich exponents from BTC data. A method was developed for solving the AD equation with a kinetically adsorbing solute (Van Kooten, 1996). The method relies on decoupling and solving separately the AD and kinetic adsorption portion of the equations. A mathematical model was presented for simulating nonlinear, rate-limited sorption in heterogeneous, structured porous media (Srivastava and Brusseau, 1996). The model was used to assess the impact of nonlinearity, rate-limitations, and heterogeneity on plume characteristics.

A model that incorporates rate-limited sorption and rate-limited mass transfer was used to demonstrate the importance of these processes on solute transport in aggregated media (Hu and Brusseau, 1996). Solute characteristics controlled the importance of the processes to transport behavior. An upstream-weighted, multiple cell balance method was developed to describe 2-D flow and transport with mobile and immobile zones and nonequilibrium sorption (Kong and Harmon, 1996). The model was based on solving mass balance equations in finite triangular elements and subdomains centered around each node. An analytic solution was derived for the 1-D equations governing the transport of a tracer in a heterogeneous porous medium subject to rate-limited adsorption with a linear equilibrium isotherm and also subject to decay (Logan, 1996). The 1-D model gives information about how adsorption and decay effects can interact with heterogeneities in the medium.

An analytical solution was derived for describing solute transport with Langmuir and kinetically controlled sorption (Manoranjan and Stauffer, 1996). The solution method was based on transforming the concentration profile into the form of a traveling wave front. A lumped-parameter, nonlinear model was applied to investigate the kinetics of metal ion sorption to humic substances (Yu *et al.,* 1996). The overall order of the sorption rate depended on time and the reactivity of the metal species. Linear and nonlinear least-squares analyses were applied to estimate Langmuir sorption constants from isotherm data (Schulthess and Dey, 1996). The regression methods were sensitive to the type of data error and isotherm nonideality.

Chemical Reactions. *Oxidation/Reduction.* Measurements of oxidation-reduction potential and concentrations of dissolved hydrogen were made in a shallow groundwater system contaminated with solvents and jet fuel to delineate the zonation of redox processes (Chapelle *et al.,* 1996b). To determine whether reduction by zero-valent iron was surface-mediated, the reduction of a probe molecule was studied, both in the solution phase and bound to a solid support in the presence of zero-valent iron (Weber, 1996).

The OC oxidation induced by a large-scale shallow water intrusion into a vertical fracture zone at the Aspo Hard Rock Laboratory and its implications on the construction of spent nuclear fuel repositories were studied (Banwart *et al.,* 1996). Selenium(VI) migration through drill-core columns of granite was investigated as a function of water velocities under oxic and anoxic conditions (de Llano *et al.,* 1996). A study described the dynamics of redox transformations of naturally occurring Se in a soil matrix as a continuous function of time during a sequence of oxic–anoxic–oxic transition (Jayaweera and Biggar, 1996).

Precipitation/Dissolution. The effect of simulated acid deposition on soil acidification and metal mobilization was investigated (Mannings *et al.*, 1996). The characterization of goethite and lepidocrocite precipitates that form from groundwater contaminated by acid mine leachate was provided (Herbert, 1996). The solubilization of Ni, Cd, and Pb from three model components of soils and sediments was investigated as a function of pH (Kedziorek and Bourg, 1996). The solubility of these metals depended not only on pH but also on interactions between soil components. The effects of pyromorphite on the bioavailability of lead were examined in urban and roadside soils (Cotter-Howells, 1996).

The natural occurrence of two iron-chromate precipitates in Cr(VI)-contaminated soil was studied (Baron *et al.*, 1996). The interactions of selected Pb minerals and a Pb-contaminated soil with apatite were examined (Laperche *et al.*, 1996). The results indicated that apatite amendments to Pb-contaminated soil materials can induce the formation of pyromorphites. A thin-film continuous flow-through reactor was used to investigate reactions between aqueous Cr(VI) and two iron oxides: goethite and magnetite (Deng *et al.*, 1996). The dissolution of biotite and chlorite in laboratory systems with flow-through and batch reactors was studied (Malmstrom *et al.*, 1996). A two- or three-phase free boundary problem for a diffusion-convection and reaction process in a bounded domain was analyzed (Pawell and Krannich, 1996). The effects of octavite on dissolved Cd were analyzed (Holm *et al.*, 1996).

Geochemistry. Sources and geochemical processes responsible for the chemical evolution of shallow groundwater along the northeast shore of Mono Lake, an alkaline saline lake located in a hydrologically closed basin in west central California, were determined (Connell and Dreiss, 1995). Concentrations of the rare earth element Nd and major ions were measured in groundwater samples obtained from four wells on the Nevada Test Site and one well located 4.8 km (3 miles) east of the proposed high-level nuclear waste repository at Yucca Mountain, adjacent to the Nevada Test Site (Johannesson *et al.*, 1995).

Statistical investigations and thermodynamic calculations with WATEQ4F of the flooded Niederschlema/Alberoda U mine (Germany) revealed that the mine water's constituents reached a local maximum (Wolkersdorfer, 1996). Twenty-seven samples from a confined Lower-Middle Jurassic aquifer and an unconfined Oxfordian aquifer of the North Aquitain Basin (France) were analyzed for their major elements (La Salle *et al.*, 1996). The effects of gamma-ray irradiation on water-rock reactions were investigated by comparing leaching experiments with and without irradiation (Yonezawa *et al.*, 1996). Uranium series disequilibrium and high thorium and radium enrichments in a karst formation were studied (Von Gunten *et al.*, 1996).

Hydrolysis. The degradation of the herbicide fenoxaprop-ethyl on homoionic Fe, Al, Ca, and Na montmorillonite in aqueous medium was studied (Pusino *et al.*, 1996). The abiotic hydrolysis of the organophosphorus insecticide chlorpyrifos was examined in 37 different soils, which were chosen to represent a wide variety of physicochemical characteristics (Racke *et al.*, 1996). Abiotic hydrolysis of simazine, atrazine, diazinon, methylparathion, and chlorpyrifos was studied in three different natural waters and buffered Milli-Q water (Noblet *et al.*, 1996).

Interactions with Organic Matter. The role of humic substances as potential vectors of radiocontaminants through natural aquifers and geological formations relevant for nuclear waste repositories was studied by using interaction constants of tri-, penta-, and hexavalent actinides (Am, Cm, Np, and U) with humic acids (Moulin and Moulin, 1995). Batch sorption and titration experiments were conducted to investigate the role of dissolved Ca on the sorption and complexation of dissolved OC and the effect on dissolved Cu concentrations (Romkens *et al.*, 1996). Naturally occurring organics in groundwater of the Whiteshell Research Area of southern Manitoba were investigated to assess their potential role in radionuclide transport within granite fractures of the Canadian Shield (Vilks and Bachinski, 1996a).

A study of the downward movement of ^{137}Cs in an undisturbed forest soil was presented (Tegen and Dorr, 1996). Absorption of Cd in the sandy soils of the Ellen catchment in Western Africa was studied by batch adsorption and by leaching small columns of soil (Gerritse, 1996). Modeling of natural OM-facilitated, polynuclear aromatic hydrocarbon (PAH) transport through low-OC sediment was developed and corrected (Johnson, W.P., *et al.*, 1996). In this study, the acid-base and Cd complexation properties of a humic acid fraction extracted from a soil were investigated using potentiometric titrations (Bolton *et al.*, 1996).

Interactions with Other Processes. The effect of upward transport in translocating napropamide to the photic zone of soils was examined (Donaldson and Miller, 1996). Soil-column experiments were performed to differentiate between abiotic and biological mechanisms for removal of residual organics from chlorinated municipal effluent (Quanrud *et al.*, 1996b). These studies were extended to consider the effects of different porous media on the removal of wastewater organics (Quanrud *et al.*, 1996a).

Modeling. Geochemical mass balance and mixing models were used to determine groundwater sources along the flow paths in the vicinity of the Idaho National Engineering Laboratory (Schramke *et al.*, 1996). The transport and mixing of solutes undergoing first-order decay in variable-velocity porous media flow were examined (Oldenburg and Pruess, 1996). A numerical formulation with a wide range of chemical reactions that could be solved either by direct substitution or sequential iteration procedures was presented (Saaltink *et al.*, 1996).

The use of the interior-point method to solve the thermodynamic equilibria was discussed (Saaf *et al.*, 1996). The development and verification of a computational algorithm to approximate the highly nonlinear transport equations of multiphase flow and reactive chemical transport was presented (Yeh *et al.*, 1996b). The development and verification of a process-level, coupled geochemical reactions and hydrological transport model was presented (Yeh *et al.*, 1996a). A new method, called (SU + C) PG, was used to solve advection-reaction-diffusion scalar equations by the FE method (Idelsohn *et al.*, 1996b).

Different mathematical models were discussed and compared, and Eulerian-Langrangian localized adjoint methods combined with specific linearization techniques to solve nonlinear transport systems were presented (Vag *et al.*, 1996). Alternative split-operator approaches for solving chemical reaction and groundwater transport models were discussed (Barry *et al.*, 1996a). Reactive chemical transport within engineered barriers was reported (Grindrod and Takase, 1996). A range of linear, single-species models has been analyzed; this has led to generalizations of earlier findings and development of new results (Barry *et al.*, 1996b). A numerical correction scheme for FD solution of the AD equation with reaction was developed from a Taylor analysis (Ataie-Ashtiani *et al.,* 1996).

Application of a reactive analytical groundwater transport model for interpreting nonconservative tracer experiments was presented (Leitao *et al.,* 1996). Laboratory experiments were performed to extrapolate reactive pollutant transport behavior in heterogeneous porous media (Schafer and Kinzelbach, 1996). A dynamic transport model that describes the downward transport of acidity in forest soils was presented (Eriksson and Karltun, 1995). A 2-D geochemical transport code was developed for simulating contaminant transport at a waste residue deposit in Denmark (Engesgaard and Traberg, 1996).

Effects of physical and chemical heterogeneity on contaminant transport in a sandy porous medium were presented (Tompson *et al.,* 1996). A small pertubation semianalytical solution was derived for solute transport in porous media with multiple spatially variable reaction processes (Xu and Brusseau, 1996). A Fickian formulation was used to model longitudinal macrodispersion, and a formula for groundwater velocity error introduced when dispersion is ignored was presented (Johnson and DePaolo, 1996). The Fokker-Planck equation and its solutions for modeling transport of conservative and reactive solutes in physically heterogeneous media were developed (Su, 1995). A correction to this work was presented (Su, 1996b).

FE techniques for solving reaction-diffusion problems with advection were examined (Liu, B., *et al.,* 1996). Theoretical analysis for Eulerian-Langrangian localized adjoint methods was conducted (Ewing and Wang, 1996). A diffusion- and reaction-corrected calculation scheme, which allowed for rapid and accurate solution of simultaneous 1-D diffusion and first-order reaction in gaseous or liquid phases, was presented (Moldrup *et al.,* 1996b).

Evolution of a solute plume developing from a pointlike, instantaneous solute injection, described by its effective velocity and dispersion, was calculated using the pertubation theory (Metzger, D., *et al.,* 1996). Implementation and performance evaluation of time integration methods for the solution of 3-D advection-diffusion-reaction equations were presented (Sommeijer and Kok, 1995). Two numerical solution methods, an explicit method and a partly implicit method, were discussed, and performance results were presented for a large-scale test problem implemented on a vector/parallel, shared-memory computer.

Biodegradation. *Aerobic Processes.* The biodegradation of benzene, toluene, and xylene (BTX) was observed under oxic conditions, and steady-state reactions were measured in flowthrough conditions where bacterial growth was negligible (Kelly *et al.,* 1996a). When measuring rate constants in batch experiments using Monod equation accounting for bacterial growth, neither mass-transport limitations in the column experiments nor solid-to-solution ratios were significant in determining kinetic parameters. Two different methods using data from monitoring wells and hydrologic properties of the aquifer were used to estimate biodegradation rate constants of benzene, toluene, ethylbenzene, and xylenes (BTEX) (Wiedemeier *et al.,* 1996). The attenuation rates furnished by the two methods were in close agreement when applied to a data set from a JP-4 jet fuel spill at Hill Air Force Base, Utah.

Factors affecting the biodegradation of toluene were examined in soil microcosms (Davis and Madsen, 1996). Biodegradation of toluene was proportional to soil substrate concentration up to a concentration of 200 $\mu g/g$, fairly insensitive to soil moisture content, and strongly dependent on the initial concentration of degrading microorganisms and inorganic nutrients availability. The effect of nutrient limitation on styrene metabolism in *Pseudomonas putida* CA-3 was investigated (O'Connor *et al.,* 1996). Glutamate and succinate had catabolite-repressing effects on the styrene degradation pathway, and lower levels of enzyme activities were found in microbial cells grown under ammonia and sulfate limitation. The *in situ* microcosm technique for measuring degradation of organic chemicals in aquifers was described (Nielsen *et al.,* 1996). Some details concerning the installation and operation were provided together with some experiences for data interpretation and monitoring of redox conditions.

The use of ethane and ethylene as primary substrates for aerobic cometabolism of vinyl chloride (VC) was studied (Freedman and Herz, 1996) Both ethane- and ethylene-grown enrichment cultures consumed VC in different ways and times. Results were presented on the aerobic degradation of dichloromethane (DCM) and 1,2-dichloroethane (DCA) in a fluidized-bed reactor in which oxygen was supplied by diffusion through a synthetic membrane (Herbst and Wiesmann, 1996). The effect of three chlorinated aliphatic hydrocarbons (CAHs) on growth rates of methanotrophic mixed cultures was studied (Anderson and McCarty, 1996). The presence of CAHs decreased the net growth rate of methanotrophic mixed culture because of both competitive inhibition and the toxicity of transformation products.

Biodegradation of trichloroethylene (TCE) was studied using a mixed culture of aerobic, phenol-induced organisms (Shurtliff *et al.,* 1996). A relationship was found between the influent phenol:TCE ratio and TCE biodegradation. The effect of bioaugmentation on the aerobic degradation of TCE in groundwater was investigated using a small-column aquifer microcosm (Munakata-Marr *et al.,* 1996). In both sterile and nonsterile microcosms, bioaugmentation with genetically altered *Burkholderia (Pseudomonas) cepacia* G4 enhanced TCE degradation, although at different levels. Abiotic and biotic transformations of 1,1,2,2-tetrachloroethane (TeCA) under methanogenic conditions were studied (Chen, C., *et al.,* 1996). The compounds 1,1,2-trichloroethane, *trans*-1,2-dichloroethene, and *cis*-1,2-dichloroethene were products of the biotic transformation.

The ability to degrade chloroform (CF) by seven different toluene-oxidizing bacterial strains was tested (McClay *et al.,* 1996). CF oxidation was inhibited in the presence of TCE, and the different abilities of the CF-oxidizing bacteria to degrade other halogenated compounds were also identified. The degradation of TCE by a soluble ethane monooxygenase-constitutive mutant strain of *Methylosinus trichosporium* OB3b, strain PP358, was investigated, and the kinetics of degradation were determined (Fitch *et al.,* 1996). Degradation of toluene and TCE by *B. cepacia* G4 in growth-limited batch-fed culture was studied (Mars *et al.,* 1996). During a 3-week period, approximately 65% of TCE was converted stably to unidentified products from which the three chlorine atoms were liberated.

The enhancement of TCE degradation by denitrifying strain PKO1 in the presence of lactate was studied (Leahy *et al.,* 1996). Methane, phenol, or toluene, under aerobic conditions, was used positively as primary substrate for inducing oxygenase enzyme (McCarty *et al.,* 1996). The results suggested using the injection of toluene, oxygen, and hydrogen peroxide in the successful full-scale aerobic co-metabolic biodegradation of TCE carried out at Edwards Air Force Base. The microbial degradation of chlorinated and nonchlorinated methanes, ethanes, and ethenes by a mixed methane-oxidizing culture grown under chemostat and batch conditions was evaluated (Chang and Alvarez-Cohen, 1996). The transformation capacity for each chlorinated aliphatic hydrocarbon was generally in inverse proportion to its chlorine content within each aliphatic group, whereas similar trends were not observed for degradation rate constants.

A rapid-growing facultatively aerobic bacterium that transforms tetrachloroethene (PCE) to *cis*-1,2-dichloroethene at high rates in a defined medium was isolated (Sharma and McCarty, 1996). PCE transformation occurred with the addition of organic substrates such as glucose, pyruvate, formate, lactate, and acetate or mixtures of amino acids. The microbial mineralization 2,4,5-trichlorophenol (2,4,5-TCP) in soil was investigated (Matus *et al.,* 1996). The absence of mineralization in sterile soil, the presence of chloroguaiacol, and the preincubation with 2,4,5-TCP supported the involvement of microorganisms in the degradative process.

The biodehalogenation of acetonitrile (ACN), chloroacetonitrile (CCN), chloroacetic acid, and chloroacetamide (ACM) by *M. trichosporium* OB-3b was investigated (Castro *et al.,* 1996). The oxidative and hydrolytic pathways in the transformations of ACN, CCN, chloroacetic acid and ACM were presented and discussed. Denitrification and nitrogen transport were quantified in a sandy glacial aquifer receiving wastewater from a septage-treatment facility in Cape Cod, Massachusetts (Desimone and Howes, 1996). Measurements and analysis evidenced that denitrification was limited by OC and not by NO_3^- concentration, but also that the denitrification influence on the total nitrogen load to receiving ecosystems was likely to be small.

A method for indicating *in situ* biodegradation of naphthalene was presented (Wilson and Madsen, 1996). The detection of the unique intermediary metabolite 1,2-dihydroxy-1,2-dihydronaphthalene was to support the hypothesis of naturally occurring microbial metabolization. The regio- and stereospecific oxidation of fluorene, dibenzofuran, and dibenzothiophene was examined with mutant and recombinant strains expressing naphthalene dioxygenase from *Pseudomonas* sp. strain NCIB 9816-4 (Resnick and Gibson, 1996). The catabolic repression of the toluene pathway by succinate in chemostat cultures at low dilution rate under different conditions of inorganic-nutrient limitation was described (Duetz *et al.,* 1996).

Oxidation of naphthenoaromatic and methyl-substituted compounds was examined with recombinant strain *P. aeruginosa* PAO1(pRE695) (Selifonov *et al.,* 1996). It was found that benzylic monooxygenation of methyl groups was strongly predominant over aromatic ring deoxygenation. The degradation of a mixture of high-molecular-weight PAHs by *Mycobacterium* strain PYR-1 was tested (Kelley and Cerniglia, 1995). The positive results strengthened the argument for the potential application of *Mycobacterium* strain PYR-1 for bioremediation of PAH-contaminated wastes. An alternative 2,3-dihydroxybiphenyl 1,2-dioxygenase, designated EtbC, was identified in RDC1 cells grown on ethylbenzene (Hauschild *et al.,* 1996).

The ability of microorganisms to degrade trace levels of hydrochlorofluorocarbons was investigated (Oremland *et al.,* 1996). It was found that $CHCl_2F$ was biodegradable in both aerobic and anaerobic soils, whereas $CHCl_2CF_3$ was biodegradable only under anaerobic conditions. The biological reductions of 2,4,6-trinitrotoluene (TNT) and 2,4- and 2,6-dinitrotoluene by *Pseudomonas* sp. clone A were presented (Haidour and Ramos, 1996). The processes for removing the nitro groups, their possible use by bacteria, and the side products were discussed. Microbial transformation of 2,4,6-TNT in aerobic soil columns was investigated (Bruns-Nagel *et al.,* 1996). Percolation with a potassium phosphate buffer supplemented with glucose and/or glucose ammonium sulfate caused a 90% decline in the amount of extractable nitroaromatics in soils for a wide range of TNT concentrations.

The ability of completely degrading 2-*sec*-butyl-4,6-dinitrophenol by *Clostridium bifermentans* KMR-1 was found (Hammill and Crawford, 1996). Substrate-stimulated soil OM mineralization in a soil-based biodegradation test was investigated (Shen and Bartha, 1996a). Actinomycete strains from 2,4,6-TNT-contaminated and -uncontaminated environments were compared for TNT tolerance and abilities to transform TNT (Pasti-Grigsby *et al.,* 1996). The effects of rhizodeposition and selected carbon substrates on biodegradation of 3-chlorobenzoate (3-CB) were studied in a series of experiments (Haby and Crowley, 1996) Results indicated that 3-CB degradation was faster in rhizosphere soil than in nonrhizosphere soil, where glucose, mannitol, or benzoate should be supplied for simulating rhizosphere effects.

The kinetics of transformation and the residual concentration of degradation of low concentrations of 3-chlorobenzoate by *Pseudomonas* sp. strain B13 were studied and measured (Tros *et al.,* 1996). The ability of the dibenzofuran- and dibenzo-*p*-dioxin-mineralizing bacterium *Sphingomonas* sp. strain RW1 to oxidize chlorinated derivatives of dibenzofuran and dibenzo-*p*-dioxins was analyzed (Wilkes *et al.,* 1996). Bacterial desulfonation of the ethanesulfonate metabolite of the chloroacetanilide herbicide Metazachlor was investigated (Laue *et al.,* 1996). A pure culture, strain HL1, was isolated, and this bacterium quantitatively desulfonated $R\text{-}CH_2\text{-}SO_3^-$, as was proved by the presence of sulfur in the cell protein.

The presence of a new sulfonic acid metabolite of metolachlor (metolachlor ESA) in soil was investigated (Aga *et al.,* 1996). A dissipation study revealed that metolachlor ESA was formed in soil under field conditions corresponding to a decrease in the concentration of the parent herbicide, metolachlor. The biodegradation of sulfolame in soil and groundwater samples from a sour gas plant site was studied (Fedorak and Coy, 1996). Under aerobic conditions, microbial populations were capable of degrading sulfolame, particularly when N and P were supplied. The effects of soil depth and temperature were studied for the degradation of 2,4-D pesticide (Veeh *et al.,* 1996). Degradation rates decreased significantly with increasing soil depth and correlated positively with bacterial plate counts, and an Arrhenius equation adequately described the effect of temperature on degradation rate.

A method based on a multilayer sampler equipped with dialysis cell for the *in situ* study of bacterial activity in aquifers at microscale environments was presented (Shati *et al.,* 1996). This method enabled the demonstration of atrazine degradation by a pure bacterial culture of *Pseudomonas* sp. strain ADP in a contaminated aquifer. The biodegradation of atrazine was studied in soil poultry litter (Gupta and Baummer, 1996). The rate of atrazine biodegradation with poultry litter was found to be almost twice as fast as without litter. The inhibition of the rapid transformation found under soil treatment with the antibiotic chloramphenicol but not with cycleheximide indicated involvement of soil bacteria in degradation of herbicide isoproturon (Cox, L., *et al.,* 1996b). Similar inhibition effects of soil treatment with antibiotic chloramphenicol but not with cycleheximide were found in field and laboratory experiments of enhanced degradation of the dicarboximide fungicides vinclozolin and iprodione (Mitchell and Cain, 1996). The enhanced degradation of vinclozolin by *P. putida* was further investigated under various culture conditions (Cain and Mitchell, 1996).

Microbial consortia were found in coumaphos-contaminated soils from eight waste sites, and their capability to mineralize insecticide coumaphos was assessed (Mulbry *et al.*, 1996). The fate of fenpropimorph and its metabolite, fenpropimorphic acid, was investigated in a silty sand soil and in clayey silt soil (Stockmaier *et al.*, 1996). The fate of bentazon [3-isopropyl-1*H*-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide] was determined in laboratory studies (Wagner *et al.*, 1996). Results showed that fate of bentazone was affected by tillage and history of application.

The rates and products of environmental dissipation of cloransulam-methyl aerobic soil metabolism were determined (Wolt *et al.*, 1996). The fate and the lifetime for biodegradation of [^{14}C]triethanolamine in aerobic surface soil, freshwater river systems, and activated-sludge waste treatment were studied (West and Gonsior, 1996). The kinetics of both primary biodegradation and mineralization were shown to be first order in triethanolamine and biomass concentrations and second order overall for the matrices and in the triethanolamine concentration range tested. The distribution of pyrimidine-2-[^{14}C]-labeled herbicide rimsulfuron applied to a sandy calcareous alluvial soil was studied under laboratory conditions for determining its availability for degradation and its possible metabolites (Metzger, L.O.Y., *et al.*, 1996).

Mineralization, degradation, and metabolites of ^{14}C-ring-labeled isoproturon were investigated for 120 days under controlled laboratory conditions in a pelosol, a brown calcareous soil, and a brown acid soil (Pieuchot *et al.*, 1996). The metabolic characteristics and the identification of some metabolites in the degradation of carbazole by *Pseudomonas* sp. LD2 were investigated (Gieg *et al.*, 1996). In a creosote-contaminated soil, carbazole was found to be used by *Pseudomonas* sp. LD2 as a sole source of carbon, nitrogen, and energy. The ready biodegradability of three fluorinated surfactants was determined under aerobic and anaerobic conditions (Remde and Debus, 1996). The metabolic efficiency and turnover of soil microbial communities in biodegradation tests were examined (Shen and Bartha, 1996b). The anomalous results in degradation kinetics and products obtained when using ^{14}C-radiolabeled glucose together with increasing dilution of unmarked glucose were discussed.

Anaerobic Processes. The biotransformation of β-hexachlorocyclohexane (HCH) under methanogenic conditions was studied (Middeldorp *et al.*, 1996). Intermediate and end products were identified, and factors inhibiting anaerobic biotransformation of β-HCH were discussed in detail. The anaerobic biodegradability of alkylbenzenes (BTEX) and TCE in aquifer sediments downgradient on an unlined landfill was investigated (Johnston *et al.*, 1996). TCE was degraded to ethylene in microcosms with aquifer material but exhibited an inhibitory effect on toluene degradation, whereas other BTEX compounds were recalcitrant in both ambient and amendment experiments.

A study was conducted successfully for demonstrating toluene and TCE degradation activity by some bacterial strains obtained by electroporating plasmids from toluene dioxygenase or toluene monooxygenase promoters into bacteria isolated from sediments found at depths of 91 to 295 m (Romine and Brockman, 1996). The presence of alternative mechanisms to reductive dehalogenation in degradation of monochlorinated and nonchlorinated aromatic compounds under iron-reducing conditions was discussed (Dolfing, 1996). Some laboratory results, however, suggested that reductive dehalogenation could be the mechanism in sulfate- and iron-reducing consortia (Kazumi *et al.*, 1996).

Substrate and microorganism concentrations were correlated positively to the degradation rate of 1,1,1-trichloroethane on *in situ* bioremediation experiments under anaerobic conditions (Doong and Chen, 1996). The anaerobic biotransformation of several hydrocarbons found in gasoline including BTEX was studied in batch laboratory microcosms using aquifer sediment and groundwater obtained from Seal Beach, California (Ball and Reinhard, 1996). Experiments indicated the ability of indigenous microorganisms to degrade BTEX compounds and the importance of sulfate- and nitrate-reducing activities in influencing intrinsic bioremediation. A laboratory experiment was conducted to investigate temperature effects on pentachlorophenol (PCP) reductive dechlorination in an interceptor trench (Cole *et al.*, 1996). An interceptor trench inoculated with a temperature- and PCP-acclimated methanogenic consortia had the potential to anaerobically biotransform PCP as low as 10°C.

Studies were conducted to determine how the concentration of a chlorinated aliphatic compound affected acetate use and its own transformation in methanogenic systems (Hughes and Parkin, 1996a). Individual dichloromethane, chloroform, and 1,1,1-trichloroethane biotransformation rates of chlorinated aliphatic mixtures were investigated in batch cultures and in continuously fed attached-growth systems under anaerobic conditions (Hughes and Parkin, 1996b). The effects of supplying nitrogen as nitrate, ammonia, and molecular nitrogen on the growth, TCE degradation capacity, and energy storage capacity of a mixture of methane-oxidizing cultures were investigated (Chu and Alvarez-Cohen, 1996). TCE product toxicity was not found to be more pronounced for the nitrate- or ammonia-supplied than for the nitrogen-fixing microbial cells, whose metabolic activity was enhanced beyond that which could be explained by increased energy storage alone.

The biotransformabilities of TCA and CCl_4 were investigated under low concentrations of acetic acid as the auxiliary substrate for evaluating the effect of the auxiliary substrate on the transformation of the chlorinated hydrocarbons (Doong and Wu, 1996). Experiments were conducted to examine the effects of several culture parameters on pentachloronitrobenzene (PCNB) and for increasing rates of biodegradation (Lièvremont *et al.*, 1996). The best PCNB degradation results were found under low concentration of carbon and nitrogen, whose presence was shown to have a strong influence on PCBN degradation.

The estimation of the changing rate of anaerobic reductive dechlorination of chlorinated aliphatic hydrocarbons in the presence of petroleum hydrocarbons was discussed (Moutoux *et al.*, 1996). The possibility of biodegradation of BTEX under iron-reducing conditions was studied successfully in batch microcosms, and the relative disappearance rates of biodegradation of different BTEX compounds were determined (Kelly *et al.*, 1996b). The fate of a mixture of six polychlorinated bornanes isolated from technical toxaphene was investigated in a loamy silt under anaerobic conditions in a laboratory study (Fingerling *et al.*, 1996). The reductive dechlorination was the leading reaction to a sequential removal of chlorine from each dichloro group.

Nitrate loading effects on controlling toluene anaerobic biodegradation were studied in connection with requirements of maintaining nitrate and toluene concentrations below drinking water standards under continuous-flow conditions (Mester and Kossom, 1996). Anoxic treatment of trifluoralin-contaminated soils was studied, and a zero-order transformation rate was estimated from fitting of experimental data (McFarland *et al.,* 1996). Evidence for acetyl coenzyme A and cinnamoyl coenzyme A in the anaerobic toluene mineralization pathway in *Azoarcus tolulyticus* Tol-4 was presented, and a degradation pathway of toluene was proposed (Chee-Sanford *et al.,* 1996). Furthermore, benzylfumaric, benzylmaleic, and Z- and E-Phenylitaconic acids were synthesized, characterized, and correlated with a metabolite generated by *A. tolulyticus* Tol-4 during anaerobic toluene degradation (Migaud *et al.,* 1996).

A novel sulfate-reducing compound isolated from fuel-contaminated subsurface soil, strain PRTOL1, was found to mineralize toluene as the sole electron donor and carbon source under strictly anaerobic conditions (Beller *et al.,* 1996). The mineralization of 80% of toluene to CO_2 was demonstrated in experiments, and 15% of toluene carbon was converted to biomass and nonvolatile metabolic byproducts. The influence of an electron donor on minimum sulfate concentration required for sulfate reduction in a petroleum hydrocarbon-contaminated aquifer was investigated (Vroblesky *et al.,* 1996a). A competition between sulfate-reducing bacteria and methanogenic bacteria was suggested by data under limited electron donor availability.

The use of methods based on tracking concentration changes of substrates or final microbial metabolism over time was presented (Chapelle *et al.,* 1996a). A combination of these methods was proposed for dealing with laboratory and field method uncertainties for measuring rates of biodegradation in petroleum hydrocarbon-contaminated aquifers. The biodegradability of phenol and all isomers of six different functional groups of monosubstituted phenols were examined under denitrifying and methanogenic conditions (O'Connor and Young, 1996). The type of anaerobic condition and the nature of the substituent group could influence both metabolism and toxicity of phenolic compounds.

The potential of microbially mediated Cr(VI) reduction during anaerobic degradation of benzoate was studied in a series of microcosms and enrichments (Shen *et al.,* 1996). Cr(VI) strongly influenced degradation of benzoate, whose degradation process was reversely promoting Cr(VI) reduction to Cr(III). Evidences of anaerobic oxidation of vinyl chloride under Fe(III)-reducing conditions in aquifer sediments were provided (Bradley and Chapelle, 1996). A batch test system was described for assessing the mineralization of ^{14}C-radiolabeled compounds to CO_2 and CH_4 under environmentally realistic anaerobic conditions (Nuck and Federle, 1996).

Aerobic/Anaerobic Processes. Toluene and xylene degradation rates by a denitrifying strain of *Xanthomonas maltophilia* were quite insensitive under oxygen-limited or anoxic conditions (Su and Kafkewitz, 1996). *X. maltophilia* had the ability to degrade vinyl chloride using ethene as a sole substrate (Verce and Freedman, 1996). The rate-controlling effect of O_2 availability on the decomposition rate of hydrocarbons in soils was examined, and a kinetic second-order model was calibrated with experimental results (Freijer, 1996). Aerobic and anoxic biotransformation of 2,4-dinitrotoluene (DNT) was examined by using a *P. aeruginosa* strain isolated from a plant treating propellant-manufacturing wastewater (Noguera and Freedman, 1996). Both DNT nitro groups were reduced by *P. aeruginosa,* which demonstrated the ability to degrade also the 4-amino-2-nitrotoluene and 2-amino-4-nitrotoluene formed by DNT reduction.

Particle size effects on aquifer microorganism activities were investigated by means of flow-through microcosms using gravel, silt, and intermediate sand (Dodds *et al.,* 1996). Di-*n*-butyl phthalate (DBP) was transformed by microorganisms under aerobic, nitrate-reducing, Fe(III)-reducing, and sulfate reducing conditions and was significantly sensitive to redox potential reduction, nutrient depletion, and toxic intermediate presence (Chauret *et al.,* 1996). The respective role of mixed culture of sulfate-reducing and methanogenic bacteria in TCE dechlorination was investigated (Cabirol *et al.,* 1996). Batch-type experiments were conducted with different concentrations of acetate as auxiliary substrate under various redox conditions for evaluating the effects of redox potential and substrate concentration on biotransformation of CCl_4 and PCE (Doong *et al.,* 1996). The redox potential of the environment was the leading factor in chlorinated hydrocarbons.

Interactions with Other Processes. The potential of phytoremediation in the cleanup of contaminated sites and in the prevention of nonpoint source pollution was examined with the pesticide atrazine in two experimental systems (Burken and Schnoor, 1996a). This study indicated that vegetative uptake and degradation of rhizosphere could influence positively the remediation of hazardous waste sites. The effects of rhizosphere on atrazine degradation were examined in soil inoculated with an atrazine-mineralizing bacterial consortium (Alvey and Crowley, 1996). Corn plants had no effect on atrazine mineralization, except that the formation of hydroxyatrazine was enhanced significantly in planted soil. ^{14}C-labeled atrazine was degraded rapidly by hybrid poplar trees (Burken and Schnoor, 1996b).

Mineralization of atrazine was enhanced significantly in soil treated with a mixture of atrazine and metolachlor in rhizospheric soil from a herbicide-resistant plant compared to nonvegetated and control soils (Perkovich *et al.,* 1996). Enhancement of anaerobic 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl) ethane (DDT) biotransformation by mixed cultures was studied with application of surfactants and redox potential reducing agents (You *et al.,* 1996). Addition of both surfactants and reducing agents extended the DDT transformation by reducing the accumulation of 1,1-trichloro-2,2-bis(*p*-chlorophenyl) ethane (DDD) and increasing the accumulation of less chlorinated compounds.

A radiotracer experiment was performed to clarify the influence of microbial activity on plant-available Tc under waterlogged conditions (Tagami and Uchida, 1996). Tc adsorption onto the soil was influenced by the activity of microorganisms; that is, the redox potential of the soil was lowered by their activity. A model accounting for kinetic sorption and aerobic biodegradation described the fate of aromatic hydrocarbons (Bjerg *et al.,* 1996). Parameters for a first-order degradation process model were obtained, and it was shown that independent estimation of sorption parameters was required to obtain accurate degradation parameters.

Alachlor biotransformation and sorption mechanisms and kinetics were evaluated in soil from two soybean tillage systems (Locke *et al.,* 1996). It was found that tillage did not influence the initial disappearance of alachlor but did affect the metabolite transformations. Sorption and aerobic biodegradation of strychnine alkaloid in various soil systems were examined, ranging from a loamy sand to a sandy clay loam (Starr, R.I., *et al.,* 1996). A direct relationship was observed between strychnine sorption and cation exchange capacity but not between sorption and OM content.

A study was conducted to determine abiotic and biotic agents for dithiopyr loss from golf course greens (Hong and Smith, 1996). Temperature, oxygen availability, and sorption to OC were the most important physicochemical and environmental factors affecting transformation rates of the herbicide metamitron in soil (Vink and van der Zee, 1996). The potential effect of soil carbon content on groundwater nitrate contamination was investigated (Adelman and Tabidian, 1996) The risk of nitrate leaching with excessive fertilizer and irrigation rates could be reduced by increasing organic soil carbon level, and the root-zone denitrification impact could not be definitely determined.

Heterogeneity in subsurface sediment grain size and contaminant distribution was examined in sediments collected in adjacent boreholes at discrete depth intervals in the saturated zone (Aelion, 1996). Sediments were analyzed for JP-4 and BTEX, and some correlations were found for individual JP-4 and BTEX and sediment grain sizes. The effects of growing ryegrass on the biodegradation of hydrocarbons were studied in laboratory-scale columns (Gunther *et al.,* 1996). Results obtained by determining hydrocarbon degradation, bacterial numbers, soil respiration rates, and soil dehydrogenase activities indicated that biodegradation of hydrocarbons in rhizosphere was stimulated by plant roots.

The migration and the direction of groundwater flux and microbial activity were examined in a drinking water source near Barrow, Alaska (Braddock and McCarthy, 1996). Results showed that the water flow was small because of shallow permafrost and constrained transport and that dispersion and microbial activity likely was restricted to the short annual thaw season. Stable carbon isotopes in dissolved inorganic carbon were used to indicate zonation of ^{13}C-depleted hydrocarbon biodegradation processes under the influence of hydrologically controlled electron-acceptor availability (Landmeyer *et al.,* 1996). In a jet-fuel–contaminated aquifer, biodegradation under aerobic and sulfate-reducing conditions was found in the shallow part of the aquifer, whereas methanogenic conditions were found in the deeper part of the aquifer.

The reduction of PCE and TCE catalyzed by vitamin B_{12} was examined in homogeneous and heterogeneous batch systems using titanium(III) citrate as bulk reductant (Burris *et al.,* 1996a). Field experiments were implemented using randomized block designs for studying *in situ* dynamics of aromatic hydrocarbons and bacteria capable of metabolizing aromatic carbons in a coal tar waste-contaminated field site (Madsen *et al.,* 1996). Microbial anaerobic dechlorination of hexachlorobenzene (HCB) was examined in sediment slurries amended using different concentrations of surfactants such as polyoxyethylene (POE) sorbitan fatty acid esters and POE alcohols for enhancing solubility and bioavailability of organic pollutants to degrading microorganisms (Van Hoof and Jafvert, 1996).

The reduced biodegradability of desorption-resistant fractions of polycyclic aromatic hydrocarbons (PAHs) in soil and aquifer solids was investigated (White and Alexander, 1996). Freshly added PAHs were more easily biodegradable than desorption-resistant fractions, but PAH mineralization could be increased by addition of a surfactant and methanol in slurry loam. The mechanisms of microbial phenanthrene mineralization in sediment samples by sorbent-sorbate contact time, inocula, and gamma-irradiation–induced sterilization artifacts were investigated, and several hypotheses were tested for explaining variations in phenanthrene metabolism (Sandoli *et al.,* 1996). A two-step oxidation process was investigated for biodegradation enhancement of phenanthrene-contaminated soil resulting from a soil-washing process (Van Kemenade *et al.,* 1995).

Biodegradation and desorption of sorbed fluorene, a three-ringed polynuclear PAH, was investigated in estuarine sediment-water slurries (Chandra *et al.,* 1996). Fluorene was degraded rapidly in biologically active systems, after a lag period, to levels less than limits of detection, and the kinetic rate was controlled by microbial degradation rates and not limited by desorption. The possibility of enhancing PAH degradation with an advanced oxidative process (Fenton's reagent: H_2O_2 + $FeSO_4$) in soil that had been exposed previously to crude oil was examined (Martens and Frankenberger, 1995). Results confirmed this possibility and indicated Fenton's reagent as a valid alternative in bioremediation practice for degrading most recalcitrant chemical PAHs.

The capacity of PAH-using bacteria to produce biosurfactants was investigated (Deziél *et al.,* 1996). Biosurfactant production was detected by surface tension lowering and emulsifying activities accompanied by an increase in aqueous concentration of napththalene in an iron-limited salt medium supplemented with dextrose and mannitol as well as with PAHs. Biodegradation and dissolution models were combined to quantify the influence of the surfactant Tergitol NP-10 on biodegradation of solid-phase phenanthrene by *P. stutzeri* P16 (Grimberg *et al.,* 1996b). A series of nonionic surfactants was identified for enhancing phenanthrene solubility and then bioavailability, and a mathematical model was formulated to describe the interaction of the biomass, contaminant, water, and surfactant system (Guha and Jaffè, 1996a). The model reproduced experimental data quite well, confirming the correctness, or at least the reliability, of the assumptions on which it was based. The removal of 2,4,6-TNT in the subsurface was simulated theoretically using a steady-state monodimensional form of the AD-reaction equation, also accounting for TNT dissolution (Voudrias and Assaf, 1996). *In situ* rates of denitrification in a nitrate-contaminated aquifer using small-scale, natural-gradient tracer tests were measured, and the results were compared with rates obtained from laboratory incubation rates (Smith, R.L., *et al.,* 1996).

Experiments were conducted in a model system at different pH to clarify the effect of adsorption of nitroacetate (NTA) on its degradation by *Chelatobacter heintzii* (Bolton and Girvin, 1996). Both experimental and simulation results demonstrated that sorbed NTA was unavailable to biodegradation and that the desorption rate limited the rate of biodegradation. Experiments were conducted on some anionic, cationic, and nonionic surfactants (Knaebel *et al.,* 1996). Results showed that interactions with kaolinite, illite, and sand had little effect on the microbial metabolism of organic compounds, whereas montmorillonite, humic acids, and especially fulvic acids significantly decreased the bioavailability of the chemicals to the microbial community.

Experiments were conducted to investigate the fate of ethylbenzoate and soil microorganisms in shallow aquifers (Yang, G.X., *et al.,* 1996). Biodegradation and volatilization were identified as the major mechanisms in attenuating ethylbenzoate in contaminated soils. A review study indicated that increased soil-chemical contact time increased the resistance of chemicals to desorption, volatilization, biodegradation, and extraction and that results obtained on chemicals freshly added to soils could not be used to predict the behavior of chemicals that had been in contact with soils for extended periods of time (Loehr and Webster, 1996a). A study was conducted on biodegradation of 1:1 nickel:citric acid by *P. fluorescens* and on modulation of nickel toxicity by iron (Francis *et al.*, 1996). The incomplete degradation of the complex was attributed to the toxicity of the Ni released and not to the change in its structure.

Modeling. A FD model for simulating the substrate-limited biotransformation of halogenated solvents such as TCE and PCE present in anoxic groundwater by sequential reductive dehalogenation under methanogenic conditions was developed (Hossain and Corapcioglu, 1996). In all cases, compounds were removed effectively, but results indicated substantial levels of intermediate product accumulations. Another 3-D FD model was proposed for simulating flow, transport, and biodegradation of NAPLs (de Blanc *et al.*, 1996). Various numerical approaches were explored for solving the system of ordinary differential equations describing biodegradation, and Gear's method was found to furnish reliable solutions under all conditions.

A mixed FE-finite volume numerical approach was developed for solving a saturated flow, transport, and diffusion-limited aerobic–anaerobic biodegradation model (Gallo and Manzini, 1996). An upwind TVD shock-capturing technique also was implemented for capturing steep concentration fronts. A simulation model was presented for modeling biologically mediated redox processes, which were incorporated in a kinetic submodel (Lensing, 1996). A completed redox sequence of five functional bacteria groups also was enclosed in the model, the application, capabilities, and limitations of which were discussed.

Two 2-D models based on U.S. Geological Survey (USGS) MOC were used to simulate the transport of reactive solutes (Muñoz *et al.*, 1996). The model, whose parameters were found by experimental results fitting, was applied for simulating both bioremediation of a hydrocarbon-contaminated aquifer and *in situ* acid leaching of copper in mining tailings. A physically based model was developed to study the transport of a solute used by microorganisms forming a biofilm coating grains in a porous medium (Dykaar and Kitanidis, 1996). A numerical study was performed on the *Pe* and Damkohler number for determining possible mass transport limitations and mechanisms controlling macroreaction rates.

A 2-D, multispecies reactive solute transport model with aerobic and anoxic degradation processes was developed (Essaid *et al.*, 1995). The model was applied successfully to study the field-scale solute transport and degradation processes at the Bemidji, Minnesota, crude-oil spill. A numerical flow and transport model was developed to simulate bacterial dissolved oxygen (DO) consumption in the aquifer and to evaluate remedial alternatives (Lieberman, 1996).

Saline Groundwater. A sharp-interface model was developed using a multiphase flow approach to simulate the saltwater intrusion problem (Huyakorn *et al.*, 1996). Pseudosaturations, capillary pressures, and constitutive relations were defined by converting traditional sharp interface equations to an equivalent set of two-phase fluid flow equations. A mixed hybrid FE method and discontinuous FE method were applied to simulate flow and transport in saltwater intrusion problems (Oltean and Bués, 1996). The model was verified by comparison with the Henry and free convection problems.

A model was developed to understand the mechanisms involved in the mineralization of the Great Bend Prairie aquifer of Kansas by saltwater originating from Permian bedrock formations (Rubin and Buddemeier, 1996b). Simulations using the model characterized the dispersion of the sharp interface between the saline and fresh water because of mixing in fracture intersections and between the fracture flow and permeable block flow. The effect of recharge intensity and duration on the motion of the saline/freshwater interface was investigated with a numerical model (Mahesha and Nagaraja, 1996). A discussion was presented with regard to a previous article on numerical modeling of the salt dome problem (Johns and Rivera, 1996, and Oldenburg *et al.*, 1996).

A model was developed for simulating transport of reactive species during saltwater intrusion (Gomis *et al.*, 1996). The model was based on chemical element mass balances rather than species; this simplified the solution process. Transport of Ca^{2+}, Na^+, and Mg^{2+} during saltwater intrusion was simulated by including cation-exchange processes (Wu, J., *et al.*, 1996). Saltwater intrusion into a Turkish groundwater basin was simulated with a coupled flow and transport model (Emekli *et al.*, 1996). The modeling results focused on establishing the width of the dispersion zone and present-day rate of interface movement.

Field data and various model simulation exercises were combined with a simplified distribution of hydraulic conductivities to simulate saline groundwater distributions and the saline/freshwater interface position in the Mono Basin, California (Rogers and Dreiss, 1995a). Simulations indicate that redistribution of Mono Basin solutes between Mono Lake and underlying groundwater may be responsible for the present-day salinity of Mono Lake (Rogers and Dreiss, 1995b). Isotopic and geochemical analyses were used to assess the hydrogeologic factors contributing to the evolution of saline groundwater in the Edwards aquifer (Oetting *et al.*, 1996). Faulting, variations in depositional, diagenetic, and mineralogic characteristics, and external contributions of saline water were significant factors.

Isotopic and geochemical analyses were used to examine the evolution of saline waters in Indian coastal groundwaters (Sukhija *et al.*, 1996b). The results were used to distinguish between contributions from paleomarine and modern seawaters. Ion exchange processes occurring during the transport of oil field brines were investigated with column studies (Cates *et al.*, 1996). It was shown that displaying the resulting chemical analyses with Piper diagrams can lead to rapid assessment of brine contamination.

The sources of fresh and saline waters in a Jamaican basin affected by saline intrusion were identified by geochemical and isotopic analyses (Howard and Mullings, 1996). Conductivity and temperature measurements were taken in two Spanish coastal aquifers affected by saltwater intrusion (Rozycki, 1996). The results were used to assess the effects of temperature distributions on saline intrusion and the temporal nature of the intrusion. A sharp interface model was used to assess the ability of freshwater injection wells to control saline intrusion (Mahesha, 1996a,b). Reductions of saline intrusion of 60 to 90% were simulated where the degree of reduction was determined by injection well location, spacing, and rate. A similar model was used to assess injection-extraction schemes (Mahesha, 1996c). Characteristic curves describing saline/groundwater interface positions were produced based on extraction and injection well spacing and rates. A simplified model was developed to explain salinity changes during varying pumping conditions in a two-layer aquifer (Sawicki, 1996).

Colloidal and Organic Matter Transport. A forced gradient tracer test of natural OM was conducted in a sandy, coastal plain aquifer (McCarthy *et al.,* 1996). The results indicated that the functional behavior of natural OM with respect to contaminants will vary with time because of differences in transport behavior of natural OM components. A review of colloid-enhanced contaminants was published (Ouyang *et al.,* 1996b). The review focused on the occurrence of colloids and association of colloids with contaminants and on models of colloid transport and colloid-enhanced contaminant transport.

Theoretical calculations of dissolved tracer and colloid flow geometries were used to determine dispersion rates of tracers and colloids (Grindrod *et al.,* 1996). Experimental data also were used to show that ratios of colloid and tracer elution and dispersion rates were functions of the colloids and porous medium. A laboratory column study was conducted to investigate colloid enhanced transport of lead as a function of aqueous cation concentrations (Grolimund *et al.,* 1996). Changes in the cation composition of the infiltrating solutions released colloidal particles and produced substantial transport of lead on the particles. Colloid-facilitated transport of metolachor was demonstrated to be a function of the physicochemical and mineralogical characteristics of the colloids (Seta and Karathanasis, 1996).

Early breakthrough of cesium in the presence of kaolinite particles was observed in column experiments (Saiers and Hornberger, 1996b). The experimental results agreed with a model incorporating first-order, irreversible, kinetic kaolinite sorption, linear adsorption of cesium onto kaolinite, and Langmuir sorption of cesium onto the solid. Clay particle transport and attendant radionuclide transport were investigated in the presence of a salinity gradient (Fauré *et al.,* 1996). The amount of clay migration depended on the NaCl concentration of the infiltrating solution.

A model accounting for deep-bed filtration of colloids was developed to describe colloid-facilitated transport in discretely fractured porous media (Ibaraki and Sudicky, 1995a). Sensitivity analyses revealed that colloid-enhanced migration was significant if contaminant sorption onto the colloids was a slow kinetic process. Further simulations indicated that colloid-enhanced solute transport was likely to increase prediction uncertainty because of uncertainty in colloid filtration coefficients and fracture network characteristics (Ibaraki and Sudicky, 1995b). The transport of colloids and suspended particles in a granite fracture was investigated (Vilks and Bachinski, 1996b). Aqueous flow path, direction, and rate and particle size affected colloid and suspended particle mobility.

The association of Pb with colloids significantly affected Pb transport in a soil profile (Wang and Benoit, 1996). Both dissolved and colloid-associated Pb were immobilized in the soil profile by adsorption processes. Goethite colloid transport was controlled by pH and initial goethite colloid concentration in column experiments (Sätmark *et al.,* 1996). BTCs of goethite and radionuclides did not display any similarities, except for iodate at low pH. The Cu and Cd content of a range of colloidal materials was analyzed with a graphite furnace atom absorption spectrometry method (Freedman *et al.,* 1996). The method produced high analyte recoveries.

Experiments conducted in a 3-D, heterogeneous porous medium demonstrated the importance of the third dimension on particle transport (Silliman, 1996). Particle transport depended on the connectivity of high-permeability pathways in the third dimension. Modeling and column experiments investigated the effects of geochemical heterogeneity on colloid transport (Johnson, P.R., *et al.,* 1996). Surface charge heterogeneity significantly affected the deposition of colloids on the porous media.

Particle deposition and accompanying permeability reductions were investigated with a pore network simulator (Skouras *et al.,* 1996) Hydrodynamic and physicochemical interactions between the particles and pore walls and changes in the pore structure were considered in 3-D particle trajectory and deposition calculations. The motion of colloidal and larger particles influenced by electric fields was studied in capillary tubes (Kuo and Papadopoulos, 1996). The direction of motion relative to the cathode-anode configuration and the dominant flow mechanisms were determined as functions of pH and electric field strength. The factors responsible for permeability reduction in aquifer materials under the influence of bioremediation efforts were assessed with column experiments (Wiesner *et al.,* 1996). Colloid deposition and gas binding were more likely explanations for the observed permeability reduction than iron precipitation.

Microorganism Transport. Deposition of two bacterial species was analyzed in terms of clean bead collision frequency and surface area blocked by attached cells (Rijnaarts *et al.,* 1996a). A collision-blocking model adequately described microbial transport. The effects of cell surface, solid media hydrophobicity, and electrolyte concentration on bacterial deposition were investigated (Rijnaarts *et al.,* 1996b). The influence of these factors on clean bead collision frequency and surface area blocked by attached cells were quantified. Macroscopic models were developed for determining changes in porosity-specific surface area and permeability caused by biomass accumulation (Clement *et al.,* 1996). The models were in good agreement with models based on biofilm growth.

A method for selecting characteristic collector diameters for bacterial filtration models was established by measuring bacterial retention in columns packed with various porous media (Martin *et al.,* 1996). Characteristic diameters based on smaller particles most accurately described bacterial transport. The presence of dissolved OM and solid-phase OM affected bacterial transport (Johnson and Logan, 1996). The degree of bacterial retention was a function of the type of OM and solid surface. Models with kinetic and equilibrium bacterial adsorption terms were compared with solute and bacterial transport (Reddy and Ford, 1996). The models yielded similar results with regard to solute concentrations but significant differences in bacterial distributions and BTCs.

A model was presented for describing bacteria-enhanced transport of contaminants where bacterial and contaminant mass-transfer processes were represented with kinetic models (Kim and Corapcioglu, 1996). Simulation results indicated that equilibrium assumptions may be used when Damkohler numbers are greater than 10. A model of bacteria-enhanced transport of DDT was developed by matching experimental data (Saiers and Hornberger, 1996c). The model incorporated a Freundlich isotherm equation for DDT-bacteria adsorption and kinetic expressions for bacterial deposition and DDT adsorption to the porous medium. A model of virus transport with time-dependent inactivation rates was developed (Sim and Chrysikopoulos, 1996a). A pseudo first-order inactivation rate coefficient compared better with experimental data than constant-rate coefficients and produced extended virus survival. A correction to a previously published article on virus transport modeling was presented (Sim and Chrysikopoulos, 1996b).

FATE AND TRANSPORT IN VADOSE ZONE SYSTEMS

Hydrodynamics. *Physical Processes.* A model was presented for simulating salt migration under nonisothermal conditions in a porous media partially saturated with saline water (Bear and Gilman, 1995). The model was applied to demonstrate that a heat source can attract salts and produce salt precipitation in the heated area. Porosity changes caused by brine transport in unsaturated porous media were investigated with a theoretical and numerical model (Olivella *et al.,* 1996). Water vapor transport and water condensation were important factors determining porosity variations. Salt diffusivity was measured as a function of water content and capillary pressure–water content curves for three soils (Olesen *et al.,* 1996) Two new models for salt diffusivity as a function of soil texture parameters were proposed and were compared with experimental results and existing models.

A methodology for analyzing unsaturated zone, chemical profiles by two extraction methods was presented for determining the direction of water flow and differentiating between upward water and vapor transport (Ronen, D., *et al.,* 1996). The methodology assessed saline transport mechanisms in the vadose zone of the Dead Sea area. Infiltration and tracer experiments were conducted in a sand and gravel vadose zone (Rudolph *et al.,* 1996). Lysimeter and time domain reflectometry networks provided tracer concentration and water content data, which were used to characterize flow and transport properties. A laboratory study was conducted in two different soils to investigate the effects of temporal variations in flow velocities on pesticide transport (Ma and Selim, 1996). The effects of temporal velocities depended on the soil type, and averaged velocities could not be used to represent the pesticide transport.

Three forms of the AD equation were fitted to BTCs obtained from undisturbed soil monoliths (Jensen *et al.,* 1996). The more complex models provided better fits to the data, but more uncertainty was associated with the resulting parameter values. A field tracer study indicated that significantly better mass recovery was obtained with destructive sampling than with solution sampling (Ellsworth *et al.,* 1996). Results also indicated that the dispersivity was scale dependent and that a log-normal transfer function model provided the best fit to the measured concentrations. Solute concentrations and water contents measured in a field tracer study showed that heterogeneity had a more pronounced effect on the concentrations (Zhang *et al.,* 1996b). A model that ignored pore-scale dispersivity was able to simulate the mean measured concentrations but produced poor simulations of concentration variance.

A two-layer transfer function model was used to determine field-scale transport parameters from tile drain BTCs (Radcliffe *et al.,* 1996). The model successfully provided transport parameter estimates as long as lateral flow in the saturated zone was accounted for in the second layer. The relationship between the field- and local-scale parameters was investigated by conducting column experiments (Gupte *et al.,* 1996). Macropore or preferential flow were found to be significant at the local scale. Undisturbed column tracer studies were conducted under ponding and sprinkler conditions to estimate solute velocities relative to piston flow velocities and the magnitude of preferential flow (Ren *et al.,* 1996). The contribution of macropores to flow and solute transport was greatest when the soil was initially dry and decreased as the soil became wetter (Shipitalo and Edwards, 1996).

A literature review of field experimental and observational studies of pesticide transport was presented (Flury, 1996). Although the literature is inconsistent about the factors controlling pesticide leaching rates, initial water content, surface preparation, and pesticide application time showed promise for controlling leaching mechanisms. Column experimental results with two pesticides and chloride tracer were better predicted with a two-site, two-region model than with the standard AD model (Singh *et al.,* 1996). A field study was conducted to investigate the transport of ions by infiltrating stormwater (Iqbal and Krothe, 1996). Preferential flow, anion exclusion, and cation attenuation were important processes controlling ion transportation, along with dilution caused by mixing of stormwater with the resident soil water.

The effects of rainfall and evapotranspiration on the transport of various organic species were assessed in a modeling study (Grifoll and Cohen, 1996). The dynamics of rainfall and period of initial concentration affected the volatilization flux and amount of chemical remaining in the vadose zone. Mobile–immobile model transport parameters were determined from tracer BTCs obtained with a series of soil columns taken along a transect (Mallants *et al.,* 1996a). The estimated pore velocities, dispersions, and mobile water content ratios were described best with log-normal distributions, whereas the mass-transfer coefficients could be described with a normal distribution. Simulations of chlorsulfuron leaching with the MACRO model were used to estimate parameters and compare results from a lysimeter leaching experiment (Bergström, 1996). The experimental results were better predicted when two flow domains were included. The dependence of soil-water chemistry on flow pathways in forested tills was reviewed (Lundin, 1995).

Modeling. An Eulerian-Lagrangian localized adjoint method (ELLAM) solution was developed for the 2-D, two-phase, contaminant transport equations (Binning and Celia, 1996a). A combined conservative–nonconservative ELLAM scheme was developed to handle boundary condition problems, and the scheme was shown to be superior to a Galerkin FE solution. A Petrov-Galerkin FE solution was applied to 1-D water flow and solute transport in the vadose zone (Nguyen, 1996). A modified weighting function, based on the least-squares FE concept, was shown to be unconditionally stable for all Courant and *Pe.* A new approximation to the analytical solution for spherical diffusion of solute in a dry soil was presented (Knight, 1996).

A macroscopic, dual-porosity model for water and solute transport was proposed based on a geometry-dependent coefficient in the mass-transfer term (Gerke and van Genuchten, 1996). The coefficient was used to represent the size and shape of soil aggregates or rock matrix blocks, and expressions for the coefficient were derived for various structural geometries. A model based on the subsystems and moving packets (SAMP) concept was developed for describing unsaturated flow and transport under equilibrium and nonequilibrium conditions (Ewen, 1996a). The model relied on tracking discrete packets of water as affected by matric potential, unsaturated hydraulic conductivities, and an internal scale parameter. A 1-D form of the SAMP model was described and used to simulate column BTCs (Ewen, 1996b).

Unimodal and bimodal models of pore size distributions were incorporated into an unsaturated flow and transport model (Zurmühl and Durner, 1996). The bimodal models yielded a preferential flow characteristic that significantly affected the transport behavior. Various conceptual models of mobile water content also were presented and incorporated into the flow and transport model. Simulations of flow and transport in 2-D, Miller-similar media were used to assess the impact of the critical point concept (Roth and Hammel, 1996). Effective transport parameters and their transitions around the critical point were found to depend strongly on the overall water flux.

Similar media scaling and conditional simulations were used to model water flow and solute transport for an experiment at the Las Cruces Trench Site (Rockhold *et al.*, 1996). Relatively good agreement between modeled and observed flow and transport behavior was found, without any model calibration. A 2-D, Galerkin FE model was developed to simulate flow and heat and solute transport in furrow-irrigated soil (Noborio *et al.*, 1996a). Model simulations of water content, temperature, and solute concentration agreed well with results from a field test (Noborio *et al.*, 1996b). A transfer function model was proposed where the travel time variance increases proportionally with depth to a specified power (Liu and Dane, 1996d). The effect of the power value on solute transport behavior and resulting special cases were discussed.

A high-resolution, Monte Carlo technique was developed for analyzing statistical moments in variably saturated, heterogeneous porous media (Harter and Yeh, 1996a). The factors contributing to and trends in concentration prediction uncertainty were analyzed. A model for conditional simulation of steady-state flow and transient transport was used to investigate using conditional simulation for assessing sampling network designs (Harter and Yeh, 1996b). Reductions in uncertainty were determined as a function of sampling schemes for saturated hydraulic conductivity and capillary pressure–water content relationships. A reliability algorithm was combined with an unsaturated flow and transport model to provide estimates of probabilities that a concentration will be exceeded and the relative importance of uncertain parameters (Piggot and Cawlfield, 1996). The probabilities of exceedance were very sensitive to changes in saturated water content.

A 3-D model of variably saturated flow and solute transport in discretely fractured media was developed (Therrien and Sudicky, 1996). The model is based on a control volume and FE and Galerkin FE techniques for solving the flow and transport equations, respectively. The use of the Green-Ampt model for describing advective solute transport was investigated by comparisons with a Richards equation-based model (Govindaraju *et al.*, 1996). Comparisons of predicted solute concentration distributions revealed that the Green-Ampt model is adequate for advective solute transport predictions. A surface irrigation model was combined with two functional solute transport models, RAO and TETrans, to simulate solute transport with intermittent irrigation (Izadi *et al.*, 1996). The ability of the two models to simulate solute concentration profiles was evaluated.

The current state of the art for coupling vadose zone flow and transport models with geographic information systems (GIS) was reviewed (Tim, 1996). Examples were provided for coupling models of contaminant transport from nonpoint sources with GIS. GIS modeling was used to partition hydrologic systems into subsystems, and the resulting descriptions were used stochastically as inputs to a nitrate leaching model (Wu, Q.J., *et al.*, 1996). The model predictions were analyzed and compared with field observations. Soil survey data were used as stochastic inputs for nitrate leaching modeling (Bouma *et al.*, 1996). Monte Carlo and geostatistical techniques were applied to illustrate the effects of soil property variability and to interpolate the soil property point data.

Four vadose zone leaching models were used to calculate soil cleanup criteria for volatile organic compounds (VOCs), based on not exceeding a critical groundwater concentration (Sanders, 1995). The predicted cleanup criteria were affected by the processes included in each of the models. A procedure for validating pesticide leaching models was proposed and applied for the CRACK-P model and a data set from a field experiment (Armstrong *et al.*, 1996).

Sorption-Desorption. Unsaturated column experiments were conducted to investigate the mechanisms of VOC uptake as a function of VOC, moisture content, and influent VOC concentration (Corley *et al.*, 1996). A pore-filling model was used to analyze the column data, and it was suggested that a capillary-phase separation process occurred in the pores. Sorption of pesticides and their subsequent degradation on macropore linings were studied in various soils (Mallawatantri *et al.*, 1996). The reactions of various polynuclear aromatic hydrocarbons with different soils were analyzed (Karimi-Lotfabad *et al.*, 1996). Moisture content, organic content, and time were varied.

A study was carried out to investigate the effect of soil:solution ratio on sorption kinetics and movement of P during unsteady unsaturated water flow conditions (Chen, J.S., *et al.*, 1996b). A technique for determining rate coefficients under water saturated–unsaturated conditions that provides a way to validate P transport models during transient, unsaturated water flow was developed. A disc permeameter methodology was developed to measure solute adsorption isotherms *in situ* (Clothier *et al.*, 1996). The sorption characteristics of two anionic surfactants in an unsaturated soil were determined (Allred and Brown, 1996b). The surfactant sorption was relatively fast and reversible and reduced the soil-water diffusivity values significantly.

An analytical solution for macrodispersivity for adsorbing solutes in physically and chemically heterogeneous, unsaturated soils was derived (Yang, J.Z., *et al.*, 1996a). The solution includes a dependence of macrodispersivity on variability in water content and unsaturated hydraulic conductivity, mean water content, and a retardation factor. Stochastic numerical simulations were used to investigate transport in physically and chemically heterogeneous, unsaturated soils (Yang, J.Z., *et al.*, 1996b). Macrodispersion values were relatively large and differed significantly from second-order moments calculated for the plumes. Solute transport in media with retardation coefficients that were correlated negatively with log hydraulic conductivity was analyzed within a Lagrangian framework (Russo, 1996). The relative impact of chemical heterogeneity on the simulated BTCs increased with increasing stratification and decreased with coarsening soil texture.

Chemistry. Enhanced metal mobilization occurred by soluble organic chelators and preferential flow paths (Camobreco *et al.*, 1996). Results indicated that preferential flow, alone or in combination with organic-facilitated transport, can accelerate metal leaching through soils.

Biodegradation. The use of chloroform as a tracer in experiments for determining toluene biodegradation in unsaturated column studies was investigated (Allen-King *et al.*, 1996a). Chloroform did not degrade significantly and did not affect the soil microorganism population. Toluene biodegradation under nitrogen-limited conditions was assessed in column infiltration experiments (Allen-King *et al.,* 1996b). Water flux and initial toluene concentrations had a secondary effect on biodegradation rates relative to nitrogen and oxygen limitations. Techniques for measuring biodegradation rates of *p*-nitrophenol (PNP) during preferential flow were developed (Pivetz *et al.,* 1996). PNP degraded rapidly in both homogeneous and heterogeneous packed columns despite the short residence times in the preferential flow paths.

Gas and Vapor Transport. *Physical Processes.* A two-chamber diffusion cell was used to investigate the dependence of gas diffusion coefficients on soil properties (Jin and Jury, 1996). Analysis of experimental data obtained from nonreactive (Freon-12) and reactive (hexafluorobenzene) tracer studies indicated that existing gas tortuosity models, such as the Penman, Millington-Quirk, and Troeh models, did not adequately relate gas diffusion coefficients to soil properties. Elberling (1996) examined the effect of cementation on gas diffusivity in columns packed with sandy sediments. Experimental results indicated that standard gas diffusion equations should be modified to account for air-space geometry and connectivity in cemented materials.

Batterman *et al.* (1996) used a soil column maintained with a constant concentration gradient to measure the effective gas-phase diffusion coefficient of VOCs in soils. A nonlinear relationship was observed between air-filled porosity and the effective diffusion coefficient, and it was shown that measured gas-phase diffusion coefficients at intermediate and high moisture contents were significantly greater than values estimated from literature correlations. Diffusion of TCE and benzene vapor mixtures through an air-dry sand was studied by Amali *et al.* (1996). Simulations matched to the experimental results indicated that a model accounting for multiple gas species and nonlinear adsorption isotherms more accurately predicted VOC concentrations compared with a single-species, linear adsorption isotherm model.

Laboratory studies were conducted by Petersen *et al.* (1996) to investigate the transient diffusion of TCE vapors through soil columns in which the soil-water content of the surface layer was varied. Both increases and decreases in the soil-water content of the surface layer resulted in large peaks of TCE emanating from the soil columns, which was simulated using a numerical model that included diffusion coefficients and retardation factors as functions of soil-water content. Gimmi and Fluhler (1996) evaluated the influence of the injection mode (flux versus resident) on the interpretation of gas-phase transport experiments. The effect of inlet type was tested in two series of column experiments at different mean flow velocities.

The volatilization of methyl bromide (MeBr), a soil fumigant, from natural soils was studied to develop application and management techniques that minimize losses of MeBr to the atmosphere (Gan, J.Y., *et al.,* 1996). Based on the experimental results, it was recommended that MeBr be applied to moist soils that have been surface-compacted and covered by a plastic tarp. Lindhardt *et al.* (1996) measured non-steady-state fluxes of aromatic hydrocarbons from surface soils contaminated with coal tar. Relatively good agreement was found between measured fluxes and fluxes predicted using an analytical solution to Fick's diffusion equation that assumed independent diffusion and local equilibrium. A second study was conducted to examine the effect of a 5-cm-thick cover layer on hydrocarbon volatilization from the contaminated soil (Lindhardt and Christensen, 1996). When microbial activity was inhibited, hydrocarbon fluxes stabilized after 10 to 20 days but were overestimated by the diffusion model.

Auer *et al.* (1996) investigated the effect of variations in ambient atmospheric pressure on the migration of air in porous and fractured materials, commonly referred to as barometric pumping. Results of this analysis suggest that barometric pumping can reduce significantly the retention time of VOCs in the unsaturated zone and may play an important role in environmental remediation of VOC-contaminated soils. Uncertainty and sensitivity analysis techniques were employed in conjunction with the BRAGFLO model to examine two-phase (gas and brine) flow at the Waste Isolation Pilot Plant operated by the U.S. Department of Energy (U.S. DOE) as a disposal facility for transuranic waste (Helton *et al.,* 1996). Gas production caused by steel corrosion and microbial activity as well as gas migration through a sealed shaft were studied.

The upward migration of TCE vapors through the unsaturated zone above contaminated groundwater at the Picatinny Arsenal in New Jersey was studied by J.A. Smith *et al.* (1996). The total gas flux (diffusion and advection), measured using a vertical flux chamber, was significantly greater than upward diffusive flux alone. Two field experiments were conducted at the Canadian Forces Base Borden to obtain detailed measurements of TCE vapor transport in the unsaturated zone (Conant *et al.,* 1996). In both experiments, TCE vapor plumes spread several meters from the source and downward to the capillary fringe within a few days of release. Vapor transport was found to be diffusion-dominated, but density-induced advection was significant during the summer.

Lineham *et al.* (1996) performed a field-scale helium gas injection experiment to examine gas migration in water-saturated fractured rock. Experimental data were modeled using several techniques, including analytical scoping calculations and numerical simulations of two-phase flow in porous media. Relative permeability relations for materials that contain water and moist air were investigated by Couture *et al.* (1996). An estimation technique, based on numerical simulations and experimental measurements, was presented to describe convective drying.

Sorption/Desorption. The effect of soil moisture content on vapor-phase sorption of VOCs was studied using a batch-equilibrium headspace method (Unger, D.R., *et al.,* 1996). Based on experimental results, an equilibrium partitioning model was developed to predict organic vapor sorption over a range of moisture contents using soil-pore–size distribution and Bruneaur, Emmett, Teller (BET) parameters measured under oven-dried and water-saturated conditions. The influence of temperature and relative humidity (RH) on sorption of organic vapors by three minerals was investigated by Goss and Eisenreich (1996). An exponential reduction in equilibrium adsorption coefficients was observed as the RH was increased from 30 to 90%, and the extrapolated adsorption coefficients for 100% RH were similar to those reported for bulk water.

Van der Zanden and Schoenmakers (1996) investigated the influence of water vapor sorption on the drying of porous materials. A mathematical model was developed to simulate evaporation with a porous medium and incorporated a mass-transfer coefficient for a specific evaporating surface. The partitioning of VOCs between soil water and the gas phase in the unsaturated zone was examined by Washington (1996). The effect of temperature on the distribution and energetics of VOCs between the gas and liquid phases was estimated using Henry's law and van't Hoff plots. The effect of sorption processes on the diffusion of VOCs in moist soils was examined by Cabbar and McCoy (1996). Sorption was assumed to occur at the air–water interface, air–solid interface, and water–solid interface. Using temporal and volume averaging methods, mathematical expressions were developed and evaluated for soils consisting of porous and nonporous particles.

Lin *et al.* (1996) studied the equilibrium partitioning and sorption kinetics of benzene by a low-OC–content soil. As the RH was increased from 0 to 33%, sorption isotherms gradually changed from nonlinear to linear and the sorption capacity decreased. The relative rates of adsorption and desorption were related to the shape of the equilibrium isotherm and could be inferred using an intragrain diffusion model and the results of a single kinetic experiment.

Modeling. A 1-D numerical gas flow model was developed by El-Fadel *et al.* (1995) to predict time development of pressure and gas profiles, and time-dependent gas emissions from landfills. The model accounted for temperature effects on gas transport properties and biochemical processes and was used to simulate gas emissions from the Mountain View Controlled Landfill Project in California. Thibaud-Erkey *et al.* (1996) presented a mathematical model to predict the adsorption and desorption profiles of organic vapors from oven-dried soil in a packed-bed column. Initial vapor breakthrough was predicted without the use of any data-adjusted parameters; however, desorption hysteresis had to be accounted for to predict the entire effluent profile.

A simple, dynamic diffusion-reaction model was used by Kruse *et al.* (1996) to simulate the methane concentration profiles in intact soil cores taken from a mixed hardwood forest. Comparisons of model simulations to measured methane profiles indicated that methane diffusion in soil air was the primary factor controlling methane consumption in the unsaturated soil cores. Moldrup *et al.* (1996a) evaluated the use of empirical equations based on the Campbell soil-water retention function to predict gas diffusivity as a function of soil-air content. The new diffusivity equations based on the Campbell *b* parameter provided better overall predictions of gas diffusion coefficients compared with the traditional Millington-Quirk model.

Using VLEACH, a 1-D FD vadose zone model, for estimating benzene vapor transport was evaluated by P.R. Johnson *et al.* (1996). A parameter-sensitivity analysis indicated that the transport of benzene vapors to the soil surface may be influenced by several factors, including contamination depth, recharge, soil-water content, and porosity. A series of diffusion models with attenuation was developed to calculate the diffusive flux of organic vapors in homogeneous porous media between a hydrocarbon source and a building foundation (Jeng *et al.*, 1996). Simulation results suggested that vapor transport was strongly dependent on soil type and properties and that model predictions were sensitive to degradation and source depletion rates.

Moore *et al.* (1996) critically evaluated the ability of various diffusion and transport models to estimate groundwater, soil, soil-gas, and indoor air concentrations of VOCs at petroleum spill sites. Results of this analysis indicated that in some cases, existing models may provide acceptable predictions of soil-gas and indoor air concentrations, but in other cases, the models greatly over- or underestimated the severity of the problem. The effect of subsurface heterogeneity on risk-based corrective action (RBCA) applied at petroleum release sites was evaluated by Marks *et al.* (1996). The analysis indicated that site-specific target levels (SSTLs) estimated for a multilayer soil profile can vary by as much as two orders of magnitude depending on the soil layer selected to represent the subsurface and the values selected for key soil properties. An interactive computer program, GASSOLVE, was developed for analyzing soil-gas pump tests under both transient and steady-state conditions (Falta, 1996). In this model approach, field gas-pressure data from multiple observation wells were inverted using a multidimensional nonlinear optimization procedure to provide fits of data to the appropriate analytical solution.

FATE AND TRANSPORT IN NON-AQUEOUS-PHASE LIQUID SYSTEMS

Hydrodynamics. *Physical Processes.* A mathematical model was introduced for heterogeneity-induced phase dispersion in multiphase flow as a Fickian diffusion process with the relative permeability gradient as the driving force (Pruess, 1996). The addition of a phase-dispersive term to the governing equations for multiphase flow was equivalent to an effective capillary pressure, and it was found that a small amount of phase dispersion can completely alter the behavior of an infiltrating NAPL plume. Existing methods available to predict capillary pressure (P_c)–saturation (S) relations for fractional wettability porous media are generally inadequate (Bradford and Leij, 1996). In this study, methods are presented to estimate two- and three-fluid phase (air, oil, and water) P_c–S relationships for porous media with a range of wettabilities.

Powers *et al.* (1996) investigated potential changes in the wettability of sands exposed to various NAPLs. It was found that NAPLs composed of high-molecular–weight constituents, such as creosote, or containing surfactant, such as gasoline, had a greater impact on wettability than low-molecular–weight NAPLs. The imbibition and drainage of three wetting-phase liquids were measured in two size fractions of silica particles (Moseley and Dhir, 1996). Based on the experiment results, a functional relationship between capillary pressure and wetting-phase saturation was developed that accounted for the dependence of capillary pressure on the contact angle of the fluid–solid interface. A network model was developed to evaluate the relationship between capillary pressure, saturation, and interfacial area (Reeves and Celia, 1996). Volume averaging was used to derive macroscopic measures of saturation and fluid–fluid interfacial area per volume of porous media.

Guigard *et al.* (1996a) investigated the retention of *n*-hexane and PCE in three soils of varying soil-water content. Retention capacities on a volume basis were independent of chemical type and decreased with decreasing porosity and increasing soil-water content. The infiltration and liquid front movement of hexane and PCE in soil columns also was studied by Guigard *et al.* (1996b). Liquid front movement in air-dry soil followed a log–log relationship with time, consistent with the Green-Ampt model. The geometry of non-wetting-phase liquids in moist unsaturated porous media was studied by Hartz and Overcamp (1996). A 3-D spreading coefficient was developed to predict the formation of pendular rings or insular lenses of nonwetting fluids as a function of water tension and nonwetting fluid concentration.

Kueper and Gerhard (1996) examined the influence of source release location, size, and strength on the infiltration rate and lateral spreading of a dense NAPL (DNAPL) introduced to a heterogeneous water-saturated porous medium. Numerical simulations were conducted to relate the point infiltration rate of source releases of NAPL to the underlying hydraulic conductivity distribution. The effect of subsurface heterogeneity on the design of free product recovery systems for light NAPLs was studied using a vertically integrated, three-phase flow model (Kaluarachchi, 1996). The results of hypothetical field-scale simulations indicated that subsurface heterogeneity has a substantial effect on predictions of free-product recovery.

Governing equations for the migration of an oil mound above an unconfined aquifer were obtained by averaging the oil-phase mass balance equation (Corapcioglu *et al.,* 1996). Analytical and numerical solutions were used to estimate the temporal and spatial distribution of the oil mound thickness. Shapiro and Stenby (1996) studied the problem of segregating a two-phase multicomponent mixture under thermal gradient, gravity, and capillary forces. For the case of binary mixtures, analytical solutions for saturation, component distribution, and flow in the two-phase zone were obtained.

Hilfer and Oren (1996) introduced a macroscopic capillary number, defined as the ratio between the macroscopic viscous pressure drop and the macroscopic capillary pressure acting upon the entrapped NAPL. This form of the capillary number depends on the length scale and provides a possible explanation for the difference in residual oil saturations measured at the field and laboratory scales. The influence of interfacial tension on the mobilization of entrapped NAPL ganglia was examined in laboratory soil columns by Ryan and Dhir (1996). After the addition of isopropyl alcohol to reduce the interfacial tension, phase saturations were measured using a dual-beam γ-densitometer. Reddi and Wu (1996) investigated mechanisms governing the vibrational destabilization of NAPLs in sands. Based on experimental studies, it was postulated that under compaction, viscous pressures destabilized NAPL ganglia, whereas buoyancy pressures increased the maximum sustainable ganglia length.

A macroscopic percolation model was employed by Ioannidis *et al.* (1996) to evaluate the effects of buoyancy and spatial structure on immiscible displacement of NAPLs. In large-scale immiscible displacements involving a nonzero fluid density difference, local saturation distributions were found to be markedly different from distributions obtained under conditions of negligible buoyancy effects. The effects of organic liquids on the permeability of Selma chalk were measured in the laboratory by Sadler and Donald (1996). Permeability measurements for six organic liquids were greater than those of water, but statistically significant differences in mean values were observed only for ethylene glycol and aniline.

J. Li *et al.* (1996) compared the intrinsic permeability of liner materials containing sand, bentonite, and two organobentonites for water, nitrobenzene, and heptane. X-ray diffraction and contact angle measurements were used to explain experimental results in terms of interlayer expansion and dispersion of the bentonites after exposure to different liquids. A study of the motion of two immiscible liquids in closed tubes was conducted to assess the influence of wetting and nonwetting fluids on flow behavior (Rimmer *et al.,* 1996). The effect of wetting–nonwetting fluid characteristics on the amount of liquid displaced, the shape of the liquid–liquid interface, and the radius of the closed tube was discussed.

Caruana and Dawe (1996) investigated fluid flow and displacement within porous media possessing wettability heterogeneities. Immiscible displacement experiments conducted in glass bead packs showed the influence of wettability differences on the entrapment of residual oil. Sandpack experiments were conducted by Dullien and Dong (1996) to determine transport coefficients for coupled equations of two-phase flow in porous media. Values of the cross coefficients ranged from 10 to 35% of the effective permeability to water and 5 to 15% of the effective permeability to oil. Lasseux *et al.* (1996) conducted a theoretical evaluation of permeability tensors for two-phase flow in homogeneous porous media. The four permeability tensors that appear in the volume-averaged Stokes' equations were essentially geometrical boundary value problems.

The onset of instabilities during immiscible displacement in fractures and porous media was examined by Neuman and Chen (1996). The analysis demonstrated that, in most cases, the fluid interface was not perpendicular to the mean direction of displacement; thus, incipient fingers did not extend in parallel. A series of groundwater flow and tracer experiments was performed on an undisturbed column of fractured clay-rich till using a solute, viruses, and an immiscible DNAPL (creosote) (Hinsby *et al.,* 1996). Results indicate that, for this till, fractures and root holes were important conduits for the transport of DNAPLs.

Modeling. A literature review of the behavior of chlorinated hydrocarbons (CHCs) in the vadose zone was presented (Yu, 1995). It was concluded that mathematical modeling efforts of CHC fate and transport in the vadose zone have been only partially successful because of the presence of heterogeneity and site-specific factors. Z. Chen (1996) presented several formulations of the governing equations used to describe three-phase flow in porous media. The mathematical development began with the phase formulations and progressed to the pseudoglobal and global pressure-saturation formulations.

The simulation of three-phase flow in groundwater hydrology and petroleum engineering applications was considered by Ewing (1996). Computational comparisons among various multiphase formulations illustrate the efficiency of proposed formulations. Pereira *et al.* (1996) developed a three-phase, 2-D network model based on pore-scale fluid distributions and displacement mechanisms. This approach, which accounts for flow through both wetting and intermediate fluid films, correctly predicted three-phase flow in glass micromodels. Three-phase displacement experiments using water, benzyl alcohol, and decane were simulated by Hicks and Grader (1996). The model predicted breakthrough of fluid phases and the formation of multiple shocks.

Y.S. Wu *et al.* (1996) presented a consistent and unified approach to describe multiphase subsurface flow for a range of boundary conditions. Boundary conditions considered include seepage face conditions for three-phase problems and multinode constant-rate pumping wells. A new model for multiphase, multicomponent transport in capillary porous media was developed by Wang and Cheng (1996). In the model formulation, multiple phases were treated as constituents of a multiphase mixture. In part II of this paper, the numerical model was used to predict the infiltration and transport of NAPLs in unsaturated porous media (Cheng and Wang, 1996). Numerical simulations indicated that a light NAPL spill results in two distinct zones: a lens of NAPL floating on the water table and a region of lower saturation previously swept by the infiltrating NAPL.

Chang *et al.* (1995) conducted a stochastic analysis of steady-state multiphase (water, oil, and air) flow in heterogeneous porous media. Perturbation theory and spectral representation techniques were used to develop closed-form expressions that described stochastic variability of key processes. In the companion article, the results of numerical simulations and closed-form expressions obtained using the perturbation approach were compared (Abin *et al.,* 1996). A.J.A. Unger *et al.* (1996) examined the use of variable spatial and temporal weighting of the advective contaminant mole fraction term as a means of reducing numerical dispersion of the dissolved plume. Simulation results were described for both homogeneous and heterogeneous permeability fields.

A multiphase flow and transport code, STOMP, was evaluated quantitatively using experimental data from a three-fluid phase container experiment (Oostrom *et al.,* 1996). Simulations of NAPL infiltration and redistribution based on two nonhysteretic and one hysteretic constitutive theory were compared and discussed. Demond *et al.* (1996) compared predictions of organic liquid flow in porous media using estimated and measured transport properties. For the systems examined, deviations resulted primarily from estimated values of relative permeability to the organic liquid. The development and use of effective parameters to describe multiphase flow in heterogeneous porous media was described by Butts and Jensen (1996).

Van Dijke and van der Zee (1996) developed a multiphase flow model that included capillary forces and oil entrapment by water to simulate the redistribution of a light NAPL lens in a 2-D domain. An analytical solution was derived and compared with a numerical simulation based on the nonreduced flow model. Simulation of lateral and vertical migration of oil spills in the unsaturated zone and capillary fringe of an unconfined aquifer was considered by Hadad *et al.* (1996). A three-phase flow model, with capillary heads of water and oil as variables, was used to examine the dynamics of water and oil phases.

The application of the fractional flow approach to multiphase flow simulation was explored by Binning and Celia (1996b). Although numerical advantages may be realized with this approach, implementation required careful attention to the form of the governing equations and the choice of numerical method. Paunov *et al.* (1996) presented a lattice-Boltzman simulator for two-phase flow in porous media. The model is based on the use of the van der Waals nonideal pressure tensor to describe equilibrium distributions of the liquid and vapor phases. The simulation of two-phase flow in large, complex, heterogeneous domains was examined by Ahmadi and Quintard (1996). To address this issue, a 3-D numerical solution was employed with a random permeability distribution.

A multidimensional FE code was developed by J.H. Kim *et al.* (1996) to solve a system of nonlinear equations describing subsurface flow and transport with complex migration and transformation processes and variable spatial dimensions. Several hypothetical problems, including 3-D composite multiphase flow, were simulated and discussed. The saturation distribution of a NAPL discharged from an underground source was modeled using a 2-D, nonlinear diffusion-convection equation (Pistiner and Shapiro, 1996). The solution may be used to check numerical models and to relate field data to the location of leaking underground storage tanks.

A three-step splitting method was presented for solving incompressible multicomponent two-phase flow in a homogeneous and isotropic porous medium, and numerical results were given for a 2-D problem (Bruneau *et al.,* 1996). In the first step, flow without diffusion or mass transfer was considered; in the second step, the diffusion terms were taken into account using a method that was semi-implicit in saturation and concentrations; the third step takes into account the mass transfer induced by the diffusion of the organic phase in the aqueous phase by solving a system of nonlinear ordinary differential equations.

Biodegradation. A study was conducted by Robertson and Alexander (1996) to examine the ability of bacteria to degrade phenanthrene dissolved in various NAPLs. Bacteria found to be sensitive to 1,2-dichlorobenzene and toluene were able to degrade phenanthrene when a nontoxic NAPL also was present in the system, thereby lowering the solubility of the toxic NAPL in the aqueous phase. Ghoshal and Luthy (1996) investigated the relationship between coal tar composition and aqueous naphthalene concentration and between the rate of naphthalene mass transfer into the aqueous phase and microbial mineralization of naphthalene. Analysis of the experimental results indicated that the rate of naphthalene biomineralization in systems containing single coal tar globules was influenced by the mass-transfer rate. Results reported for a similar study showed that mass transfer was relatively rapid and did not limit biodegradation in slurry systems where the coal tar was distributed among a large number of microporous silica particles (Ghoshal *et al.,* 1996).

A diesel-fuel–contaminated aquifer in Switzerland was the target of bioremediation efforts involving the addition of O_2, NO_3^-, PO_4^{3-}, and NH_4^- through an infiltration well (Bregnard *et al.,* 1996). The aerobic and anaerobic degradation of weathered fuel was examined in batch microcosms using aquifer material from the field site. Apitz and Meyers-Schulte (1996) studied the effects of substrate mineralogy on the biodegradation of fuel components. In these experiments, illite inhibited the bioavailability of some petroleum hydrocarbon components, and systems containing a quartz sand did not exhibit inhibitory effects.

Experiments were conducted to investigate the biodegradation of phenanthrene dissolved in NAPLs of differing viscosities (Birman and Alexander, 1996). The rate and extent of phenanthrene biodegradation were found to decrease as the viscosity of the nontoxic NAPLs increased. Methane production and consumption were measured at a crude oil spill site in Bemidji, Minnesota, using stable isotope ratios (Revesz *et al.,* 1995). Calculations of carbon fluxes in the saturated and unsaturated zone suggested that the minimum life expectancy of the oil source zone was 110 years.

Dissolution. A mathematical model incorporating mass-transfer limitations was developed to predict the long-term dissolution of organic constituents in BTEX entrapped in a sand (Rixey, 1996). In this model, the NAPL phase is divided into a region that undergoes equilibrium dissolution and a region that experiences rate-limited dissolution. Rixey and Garg (1996) presented an evaluation of finite leaching characteristics of contaminated soils and oily wastes. An approach was developed to determine waste and site-specific correction factors to account for time-dependent leaching of contaminants. A model was developed by Gonullu (1996) to predict dissolution of NAPL mixtures in porous media. Model simulations were compared with experimental results obtained from sand columns treated with a mixture of PCE and TCE.

Holman and Javandel (1996a) presented a transient 2-D mathematical model to describe the dissolution and transport of slightly water-soluble compounds from a pool of light NAPL. Simulations were performed for a light NAPL pool located in the capillary fringe, with constituents dissolving into steady horizontal groundwater flow. Holman and Javandel later corrected several equations (1996b). The chemical characteristics of coal tar–water interfacial films after 1 year of aging were studied by Nelson *et al.* (1996) using a number of spectroscopic techniques. Results of these studies suggested that a semigelatinous film formed at the interface that is similar in properties to a thin emulsion layer.

Van der Kwaak and Sudicky (1996) developed a transient, 2-D groundwater flow and transport model to examine DNAPL dissolution in discretely fractured porous media. In all scenarios considered, DNAPL dissolution is promoted by maintaining high concentration gradients adjacent to the DNAPL source. A 2-D multiphase flow and transport model was developed and applied to the case of NAPL dissolution and entrapment in homogeneous and heterogeneous porous media (Mayer and Miller, 1996). In heterogeneous media, reduced dissolution rates were attributed to relatively immobile regions of NAPLs and NAPL pools.

A mathematical model was developed by Imhoff and Miller (1996) to account for observations of dissolution fingering during water flushing of porous media containing NAPLs. Predicted finger properties were a function of both the residual NAPL saturation and the aqueous-phase flow rate. Imhoff *et al.* (1996) reported experimental observations of dissolution fingering in 2- and 3-D cells. The effects of Darcy flux, initial NAPL saturation, particle size, gravity, and NAPL composition on dissolution fingering were discussed. Zaidel *et al.* (1996) presented analytical and semianalytical solutions to four steady-state flow and transport problems related to the movement of VOC liquids in homogeneous, unsaturated porous media. Volatilization of the organic liquid can reduce significantly the lateral spread above an impermeable layer and may lead to a reduction in the capillary rise of the organic liquid.

Volatilization. A mathematical model was developed by Kang and Oulman (1996) to predict the volatilization of petroleum hydrocarbons, existing as liquids, from contaminated soils. Model predictions were compared with gravimetric measurements of *n*-heptane, unleaded gasoline, and diesel fuel volatilization from a sand under laboratory conditions. Arthurs *et al.* (1995) monitored the volatilization of gasoline from three air-dried soils during a 16-day period. The volatilization rate of gasoline constituents was dependent on soil type, chemical properties, and depth. Experimental methods for assessing the translocation and evaporation of Hg in soils was presented by Schlüter *et al.* (1995a). The volatilization and distribution of Hg in soil lysimeters treated with ^{203}Hg-labeled $HgCl_2$ and CH_3HgCl was measured for γ-activity using an Na(Tl)I detector. In the second phase of this work (Schlüter *et al.*, 1995b), the effects of rain acidity, rain duration, and rain intensity on Hg volatilization were investigated. The applied Hg compounds were transformed to highly volatile Hg^0 and $(CH_3)_2Hg$; however, Hg evaporation decreased with increasing rain acidity, which could lead to accumulation of Hg in soil.

MONITORING

Soil and Groundwater. *Installation and Sampling Methods.* To evaluate the effect of well-purging practices on contaminant levels, Williams *et al.* (1996) conducted a study of monitoring wells at underground storage tank (UST) sites in Southern California. Statistical analyses of well data indicated that unpurged sample concentrations were higher than purged sample concentrations. Byrnes *et al.* (1996) measured BTEX and MTBE concentrations in monitoring wells at 13 field sites before and after traditional well-purging procedures. No significant differences in sample concentrations were observed, and it was recommended that bridged monitoring wells not be purged before collecting groundwater samples. A similar study was conducted at 101 sites to compare the concentrations of gasoline components in no-purge and postpurge groundwater samples (Horton and Ihnen, 1996).

Serlin and Kaplan (1996) evaluated the use of micropurge groundwater sampling, which involves the use of low flow rates, typically on the order of 0.2 to 0.3 L/min. Although measured hydrocarbon concentrations obtained using micropurge and traditional purge methods were equivalent, the micropurge technique decreased the amount of water produced by 95%. Christy (1996) employed a permeable membrane device to detect VOCs as the probe was driven into the soil. Because the sensor is based on diffusion of VOCs across a permeable membrane, it can be operated in both the unsaturated and saturated zones. The use of a cone penetrometer in conjunction with a laser-induced fluorescence detector was evaluated at a 113-ha (280-ac) oil field assessment project in California (Taer *et al.*, 1996). Screening procedures were used successfully to delineate the lateral and vertical extent of soil contamination both above and below the water table.

Vroblesky *et al.* (1996b) used passive vapor collectors buried in the bottom sediment of a creek to locate fractures that were discharging contaminated groundwater to surface water. A new method for sampling groundwater colloids using a multilayer sampler was described by Weisbord *et al.* (1996). Dialysis cells with large–pore-size membranes were used to sample groundwater colloids during long time periods under very turbid conditions. A multiport sampling well that is relatively easy to construct and install was developed by Delin and Landon (1996). The sampling device consisted of multiple stainless-steel tubes within a polyvinyl chloride (PVC) protective casing and was used successfully to collect groundwater samples at an agricultural research site.

Schirmer *et al.* (1995) developed and tested multiport sock samplers for use in open boreholes. The technique involved displacing the water column and then sealing the borehole with a low-pressure packer. The samplers were evaluated for their ability to collect representative groundwater samples from two gravel-packed boreholes in different hydrogeologic settings (Nilsson *et al.*, 1995b). The multiport samplers achieved mixed results compared with active sampling, indicating the need to consider system conditions when selecting samplers. Two sock samplers and two active devices were tested in a 90-m uncased borehole (Jones and Lerner, 1995). Groundwater samples were not consistent with those collected from a nearby piezometer; possible explanations for this behavior were discussed.

Lerner and Teutsch (1995) assessed seven alternative methods for collecting level-determined groundwater samples. Two different types of active sampling techniques, the separation pumping technique and the packer baffle system, were tested by Nilsson *et al.* (1995a). Results of this study demonstrated that active groundwater sampling techniques can be used for pumping optimization and for obtaining hydraulic data. Kaleris *et al.* (1995) used numerical models to evaluate the reliability of three sampling techniques, including separation pumping, packer-baffle systems, and multiport sock sampler. The analysis highlighted conditions under which each technique was reliable.

The structural integrity of monitoring wells, sampling, and remediation materials could be compromised by the presence of NAPLs or their dissolved constituents (McCaulou *et al.,* 1996). A chemical compatibility table was developed for 73 chemicals and 28 commonly used well materials. The effect of different materials used in the construction of multilevel samplers on contaminant concentrations was evaluated by Papiernik *et al.* (1996). Results of this study indicated that groundwater concentrations of relatively polar or ionized compounds were not dependent on the material used for the samplers. Oakley and Korte (1996) conducted an investigation of elevated nickel and chromium concentrations in groundwater samples collected at Williams Air Force Base. The corrosion of type 304 stainless-steel well materials was identified as the source of contamination.

Laboratory studies were performed by Thompson (1996) to measure the amount and rate of radionuclide sorption on well components. Campbell (1996) commented on a paper that attributed differences in measured solute concentrations between adjacent sampling points to dilution effects. A specialized mud rotary/circulatory drilling procedure was developed by Adilman *et al.* (1996) to minimize the potential for vertical migration or smearing of DNAPLs during well installation. Simon and Cooper (1996) presented a cryogenic drilling technique for use in unstable sediments, characterization, and remediation wells. The technique involves the use of cold nitrogen rather than ambient air as the circulating fluid to freeze and stabilize the borehole wall.

A study was conducted to determine whether removal of the volume of water inadvertently injected during coring of a monitoring well necessarily ensures collection of representative groundwater samples (Schilling and Hoyle, 1996). Results from monitoring dilution of the groundwater caused by lost circulation indicate that the determination of the quantity of water to be purged before sampling must be based on aquifer lithology and hydraulic characteristics. Methods to rehabilitate monitoring wells clogged with calcite and drilling mud were evaluated by Kroening *et al.* (1996). Well treatments included acidification, swabbing, surfactant flushing, and surging. Lizanec and Fahey (1996) conducted a field test to evaluate the use of clear PVC casing; this allowed for visual inspection of the borehole wall with downhole cameras.

Vadose Water Sampling. Knutson and Selker (1996) evaluated the effectiveness of fiberglass wick samplers to measure solute transport in the vadose zone by performing tracer tests to determine dispersivities of the wicks and using a finite difference model to model the transport. Simulation results determined that for a 55-cm wick, which samples 100 cm^2 of sand or silt soil, additional travel time and dispersion resulting from the wick were negligible. Brandi-Dohrn *et al.* (1996) investigated suction cup sampler bias in characterization of leaching loss in the vadose zone. Leachate collected in suction cup samplers during a 2-year period was compared with leachate collected in passive capillary samplers. For resident concentrations of tracers, the mass leached was prone to bias for short-term monitoring.

Soil and Groundwater Analytical Methods. Research presented by van Warmerdam *et al.* (1995) showed that by combining stable chlorine and carbon isotope measurements, chlorinated solvents could be identified specifically by compound and manufacturer. Results were deemed to be useful to engineers and scientists attempting to delineate contamination of groundwater by these compounds. C.S. Chen *et al.* (1996) evaluated extraction and detection methods for PAHs in coal-tar–contaminated soils by considering batch, soxhlet, and sonication extraction techniques and ion trap and flame ionization detection (FID). Batch extraction was determined to be the least labor-intensive and most cost-effective extraction technique, whereas gas chromatography (GC)/FID was found to be an appropriate means of analysis.

The use of pyrohydrolytic decomposition for fast and efficient extraction of iodine from geochemical samples was investigated by Rae and Malik (1996). After extraction, automated colorimetry was used to quantify iodine with a detection limit of 0.05 μg/g. Hottenstein *et al.* (1996) investigated the use of a sensitive magnetic-particle–based enzyme immunoassay for determination of trace atrazine levels in water samples. The immunoassay technique provided accurate detection to a lower limit of 15 ppt. Enzyme-linked immunosorbent assays (ELISAs) were developed to quantify fluroxypyr and triclopyr in soil and water (Johnson and Hall, 1996). The detection range of fluroxypyr was from 0.1 to 10 ng/mL and for triclopyr 0.1 to 5 ng/mL.

Simplified methods, including portable meters and simple GC techniques, for monitoring petroleum hydrocarbon contaminated soil vapor and groundwater were the subject of an investigation conducted by Aelion *et al.* (1996). Meters simplified total hydrocarbon estimates and provided a means to estimate the biological contribution of contaminant removal during the remediation process. Sawyer (1996) used flame ionization GC to evaluate the gasoline, diesel, and mineral oil ranges of organics in soil and water. The author attempted to develop a cost-effective method to enable analysts to quantify all three hydrocarbon components in a single GC run. Synchronous scanning ultraviolet fluorescence was evaluated as a screening method for hydrocarbons and byproducts in groundwater and soil (Edmondson *et al.,* 1996).

The use of an on-site laser probe for the detection of petroleum products in soil and groundwater was investigated by Schade and Bublitz (1996). The time-resolved, laser-induced fluorescence spectroscopy and fiber optics showed good separation of different classes of aromatic components in petroleum-contaminated samples. Gerlach (1996) used a field-portable scanning spectrofluorometer to conduct PAH analysis in the field. The instrument met specifications for on-site analysis of PAHs, creosotes, and PCBs.

Characterization of groundwater samples from Superfund sites by GC/mass spectrometry (MS) and liquid chromatography (LC/MS) was investigated by Betowski *et al.* (1996). The study specifically targeted the identification of highly polar, nonvolatile, and ionic compounds by particle-beam LC/MS, thermospray LC/MS, and GC/MS equipped with a capillary column designed for polar organic compounds. Potter (1996) investigated the use of GC/FID with direct aqueous injection for analysis of petroleum-contaminated water. The separation of C_1–C_4 alcohols, C_6–C_9 monoaromatics, MTBE, phenol, aniline, and BTEX compounds was reported. A method to assess analytical uncertainties over large contamination ranges for VOCs was presented by Devlin (1996). The method relies on multiple calibration line analysis to calculate meaningful analytical uncertainty over wide concentration ranges.

Welch *et al.* (1995) presented a discussion of gross beta activity in groundwater sources. Primary natural sources of beta activity in natural waters were summarized, and ingrowth of radionuclides during sample holding times contributing to overestimated gross beta activity was discussed. To quantify nitrophenols in soil, Voznakova *et al.* (1996) proposed a procedure to extract the compounds. The process called for 5% extraction with NaOH, removal of humic acids from extract, sorption of nitrophenols on Separon SGX C18, desorption with MTBE, and analysis by capillary GC. To directly determine lead speciation in three soils contaminated by industrial activity, Manceau *et al.* (1996) investigated the use of EXAFS spectroscopy.

Barona and Romero (1996) compared the distribution of lead in three soils with varying levels of contamination and then evaluated the influence of extraction with EDTA using multiple regression analysis. Lead predominately accumulated in the residual fraction and with Fe/Mn oxides; the amount of lead extracted was related directly to fractions associated with oxides and OM. To characterize the elemental content of contaminated soils, the use of energy-dispersive x-ray fluorescence (EDXRF) was investigated (Goldstein *et al.,* 1996). Laboratory, transportable, and portable instruments were evaluated, and it was concluded that the EDXRF technique yielded fast quantitative analyses for contaminated soils.

Morris *et al.* (1996) used x-ray absorption, optical luminescence, Raman vibrational spectroscopies, energy dispersive scanning electron microscopy, and powder x-ray diffraction to evaluate the speciation of uranium in contaminated soils from the Fernald Superfund site. Most of the uranium (75 to 95%) was in the hexavalent oxidation state, whereas other forms included autunitelike and schoepitelike compounds. A soil radioactivity and soil survey study, which consisted of evaluating dead time, bulk density, and rubification, was designed to develop a field protocol for determining radioactivity of soils, determine whether radioactivity levels in soils could be differentiated at the series level, and ascertain whether radioactivity could be correlated to specific soil properties that may be determined routinely in the course of soil survey field operations (Morton and Evans, 1996). Results showed that rubification and dead time were positively correlated, but bulk density was not correlated with dead time.

Various portable electrodes and an on-line colorimetric test kit were used in the field to examine groundwater quality as an indicator of natural bioremediation across two sites in Connecticut having subsurface gasoline contamination (Norkus *et al.,* 1996). The new on-line colorimetric test kit for determination of oxygen was more accurate than a commonly used dissolved oxygen electrode.

Data Analysis. The use of a weighted average of contaminant concentrations from monitoring wells under static conditions to design remediation systems was assessed (Hill and Walker, 1996). The authors examined the effectiveness of this approach and compared calculated concentrations with treatment system influent concentrations from 10 remediation sites. An alternative to expensive and time-consuming traditional site characterization was presented by Rautman and Istok (1996). The approach, which consisted of a probability assessment based on acceptance of uncertainty and a finite probability of making classification errors, used geostatistical techniques to identify and model spatial continuity of contamination at a site and to develop simulations of contamination fields.

Results of a case study, which were used to evaluate the spatial extent and severity of nitrate and herbicide contamination at a site near Ontario, Oregon, demonstrated that interpretation of characterization data to evaluate extent and magnitude of site contamination will vary depending on the level of uncertainty tolerated (Istok and Rautman, 1996). Christakos and Hristopulos (1996) formulated and calculated stochastic indicators for use in waste-site characterization. The indicators provided an assessment of site exposure levels, contaminant distribution, and cost-effective cleanup information. A nonlinear kriging geostatistical interpolation methodology was presented by Kitanidis and Shen (1996) for estimation of contaminant concentrations at hazardous waste sites. Data from groundwater and soil analysis were compiled to form solute concentration contour maps and volume averages.

Rhode (1996) addressed the issue of quality assurance in data interpretation as applied to Resource Conservation and Recovery Act (RCRA) and Superfund programs. The author stressed that high-quality assurance measures would increase confidence in the investigation, benefit the decision-making process in selection of the most appropriate remediation technologies, and result in cost savings. To evaluate trends in groundwater quality, Loftis (1996) presented a review of regional and localized studies of groundwater quality around the world. A statistical model was formulated with a trend component that provided a description of water-quality conditions and considered changes with time and statistical analysis of long-term trends. Case studies presented include agricultural, urban, point source, and hazardous waste site scenarios. Dakins *et al.* (1996) used uncensored, trace-level measurements to define trends in groundwater quality. A nonparametric trend analysis was applied to uncensored trace-level groundwater monitoring data for arsenic and chromium.

D. Chen *et al.* (1996) investigated the use of GIS to improve groundwater flow and solute transport analysis. A GIS system was used at a Florida Superfund site for development of database structures, model configuration, and parameterization. Modeling of nonpoint source pollutants in the vadose zone using GIS was reviewed by Corwin and Wagenet (1996). Identification and mitigation of nitrate leaching using GIS technology was the subject of research presented by Shaffer *et al.* (1995). A nitrate model called NLEAP was combined with GIS to aid in determining the long-term potential mass of nonpoint NO_3 sources leached from the crop root zone. Lipson and McGuire (1996) used Spider diagrams to show the relative concentrations of parent VOC compounds and breakdown products over time and distance from the source. The new graphical approach illustrated dechlorination sequences in groundwater caused by naturally attenuating VOCs.

A visualization method using radical diagrams aligned in the same sequence as electron acceptors to depict spatial variation in redox potential was applied as part of an innovative demonstration at a landfill Superfund site (Carey, G.R., *et al.,* 1996). The visualization process allowed for effective demonstration of remediation using contour maps or tabulated data. Jorgensen (1996) demonstrated the use of the ratio method to estimate water resistivity and total dissolved solids. The method is based on the ratio of resistivity of a saturated formation to the resistivity of the flushed zone adjacent to the annulus in a mud-filled borehole.

The use of chemical and biogeochemical markers for monitoring hydrocarbons during *in situ* bioremediation was investigated by Barcelona *et al.* (1996). Markers included horizontal and vertical profiles of aromatic hydrocarbons, aromatic acid products, and phospholipid ester-linked fatty acids. Piontek *et al.* (1996) presented and compared methods for sampling and analyzing indicators of intrinsic bioremediation. The information presented was designed to aid in the selection of methods most appropriate for specific projects, implementation of procedures to improve representativeness of data collected, and interpretation of data with regard to biases introduced from sampling and analysis.

Geochemical indicators such as dissolved oxygen, oxidation-reduction potential, nitrate, sulfate, iron, and manganese concentrations were collected as part of a corrective action plan to evaluate natural and enhanced attenuation of hydrocarbons in soil and groundwater (Boone *et al.,* 1996). The remedial objective was to accelerate degradation of hydrocarbons by soil vapor extraction. Schmidt (1996) reported on the technique of hydrocarbon fingerprinting using capillary column GC. A discussion on principles of use and interpretation of weathered and altered chromatogram samples was presented. The evaluation of stable lead isotope ratios was used in a fingerprinting analysis by Hurst *et al.* (1996) to determine the time of petroleum hydrocarbon release.

Network and Sampling Design. A method for designing sampling networks to delineate groundwater contaminant plumes was presented by McGrath and Pinder (1996). The sampling scheme, which produced the greatest reduction in plume boundary location uncertainty, was considered optimum. Andricevic (1996) developed a method to evaluate sampling performance that can be used in the design of monitoring activity and for measurement conditioning of stochastic theories. The scales at which model parameters are measured was examined by Beckie (1996). Two operational scales were considered: the measurement scale associated with a single field test and the network scale corresponding to the separation between samples on a network.

Jardine *et al.* (1996) used hydrogeological decision analysis to design a performance monitoring network at a waste management facility overlying fractured rock. Parameters considered in the design included the number of monitoring wells to be installed, well locations, position of discrete monitoring zones, and sampling frequency. Site characterization of a large industrial facility under RCRA corrective action was described by Curtin (1996). Hydrology at the site was complicated by the presence of fill material, dewatering activities in basements, settling ponds, and large waste piles. Harquail (1996) discussed the components of a complex groundwater monitoring program used to detect dissolved VOCs near a municipal well field.

Statistical methods were developed to determine the optimal sampling frequency for measuring bulk temporal changes in groundwater quality (Moline *et al.,* 1996). The method incorporated historical data and allowed users to test the statistical significance of a linear trend or compare annual changes in water quality to baseline data. Datta and Dhiman (1996) presented a mathematical model for designing monitoring networks using a groundwater transport code and an optimization model. The chance-constrained optimization model solution specified the optimal location of wells subject to a maximum number of wells.

Non-Aqueous-Phase Liquid Thickness and Composition. Marinelli and Durnford (1996) investigated the thickness of LNAPL in monitoring wells by evaluating the behavior of fluid saturations in an air–LNAPL–water system in porous media. Specifically, a semianalytical model was developed that considered the effects of saturation hysteresis and air/LNAPL entrapment to predict LNAPL thickness. Batch, Soxhlet, and column extraction techniques were compared for removal of LNAPL constituents from three soils by Atalay and Hwang (1996). High-molecular-weight compounds were recovered at 80% and BTEX compounds at 50%, and the average recovery of light hydrocarbon was 78%. Batch and column experiments yielded similar results, but column extraction achieved faster equilibrium concentrations.

The influence of avian guano in analyses of fuel-contaminated soils was investigated by D.E. James *et al.* (1996a). Results indicated that the presence of seabird guano interfered with hydrocarbon quantification methods, including portable vapor meter detection (catalytic detection), immunoassay testing, and U.S. EPA 8015 Modified Method, by overestimating the amount of hydrocarbons present because the techniques also detect guano volatiles. NAPL field-screening techniques were compared with respect to effectiveness and limitations for three hazardous waste sites (Soukup and Scheuing, 1996). No single screening technique was determined to be optimal; instead, recommendations hinged on combining techniques such as headspace analysis to evaluate NAPL presence and ultraviolet fluorescence to screen for BTEX compounds.

A field study of a partitioning tracer method used to detect DNAPLs at a field site was described by Nelson and Brusseau (1996). The tracer technique is based on the relative retardation of reactive tracers that partition into the NAPL phase. Watkins *et al.* (1996) described the calibration of NAPL field-screening methods such as field headspace measurement, hydrophobic dye shake testing, and ultraviolet fluorescence. The screening method development led to a comprehensive field monitoring program at a New Jersey Superfund site where field-screening methods were the primary means of delineating NAPL-affected areas.

The environmental stability of petroleum hydrocarbon components was used to identify contaminant sources and weathering of a hydrocarbon spill (Douglas *et al.,* 1996). The ratios of alkylated dibenzothiophenes and phenanthrenes were used to identify contaminant sources, and the ratios of alkylated naphthalenes, phenanthrenes, and chrysenes were used to assess extent of weathering for assessment of data from various oil spills. I.R. Kaplan *et al.* (1996) discussed major patterns of chemical change that occur during environmental alterations of fuel hydrocarbons. A set of chemical tests were detailed that were designed to monitor compositional changes by recognition of chemical patterns and degradation levels of fuels released to the environment.

Vapor-Phase Sampling and Analysis. Continuous monitoring of soil gases, such as oxygen, carbon dioxide, and contaminant vapors, can provide information useful for interpreting the progress of air sparging and soil venting (Li and Lundegard, 1996). Laboratory and field tests demonstrated that a commercially available oxygen sensor was capable of providing rapid and accurate measurements of oxygen concentrations in the unsaturated zone. An investigation showed that environmental isotope analysis of the major constituents of landfill gas (CO_2 and CH_4) and leachate (water and dissolved inorganic carbon) could be used as a technique for identifying landfill contamination (Hackley *et al.,* 1996). The unique isotopic characteristics observed in landfill leachates and gases provide a useful technique for confirming whether contamination is from a landfill or some other local source.

Geophysics and Remote Sensing. Applications of remote-sensing technologies to groundwater systems were reviewed by Meijerink (1996). Remote-sensing developments pertained to groundwater management, groundwater-discharge monitoring, and the use of thermal and multispectral imagery. McCall

(1996) investigated the use of electrical conductivity logging to determine how changes in lithology can affect hydrocarbon flow paths in alluvial deposits. The logs were used to define high-conductivity zones (coarse-grained, permeable zones), which were potential migration pathways for hydrocarbons, and elevation contacts between the permeable zones and clay boundaries, which were plotted on a contour map to define domelike structures where hydrocarbons could be trapped. Placement of monitoring and extraction wells was optimized by installing wells in migration pathways and areas where hydrocarbons could be trapped.

Thermal neutron logging was evaluated as a means to detect and monitor chlorinated solvent contamination (Endres and Greenhouse, 1996). The device, which measures the elastic scattering caused by hydrogen in the subsurface and is sensitive to capture of thermal neutrons by all elements, was used to respond to the presence of chlorinated hydrocarbons. Laboratory tests confirmed the sensitivity of thermal neutron logging to chlorine-containing compounds, indicating potential application of the technology as a means to detect and monitor chlorinated hydrocarbon contamination.

Neutron moisture probe measurements of fluid displacement during air sparging were investigated by McKay and Acomb (1996). The measurements indicated that air distributions were defined by an initial rapid-expansion phase followed by a consolidation phase; air distribution was stable within 12 hours of system start-up with an air saturation of more than 50%; and the radius of expansion varied with time and depth, and fluid was displaced beyond 3.7 m (12 ft) from the sparge well. Based on these observations, frequent pulsing was introduced to optimize air distribution to enhance bioremediation.

Vogeler *et al.* (1996) investigated the use of time domain reflectometry (TDR) and disk permeametry to characterize KCl dispersivity and retardation under unsaturated, transient-flow conditions in column studies. Results illustrated that only Cl^- ion concentration could be monitored because K^+ exchanged with Ca^{2+} present in the soil and retardation of the solute resulted from the anion-exchange capacity of the soil. Three methods to calibrate TDR instrumentation for monitoring solute movement in columns were presented and compared by Mallants *et al.* (1996b). The three methods included application of a long solute pulse such that the solute concentration in the soil system equaled the input concentration, numerical integration of an observed tracer pulse input function from which impedance could be obtained, and independent determination of impedance and solute concentration. The first method was only useful for shallow depths, and the third method underpredicted impedance in approximately 50% of the studies; therefore, the second method was deemed most appropriate for calibrating TDR instruments.

Electrical resistance tomography was evaluated as a means to examine solute transport in an undisturbed soil column (Binley *et al.*, 1996). Images produced from the data displayed spatial variation of transport characteristics in the column. M.R. Chen *et al.* (1996) used X-ray computerized tomography imaging to evaluate air distribution patterns during air sparging in water-saturated cylindrical cells packed with Ottowa sand. The images provided detailed porosity and air saturation distributions. Resistivity tomography was used by Schima *et al.* (1996) to monitor air sparging. Results indicated that at early sparge times, air moved outward and upward from the sparge well until the air flow reached a stable cone-shaped pattern, and when sparging was discontinued for 2 days, entrained air remained in the saturated zone with 20 to 40% saturation values.

FIELD STUDIES

Pesticides. A study was conducted to compare leaching of recently applied and aged residues of herbicides atrazine and isoproturon through a large, heavily cracked clay soil core (Beck *et al.*, 1996b). Newly applied herbicide losses occurred mainly from gravity drainage samplers at 0.55 m, whereas 21 months later losses were mainly from samplers at 0.175 m. Relative mobilities of atrazine, five atrazine degradates, metolachlor, and simazine were determined in both surface and subsurface soils from five locations in Iowa by soil thin-layer chromatography methods (Kruger *et al.*, 1996a). Didealkylatrazine, with similar a mobility to atrazine, could reach groundwater and therefore should be looked for in routine monitoring.

Atrazine and atrazine-residue concentrations were examined in groundwater of the midcontinental U.S. (Liu, S.P., *et al.*, 1996a). The mean of atrazine-residue concentrations was 53% greater than that of atrazine alone for those observations above the detection limit. Effects of crop presence on persistence of atrazine, metribuzin, and clomazone in surface soil were investigated (Gallaher and Mueller, 1996). Lower soil moisture slowed soil microbial activities, thus suppressing atrazine and metribuzin degradation. Degradation of atrazine in a Webster clay loam soil and Esterville sandy loam was determined over a concentration range of 5 to 5 000 mg/kg in field and laboratory experiments to test the effects of concentration on degradation (Gan, J., *et al.*, 1996).

Atrazine degradation in various soils was studied (Qiao *et al.*, 1996). Atrazine was depleted mostly through microbial degradation in alkaline soil and was degraded in acidic soil mainly through chemical transformation or both chemical and microbial transformation. The PRZM model was used to investigate herbicide atrazine in corn production under no-till (NT) and conventional-till (CT) management practices, and results were compared with the actual values measured in soil samples taken from the root zones during three growing seasons (Sadeghi *et al.*, 1995). Studies demonstrated greater pesticide leaching to groundwater under well-established NT than under CT (Isensee and Sadeghi, 1996). Evaluation of the effect of reversing the tillage of 7-year-old NT and CT field plots on the leaching patterns and dissipation of atrazine in soil was established in a field study (Sadeghi and Isensee, 1996).

Tobit models were documented as the correct methods to determine factors that affect atrazine concentrations in near-surface aquifers while accommodating the high degree of data censoring (Liu, S.P., *et al.*, 1996b). The comparison of the transport of Br^- and pentafluorobenzoic acid (PFBA) under cropped and fallow conditions for a range of soil-water contents and evapotranspiration demands was conducted (Pearson *et al.*, 1996a). The predictive capability of a computer simulation model (LEACHM) was evaluated in this study using independent estimates of model parameters (Pearson *et al.*, 1996b).

A U.S. Geological Survey (USGS) investigation identified alachlor and its metabolite in 76 reservoirs in the midwestern U.S. (Thurman *et al.*, 1996). The importance of sulfonation in the transport of chloroacetanilide herbicides was evaluated. Another USGS study investigated the occurrence of herbicide acetochlor in the midwestern U.S. during its first season of extensive use in the area (Kolpin *et al.*, 1996). Acetochlor was detected in 29% of the rain samples from four sites in Iowa, 17% of the stream samples from 51 sites across nine states, and 0% of the groundwater samples from 38 wells across eight states.

Multiple residues of organochlorine insecticides were monitored in the agricultural fields in northern India for 1 year, and almost all soil samples were contaminated with residues of hexachlorocyclohexane (HCH) and DDT (Agnihotri *et al.*, 1996). The effect of soil-water content on the fate of 1,1,1-trichloro-2,2-bis (*p*-chlorophenyl) ethane (*p,p*'-DDT), and 1,1-dichloro-2,2-bis (*p*-chlorophenyl) ethylene (*p,p*'-DDE) was examined in laboratory microcosm experiments (Boul, 1996). Increased binding of *p,p*'-DDT and *p,p*'-DDE was observed under flooded unautoclaved conditions. Soil column studies were undertaken to investigate the influence of soil-water content and irrigation on leaching, distribution, and persistence of methyl isothiocyanate in a sandy soil chemigated with the soil fumigant metam-sodium (Saeed *et al.*, 1996). It was found that leaching increases with soil moisture.

The volatilization and degradation behavior of MeB were studied with undisturbed soil column tests (Rice *et al.*, 1996). MeBr volatilized rapidly and did not leach into subsurface soil, and the residual MeBr was degraded in the soil column. Degradation of terbutol in soils from turfgrass and drainage basins on golf courses was investigated (Suzuki *et al.*, 1996). Movement of isazofos, chlorpyrifos, metalaxyl, and pendimethalin was investigated using soil column tests (Starrett *et al.*, 1996). Metalawyl most likely is to be leached because of its low soil sorption, followed by isazofos, pendimithalin, and chlorpyrifos. Persistence and leaching of metribuzin and metabolites in two subarctic soils under irrigated potato and dryland barley conditions was discussed by Conn *et al.* (1996).

The effects of fluazifop-butyl on soil fungal populations and activities were studied by incubating soil samples with a range of fluazifop-butyl concentrations over 8 weeks (Abdel-Mallek *et al.*, 1996). Fluazifop-butyl had no significant effect on total fungal populations at 0.6 mg/kg but caused temporary reduction in fungal populations observed after 1- and 2-week incubation at 3 and 6 mg/kg concentrations. Greenhouse experiments determined differences in imazaquin bioavailability over time under various soil moisture regimes (Baughman and Shaw, 1996). A 3-year study was conducted on a 1-ha field with a history of previous herbicide applications at Lethbridge, Alberta, Canada, to determine herbicide levels in shallow groundwater and the effect of seasonal events such as herbicide application and rainfall/irrigation (Hill *et al.*, 1996).

A field study was conducted to determine the karst groundwater effect of herbicide application to feed crops in support of livestock production in southeast West Virginia (Pasquarell and Boyer, 1996). The persistence and degradation of carbofuran in water suspensions of five soils of southern Spain were studied (Mora *et al.*, 1996). The kinetic profile of carbofuran disappearance in the presence of soil suspensions is consistent with three consecutive steps assumed as sorption and fast and slow degradation.

The effects of the management of straw, nitrogen fertilization, and application rates on the dissipation of metsulfuron-methyl, methabenzthiazuron, and trifluralin were investigated in a 3-year field crop rotation study (Berger *et al.*, 1996). Field studies were conducted to investigate pesticide reactivity toward hydroxyl and its relationship to field persistence (Mabury and Crosby, 1996). It was observed that Pesticide dissipation rates were observed to follow the order of reactivity with hydroxyl radical. Leaching, downward mobility, and the persistence of tebufenozide were investigated under laboratory conditions in columns packed with forest litter and soil (Sundaram, 1996).

Pesticides were detected in groundwater samples collected from 20 springs and nine wells in the Ozark Plateaus Province (Adamski and Pugh, 1996). Detectable concentrations of pesticides were found in soil samples collected from 49 agrichemical facilities located throughout Illinois (Krapac *et al.*, 1995). Analysis of 822 soil samples resulted in the detection of 53 pesticides and nitrate; 20 pesticides were found in fewer than 1% of the samples. A study compared agricultural chemical contaminations in rural private wells over a large area in the U.S. (Ray and Schock, 1996). Undisturbed soil columns were used to assess the fate of [^{14}C] deethylatrazine and its degradates (Kruger *et al.*, 1996b). A field experiment in which isoproturon concentrations were monitored after application revealed that most of the pesticide was removed in the field drain system (Johnson, A.C., *et al.*, 1996).

Nitrates. Water and nitrate–nitrogen present in the soil and flowing into a subsurface drainage system were studied (Weed and Kanwar, 1996). Leaching can be best minimized by applying fertilizer in amounts to meet crop N demand and at times closest to peak uptake. A 2-year field study was conducted on a Verndale sandy loam soil at Staple, Minnesota, to assess the influence of irrigation scheduling and N source and rate on corn yield and nitrate leaching (Sexton *et al.*, 1996).

A study was conducted to investigate the effects of a 44-year-old septic system on a sand aquifer in Ontario, Canada (Harman *et al.*, 1996). High nitrate concentrations (20 to 120 mg/L as N) were detected in the aquifer. A 3-year field study was conducted to test the effects of different regimes on the carryover, leaching, and uptake of depleted ^{15}N (Porter, 1995). Nitrogen transformation and ^{15}N balance under urine-affected areas of irrigated and nonirrigated pastures were studied (Pakrou and Dillon, 1996). Field experiments showed that within a day of urine application, up to 40% of the applied urinary-N was leached below a depth of 150 mm as a result of macropore flow in irrigated paddock and up to 24% in the nonirrigated one. Another field study was conducted during 1992 to 1993 in the Central Platte Valley of Nebraska to assess the nitrate leaching potential under recommended center-pivot irrigation and fertilizer best management practices for continuous corn (Kessavalou *et al.*, 1996). In this study, bromide and ^{15}N were used as tracers to determine the mass balance of nitrate.

The temporal changes in the groundwater dissolved organic nitrate and C concentrations were measured (Clay *et al.*, 1996). Findings indicated that seasonally driven physical processes, such as freezing and thawing, influence organic substrate transport form surface to subsurface environments, and that this process should be taken into account when assessing agrichemical detoxification rates in shallow aquifers. Twenty-one pore water chemistry profiles were obtained for a range of inorganic solutes from a chalk unsaturated zone under a beech forest in southern England (Kinniburgh and Trafford, 1996). It was found that the NO_3–N concentrations in clearings within the wood were slightly higher, indicating different nitrate leaching processes. Column tests were conducted to study the nitrification in porous media at conditions corresponding to a rapid infiltration (RI) treatment system (Yamaguchi *et al.*, 1996). Complete nitrification was obtained after 3 to 5 days at 30°C and after approximately 50 days at 10°C.

A model called MORELN, which coupled surface and subsurface flows and nitrate migration in an aquifer system, was developed to calculate the nitrate flux percolating from soils into an aquifer (Geng *et al.*, 1996). This model gave a quantitative global description of nitrate transfer, taking into account both leaching in soils and nitration in aquifers. The NLEAP model was used to evaluate effects of climate and N fertility on nitrate leaching from a 3-year field experiment of continuous corn growing (Follett, 1995). The model provided valuable insights concerning effects of climate and N and irrigation management on N leaching. The WHNSIM model was employed to simulate deterministically and stochastically water, heat, and nitrogen dynamics in the soil compartments of agricultural ecosystems (Huwe and Totsche, 1995).

Nitrate leaching from drained plots of structured clay soil under winter wheat was simulated for one growing season using the SOILN model (Ragab *et al.*, 1996). Simulation results showed that the model captured the main features of the cumulative loss of nitrate during the year. A nonmoral and heteroscedastic Tobit model was used to determine the primary factor that affects nitrate concentrations in near-surface aquifers (Yen *et al.*, 1996). Well screen interval; depth to top of aquifers; percentages of urban residential land, forest land, and pasture within 3.2 km; dissolved oxygen concentration level; and presence of a chemical facility and feedlot had significant effects on nitrate concentration in groundwater.

Nitrate was commonly found to exceed drinking water standards in a shallow glaciofluvial aquifer system in southwestern Michigan (Kehew *et al.*, 1996). It is suggested that high capacity pumping from a deeper flow system likely will draw contaminants downward from the shallow flow system. Analysis of water from wide-diameter open wells was carried out in two districts of Conakry, Republic of Guinea, to evaluate its bacteriological and physicochemical quality and to compare well water with the piped city water (Gelinas *et al.*, 1996). Widespread well-water contamination by nitrate and fecal bacteria was found throughout both districts.

The relationship between nitrogen management and groundwater protection in Hungary was investigated (Nemeth, 1995). Comparison of the results of several long-term field trials, which differed in environmental characteristics, was shown to provide a good basis for a more generalized quantification of the overall turnover of nitrogen and for calculating improved N balances. A study of nitrate pollution of groundwater in developing countries showed that because of low N application rates during the last three or four decades, negative N balances in the soil are a characteristic feature of the crop production systems in these countries (Bijay-Singh *et al.*, 1995). In the future, however, with increasing fertilizer-N application rates, the possibility of nitrate pollution of groundwater in developing countries will be strongly linked with fertilizer-N use efficiency.

The process affecting nitrate concentrations in groundwater beneath riparian zones in an agricultural watershed in southern Minnesota was evaluated (Komor and Magner, 1996). To evaluate nitrogen- and water-management strategies for reducing nitrate leaching under irrigated maize, two maize fields under improved water and N-management practices at the Nebraska Management Systems Evaluation Area project were compared with an adjacent field under conventional furrow irrigation (Schepers *et al.*, 1995). Field experiments conducted in New Zealand showed that the most reliable way to minimize N leaching losses is to delay the ploughing of pasture for as long as possible in autumn or winter (Francis, 1995).

Nearly 35 000 wells have been tested in Ohio, Indiana, Illinois, West Virginia, and Kentucky to investigate agricultural contamination in well water (Richards *et al.*, 1996a). Median nitrate concentration was 0.07 mg/L; 3.4% of wells exceeded the drinking water standard of 10 mg/L; 23% exceeded 1 mg/L. A correction to this article was published (Richards *et al.*, 1996b). The effects of tillage and cropping on preferential flow and agricultural chemicals transport has been evaluated (Kamau *et al.*, 1996). Variables that describe well construction, hydrogeology, and land use were evaluated for use as possible indicators of the susceptibility of groundwater in bedrock aquifer to contamination by nitrate from the land surface in the Newark Basin, New Jersey (Clawges and Vowinkel, 1996).

Metals. Chemical and mineralogical forms of Cu and Ni in contaminated soils from the Sudbury mining and smelting region in Canada were studied (Adamo *et al.*, 1996). Most Cu was associated with nonresidual soil forms, whereas Ni mainly was associated with inorganic residual forms of a sulphide and oxide nature. The mobility of selected heavy metals in contaminated soil at a previous industrial site in Brisbane, Australia, was assessed using a sequential extraction technique (Phillips and Chapple, 1995). Cu and Pb were adsorbed largely by the organic and oxide fractions, whereas a significant amount of Zn was extracted from the carbonate fraction. Zn was the most mobile metal in these soil.

The metals Cd, Pb, and Zn occurring in sandy and loamy textures in an area that has been subjected to severe metal contamination in the vicinity of Tarnowskie Vory in southwest Poland were studied according to a procedure based on sequential extraction analysis (Chlopecka *et al.*, 1996). Soil type, texture, OM, and cation exchange capacity (CEC) did not influence the relative proportions of heavy metal forms in any consistent manner. Soil samples of pH less than 5.6 contained more of all metals in the exchangeable form than samples of pH greater than 5.6.

Arsenic and selenium concentrations along with the major solutes were measured in groundwater sampled from south-central Nevada and Death Valley, California (Johannesson *et al.*, 1996). Correspondence analysis indicated that a strong relationship exists between Cl and Se in the groundwater and that As was not associated with chloride. Groundwater samples were collected from shallow aquifers underneath an industrial complex in the Eastern Province of Saudi Arabia to analyze arsenic (Sadiq and Alam, 1996). Results showed that sampling locations had significantly affected As concentrations in the groundwater samples. Analytical and thermodynamic calculations showed that $H_2AsO_4^-$ was the most predominant form of As in acidic groundwater samples, and $HAsO_4^{2-}$ was the most abundant species in alkaline groundwater samples.

The distribution of mercury and arsenic in samples from 14 sampling sites around the mining town of Obuasi, Ghana, was determined (Amonoo-Neizer *et al.*, 1996). The results substantiated a mercury and arsenic concentration gradient in the area, indicating that the local environment is contaminated by mining activities. Long-term vertical migration of metals in soils and rocks was assessed at three historical Pb smelters ranging in age from ca. 600 to ca. 1800 (Maskall *et al.*, 1996). The rate of vertical migration of Pb varies with rock type, with sandstone being greater than limestone, which is greater than a clay/sandstone matrix.

Radionuclides. Groundwater investigations at a former U.S. Department of Energy nuclear weapons complex in southwestern Ohio were conducted (Sidle and Lee, 1996). Uranium contamination occurs in a buried valley and has migrated more than 1.5 km south-southeast of the facility boundary. Groundwater flow and uranium migration from natural reactor zones in Oklo (Gabon) were investigated (Toulhoat *et al.,* 1996).

A near-field release model was developed to simulate the release and transport of various aqueous species including some radionuclides in the Cigar Lake uranium ore deposit, Saskatchewan, Canada (Liu, J.S., *et al.,* 1996). Fate and transport of actinides (^{239}Pu, ^{240}Pu, and ^{241}Am) through contaminated soils in Rocky Flats, Colorado, were studied using an advanced, fully automated, remotely controlled monitoring system (Litaor *et al.,* 1996). The movement of actinides was restricted to the top 20 cm in the soil under the controlled rain experimental conditions applied in the tests. A sequential extraction experiment was conducted to assess the geochemical association of Pu with selected mineralogical and chemical phases of the soil in the same area in Colorado (Litaor and Ibrahim, 1996). Retention of inorganic ^{14}C through isotopic exchange with soil carbonates was addressed (Sheppard and Evenden, 1996). Correlations between gamma-emitting radiative constituents and type of soil from Biscay, Spain, were studied (Elejalde *et al.,* 1996).

Landfill Leachates. Leachate contaminant distribution from a sanitary landfill in Sofia (Suhodol) was traced in different liner depths (Radenkova-Yaneva *et al.,* 1995). It was shown that soil monoliths of proper thickness might serve as sufficiently safe barriers against leachate filtration in adjacent aquifers. Field data from 44 waste sites contaminated with creosote were used to study groundwater contamination from creosote sites (Kiilerich and Arvin, 1996). The leachate composition of an uncontrolled waste dump in the suburbs of Buenos Sires, Argentina, has been studied (de Rosa *et al.,* 1996).

Hydrologic evaluation of landfill performance (HELP) codes, and the multimedia exposure assessment model (MULTIMED) were employed to simulate the effect of small landfill scenarios in western Kansas on underlying aquifers (Sophocleous *et al.,* 1996). It was demonstrated that requiring landfill cover, leachate collection system (LCS), and compacted soil liner will reduce leachate production by 56%, whereas requiring only a cover without LCS and liner will reduce leachate by half as much. The most vulnerable small landfills were shown to be the ones that have no vegetative cover underlain by both a relatively thin vadose zone and aquifer and that overlie an aquifer characterized by cool temperatures and low hydraulic gradients.

Human and Animal Wastes. Long-term monitoring of the chemical composition of recharge-treated wastewater effluent and associated contaminated groundwater from the Dan Region Sewage Reclamation Project showed that, after 16 years of recharge operation, a distinct saline plume extending 1 600 m downgradient in the Coastal Plain aquifer of Israel was formed (Vengosh and Keren, 1996). Aqueous geochemical data from unconfined sand aquifers beneath two operating domestic septic systems were used to illustrate and evaluate a conceptual model of septic system geochemistry (Wilhelm *et al.,* 1996). The conceptual model offers an organized approach to interpreting the major geochemical trends observed in the two systems, which are determined mostly by the well-aerated unsaturated zones below the drain fields and the amount of buffering material present in the sediments. A pilot-scale study was conducted to quantify VOC losses from biosolids-amended soil (Wilson, S.C., *et al.,* 1996). Measured emissions accounted for only approximately 9% of total VOC loss from soil column after 150 hours with biodegradation possibly accounting for much of the remaining 68%. Groundwater quality was monitored in a wastewater-irrigated area in Egypt during 1991 and 1994 (Rashed *et al.,* 1995).

Other Sources. Using hierarchical cluster analysis and principal component analysis, sediment and soil samples from the state of Mississippi were compared with the effluent of a pulp mill, a potential point source (Fiedler *et al.,* 1996). The mill could not be identified as the contamination source of the PCDD/PCDF in the sediments and soils in the flood plain. Structural, chemical, and isotopic parameters were used to identify the origins of groundwater humic substances in three Danish aquifers (Gron *et al.,* 1996). Analyses suggested that native rocks were sources for two aquifers, and multiple fossil and recent OC sources were suggested as sources of the humic substance for the third aquifer.

PAH pools in soils affected by depositions were characterized (Wilcke *et al.,* 1996). Microscale heterogeneity was found to affect PAH bioavailability and has to be considered when assessing environmental risks. Volatilization and sorption of dimethylsilanediol was studied (Lehmann and Miller, 1996). Processes affecting the fate of monoaromatic hydrocarbons in an aquifer contaminated by crude oil in north-central Minnesota were evaluated (Eganhouse *et al.,* 1996). Degradation reactions of 13 chlorinated organic compounds were investigated in a water system and a water-soil system (Miyamoto and Urano, 1996). The degradation data showed that the 1,1,1-trichloroethane did not react on the soil surface and only reacted in the water phase.

Reversal of groundwater flow caused by overpumping from a volcanic crater in Managua, Nicaragua, allowed contaminants in a lake to be transported to the volcanic lake (Bethune *et al.,* 1996). A regional groundwater-monitoring program focused on pH, alkalinity, sulphate, and total aluminum was carried out in southwestern Sweden to evaluate the threat of acidification (Swedberg, 1995). Chemical time trends for precipitation, throughfall, soil-water, and groundwater at Birkenes, southern Norway, were compared with gain insights into possible causes for the recent increase in groundwater acidification there (de Caritat and Aamlid, 1995).

A field study showed that sludge-applied silicone polymer degradation occurs under field conditions (Lehmann *et al.,* 1996). The spatial variability of soil contamination around an isolated sulphurous-acid–producing factory in Russia was investigated (Meshalkina *et al.,* 1996). The interactions between OM, bacterial biomass, enzyme activities, and environmental factors were studied during band filtration of humus-rich lake water (Miettinen *et al.,* 1996). A study concluded that the degraded groundwater quality associated with the 30 to 40 saline lake basins on the southern half of the southern High Plains of Texas and New Mexico and many other arid and semiarid areas was a result of eolian transport (Wood and Sanford, 1995).

The fate of MTBE was compared with that of BTEX in shallow aquifers (Barker and Schirmer, 1996). Approximately 2 800 L of groundwater spiked with chloride, gasoline-derived organics, and MTBE was injected below the water table into the shallow sand aquifer at Canada Forces Base Borden, and the migration of contaminants and chloride was monitored in detail. Results showed that the mass of BTEX compounds in the plume diminished significantly with time because of intrinsic aerobic biodegradation. MTBE, conversely, was not measurably attenuated. Based on an analysis conducted by USGS, MTBE was the second most frequently detected chemical in shallow ambient groundwater samples from drinking water wells, springs, and monitoring wells (Squillace *et al.,* 1996). Possible sources of MTBE in groundwater include point sources, such as leaking storage tanks, and nonpoint sources, such as recharge of precipitation and stormwater runoff.

REMEDIATION

Management, Policy, and Regulations. A program that streamlined and reduced the costs of remediation was designed by the Massachusetts Department of Environmental Protection (Race and Phillips, 1996). The program created Licensed Site Professionals, individuals certified to implement the program and render closure options. The program included risk-based cleanup standards and defined a variety of regulatory endpoints. To facilitate remedial decision making, the Superfund Innovative Technology Evaluation Program has conducted more than 80 field demonstrations, which have aided in identifying new cost-effective treatment technologies (Kovalick and Kingscott, 1996).

Privatization of Superfund site remediation also can provide opportunities for large cost savings that are not possible when projects are funded federally, as illustrated in the case study of the C&R Battery Company Superfund Site (Moore and Claypool, 1995). Privatization of remedial actions allowed for reevaluation of basic design concepts that did not need administrative approval, did not disrupt the remedial schedule mandated by U.S. EPA, and provided tremendous cost savings. A National Research Council committee found that the predominant groundwater remediation strategy, pump and treat (PAT), can contain contaminated groundwater but does not effectively remediate contaminated sites (Kavanaugh, 1995).

Oak Ridge National Laboratory's Center for Risk Management (CRM) developed a database of groundwater-contaminated sites to evaluate trends in analyses performed at many sites (Arquiett *et al.,* 1996). Several sites were evaluated for residual and remedial risk, as well as for general impact trends and associated costs, to aid in evaluation of groundwater cleanup objectives. The U.S. Air Force used a groundwater-quality modeling advisory system to investigate remedial alternatives for cleanup of subsurface contamination (Medina *et al.,* 1996). The system accounted for uncertainty in the prediction of solute transport and optimization of remedial schemes by guiding users in the selection of appropriate transport models.

In an effort to increase the effectiveness of remedial design decision making at groundwater-contaminated sites, a risk-cost decision framework was presented by B.R. James *et al.* (1996). The framework combined elements from Latin-hypercube simulation of contaminant transport, economic risk-cost analysis, and regional sensitivity analysis. A screening comparison of remedial alternatives to mitigate risks from the groundwater pathway was studied as part of the Fernald Environmental Management Project (Bumb *et al.,* 1996). Preliminary remediation levels and waste acceptance criteria were developed through integration of an infiltration model, a surface water model, a vadose zone model, and a 3-D contaminant migration model.

An RBCA plan was developed and implemented at Carswell Air Force Base for fuel-contaminated soil and groundwater (Vanderglas *et al.,* 1996). The plan included data compilation, scientific documentation, discussions of natural chemical attenuation, contaminant mass, persistence, toxicity, and mobility calculations, and potential exposure risks. Gonzalez and Ririe (1996) evaluated the use of scientific criteria to evaluate reserve pits in Alaska and to determine the environmental risk associated with a variety of metals.

Parameter estimation guidelines for RBCA modeling provided an effective means for estimating exposure concentrations and developing risk-based soil and groundwater remediation standards (Connor *et al.,* 1996). An analytical fate and transport model was compiled for use with the ASTM RBCA standard and provided practical guidelines for the measurement or estimation of input parameters for each model. Contaminant transport pathways evaluated included soil-to-air volatilization, soil-to-groundwater leaching, lateral air transport, and lateral groundwater transport. Risk-based guidelines for remediation of BTEX and PAHs in three hydrogeologically distinct groundwater systems in Kentucky were presented by Birge and Sendlein (1996). Groundwater and soil transport models were integrated with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) risk-assessment procedures to calculate combined risk for groundwater and soil exposure.

Bowers *et al.* (1996) presented a statistical approach for calculating a confidence response goal (CRG) that placed limits on contaminants requiring remediation while ensuring target average concentrations were satisfied. The site-specific CRG approach was able to address typical data uncertainties quantitatively using the upper confidence limit as a measure of mean concentration. A methodology also was presented by Labieniec *et al.* (1996a) to evaluate variability in risk caused by differences in site characteristics that affect transport and fate of contaminants.

Soil-cleanup criteria calculated using a mathematical model that employed soil-water partition coefficients obtained from the literature were compared with criteria based on site-specific partition coefficients for VOCs (Greacen *et al.,* 1996a). Model predictions based on experimentally determined coefficients indicated that VOCs were less likely to leach from soil to groundwater than was predicted based on literature values. Current and emerging technologies for remediating MTBE from the subsurface environment were discussed by Davidson and Parsons (1996). Remedial coordinators for the Tibbets Road Superfund Site proposed an innovative alternative, vacuum-enhanced recovery and natural bioattenuation, to remediate contaminants from the subsurface environment (Jalajas *et al.,* 1996). This alternative approach was estimated to save $15 to 25 million and 17 to 27 years in remediation time.

Hydraulic Methods. *Design.* A case history of a leaking underground storage tank (UST), which threatened a Michigan community drinking water supply, was described by Bulcher *et al.* (1996). A barrier well system was used to intercept contaminated water, while granular activated carbon was employed to treat the contaminated effluent. D. Mills *et al.* (1996a) constructed a 122-m (400-ft) cutoff wall in a shallow aquifer to capture VOC-contaminated groundwater before it could recharge into a deeper aquifer. Trench design and construction details, operational data, and capture effectiveness were presented. A groundwater remediation technique, in which water was drawn into a well bottom, treated in the casing, and returned to the aquifer at the top of the well, was presented by Stallard *et al.* (1996). The hydraulics of the recirculating groundwater wells were examined with models and a pilot-scale experiment.

Horizontal drilling technologies were adapted from the oil recovery and utility installation industries for use in the remediation of contaminated groundwater sites. Parmentier and Klemovich (1996) discussed the appropriateness of horizontal wells compared with vertical wells for various contamination scenarios. Horizontal wells were used for groundwater remediation in an effort to treat water contaminated by past management practices and product spills (Meyer and Bardsley, 1996). A comprehensive database prepared for the project permitted the development of a 3-D model, which detailed stratigraphy, lithology, and concentrations of pollutant compounds.

Maccagno *et al.* (1996) used a horizontal well to contain a dissolved contaminant plume in a deep, thin-layer, heterogeneous aquifer. Estimated cost savings for the horizontal well during a 10-year time period were substantial compared with multiple vertical wells. Horizontal well efficiency was shown to depend on area stratigraphy, distribution of screen, filter pack locations, degree of well development, and formation damage (Losonsky *et al.,* 1996). A method to calculate the efficiency of a horizontal well to avoid increased cost of prolonged well development was detailed.

Horizontal well flows were influenced by well and aquifer geometry, aquifer hydraulic characteristics, and boundary conditions, yet many horizontal well projects are designed with no modeling efforts to predict efficiency or duration of remediation (Speake *et al.,* 1996). Seven hypothetical horizontal well simulations were presented using the USGS's MODFLOW model. Schafer (1996) evaluated steady-state capture zones around horizontal drains and vertical wells using a second-order Runge-Kutta particle-tracking algorithm to trace streamlines.

Recovery wells were installed in a low-yield aquifer at the Silnesim Superfund site in Lowell, Massachusetts, to retrieve chemical waste from a former waste reclamation facility (Ehret *et al.,* 1996). The wells were designed to capture contaminated groundwater and dewater soils for subsequent *in situ* vacuum/vapor extraction. Enhanced vacuum recovery was used to increase the yield from a shallow aquifer in a study by Schaal and Cox (1996). Advantages of enhanced vacuum recovery include increased well recovery, decreased number of wells necessary to achieve production, and reduced remediation time.

A field study was conducted by Frieseke and Christensen (1996) to evaluate the use of a granular groundwater collection system designed to increase groundwater well yield and radial influence during remediation field studies at a gasoline-contaminated site in Kenosha, Wisconsin. The remediation effort consisted of removing the UST and surrounding soil, and backfilling with a granular material into which a well was installed to extract contaminated groundwater.

Modeling and Optimization. A nonlinear programming formulation was used to find the minimum cost design for a pump-and-treat remediation system (McKinney and Lin, 1996). The formulation was used to examine tradeoffs between total costs and cleanup standards, remediation period, and design parameters for the treatment system. The impact of constraint values and locations on optimal well locations was investigated with a hydraulic control optimization model (Ahlfeld and Verdon Lewis, 1996). Numbers of wells and their locations were sensitive to the number and location of head difference constraints. The impact of the degree of remediation required and the time by which compliance must be achieved on remedial design was studied for a hypothetical PAT system (Ahlfeld and Hill, 1996).

Enhanced annealing was applied to the groundwater remediation optimization problem, with a view toward reducing the number of objective function evaluations (Skaggs *et al.,* 1996). Enhanced annealing required significantly fewer evaluations than conventional simulate annealing (SA). A differential genetic algorithm was used to solve a nonlinear groundwater remediation optimization problem (Aral and Guan, 1996). An optimization-simulation model based on SA was developed that allowed multiple remediation technologies, that is, pumping wells, drains, trenches, slurry walls, and caps (Marryott, 1996). The selected remediation technologies were sensitive to the cost functions used for the technologies.

The outer approximation method was applied to solve remediation design optimization problems where a combination of wells and drains are allowed (Karatzas and Pinder, 1996a). The inclusion of drains significantly affected total remediation costs. A cutting plane optimization technique was developed to solve problems with nonconvex feasible regions (Karatzas and Pinder, 1996b). The technique is applied to example problems and is shown to avoid the elimination of any part of the feasible region. SA was combined with an importance function to produce a time-varying remediation optimization model (Rizzo and Dougherty, 1996b). The model was applied to a large-scale, complex remediation problem, where different cleanup goals could be imposed on different regions of the site.

The effect of parameter uncertainty on optimal dynamic pumping policies was investigated by generating spatially correlated, 3-D random fields and determining optimal designs for each field (Huang and Mayer, 1996). Remediation costs were underestimated by 2-D, vertically averaged representations of the 3-D fields, and the cost uncertainty was significantly higher than the parameter uncertainty. The effects of parameterization and measurement errors on optimal hydraulic gradient control design were assessed in a series of numerical experiments (Zhen and Uber, 1996). Head measurements could not improve remediation design reliability in the presence of parameterization error.

Procedures were developed for determining capture zone locations as a function of time by using the location of stagnation points (Bakker and Strack, 1996). The procedures are implemented in an analytic element model. Unconditional and conditional Monte Carlo simulations were used to produce probability distributions of capture zone locations as a function of transmissivity and recharge rate uncertainty (Kinzelbach *et al.,* 1996). Increasing the amount of conditioning data was shown to narrow the probability distribution of the capture zones.

Physical Containment. Devlin and Parker (1996) used steady-state contaminant flux equations to evaluate an optimal range of hydraulic conductivities for the design of cutoff walls. The research design focused on eliminating the potential for contaminant flux to be controlled by outward diffusion through the selection of low-conductivity cutoff wall materials. The use of industrial coproduct solutions (grout) as an iron source for precipitation of iron hydroxides and oxyhydroxides in barrier walls was investigated by Hapka and Whang (1996). Column studies were performed to quantify precipitation of iron hydroxides and to determine the effects of precipitation on soil permeability.

Chemical Methods. A rapidly evolving remediation technology involves the use of funnel-and-gate systems, in which sheet pilings are used to route contaminated groundwater through a permeable zone (gate) of reactive porous media (Hatfield *et al.*, 1996). An analytical model that incorporated convective and dispersive transport, dissolved constituent decay, surface-mediated degradation, and time-dependent mass transfer between phases was developed to aid in prediction of funnel-and-gate performance. Burris *et al.* (1996b) conducted batch and column experiments to evaluate the use of granular metallic iron for *in situ* treatment zones. Result of these studies demonstrated that the nitrobenzene transformation was more rapid in batch than in column systems, indicating the potential importance of mass-transfer limitations in flow-through applications.

A pilot-scale funnel-and-gate system was tested by Clark *et al.* (1996) as part of a SITE demonstration at a former industrial facility in New York. Initial results indicated that the iron-sand permeable reactor zone reduced the concentration of TCE in the contaminated plume by 98%. D.I. Kaplan *et al.* (1996), evaluated the retention of zero-valent iron colloids in soil columns. The effect of influent iron colloid concentration and injection rate on colloid retention was discussed.

The use of a sand and powdered activated carbon mixture for removal of benzene from a groundwater system was discussed (Basheer and Najjar, 1996, and Kapoor and Viraraghavan, 1996) with regard to cost effectiveness and feasibility. Chromium-contaminated soils, their complex chemistry, regulatory challenges, and treatment technologies were discussed by James (1996). Surfactants were used to enhance extraction of chromium from contaminated soils obtained from the U.S. Coast Guard Support Center (Nivas *et al.*, 1996). The surfactant Dowfax 8390 and a complexing agent, diphenyl carbazide, yielded optimal results.

A critique of a zinc(II) column washing study was presented by Niven and Khalili (1996), who criticized using zinc sulfate to simulate zinc contamination in soil systems and recommended the use of a less water-soluble zinc compound, which would be more representative of true site-contaminated soils. In a rebuttal, the use of zinc sulfate was justified as a source of metal contamination for column experiments that were designed to evaluate the effects of pH variation, EDTA and DTPA concentrations, ionic strength, dissolved chlorine, flow rate, and temperature on removal efficiency of zinc (Davis, 1996). To limit the uptake of zinc by agricultural crops, *in situ* stabilization of the soil was attempted with lime, natural zeolite, hydroxyapatite, and an iron oxide waste byproduct (Chlopecka and Adriano, 1996).

A treatment technology was used at a Newport, Delaware, Superfund site to immobilize barium, zinc, lead, and cadmium with soluble sulfate and sulfide salts (Scrivner *et al.*, 1996). The *in situ* treatment saved an estimated $22 million over the U.S. EPA-preferred treatment technology of deep soil mixing. Modeling simulations produced from HELP3, VLEACH, and Summers models were used to assess whether soils and waste pile materials with high lead concentration could be contained effectively in place (Fullerton *et al.*, 1996).

Column results of soil-flushing experiments for a lead-contaminated sandy loam were presented by Reed *et al.* (1995). Pb(II), $PbSO_4$(s), $PbCO_3$(3), and Pb-naphthalene served as the contaminants, whereas HCl, EDTA, and $CaCl_2$ served as the flushing solutions. Rebhun *et al.* (1996) investigated the use of dissolved humic substances (DHSs) for remediation of sites contaminated by organic pollutants. DHSs bind hydrophobically to organic contaminants and may reduce sorbability of the contaminant, thus enhancing desorption-remediation of contaminated sites. Mathematical models predicted 50- to 100-fold reductions in sorbability and retardation of highly hydrophobic organic solutes in the presence of a DHS.

Electrokinetics. An *in situ* electrokinetic technique was evaluated for removal of hexavalent chromium from a sand matrix in column-scale experiments (Haran *et al.*, 1996). Application of a constant potential gradient across the soil matrix resulted in the migration of chromate toward the anode, and hexavalent chromium ions then were reduced by reaction with the anodic dissolution product, Fe^{2+}. *In situ* remediation of lead-contaminated soil was investigated by Reed *et al.* (1996b). A correlation between the amount of electro-osmosis flow and the desorption and transport of soil-bound lead in electrokinetic soil-flushing experiments was reported. C.D. Cox *et al.* (1996) used an enhanced electrokinetic technique to remediate HgS-contaminated soils with iodine/iodide lixiviant using bench-scale electrokinetic cells. A mercury removal efficiency of 99% was achieved in laboratory contaminated soils.

Remediation efficiency of the electrokinetic method may be limited when metals precipitate in regions of soil with elevated pH (Li, Z.M., *et al.*, 1996). A new approach to electrokinetics was presented in which a conductive solution was inserted between the cathode and treated soil, quenching the generation of hydroxide ions that result from electrolysis of water during treatment. Patterson and Runnels (1996) proposed an electromigration method for remediating groundwater contaminated with highly soluble compounds such as Na^+, Cl^-, NO_3^-, and SO_4^{2-}. A field test then was conducted to test the efficacy of electromigration for preconcentrating SO_4^{2-} in groundwater associated with a fossil-fuel power plant.

Thermal Methods. A thermal blanket was used to treat surficial PCB-contaminated soil in a pilot-scale test (Iben *et al.*, 1996). PCB concentrations were reduced from approximately 2 000 ppm to less than 2 ppm within 24 hours of heating the soil with the thermal blanket, which operated at temperatures from 815 to 925°C.

Biological Methods. *Active Bioremediation.* Laboratory and field experiments were carried out for bioremediation of soils contaminated by fuel oil and motor oil (Gruiz and Kriston, 1995). Biodegradation and microbial activity were measured, and results showed an almost complete degradation of the organic pollutant. The ability of soil microorganisms to degrade fuel in soils under extreme climatic conditions was investigated by isolating bacteria from the fuel-contaminated soil at McMurdo Station, Antarctica (Wardell, 1995). Field experiments showed significant BTEX mass reductions through the zone affected by passive treatment wells containing a solid oxygen releasing product (Chapman *et al.*, 1996). Pulse injections of electron donor and acceptor were suggested to evenly distribute biomass for more effective *in situ* bioremediation, and laboratory experiments supported this by accounting for tryptic soy agar plate counts and total protein (Peyton, 1996).

A laboratory study was conducted to investigate the effect of nitrogen and phosphorus levels and temperature on petroleum bioremediation in cold areas (Walworth and Reynolds, 1995). It was found that the rate of diesel loss was lower at 10°C than at 20°C, and only at the latter did temperature addition of P increase degradation. Different results were obtained on addition of phosphorus for enhancing oil degradation (Chang *et al.*, 1996). It was found that the phosphorus addition was beneficial for oil concentrations greater than 3%, and that the positive effect of higher concentrations was only transitory. A pilot study showed that oxygen released by solid oxygen releasing compounds into the subsurface, as indicated by increases in dissolved oxygen concentration in groundwater, was promoting bioremediation in various points of the system, and that BTEX concentration was decreasing (Johnson and Methvin, 1996).

Laboratory experiments were conducted on flow-through columns filled with homogeneously contaminated aquifer material from diesel fuel for evaluating *in situ* bioremediation (Hess *et al.,* 1996). Results showed that O_2 was depleted rapidly and that both O_2 and NO_3^- could serve as oxidants for the mineralization of hydrocarbons. The cleanup of residual solvents in the saturated zone using an *in situ* biochemical treatment was studied in a laboratory column by using PCE as a model compound and in the presence of vitamin B_{12} (Lesage *et al.,* 1996). Vitamin B_{12} increased degradation rates and was compatible with anaerobic bacteria survival, and degradation was not dependent on the concentration range of PCE.

Bench-scale laboratory methods were used to evaluate the feasibility of bioaugmentation with *Pseudomonas* sp. strain KC to remediate aquifer materials from an aquifer of documented CCl_4 contamination at Schoolcraft, Michigan (Mayotte *et al.,* 1996). Results indicated that niche adjustment enabled rapid growth and colonization of the aquifer solids by strain KC and that conditions favorable for CCl_4 removal could be realized. A field test was conducted successfully for demonstrating the effectiveness of *in situ* biofilter using resting-state cells for remediating groundwater, with approximately 425 ppb of TCE as the sole contaminant species (Duba *et al.,* 1996). TCE concentration extracted through the biofilter gradually returned to background values 40 days after termination of the experiment.

Oxygen and nutrients injection into an aquifer to stimulate biodegradation of target PAH and pentachlorophenol was examined (Korom *et al.,* 1996). Preliminary field evaluations indicated that oxygen demand could be exerted by uncontaminated oxygen sediments and suggested that this fact could significantly increase remediation costs by additional oxygen delivery for sediments oxidation. Laboratory-scale, porous media biofilm reactors were used to evaluate the effect of biofilm thickness on media porosity and permeability in phenol-contaminated aquifer (Essa *et al.,* 1996). Results showed that reductions in hydraulic conductivity were found because of biomass growth. The effects of phenol concentration on hydraulic conductivity also were investigated (Farooq *et al.,* 1996).

Three long-term studies were conducted for demonstrating the effectiveness of bioremediation at reducing chemical conditions, mobility, and toxicity in soils and wasterwater solids over a long time period (Loehr and Webster, 1996b). Results confirmed that chemical bioremediation residues were present in treated soils and that both chemical concentration and toxicity continued to decline after active remediation stopped. A passive-release wells technique for *in situ* remediation of contaminant plumes was described (Wilson and Mackay, 1996). Characteristics and limitations of the technique were discussed, and some suggestions for a correct application also were given.

Different alternative methods and algorithms for dynamic nonlinear optimization for cost-effective designs of groundwater *in situ* bioremediation were presented (Yoon and Shoemaker, 1996). Optimizations included local injection wells, time-varying pumping rates, and oxygen concentration in injected water, and the scheme was coupled with a highly nonlinear model of groundwater transport and biodegradation. Another optimal control model was developed for improving the design and optimizing pumping strategies of *in situ* bioremediation of groundwater (Minsker and Shoemaker, 1996).

A case study of application of *in situ* bioremediation using direct current to emplace nutrients and microorganisms in tight soils was presented (Cullen *et al.,* 1996). Results proved the successful application of this technology, the features of which were described in detail, and it was compared with other remediation techniques that remained ineffective. Two-dimensional transport of dissolved oxygen was investigated in experiments conducted in a large-scale physical aquifer model where a gas phase was trapped in the pore spaces on an otherwise saturated porous medium (Fry *et al.,* 1996). Results showed that the presence of even a small amount of a trapped gas phase in an aquifer would significantly affect the distribution and transport of dissolved oxygen. A brief discussion on limits of applications to *in situ* bioremediation was presented (Hart, 1996).

The potential for bioremediation of groundwater with various alkylpyridines was investigated (Ronen, Z., *et al.,* 1996). Laboratory experiments demonstrated that biodegradation occurred only under aerobic conditions, suggesting that oxygen limitation could strongly affect biodegradation of pollutants. A test-plot infiltration test and a conservative tracer test at Eglin Air Force Base, Florida, confirmed the potential for transporting solutes to the subsurface via recharging water (Sweed *et al.,* 1996). Experimental results indicated dilution as the dominant attenuation mechanism associated with high surface application rates.

A field investigation of nutrient pulse mixing in an *in situ* biostimulation experiment in a portion of the Borden aquifer was presented (Devlin and Barker, 1996). Results indicated that large-period pulsed injections of a substrate could be useful for promoting injected and ambient water mixing in bioremediation programs. The use and cost effectiveness of plants for remediating soils contaminated by toxic metals and isotopes was discussed (Comis, 1996). The same remediation method was proposed for removing from soil radionuclides ^{135}Cs and ^{90}Sr, whose remediations using energy-intensive engineering solutions were considered infeasible and not economical, especially for huge volumes of soil (Entry *et al.,* 1996). A diesel-fuel–contaminated aquifer in Switzerland was the target of bioremediation efforts involving the addition of O_2, NO_3^-, PO_4^{3-}, and NH_4^- through an infiltration well (Bregnard *et al.,* 1996). The aerobic and anaerobic degradation of weathered fuel was examined in batch microcosms using aquifer material from the field site.

Intrinsic Bioremediation. Implications of the presence of ethanol on intrinsic bioremediation of BTX plumes in Brazil were discussed (Corseuil *et al.,* 1996). Preliminary laboratory studies showed that ethanol could enhance BTX solubilization in water and might exert diauxic effects during BTX biodegradation. A survey was conducted on 119 dissolved hydrocarbon plumes in California to evaluate evidence of natural attenuation (Buscheck *et al.,* 1996). Petroleum hydrocarbon plumes were stabilizing at relatively short distances, rarely exceeding 79 m (260 ft) in length. Sulfate-reduction biodegradation of petroleum hydrocarbons appeared to play a major role in many of the sites investigated.

An investigation was conducted for evaluating vertical geochemical changes induced by an accumulation of diesel fuel #2 in contact with groundwater (Stout and Lundegard, 1996). Results suggested that significant changes in biodegradation and in composition might be attributed to the availability of dissolved oxygen and reduced product concentration. A field study of oxygen injection was carried out in a sandy iron-rich groundwater system contaminated with gasoline hydrocarbons for evaluating enhancement of intrinsic bioremediation (Gibson *et al.*, 1996). Results indicated enhancement of both bacterial population and rate of aerobic degradation, especially of benzene and ethylbenzene, which were recalcitrant to intrinsic remediation under low-oxygen conditions. Degradation of gasoline contaminants by indigenous microorganisms was found in glacial and postglacial sediments (Rogers *et al.*, 1996). Favorable aquifer geochemistry, presence of indigenous microorganisms, and contaminant concentrations within a certain range were identified as ideal factors for rapid and significant gasoline degradation.

An evaluation of intrinsic bioremediation in support of RBCA was presented (Douthit *et al.*, 1996). A comparison of regulatory outcomes with and without intrinsic bioremediation considerations was presented, and the relevance of intrinsic bioremediation to RBCA was discussed on a set of data from a site located in New York state. Screening model approaches were presented for evaluating BTEX natural attenuation in groundwater (McAllister, 1996). The estimation of the maximum extent of the soluble contaminant plume, the determination of soluble plume attenuation rates, and estimations of the time required for the plume to stabilize were the aims of the two methods proposed. A review was presented on regulatory progress toward risk-based remediation together with a description of the successful application of RBCA at two fuel-contaminated sites on Air Force installations (Downey *et al.*, 1996). A user-friendly screening tool, BIOSCREEN, for simulating natural attenuation of dissolved hydrocarbons at petroleum fuel release sites was described (Newell *et al.*, 1996). The program was aimed at estimating the plume extension without human intervention and evaluating the plume residence time before natural attenuation occurred.

An approach for evaluating the use of intrinsic remediation in conjunction with other technologies for implementing an optimal site-dependent remedial strategy was developed (Norris *et al.*, 1996). The method relied on multiple application of models with successively increasing levels of engineering and cost requirements to tailor the final intervention to the site under study. A spreadsheet model was developed to project adsorbed and dissolved phase concentrations at any distance from a 2-D line source considering both natural and biological degradation (Henry and Herman, 1996). Similar spreadsheet models were developed, based on the Domenico analytical model, and provided results in close agreement with the numerical model BIOPLUME II (Ollila, 1996).

A screening study of CAH intrinsic bioremediation at a southern New Hampshire site was conducted (Schaffner *et al.*, 1996). Results showed the occurrence of reductive dehalogenation and co-metabolism of CAHs, and the latter process was dissolved-oxygen and CH_4 limited. Incorporation of intrinsic bioremediation potential of CAHs as a part of a site's remediation strategy was discussed (Swindoll and Troy, 1996). A careful evaluation of the factors affecting biodegradation of aquifers, as well as an assessment of potential human and environmental risk, was strongly recommended for avoiding excessively optimistic predictions.

Two case histories on natural attenuation in New Jersey were documented (Valdes, 1996). Measurements of indicator parameters indicated that BTEXs were rapidly degrading, both aerobically and anaerobically, with no assistance. Resident bacteria showed marked preferences for some of the available specific electron acceptors in the attenuation process, namely oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide. An informal survey of 125 regulators from environmental agencies was conducted to determine each agency's position regarding natural attenuation (Ritz and Weston, 1996). The results of the inquiry indicated that natural attenuation could be more expensive and risky than proactive remediation methods, but that no general evaluation could be made since remediation was found to be strongly site specific.

A review of parameters for evaluation and a discussion of the strategy to be used for applying natural attenuation were presented (Testa, 1996). The site-specific nature of natural attenuation was supported by results obtained from two case studies. A discussion was presented regarding the real advantages and disadvantages of active soil cleanup interventions, and an evaluation of the indirect financial and environmental related costs was discussed (Hicks and Rizvi, 1996).

Non-Aqueous-Phase Liquid Recovery. *Hydraulics.* Vacuum-enhanced NAPL recovery, commonly referred to as dual-phase extraction or bioslurping, has the potential to increase NAPL recovery rates, accomplish dewatering, and facilitate vapor-based unsaturated zone cleanup (Baker and Bierschenk, 1995). A conceptual model was presented to evaluate the effects of vacuum-enhanced recovery on soil water and NAPL, which was tested during a pilot-scale study at a diesel-fuel–contaminated site. A modeling study focused on numerical simulation of a two-phase vacuum extraction process (Kuehne, 1996). A 2-D radial flow model that incorporated information regarding extraction wells, soil properties, and hydrogeology was developed to evaluate the appropriateness of the modeling effort to aid in the design and analysis of two-phase extraction systems.

Remediation of JP-4 aircraft fuel by bioslurping was investigated at a refueling facility at Honshu, Japan (Shih and Griffin, 1996). The system was designed to remove fuel floating on, and dissolved in, groundwater and to remove organic vapors in the vadose zone. Jet fuel was remediated from soil and groundwater by high-vacuum dual-phase extraction at the Kennedy International Airport (Kirshner *et al.*, 1996). Case study results indicated that 62% of contaminant removal resulted from biodegradation, 27% from liquid removal, and 11% from VOC extraction. In an effort to assess the recoverability of free-LNAPL, LNAPL transmissivities were determined and compared with the Bouwer and Rice method and a numerical solution (Lundy and Zimmerman, 1996). Results of LNAPL transmissivities determined by the Bower and Rice method and the numerical solution were in good agreement with measured values and calculations of transmissivity based on known soil and fluid properties.

Hydraulic fracturing, an enhanced oil-recovery technology, was modified for application in environmental site remediation (Hedgcoxe *et al.*, 1996). Hydraulic fracturing was used to emplace sand-filled lenses within low permeability clays to link trapped residual NAPL and provide a pathway for NAPL extraction. Sale and Applegate (1996) proposed a method to limit the potential for DNAPL migration and recovered the mobile phase of DNAPL pooled on subsurface confining layers. The technology, which relied on recirculating drain lines, achieved 95% recovery of mobile DNAPL. Gomez-Lahoz *et al.* (1996) explored the effects of matrix diffusion and the presence of NAPLs on the remediation of fractured rock aquifers. One model was used to predict the flushing of organic compounds initially distributed as NAPL droplets in a fracture, and the second model was used to evaluate the removal of organic compounds initially present as NAPL in an aquifer containing low-permeability porous clay lenses. Spacing of fractures and thickness of clay lenses were determined to be more important than NAPL droplet size in the models.

Surfactants and Cosolvents. Surfactant-enhanced solubilization and biodegradation were investigated in batch experiments to determine the effectiveness of four different surfactants to increase the solubility of octadecane in solution and evaluate biodegradation rates (Thai *et al.,* 1996). All surfactants, Brij 35, Corexit 0600, Triton X-114, and Tween 40, enhanced solubility, whereas only Corexit 0600 and Tween 40 enhanced biodegradation rates. Dissolution and biodegradation kinetic studies of phenanthrene in the presence of nonionic surfactants were conducted in an attempt to enhance the bioavailability of the PAH dissolved in NAPLs (Grimberg, 1996). The experimental study was designed to evaluate the effect of mass-transfer limitations in a completely mixed reactor on the rate of phenanthrene biodegradation in the presence of different nonionic surfactants and perform model simulations to compare with experimental observations. A related study investigated surfactant-enhanced dissolution of phenanthrene for laminar flow conditions (Grimberg *et al.,* 1996a). The model developed for the previous completely mixed reactor study was applied to a flow-through system with well-defined hydrodynamics, and modeling results were compared with experimental work.

A model describing the bioavailability of hydrophobic PAHs partitioned into the micellar phase of nonionic surfactants was presented by Guha and Jaffè (1996b). Biodegradation kinetics were explained in terms of a series of mass-transfer processes resulting in an equation similar to Monod kinetics. Kinetic aspects of nonionic polyoxyethylene surfactants on the solubilization rate of soil-bound PAHs were investigated (Yeom *et al.,* 1996a). A modified radial diffusion model to evaluate surfactant enhancement mechanisms was presented.

Physicochemical processes, which occur during surfactant flushing, are not well understood. A study was performed to observe and quantify various physicochemical transport processes operating during removal of PCE by a nonionic surfactant (Okuda *et al.,* 1996). The phase behavior of the water/PCE/surfactant system in batch tests was examined, and column experiments were performed to evaluate residual PCE removal mechanisms, nonreactive tracer transport, and surfactant transport. A controlled DNAPL surfactant-flushing field test was performed at Canadian Forces Base Borden (Fountain *et al.,* 1996). The remediation effort removed the majority of the DNAPL with little vertical migration of the contaminant.

To evaluate the potential of precipitation and sorption of anionic ethoxylated alkyl-sulfate surfactant in the subsurface, batch experiments were conducted (Rouse *et al.,* 1996). Results demonstrated that there was no significant precipitation where the degree of ethoxylation was two or greater, anionic ethoxylated surfactants were less susceptible to sorption by soils than nonethoxylated anionics or nonionics, and the surfactants served readily as substrates for microbes.

An economic study of surfactant-enhanced PAT remediation for removal of PCE from different-sized spills was presented (Krebs-Yuill *et al.,* 1996). Five different surfactants were compared by evaluating solubilization and mobilization. Conclusions of the study included the following: the estimated cost for solubilization of PCE from a 0.8-ha (2-ac) site was approximately \$7–15 million, the estimated cost for mobilization of PCE from a 0.8 ha (2-ac) site was approximately \$5–7 million, and 35 to 40% of remediation costs was for surfactant. Delshad *et al.* (1996) used a 3-D, multicomponent, multiphase compositional FD simulator to predict contaminant transport during surfactant-enhanced NAPL remediation. Phase behavior of NAPL, water, and surfactant; adsorption; interfacial tension; capillary pressure; capillary number; and microemulsion viscosity were dependent on accurate phase behavior modeling.

A complete description of a physical-property model for evaluating pseudophase representations of micellar/polymer-phase behavior using numerical methods was presented by S.A. Khan *et al.* (1996). The model allowed for a variety of physical/chemical phenomena such as formation of one to three phases, the effect of salinity and cosolvents on phase behavior, adsorption of several chemical species, capillary desaturation, polymer shear thinning, and permeability reduction to be considered. A 1-D numerical model that simulates surfactant-enhanced solubilization of pooled DNAPL was presented by Mason and Kueper (1996). The nonequilibrium mass-transfer coefficient was based on the wetting-phase Darcy flux and accounted for mass transfer between DNAPL and surfactant solution over time.

Surfactant/cosolvent-microemulsion–mediated removal of residual gasoline was investigated in column experiments (Mansell *et al.,* 1996). Extremely low interfacial tension generated between the microemulsion and NAPL mobilized the residual NAPL in the porous matrix, and eventually the NAPL was solubilized by the microemulsion and underwent miscible displacement as a new microemulsion of water/surfactant/cosolvent/NAPL. A related study detailed the results of column studies of a loam soil contaminated with leaded gasoline (Ouyang *et al.,* 1996a). Approximately 95% of the gasoline was removed as a microemulsion, and 90% of the lead originally associated with the gasoline was removed. Baran *et al.* (1996) presented an investigation to remove chlorocarbons (including PCE, TCA, TCE, DCB, chloroform, and methylene chloride) in a microemulsion using alkyl glucamide surfactants.

A 1-D, ternary, two-phase simulator was used to evaluate physical properties such as interfacial tension, residual saturation, relative permeability, phase viscosity, wettability, capillary pressure, adsorption, and dispersion on chemical flood transport (Bidner and Porcelli, 1996a,b). The influence of viscous and buoyancy forces on the mobilization of residual PCE was the subject of research conducted in column-displacement studies (Pennell *et al.,* 1996). Desaturation curves were expressed in terms of a total trapping number, which related both viscous and buoyancy forces to capillary forces. This approach can be used to predict the onset and extent of NAPL displacement during surfactant flushing.

Hayden and Van der Hoeven (1996) investigated the use of alcohol flushing for enhanced removal of coal tar from contaminated soil columns. Isopropyl alcohol was flushed through columns to increase removal of coal tar by three to five orders of magnitude. Additions and corrections published in 1995 to an article that addressed the topic of micellar solubilization of PAHs in coal-tar–contaminated soils were detailed (Yeom *et al.,* 1996b). Three equations in the original article were published incorrectly. The effects of moisture were evaluated on the remediation of PAH-contaminated soil with supercritical carbon dioxide (Schleussinger *et al.,* 1996). Addition of water to the soil system tended to increase the removal efficiency of

PAH, indicating that extraction was limited by adsorption, not diffusion.

Vapor-Phase Methods. *Soil Vapor Extraction.* Soil vapor extraction (SVE) studies published can be divided into the subjects of mathematical modeling, applications, and economic considerations. A fugacity model, which accounted for natural processes such as volatilization, degradation, leaching, and gas-phase advection to predict the effectiveness of SVE, was presented by She *et al.* (1995). For one case study modeled, a 13-kg TCE spill was reduced to 0.001 μg/L in 2 years with SVE remediation. Another modeling simulation was performed as part of a field-scale study at a CERCLA site at Lawrence Livermore National Laboratory (Vogele and Nitao, 1996). The numerical, multiphase, multicomponent computer code, NUFT, was used to evaluate the feasibility of SVE remediation and guide system design. The model was used to simulate nonisothermal flow and transport of multiple phases and contaminants in 3-D using FD grids.

Quantitative SVE performance standards were developed for the Hassayampa Landfill Superfund Site using a 1-D vadose zone transport model, SESOIL (Lindquist *et al.*, 1996). The iterative modeling procedure helped to establish the size of remedial target zones in addition to producing performance standard curves for VOCs posing a risk to the environment. To evaluate the effects of SVE on contaminant flux to the atmosphere and groundwater, a 2-D numerical simulation of contaminant loading was performed (Poulsen *et al.*, 1996). Results showed that well vacuum, NAPL–air mass-transfer rate, and inhomogeneities in soil-air conductivity significantly influence contaminant flux and remediation time.

The efficiency of air flow to inlet wells under conditions of leaky surface boundary, anisotropic soils, and partially screened extraction was the subject of another modeling study (Ge and Liao, 1996). An SVE modeling study presented by Ng and Mei (1996) evaluated aggregate diffusion in unidirectional and radial flows. The model used *Pe,* the ratio of advection time to aggregate diffusion time, and the ratio of mass within aggregate to mass in gas to account for diffusion within saturated aggregates and convective diffusion in air-filled macropores.

A series of bench-scale experiments to evaluate the effectiveness of air stripping of VOC-contaminated soils was conducted by Shah *et al.* (1995). The experiments examined the effect of soil grain size, air injection flow rate, and air inlet temperature on benzene recovery. Increases in grain size from 0.31 to 1.2 mm enhanced benzene recovery from 49 to 65%, increasing the air-flow rate enhanced recovery from 56% at 5 L/min to 70% at 10 L/min, and preheating the air to 45°C resulted in an increase in recovery from 70 to 90%. To implement extraction of VOCs from a contaminated site in a remediation project at a U.S. Air Force facility, two horizontal wells were installed (Overby and Pedlar, 1996). The details of a multimedia risk-based SVE project to remediate gasoline-contaminated soils at a utility service center were presented in another study (Mills, W.B., *et al.*, 1996).

Sun *et al.* (1995) discussed three SVE system design optimization methodologies: implicit enumeration, systematic reduction, and local search. The methodologies are discussed to portray the combinatorial nature of SVE design and to evaluate well interferences in a multiwell system. Another method for conceptual design of economically based SVE systems was described with the objective of providing cost estimation and cleanup scheduling (DePaoli *et al.*, 1996). Results for a case study for a 95-m^3 (25 000-gal) JP-4 jet fuel spill indicated that emissions control would increase costs and that carbon adsorption would be more costly than catalytic conversion in the remediation process.

An SVE system cost analysis was performed at a site to evaluate the use of an internal combustion engine to abate extracted vapors versus operating a granular activated carbon (GAC) absorption system (Kelly, 1996). It was determined that the GAC system would be more cost effective for the period of remediation. The secondary effects of soil venting and potential low-cost enhancements were the subjects of a similar report by Walton and Anker (1996). The ability of humidified, slightly heated air to enhance SVE removal efficiency was noted.

Bioventing. A numerical model of soil vapor extraction and bioventing was developed to study physical, chemical, and biological transformations and to evaluate performance of soil vapor extraction/bioventing systems (Rathfelder *et al.*, 1996). The model included air and water phases, multicomponent transport, and kinetic expressions describing substrate, electron-acceptors, and biomass growth/decay. At a VOC-contaminated site in New Jersey, a PAT system was designed to control contaminants. The high cost of operating the system, however, forced the remediation team to reconsider the bioventing alternative (Haight *et al.*, 1996). The bioventing system was successful, increasing removal efficiency by nearly one order of magnitude and saving an estimated $3.3 million over the PAT system.

Results of a 2-year bioventing demonstration, which enhanced biodegradation and volatilization, were presented by Downey *et al.* (1995). The demonstration, recently completed at a large diesel spill site, resulted in the cleanup of an estimated 11 500 m^3 of soil. Moyer *et al.* (1996) presented results of petroleum hydrocarbon bioventing kinetic studies performed in soil core, microcosm, and tubing cluster experiments. Total hydrocarbon concentrations were reduced by 75% in lab studies, and first-order rate constants were consistent with kinetic parameters determined from microcosm and tubing cluster studies.

Respiration tests were performed by researchers who evaluated the effect of subsurface aeration on biodegradation rates of petroleum hydrocarbons in the vadose zone (Gray *et al.*, 1996). Case study results indicated that flow rates of less than 4.7 L/s (10 cu ft/min) of atmospheric air were sufficient to aerate soils, but low enough to prevent excessive volatilization and spreading of hydrocarbon vapors. Hickey and Paek (1996) investigated mineralization versus volatilization of naphthalene in a gasoline-contaminated subsurface soil during the bioventing process. Continuous ventilation resulted in 38.8% volatilization and 10.4% mineralization, but intermittent ventilation decreased volatilization 10-fold and resulted in negligible mineralization.

Methods for measuring contaminant mass-transfer rates were presented by Anderson *et al.* (1996). In the vadose zone, the area of influence of the bioventing well was determined by the distribution of oxygen, carbon dioxide, and air pressure using *in situ* sensors at various distances and directions from the air injection point. A 3-D finite difference model developed by McClure and Sleep (1996) was used to simulate bioventing. The model incorporated gas, water, and organic flow with equilibrium interphase mass-transfer and dispersive transport of organic compounds, oxygen, and carbon dioxide. The model was able to predict microorganism growth, substrate and oxygen consumption, and carbon dioxide production caused by microbial activity.

Air Sparging. Air sparging is an increasingly popular remediation technology that is based on injecting air into groundwater to remove VOCs through air stripping or enhanced biodegradation (Abbasi, 1996). A full description of the air-sparging process and modifications for cost-effective groundwater treatment was provided. A PAT system was replaced by an air-sparging cutoff wall designed to enhance biodegradation of BTEX compounds (Gallagher *et al.,* 1996). The air-sparging results indicated enhanced biodegradation of BTEX, increased dissolved oxygen in groundwater, and increased oxygen soil-gas concentrations. In another publication, a pilot study was described that was conducted to evaluate air sparging in a gravel-filled trench that was reducing a hydrocarbon plume (Brubaker *et al.,* 1996). It was determined that the main degradation pathway was biodegradation, not volatilization, and an intermittent sparging schedule to maximize the biodegradation rate was developed.

Greacen *et al.* (1996b) performed a pilot test to evaluate aboveground vapor collection for an air-sparging system. The system was installed where the water table was very shallow, typically a low-efficiency scenario for air-sparging remediation. Pure gaseous oxygen was injected into a confined aquifer in an innovative pilot test at a Gulf Coast Chemical Manufacturing Company (Leethem *et al.,* 1996). The technique, designed to enhance bioremediation, also controlled the production of fugitive offgases, avoiding the need for an SVE system. In a separate study, oxygenation rates were measured to evaluate the effects of process control changes during air sparging (Rutherford and Johnson, 1996). Results suggested that there was an optimum air injection rate, advective groundwater flow can be a significant factor, and pulsing the air injection had little effect on oxygenation rate compared with continuous injection.

To effectively design an air-sparging system, the zone of influence of sparge wells must be defined (Joss, 1996). An approach was presented to use pressure measurements above the water table as inputs to an unsaturated zone airflow model to quantify fluxes across the water table during air sparging. McCray and Falta (1996) defined the air-sparging radius of influence by developing a relationship between observed subsurface pressure caused by sparging and gas saturation at the location. A multiphase numerical simulation, which illustrated the transient and steady-state behavior of air-sparging systems, was presented to confirm the relationship.

The utility of horizontal wells for air-sparging systems was reported in several pilot-scale studies. A horizontal well was installed in one study to evaluate the appropriateness of the technique for air sparging (Lundegard *et al.,* 1996). Nonuniform airflow and preferential exit of air at the blower end of the well were evaluated. Results indicated that the pressure drop within the well was negligible, and soil-gas pressure and groundwater monitoring responses were similar at both ends of the well, suggesting uniform delivery of air throughout the well. Horizontal wells were incorporated into an integrated multimedia remediation system described by Downs (1996). The system coupled horizontal well air sparging with SVE, soil washing, and enhanced natural biodegradation through bioventing. The system, which was 20% less expensive than a vertical-well–based system, achieved the intended remedial objective in 6 months.

A performance comparison between horizontal and vertical air-sparging well systems was the subject of a 1-year pilot study by Wade *et al.* (1996). The sparging capacity of the horizontal well was 10 times that of the vertical well and was significantly more effective at reducing TCE concentrations in groundwater under all operating conditions. Computer modeling and supporting pilot-scale results were presented to demonstrate the effectiveness of a trench biosparge system for treatment of organic compounds in groundwater (Christodoulatos *et al.,* 1996). Results indicated that velocity equalization was necessary to attain uniform residence time distribution of organic contaminants and that the geometry of the plume diversion system was important to design.

An AD air-sparging model was presented to simulate migration through a saturated soil system contaminated with VOCs (Drucker and Dijulio, 1996). A screening model was used by Russell and Rabideau (1996) to evaluate expected performance for an air-sparging and SVE remediation design. Numerical simulations with a multiphase modeling program, TETRAD, were used to evaluate the performance of air-sparging systems (Lundegard and Andersen, 1996). Three stages of flow behavior were predicted after air injection: an expansion stage, a collapse stage, and a steady-state stage.

MANAGEMENT

A risk assessment was performed using a multimedia environmental transport model to estimate public risk from a contaminated groundwater plume (Datskou and North, 1996). Baseline health risks to the public, health risk reduction to the public as a result of the remedial activities, health risk to the workers directly involved in cleaning up the site, and costs associated with each remedial activity were evaluated. A simulation framework that can be used to include human health exposure as a criterion in regional-scale aquifer management problems was developed (Pelmulder *et al.,* 1996).

A general framework that can be used to relate physical and chemical processes to the evaluation of risk from contaminants migrating by groundwater was constructed (Andricevic and Cvetkovic, 1996). Simulation results indicated that the geological heterogeneity and uncertainty in the sorption estimate were the two most important factors for the risk evaluation from the physical and chemical processes, whereas the mean risk factor was a crucial parameter in the risk formulation. Research was carried out to identify chemical, physical, bacteriological, and viral contaminants and their sources, and to classify such contaminants relative to their health concerns (Knox and Canter, 1996). The effect of spatial variability in the net applied water distribution on leaching risk assessment and identification of leaching risk categories in the field scale was evaluated (Mallawatantri and Mulla, 1996).

The validity of efforts to protect groundwater quality for a variety of beneficial uses by using a widely accepted nitrate-accounting procedure as the mechanism to obtain reductions, farmer-applied nitrogen fertilizers was investigated (Kim, C.S., *et al.,* 1996). An optimal tax rate on nitrogen fertilizer use was derived that would lead to reduced levels of nitrogen fertilizer use intended by the nitrate accounting procedure. A comparison of the representative profile and the randomly sampled profile approaches of characterizing soil map unit (SMU) behavior in solute transport was performed (Finke *et al.,* 1996).

Wisconsin's atrazine regulatory framework, which was adopted from the nation's most restrictive atrazine management policy, was evaluated (Wolf and Nowak, 1996). A series of papers that focused on characterization of uncertainty in pesticide mobility estimates, using the attenuation and retardation indices for agricultural regions in Hawaii, was reviewed (Loague *et al.*, 1996). A study was conducted to compare several modeling approaches, including CMLS and LEACHM, that might be applicable for classifying SMU according to their leaching potential (Inskeep *et al.*, 1996). It was found that CMLS and LEACHM performed adequately with high-resolution model inputs, and that CMLS predictions were less sensitive to data input resolution in part because CMLS provides an oversimplified description of transport processes.

The effect of spatial variability of selected intrinsic soil properties and extrinsic management practices on the groundwater quality in the 330-ha recharge area of a high-yield well site in Rhode Island was evaluated using a GIS database and stratified sampling for both soil characterization and assessment of spatial variability of NO_3 leaching (Gorres and Gold, 1996). The results suggest that GIS databases generated at scales available to resource managers may be well suited to manage the water quality of large-production-scale wells. Issues such as scale dependency of solute transport modeling and GIS applications in modeling processes were discussed (Wagenet and Hutson, 1996). The scale effects of soil and climate data input on GIS-based solute transport modeling were evaluated (Wilson, J.P., *et al.*, 1996b).

Soil survey information and water balance simulation modeling were used in GIS framework to identify areas at risk of salinization after tree cleaning in North Queensland (Bui *et al.*, 1996). Results suggested that tree clearing may increase deep drainage by up to 10 times. GIS modeling and a significant logistic regression model, which was developed based on the soil particle-size class composition of sections containing wells, were used to predict groundwater vulnerability to pesticides (Teso *et al.*, 1996).

A site-specific farm-scale GIS approach was used to evaluate the feasibility of reducing groundwater contamination by precision farming (Mulla *et al.*, 1996). GIS was used to apply a modified DRASTIC method to the assessment of groundwater contamination sensitivity in Wyoming, and the GIS sensitivity map was compared with groundwater-sensitivity indexes developed based on a numerical modeling results to verify the reliability of the map (Zhang *et al.*, 1996a). An interactive modeling system that combined three widely used screening models with the ARC/INFO GIS software and a graphical user interface was developed within a GIS environment to facilitate rapid appraisal of the susceptibility of groundwater to contamination by pesticides (Tim *et al.*, 1996). In this system, instead of ad hoc linkage between GIS software and a simulation model, a fully integrated and interactive system in which the model equations were programmed within the GIS was developed.

SoilRisk, a new integrated risk assessment model for low levels of organic pollutants in soil, was developed (Labieniec *et al.*, 1996b). A framework for evaluation of nitrate control strategies that use spatially variable nitrogen input in the presence of imprecise information was presented (Woldt *et al.*, 1996). A hydrological simulation program was used to simulate surface runoff, groundwater recharge, and transport of sediments, nutrients, and pesticides in an area in south Florida (Tsihrintzis *et al.*, 1996). Model results showed that under the current practices, sediments, nutrients, and pesticides were present in surface runoff, and nutrients entered the groundwater, and that both urbanization and preventive actions resulted in pollutant reductions.

Uncertainty in recharge estimates was investigated relative to its impact on assessments of groundwater contamination vulnerability using a relatively simple pesticide mobility index and attenuation factor (Giambelluca *et al.*, 1996). The scientific basis for use of fuel constituents other than TPH in establishing soil cleanup standards at a JP-4–contaminated site was determined (McKenna *et al.*, 1995). A series of criteria, including chemical fate and transport, toxicity, and regulatory standards, was applied to assess the viability of the use of specific JP-4 constituents as TPH alternatives and to select the most appropriate alternative. A general strategy has been developed to estimate the regional vulnerability of groundwater to agricultural chemicals in midwestern U.S. and most of Hungary (Burkart and Feher, 1996). A study showed that agriculture was significantly affecting nitrate concentrations in karst aquifers within the Appalachian Region, and best management practices may protect the groundwater resources (Boyer and Pasquarell, 1996).

OTHER RELEVANT LITERATURE

Various professional and institutional conferences included presentations concerning groundwater quality. The conferences that produced published papers or abstracts include meetings of the American Geophysical Union (Am. Geophys. Union, 1996); the summer meeting of the American Institute of Chemical Engineers (Am. Inst. Chem. Eng., 1996); the American Chemical Society Division of Environmental Chemistry meetings (ACS, 1996b,c); the Emerging Technologies in Hazardous Waste Management VII conference (ACS, 1996a); and the American Society of Agronomy annual meeting (Am. Soc. Agron., 1996).

Additional reference sources exist within various organizations such as U.S. EPA in Ada, Oklahoma, and the USGS in Reston, Virginia, for in-house and extramural research. Conference proceedings and general database information may be obtained from the National Ground Water Association in Dublin, Ohio. The International Ground Water Modeling Center in Golden, Colorado, is an international clearinghouse for computer models, documentation, and software.

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REFERENCES

Abbasi, R.A. (1996) Ground-Water Treatments Gain Ground. *Civil Eng.*, **66,** 53.

Abdel-Mallek, A.Y.; Abdelkader, M.I.A.; and Omar, S.A. (1996) Effect of the Herbicide Fluazifop-Butyl on Fungal Populations and Activity in Soil. *Water, Air, Soil Pollut.* (Neth.), **86,** 151.

Abin, A.; Kaluarachchi, J.J.; Kemblowski, M.W.; and Chang, C.M.

(1996) Stochastic Analysis of Multiphase Flow in Porous Media. II. Numerical Simulations. *Stoch. Hydrol. Hydraul.*, **10,** 231.

Adamo, P.; Dudka, S.; Wilson, M.J.; and Mchardy, W.J. (1996) Chemical and Mineralogical Forms of Cu and Ni in Contaminated Soils from the Sudbury Mining and Smelting Region, Canada. *Environ. Pollut.* (G.B.), **91,** 11.

Adamski, J.C., and Pugh, A.L. (1996) Occurrence of Pesticides in Ground Water of the Ozark Plateaus Province. *Water Resour. Bull.* (Urb.), **32,** 97.

Adelman, D.D., and Tabidian, M.A. (1996) The Potential Impact of Soil Carbon Content on Ground Water Nitrate Contamination. *Water Sci. Technol.* (G.B.), **33,** 227.

Adilman, D.J.; Norman, W.R.; and Shaw, M.M. (1996) A Drilling Method for Minimizing Vertical Migration of High Concentrations of Volatile Organics. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 395.

Aelion, C.M. (1996) Impact of Aquifer Sediment Grain Size on Petroleum Hydrocarbon Distribution and Biodegradation. *J. Contam. Hydrol.,* **22,** 109.

Aelion, C.M.; Shaw, J.N.; Ray, R.P.; Widdowson, M.A.; and Reeves, H.W. (1996) Simplified Methods for Monitoring Petroleum-Contaminated Ground Water and Soil Vapor. *J. Soil Contam.,* **5,** 225.

Aga, D.S.; Thurman, E.M.; Yockel, M.E.; Zimmerman, L.R.; and Williams, T.D. (1996) Identification of a New Sulfenic Acid Metabolite of Metolachlor in Soil. *Environ. Sci. Technol.,* **30,** 592.

Agnihotri, N.P.; Kulshrestha, G.; Gajbhiye, V.T.; Mohapatra, S.P.; and Singh, S.B. (1996) Organochlorine Insecticide Residues in Agricultural Soils of the Indo-Gangetic Plain. *Environ. Monit. Assessment,* **40,** 279.

Ahlfeld, D.P., and Hill, E.H. (1996) The Sensitivity of Remedial Strategies to Design Criteria. *Ground Water,* **34,** 341.

Ahlfeld, D.P., and Verdon Lewis, C. (1996) Robustness of Optimal Well Location in a Linear Optimal Groundwater Control Problem. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 43.

Ahmadi, A., and Quintard, M. (1996) Large-Scale Properties for Two-Phase Flow in Random Porous Media. *J. Hydrol.* (Neth.), **183,** 69.

Al-Suwaiyan, M.S. (1996) Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale (Discussion). *Ground Water,* **34,** 578.

Ali, M.A., and Dzombak, D.A. (1996) Competitive Sorption of Simple Organic Acids and Sulfate on Goethite. *Environ. Sci. Technol.,* **30,** 1061.

Allen-King, R.M.; Gillham, R.W.; and Barker, J.F. (1996a) Fate of Dissolved Toluene During Steady Infiltration Through Unsaturated Soil. I. Method Emphasizing Chloroform as a Volatile, Sorptive, and Recalcitrant Tracer. *J. Environ. Qual.,* **25,** 279.

Allen-King, R.M.; Gillham, R.W.; Barker, J.F.; and Sudicky, E.A. (1996b) Fate of Dissolved Toluene During Steady Infiltration Through Unsaturated Soil. II. Biotransformation Under Nutrient-Limited Conditions. *J. Environ. Qual.,* **25,** 287.

Allen-King, R.M.; Groenevelt, H.; Warren, C.J.; and Mackay, D.M. (1996c) Non-Linear Chlorinated-Solvent Sorption in Four Aquitards. *J. Contam. Hydrol.,* **22,** 203.

Allred, B., and Brown, G.O. (1996a) Boundary Condition and Soil Attribute Impacts on Anionic Surfactant Mobility in Unsaturated Soil. *Ground Water,* **34,** 964.

Allred, B., and Brown, G.O. (1996b) Anionic Surfactant Transport Characteristics in Unsaturated Soil. *Soil Sci.,* **161,** 415.

Alvarez, P.J. (1996) Caution Against the Inappropriate Use of Analytical Fate and Transport Models to Estimate the Age and Risk of Petroleum Product Releases (Reply). *Ground Water Monit. Remed.,* **16,** 185.

Alvey, S., and Crowley, D.E. (1996) Survival and Activity of an Atrazine-Mineralizing Bacterial Consortium in Rhizosphere Soil. *Environ. Sci. Technol.,* **30,** 1596.

American Chemical Society (1996a) Emerging Technol. Haz. Manage. VIII Conf., Div. Indust. Eng. Chem., Atlanta, GA.

American Chemical Society (1996b) *Proc. 211th Am. Chem. Soc. Meeting,* Div. Environ. Chem., Milwaukee, Wis.

American Chemical Society (1996c) *Proc. 212th Am. Chem. Soc. Meeting,* Div. Environ. Chem., Milwaukee, Wis.

American Geophysics Union (1996) *EOS, Trans. Am. Geophys. Union,* **77.**

American Institute of Chemical Engineers (1996) *Proc. Am. Inst. Chem. Eng. Summer Natl. Meeting,* New York, N.Y.

American Society of Agronomy (1996) *1996 Agron. Abstr.,* Madison, Wis.

Amali, S.; Rolston, D.E.; and Yamaguchi, T. (1996) Transient Multicomponent Gas-Phase Transport of Volatile Organic Chemicals in Porous Media. *J. Environ. Qual.,* **25,** 1041.

Amonoo-Neizer, E.H.; Nyamah, D.; and Bakiamoh, S.B. (1996) Mercury and Arsenic Pollution in Soil and Biological Samples Around the Mining Town of Obuasi, Ghana. *Water, Air, Soil Pollut.* (Neth.), **91,** 363.

Anderman, E.R.; Hill, M.C.; and Poeter, E.P. (1996) Two-Dimensional Advective Transport in Ground-Water Flow Parameter Estimation. *Ground Water,* **34,** 1001.

Anderson, J.E., and McCarty, P.L. (1996) Effect of Three Chlorinated Ethenes on Growth Rates for a Methanotrophic Mixed Culture. *Environ. Sci. Technol.,* **30,** 3517.

Anderson, K.S.; Brearley, M.; Widness, S.E.; Cook, D.A.; and Baird, B. (1996) Biosparging/Bioventing Advantages and Limitations—Methods for Measuring Contaminant Mass Transfer Effectiveness. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 433.

Andricevic, R. (1996) Evaluation of Sampling in the Subsurface. *Water Resour. Res.,* **32,** 863.

Andricevic, R., and Cvetkovic, V. (1996) Evaluation of Risk From Contaminants Migrating by Groundwater. *Water Resour. Res.,* **32,** 611.

Apitz, S.E., and Meyers-Schulte, K.J. (1996) Effects of Substrate Mineralogy on the Biodegradability of Fuel Components. *Environ. Toxicol. Chem.,* **15,** 1883.

Aral, M.M., and Guan, J. (1996) Optimal Groundwater Remediation Design Using Differential Genetic Algorithm. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K. **1,** 349.

Armstrong, A.C.; Portwood, A.M.; Leedsharrison, P.B.; Harris, G.L.; and Catt, J.A. (1996) The Validation of Pesticide Leaching Models. *Pestic. Sci.,* **48,** 47.

Arocha, M.A.; Jackman, A.P.; and Mccoy, B.J. (1996) Adsorption Kinetics of Toluene on Soil Agglomerates: Soil as a Biporous Sorbent. *Environ. Sci. Technol.,* **30,** 1500.

Arquiett, C.; Gerke, M.; and Datskou, I. (1996) Evaluation of Contaminated Groundwater Cleanup Objectives. *Water, Air, Soil Pollut.* (Neth.), **90,** 83.

Arthurs, P.; Stiver, W.H.; and Zytner, R.G. (1995) Passive Volatilization of Gasoline from Soil. *J. Soil Contam.,* **4,** 123.

Ataie-Ashtiani, B.; Lockington, D.A.; and Volker, R.E. (1996) Numerical Correction for Finite-Difference Solution of the Advection-Dispersion Equation with Reaction. *J. Contam. Hydrol.,* **23,** 149.

Atalay, A., and Hwang, K.J. (1996) Extraction of Light Hydrocarbons from Soil. *Water, Air, Soil Pollut.* (Neth.), **90,** 451.

Auer, L.H.; Rosenberg, N.D.; Birdsell, K.H.; and Whitney, E.M. (1996) The Effects of Barometric Pumping on Contaminant Transport. *J. Contam. Hydrol.,* **24,** 145.

Bai, M.; Roegiers, J.C.; and Inyang, H.I. (1996) Contaminant Transport in Nonisothermal Fractured Porous Media. *J. Environ. Eng.,* **122,** 416.

Baker, R.S., and Bierschenk, J. (1995) Vacuum-Enhanced Recovery of Water and NAPL: Concept and Field Test. *J. Soil. Contam.,* **4,** 57.

Bakker, M., and Strack, O.D.L. (1996) Capture Zone Delineation in Two-Dimensional Groundwater Flow Models. *Water Resour. Res.,* **32,** 1309.

Ball, H.A., and Reinhard, M. (1996) Monoaromatic Hydrocarbon Transformation Under Anaerobic Conditions at Seal Beach, California: Laboratory Studies. *Environ. Toxicol. Chem.*, **15**, 114.

Balsley, S.D.; Brady, P.V.; Krumhansl, J.L.; and Anderson, H.L. (1996) Iodide Retention by Metal Sulfide Surfaces: Cinnabar and Chalcocite. *Environ. Sci. Technol.*, **30**, 3025.

Banwart, S.; Tullborg, E.L.; Pedersen, K.; Gustafsson, E.; Laaksoharju, M.; Nilsson, A.C.; Wallin, B.; and Wikberg, P. (1996) Organic Carbon Oxidation Induced by Large-Scale Shallow Water Intrusion into a Vertical Fracture Zone at the Aspo Hard Rock Laboratory (Sweden). *J. Contam. Hydrol.*, **21**, 115.

Baran, J.R.; Pope, G.A.; Wade, W.H.; and Weerasooriya, V. (1996) Water/Chlorocarbon Winsor I ⇔ III ⇔ II Microemulsion Phase Behavior with Alkyl Glucamide Surfactants. *Environ. Sci. Technol.*, **30**, 2143.

Barcelona, M.J.; Fang, J.; and West, C. (1996) Monitoring In Situ Bioremediation of Fuel Hydrocarbons—The Use of Chemical and Biogeochemical Markers. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 511.

Barker, J.F., and Schirmer, M., (1996) The Longer Term Fate of MTBE in the Borden Aquifer. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 5.

Barlag, C., and Zielke, W. (1996) Dynamic Adaptive Transport Simulation in Fractured Subsurface. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1**, 255.

Baron, D.; Palmer, C.D.; and Stanley, J.T. (1996) Identification of Two Iron-Chromate Precipitates in a Cr(VI)-Contaminated Soil. *Environ. Sci. Technol.*, **30**, 964.

Barona, A., and Romero, F. (1996) Fractionation of Lead in Soils and Its Influence on the Extractive Cleaning with EDTA. *Environ. Technol.*, **17**, 63.

Barriuso, E., and Koskinen, W.C. (1996) Incorporating Nonextractable Atrazine Residues into Soil Size Fractions as a Function of Time. *Soil Sci. Soc. Am. J.*, **60**, 150.

Barry, D.A.; Bajracharya, K.; and Miller, C.T. (1996a) Alternative Split-Operator Approach for Solving Chemical Reaction Groundwater Transport Models. *Adv. Water Resour.*, **19**, 261.

Barry, D.A.; Miller, C.T.; and Culligan-Hensley, P.J. (1996b) Temporal Discretisation Errors in Non-Iterative Split-Operator Approaches to Solving Chemical Reaction Groundwater Transport Models. *J. Contam. Hydrol.*, **22**, 1.

Barten, W. (1996) Linear Response Concept Combining Advection and Limited Rock Matrix Diffusion in a Fracture Network Transport Model. *Water Resour. Res.*, **32**, 3285.

Basheer, I.A., and Najjar, Y.M. (1996) Permeable Barriers to Remove Benzene: Candidate Media Evaluation (Discussion). *J. Environ. Eng.*, **122**, 885.

Baskaran, S.; Bolan, N.S.; Rahman, A.; and Tillman, R.W. (1996) Non-Equilibrium Sorption During the Movement of Pesticides in Soils. *Pestic. Sci.*, **46**, 333.

Batterman, S.; Padmanabham, I.; and Milne, P. (1996) Effective Gas-Phase Diffusion Coefficients in Soils at Varying Water Content Measured Using a One-Flow Sorbent Based Technique. *Environ. Sci. Technol.*, **30**, 770.

Batu, V. (1996) A Generalized Three-Dimensional Analytical Solute Transport Model for Multiple Rectangular First-Type Sources. *J. Hydrol.* (Neth.), **174**, 57.

Baughman, T.A., and Shaw, D.R. (1996) Effect of Wetting/Drying Cycles on Dissipation Patterns of Bioavailable Imazaquin. *Weed Sci.*, **44**, 380.

Bear, J., and Gilman, A. (1995) Migration of Salts in the Unsaturated Zone Caused by Heating. *Transp. Porous Media,* **19**, 139.

Beck, A.J., and Jones, K.C. (1996) The Effects of Particle Size, Organic Matter Content, Crop Residues and Dissolved Organic Matter on the Sorption Kinetics of Atrazine and Isoproturon by Clay Soil. *Chemosphere,* (.G.B.), **32**, 2345.

Beck, A.J.; Harris, G.L.; Howse, K.R.; Johnston, A.E.; and Jones, K.C. (1996a) Spatial and Temporal Variation of Isoproturon Residues and Associated Sorption/Desorption Parameters at the Field Scale. *Chemosphere,* (.G.B.), **33**, 1283.

Beck, A.J.; Stolting, H.; Harris, G.L.; Howse, K.R.; and Jones, K.C. (1996b) Leaching of Recently Applied and Aged Residues of the Herbicides Atrazine and Isoproturon Through a Large, Structured Clay Soil Core. *Chemosphere,* (.G.B.), **33**, 1297.

Beckie, R. (1996) Measurement Scale, Network Sampling Scale, and Groundwater Model Parameters. *Water Resour. Res.*, **32**, 65.

Beller, H.R.; Spormann, A.M.; Sharma, P.K.; Cole, J.R.; and Reinhard, M. (1996) Isolation and Characterization of a Novel Toluene-Degrading, Sulfate-Reducing Bacterium. *Appl. Environ. Microbiol.*, **62**, 1188.

Bellin, A.; Dagan, G.; and Rubin, Y. (1996) The Impact of Head Gradient Transients on Transport in Heterogeneous Formations: Application to the Borden Site. *Water Resour. Res.*, **32**, 2705.

Bellini, G.; Sumner, M.E.; Radcliffe, D.E.; and Qafoku, N.P. (1996) Anion Transport Through Columns of Highly Weathered Acid Soil: Adsorption and Retardation. *Soil Sci. Soc. Am. J.*, **60**, 132.

Beltman, W.H.J.; Boesten, J.J.T.I.; Vanderzee, S.E.A.T.M.; and Quist, J.J. (1996) Analytical Modeling of Effects of Application Frequency on Pesticide Concentrations in Wells. *Ground Water,* **34**, 470.

Berger, B.M.; Bernd, T.; Menne, H.J.; Hackfeld, U.; and Siebert, C.F. (1996) Effects of Crop Management on the Fate of Three Herbicides in Soil. *J. Agric. Food Chem.*, **44**, 1900.

Berglund, S., and Cvetkovic, V. (1996) Contaminant Displacement in Aquifers: Coupled Effects of Flow Heterogeneity and Nonlinear Sorption. *Water Resour. Res.*, **32**, 23.

Bergström, L. (1996) Model Predictions and Field Measurements of Chlorsulfuron Leaching Under Non-Steady-State Flow Conditions. *Pestic. Sci.*, **48**, 37.

Berkowitz, B., and Zhou, J.Y. (1996) Reactive Solute Transport in a Single Fracture. *Water Resour. Res.*, **32**, 901.

Bernard, D., and Gouze, P. (1996) A Finite Element Study of Natural Convection in a Heterogeneous Sloped Porous Layer Bounded by Impervious Domains. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1**, 369.

Bethune, D.N.; Farvolden, R.N.; Ryan, M.C.; and Guzman, A.L. (1996) Industrial Contamination of a Municipal Water-Supply Lake by Induced Reversal of Ground-Water Flow, Managua, Nicaragua. *Ground Water,* **34**, 699.

Betowski, L.D.; Kendall, D.S.; Pace, C.M.; and Donnelly, J.R. (1996) Characterization of Groundwater Samples from Superfund Sites by Gas Chromatography Mass Spectrometry and Liquid Chromatography Mass Spectrometry. *Environ. Sci. Technol.*, **30**, 3558.

Bhandari, A.; Novak, J.T.; and Berry, D.F. (1996) Binding of 4-Monochlorophenol to Soil. *Environ. Sci. Technol.*, **30**, 2305.

Bidner, M.S., and Porcelli, P.C. (1996a) Influence of Capillary Pressure, Adsorption and Dispersion on Chemical Flood Transport Phenomena. *Transp. Porous Media,* **24**, 275.

Bidner, M.S., and Porcelli, P.C. (1996b) Influence of Phase Behavior on Chemical Flood Transport Phenomena. *Transp. Porous Media,* **24**, 247.

Bijay-Singh, Yadvindersingh, Sekhon, G.S. (1995) Fertilizer-N Use Efficiency and Nitrate Pollution of Groundwater in Developing Countries. *J. Contam. Hydrol.*, **20**, 167.

Binley, A.; Henrypoulter, S.; and Shaw, B. (1996) Examination of Solute Transport in an Undisturbed Soil Column Using Electrical Resistance Tomography. *Water Resour. Res.*, **32**, 763.

Binning, P., and Celia, M.A. (1996a) A Finite Volume Eulerian-Lagrangian Localized Adjoint Method for Solution of the Contaminant Transport Equations in Two-Dimensional Multiphase Flow Systems. *Water Resour. Res.*, **32**, 103.

Binning, P., and Celia, M.A. (1996b) Practical Application of the Fractional Flow Approach to Multi-Phase Flow Simulation. *Computat.*

Methods Water Resour. XI, Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 401.

Birge, W.J., and Sendlein, L.V. (1996) Risk-Based Guidelines for Remedial Action of Petroleum Chemicals (BTEX, PAHs) in Kentucky Soils and Ground Water Systems. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 61.

Birkholzer, J., and Karasaki, K. (1996) A New Eulerian-Lagrangian Finite Element Simulator for Solute Transport in Discrete Fracture-Matrix Systems. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 263.

Birman, I., and Alexander, M. (1996) Effect of Viscosity of Nonaqueous-Phase Liquids (NAPLs) on Biodegradation of NAPL Constituents. *Environ. Toxicol. Chem.,* **15,** 1683.

Bjerg, P.L.; Brun, A.; Nielsen, P.H.; and Christensen, T.H. (1996) Application of a Model Accounting for Kinetic Sorption and Degradation to In Situ Microcosm Observations on the Fate of Aromatic Hydrocarbons in an Aerobic Aquifer. *Water Resour. Res.,* **32,** 1831.

Bolton, H., and Girvin, D.C. (1996) Effect of Adsorption on the Biodegradation of Nitrilotriacetate by *Chelatobacter heintzii. Environ. Sci. Technol.,* **30,** 2057.

Bolton, K.A.; Sjoberg, S.; and Evans, L.J. (1996) Proton Binding and Cadmium Complexation Constants for a Soil Humic Acid Using a Quasi-Particle Model. *Soil Sci. Soc. Am. J.,* **60,** 1064.

Bonczek, J.L., and McNeal, B.L. (1996) Specific-Gravity Effects on Fertilizer Leaching from Surface Sources to Shallow Water Tables. *Soil Sci. Soc. Am. J.,* **60,** 978.

Boone, R.L.; Lyverse, M.; and Buscheck, T. (1996) Evaluation of Geochemical Indicators of Microbial Activity as Part of a Corrective Action Plan. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 525.

Borkovec, M.; Burgisser, C.S.; Cernik, M.; Glattli, U.; and Sticher, H. (1996) Quantitative Description of Multi-Component Reactive Transport in Porous Media: An Empirical Approach. *Transp. Porous Media,* **25,** 193.

Bosma, W.J.P.; Vanderzee, S.E.A.T.M.; and Vanduijn, C.J. (1996) Plume Development of a Nonlinearly Adsorbing Solute in Heterogeneous Porous Formations. *Water Resour. Res.,* **32,** 1569.

Bottoni, P.; Keizer, J.; and Funari, E. (1996) Leaching Indices of Some Major Triazine Metabolites. *Chemosphere* (G.B.), **32,** 1401.

Bouma, J.; Booltink, H.W.G.; and Finke, P.A. (1996) Use of Soil Survey Data for Modeling Solute Transport in the Vadose Zone. *J. Environ. Qual.,* **25,** 519.

Bowers, T.S.; Shifrin, N.S.; and Murphy, B.L. (1996) Statistical Approach to Meeting Soil Cleanup Goals. *Environ. Sci. Technol.,* **30,** 1437.

Boyer, D.G., and Pasquarell, G.C. (1996) Agricultural Land Use Effects on Nitrate Concentrations in a Mature Karst Aquifer. *Water Resour. Bull.* (Urb.), **32,** 565.

Braddock, J.F., and McCarthy, K.A. (1996) Hydrologic and Microbiological Factors Affecting Persistence and Migration of Petroleum Hydrocarbons Spilled in a Continuous-Permafrost Region. *Environ. Sci. Technol.,* **30,** 2626.

Bradford, S.A., and Leij, F.J. (1996) Predicting Two- and Three-Fluid Capillary Pressure Saturation Relationships of Porous Media with Fractional Wettability. *Water Resour. Res.,* **32,** 251.

Bradley, P.M., and Chapelle, F.H. (1996) Anaerobic Mineralization of Vinyl Chloride in Fe(III)-Reducing, Aquifer Sediments. *Environ. Sci. Technol.,* **30,** 2084.

Brandi-Dohrn, F.M.; Dick, R.P.; Hess, M.; and Selker, J.S. (1996) Suction Cup Sampler Bias in Leaching Characterization of an Undisturbed Field Soil. *Water Resour. Res.,* **32,** 1173.

Bregnard, T.P.A.; Hohener, P.; Haner, A.; and Zeyer, J. (1996) Degradation of Weathered Diesel Fuel by Microorganisms from a Contaminated Aquifer in Aerobic and Anaerobic Microcosms. *Environ. Toxicol. Chem.,* **15,** 299.

Brown, M.J., and Burris, D.R. (1996) Enhanced Organic Contaminant Sorption on Soil Treated with Cationic Surfactants. *Ground Water,* **34,** 734.

Brubaker, G.R.; Richey, M.; Stecker, J.; and Bailey, M. (1996) Air Sparging Within a Gravel-Filled Trench: Is it Biodegradation or Volatilization? *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 679.

Bruneau, C.H.; Fabrie, P.; and Laquerie, N. (1996) Numerical Simulation of the Contaminant Dispersion in Porous Media. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 145.

Bruns-Nagel, D.; Breitung, J.; Vonlow, E.; Steinbach, K.; Gorontzy, T.; Kahl, M.; Blotevogel, K.H.; and Gemsa, D. (1996) Microbial Transformation of 2,4,6-Trinitrotoluene in Aerobic Soil Columns. *Appl. Environ. Microbiol.,* **62,** 2651.

Buchter, B.; Hinz, C.; Gfeller, M.; and Fluhler, H. (1996) Cadmium Transport in an Unsaturated Stony Subsoil Monolith. *Soil Sci. Soc. Am. J.,* **60,** 716.

Bui, E.N.; Smettem, K.R.J.; Moran, C.J.; and Williams, J. (1996) Use of Soil Survey Information to Assess Regional Salinization Risk Using Geographical Information Systems. *J. Environ. Qual.,* **25,** 433.

Bulcher, T.J.; Hayes, R.F.; and Couturier, R.J. (1996) Drinking Water Pretreatment Facilities and Aquifer Restoration Project. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 125.

Bumb, A.C.; Jones, G.N.; and Warner, R.D. (1996) Screening and Comparison of Remedial Alternatives for the South Field and Flyash Piles at the Fernald Site. *Proc. 10th Natl. Outdoor Action Conf.,* Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 99.

Burgos, W.D.; Novak, J.T.; and Berry, D.F. (1996) Reversible Sorption and Irreversible Binding of Naphthalene and Alpha-Naphthol to Soil: Elucidation of Processes. *Environ. Sci. Technol.,* **30,** 1205.

Burkart, M.R., and Feher, J. (1996) Regional Estimation of Ground Water Vulnerability to Nonpoint Sources of Agricultural Chemicals. *Water Sci. Technol.* (G.B.), **33,** 241.

Burken, J.G., and Schnoor, J.L. (1996a) Phytoremediation: Plant Uptake of Atrazine and Role of Root Exudates. *J. Environ. Eng.* **122,** 958.

Burken, J.G., and Schnoor, J.L. (1996b) Atrazine Phytoremediation and Metabolism by Poplar Trees. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 151.

Burris, D.R.; Delcomyn, C.A.; Smith, M.H.; and Roberts, A.L. (1996a) Reductive Dechlorination of Tetrachloroethylene and Trichloroethylene Catalyzed by Vitamin B-12 in Homogeneous and Heterogeneous Systems. *Environ. Sci. Technol.,* **30,** 3047.

Burris, D.R.; Hatfield, K.; and Wolfe, N.L. (1996b) Laboratory Experiments with Heterogeneous Reactions in Mixed Porous Media. *J. Environ. Eng.,* **122,** 685.

Buscheck, T.E.; Wickland, D.C.; and Kuehne, D.L. (1996) Multiple Lines of Evidence to Demonstrate Natural Attenuation of Petroleum Hydrocarbons. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 445.

Butts, M.B., and Jensen, K.H. (1996) Effective Parameters for Multiphase Flow in Layered Soils. *J. Hydrol.* (Neth.), **183,** 101.

Byrnes, J.P.; Briglia, J.E.; and Bealer, L.J. (1996) Evaluation of Well Purging in Ground-Water Sampling for BTEX and MTBE. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 221.

Cabbar, H.C., and McCoy, B.J. (1996) Nonconvective Movement of VOCs in Moist Soil. *Environ. Prog.,* **15,** 159.

Cabirol, N.; Perrier, J.; Jacob, F.; Fouillet, B.; and Chambon, P. (1996) Role of Methanogenic and Sulfate-Reducing Bacteria in the Reductive Dechlorination of Tetrachloroethylene in Mixed Culture. *Bull. Environ. Contam. Toxicol.,* **56,** 817.

Cain, R.B., and Mitchell, J.A. (1996) Enhanced Degradation of the

Fungicide Vinclozolin: Isolation and Characterisation of a Responsible Organism. *Pestic. Sci.*, **48,** 13.

Camobreco, V.J.; Richards, B.K.; Steenhuis, T.S.; Peverly, J.H.; and Mcbride, M.B. (1996) Movement of Heavy Metals Through Undisturbed and Homogenized Soil Columns. *Soil Sci.*, **161,** 74.

Campbell, A.M. (1996) The Relationship Between Monitoring Well and Aquifer Solute Concentrations (Discussion). *Ground Water,* **34,** 386.

Campbell, L.S., and Davies, B.E. (1995) Soil Sorption of Caesium Modelled by the Langmuir and Freundlich Isotherm Equations. *Appl. Geochem.*, **10,** 715.

Carey, G.R.; Mateyk, M.G.; Turchan, G.T.; McBean, E.A.; Rovers, F.A.; and Murphy, J.R. (1996) Application of an Innovative Visualization Method for Demonstrating Intrinsic Remediation at a Landfill Superfund Site. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 693.

Carrano, C.S., and Yeh, G. (1995) A Fourier Analysis and Dynamic Optimization of the Petrov-Galerkin Finite Element Method. *Int. J. Numerical Methods Eng.*, **38,** 4123.

Caruana, A., and Dawe, R.A. (1996) Flow Behaviour in the Presence of Wettability Heterogeneities. *Transp. Porous Media,* **25,** 217.

Castro, C.E.; Oshea, S.K.; Wang, W.; and Bartnicki, E.W. (1996) Biodehalogenation: Oxidative and Hydrolytic Pathways in the Transformations of Acetonitrile, Chloroacetonitrile, Chloroacetic Acid, and Chloroacetamide by Methylosinus Trichosporium OB-3b. *Environ. Sci. Technol.*, **30,** 1180.

Cates, D.A.; Knox, R.C.; and Sabatini, D.A. (1996) The Impact of Ion Exchange Processes on Subsurface Brine Transport as Observed on Piper Diagrams. *Ground Water,* **34,** 532.

Celi, L.; Negre, M.; and Gennari, M. (1996) Adsorption of the Herbicide Acifluorfen on Soil Humic Acids. *J. Agric. Food Chem.*, **44,** 3388.

Cenedese, A., and Viotti, P. (1996) Lagrangian Analysis of Nonreactive Pollutant Dispersion in Porous Media by Means of the Particle Image Velocimetry Technique. *Water Resour. Res.*, **32,** 2329.

Chandra, S.D.; Ward, C.H.; and Hughes, J.B. (1996) Biodegradation of Sorbed Fluorene in Sediment Slurries. *Haz. Waste Haz. Mater.*, **13,** 375.

Chang, C.M.; Kemblowski, M.W.; Kaluarachchi, J.; and Abdin, A. (1995) Stochastic Analysis of Multiphase Flow in Porous Media. I. Spectral Perturbation Approach. *Stoch. Hydrol. Hydraul.*, **9,** 239.

Chang, H.L., and Alvarez-Cohen, L. (1996) Biodegradation of Individual and Multiple Chlorinated Aliphatic Hydrocarbons by Methane-Oxidizing Cultures. *Appl. Environ. Microbiol.*, **62,** 3371.

Chang, Z.Z.; Weaver, R.W.; and Rhykerd, R.L. (1996) Oil Bioremediation in a High and a Low Phosphorus Soil. *J. Soil Contam.*, **5,** 215.

Chapelle, F.H.; Bradley, P.M.; Lovley, D.R.; and Vroblesky, D.A. (1996a) Measuring Rates of Biodegradation in a Contaminated Aquifer Using Field and Laboratory Methods. *Ground Water,* **34,** 691.

Chapelle, F.H.; Haack, S.K.; Adriaens, P.; Henry, M.A.; and Bradley, P.M. (1996b) Comparison of E(h) and H-2 Measurements for Delineating Redox Processes in a Contaminated Aquifer. *Environ. Sci. Technol.*, **30,** 3565.

Chapman, S.W.; Byerley, B.T.; and Smyth, D.J. (1996) A Detailed Pilot Test of Passive Oxygen Release for Enhancement of In-Situ Bioremediation of BTEX Contaminated Groundwater. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 575.

Chauret, C.; Inniss, W.E.; and Mayfield, C.I. (1996) Biotransformation at 10 Degrees C of Di-n-Butyl Phthalate in Subsurface Microcosms. *Ground Water,* **34,** 791.

Chee-Sanford, J.C.; Frost, J.W.; Fries, M.R.; Zhou, J.Z.; and Tiedje, J.M. (1996) Evidence for Acetyl Coenzyme A and Cinnamoyl Coenzyme A in the Anaerobic Toluene Mineralization Pathway in Azoarcus Tolulyticus Tol-4. *Appl. Environ. Microbiol.*, **62,** 964.

Chen, C.; Puhakka, J.A.; and Ferguson, J.F. (1996) Transformations of 1,1,2,2-Tetrachloroethane Under Methanogenic Conditions. *Environ. Sci. Technol.*, **30,** 542.

Chen, C.S.; Rao, P.S.C.; and Lee, L.S. (1996) Evaluation of Extraction and Detection Method for Determining Polynuclear Aromatic Hydrocarbons from Coal Tar Contaminated Soils. *Chemosphere* (G.B.), **32,** 1123.

Chen, C.Y., and Meiburg, E. (1996) Miscible Displacements in Capillary Tubes II. Numerical Simulations. *J. Fluid Mech.*, **326,** 57.

Chen, D.; Winkie, J.; Carsel, R.; Moeti, L.; and Vona, B. (1996) Enhancing Groundwater Flow and Solute Transport Analyses Using GIS at a Florida Superfund Site. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 701.

Chen, J.S.; Liu, C.W.; Chen, C.S.; and Yeh, H.D. (1996a) A Laplace Transform Solution for Tracer Tests in a Radially Convergent Flow Field with Upstream Dispersion. *J. Hydrol.* (Neth.), **183,** 263.

Chen, J.S.; Mansell, R.S.; Nkedikizza, P.; and Burgoa, B.A. (1996b) Phosphorus Transport During Transient, Unsaturated Water Flow in an Acid Sandy Soil. *Soil Sci. Soc. Am. J.*, **60,** 42.

Chen, M.R.; Hinkley, R.E.; and Killough, J.E. (1996) Computed Tomography Imaging of Air Sparging in Porous Media. *Water Resour. Res.*, **32,** 3013.

Chen, Z. (1996) Formulation of Three-Phase Flow in Porous Media. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 433.

Cheng, H.P.; Cheng, J.R.; and Yeh, G.T. (1996) A Particle Tracking Technique for the Lagrangian-Eulerian Finite Element Method in Multi-Dimensions. *Int. J. Numerical Methods Eng.*, **39,** 1115.

Cheng, J.R.; Cheng, H.P.; and Yeh, G.T. (1996) A Lagrangian Eulerian Method with Adaptively Local Zooming and Peak Valley Capturing Approach to Solve Two-Dimensional Advection Diffusion Transport Equations. *Int. J. Numerical Methods Eng.*, **39,** 987.

Cheng, P., and Wang, C.Y. (1996) A Multiphase Mixture Model for Multiphase, Multicomponent Transport in Capillary Porous Media. II. Numerical Simulation of the Transport of Organic Compounds in the Subsurface. *Int. J. Heat Mass Transfer,* **39,** 3619.

Chin, Y.P.; Kimble, K.D.; and Swank, C.R. (1996) The Sorption of 2-Methylnaphthalene by Rossburg Soil in the Absence and Presence of a Nonionic Surfactant. *J. Contam. Hydrol.*, **22,** 83.

Chlopecka, A., and Adriano, D.C. (1996) Mimicked In-Situ Stabilization of Metals in a Cropped Soil: Bioavailability and Chemical Form of Zinc. *Environ. Sci. Technol.*, **30,** 3294.

Chlopecka, A.; Bacon, J.R.; Wilson, M.J.; and Kay, J. (1996) Forms of Cadmium, Lead, and Zinc in Contaminated Soils from Southwest Poland. *J. Environ. Qual.*, **25,** 69.

Choi, J.W., and Oscarson, D.W. (1996) Diffusive Transport Through Compacted Na- and Ca-Bentonite. *J. Contam. Hydrol.*, **22,** 189.

Christakos, G., and Hristopulos, D.T. (1996) Stochastic Indicators for Waste Site Characterization. *Water Resour. Res.*, **32,** 2563.

Christensen, T.H.; Lehmann, N.; Jackson, T.; and Holm, P.E. (1996) Cadmium and Nickel Distribution Coefficients for Sandy Aquifer Materials. *J. Contam. Hydrol.*, **24,** 75.

Christodoulatos, C., and Mohiuddin, M. (1996) Generalized Models for Prediction of Pentachlorophenol Adsorption by Natural Soils. *Water Environ. Res.*, **68,** 370.

Christodoulatos, C.; Korfiatis, G.P.; Pal, N.; and Koutsospyros, A. (1996) In Situ Groundwater Treatment in a Trench Bio-Sparge System. *Haz. Waste Haz. Mater.*, **13,** 223.

Christy, T.M. (1996) A Driveable Permeable Membrane Sensor for the Detection of Volatile Compounds in Soil. *Proc. 10th Natl. Outdoor Action. Conf.*, Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 169.

Chu, K.H., and Alvarez-Cohen, L. (1996) Trichloroethylene Degradation by Methane-Oxidizing Cultures Grown with Various Nitrogen Sources. *Water Environ. Res.*, **68,** 76.

Cifuentes, F.R.; Lindemann, W.C.; and Barton, L.L. (1996) Chromium Sorption and Reduction in Soil with Implications to Bioremediation. *Soil Sci.*, **161,** 233.

Clark, D.K.; Hineline, T.L.; Vogan, J.; and O'Hannesin, S. (1996) In-Situ Treatment of a TCE Plume Using a Funnel and Gate System: A Case Study. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 165.

Clawges, R.M., and Vowinkel, E.F. (1996) Variables Indicating Nitrate Contamination in Bedrock Aquifers, Newark Basin, New Jersey. *Water Resour. Bull.* (Urb.), **32,** 1055.

Clay, D.E.; Clay, S.A.; Moorman, T.B.; Brixdavis, K.; Scholes, K.A.; and Bender, A.R. (1996) Temporal Variability of Organic C and Nitrate in a Shallow Aquifer. *Water Res.* (G.B.), **30,** 559.

Clement, T.P.; Hooker, B.S.; and Skeen, R.S. (1996) Macroscopic Models for Predicting Changes in Saturated Porous Media Properties Caused by Microbial Growth. *Ground Water,* **34,** 934.

Clothier, B.E.; Magesan, G.N.; Heng, L.; and Vogeler, I. (1996) In Situ Measurement of the Solute Adsorption Isotherm Using a Disc Permeameter. *Water Resour. Res.,* **32,** 771.

Cole, J.D.; Woods, S.L.; and Bricker, T.R. (1996) Pentachlorophenol Reductive Dechlorination in an Interceptor Trench: Temperature Effects. *Ground Water,* **34,** 784.

Comini, G.; Manzan, M.; and Nonino, C. (1995) Analysis of Finite Element Schemes for Convection-Type Problems. *Int. J. Numerical Methods Fluids,* **20,** 443.

Comis, D. (1996) Green Remediation: Using Plants to Clean the Soil. *J. Soil Water Conserv.,* **51,** 184.

Conant, B.H.; Gillham, R.W.; and Mendoza, C.A. (1996) Vapor Transport of Trichloroethylene in the Unsaturated Zone: Field and Numerical Modeling Investigations. *Water Resour. Res.,* **32,** 9.

Conn, J.S.; Koskinen, W.C.; Werdin, N.R.; and Graham, J.S. (1996) Persistence of Metribuzin and Metabolites in Two Subarctic Soils. *J. Environ. Qual.,* **25,** 1048.

Connell, T.L., and Dreiss, S.J. (1995) Chemical Evolution of Shallow Groundwater Along the Northeast Shore of Mono Lake, California. *Water Resour. Res.,* **31,** 3171.

Connor, J.A.; Newell, C.J.; and Malander, M.W. (1996) Parameter Estimation Guidelines for Risk-Based Corrective Action (RBCA) Modeling. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 79.

Cook, P.G.; Solomon, D.K.; Sanford, W.E.; Busenberg, E.; Plummer, L.N.; and Poreda, R.J. (1996) Inferring Shallow Groundwater Flow in Saprolite and Fractured Rock Using Environmental Tracers. *Water Resour. Res.,* **32,** 1501.

Corapcioglu, M.Y.; Tuncay, K.; and Ceylan, B.K. (1996) Oil Mound Spreading and Migration with Ambient Groundwater Flow in Coarse Porous Media. *Water Resour. Res.,* **32,** 1299.

Corley, T.L.; Farrell, J.; Hong, B.; and Conklin, M.H. (1996) VOC Accumulation and Pore Filling in Unsaturated Porous Media. *Environ. Sci. Technol.,* **30,** 2884.

Cornett, R.J.; Cramer, J.; Andrews, H.R.; Chant, L.A.; Davies, W.; Greiner, B.F.; Imahori, Y.; Koslowsky, V.; Mckay, J.; Milton, G.M.; and Milton, J.C.D. (1996) In Situ Production of Cl-36 in Uranium Ore: A Hydrogeological Assessment Tool. *Water Resour. Res.,* **32,** 1511.

Corseuil, H.X.; Aires, J.R.; and Alvarez, P.J.J. (1996) Implications of the Presence of Ethanol on Intrinsic Bioremediation of BTX Plumes in Brazil. *Haz. Waste Haz. Mater.,* **13,** 213.

Corwin, D.L., and Wagenet, R.J. (1996) Applications of GIS to the Modeling of Nonpoint Source Pollutants in the Vadose Zone: A Conference Overview. *J. Environ. Qual.,* **25,** 403.

Cotter-Howells, J. (1996) Lead Phosphate Formation in Soils. *Environ. Pollut.* (G.B.), **93,** 9.

Couture, F.; Jomaa, W.; and Puiggali, J.R. (1996) Relative Permeability Relations: A Key Factor for a Drying Model. *Transp. Porous Media,* **23,** 303.

Cox, C.D.; Shoesmith, M.A.; and Ghosh, M.M. (1996) Electrokinetic Remediation of Mercury-Contaminated Soils Using Iodine/Iodide Lixiviant. *Environ. Sci. Technol.,* **30,** 1933.

Cox, L.; Hermosin, M.C.; and Cornejo, J. (1996a) Sorption of metamitron on Soils with Low Organic Matter Content. *Chemosphere,* **32,** 1391.

Cox, L.; Walker, A.; and Welch, S.J. (1996b) Evidence for the Accelerated Degradation of Isoproturon in Soils. *Pestic. Sci.,* **48,** 253.

Criss, R.E., and Davisson, M.L. (1996) Isotopic Imaging of Surface Water/Ground Water Interactions, Sacramento Valley, California. *J. Hydrol.* (Neth.), **178,** 205.

Cullen, P.G.; Carmel, C.P.; and Coffman, J. (1996) In-Situ Bioremediation Using Direct Current to Emplace Nutrients and Microorganisms in Tight Soils. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 587.

Curtin, C. (1996) Site Characterization of a Large Industrial Faculty Under RCRA Corrective Action. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 427.

Cvetkovic, V.; Cheng, H.; and Wen, X.H. (1996) Analysis of Nonlinear Effects on Tracer Migration in Heterogeneous Aquifers Using Lagrangian Travel Time Statistics. *Water Resour. Res.,* **32,** 1671.

Dagan, G.; Bellin, A.; and Rubin, Y. (1996a) Lagrangian Analysis of Transport in Heterogeneous Formations Under Transient Flow Conditions. *Water Resour. Res.,* **32,** 891.

Dagan, G.; Butera, I.; and Grella, E. (1996b) Impact of Concentration Measurement Upon Estimation of Flow and Transport Parameters: The Lagrangian Approach. *Water Resour. Res.,* **32,** 297.

Dakins, M.E.; Porter, P.S.; West, M.; and Rao, S.T. (1996) Using Uncensored Trace-Level Measurements to Detect Trends in Ground Water Contamination. *Water Resour. Bull.,* **32,** 799.

Datskou, I., and North, K. (1996) Risks Due to Groundwater Contamination at a Plutonium Processing Facility. *Water, Air, Soil Pollut.* (Neth.), **90,** 133.

Datta, B., and Dhiman, S.D. (1996) Chance-Constrained Optimal Monitoring Network Design for Pollutants in Ground Water. *J. Water Resour. Plann. Div., Proc. Am. Soc. Civ. Eng., Manage.,* **122,** 180.

Datta, P.S.; Bhattacharya, S.K.; and Tyagi, S.K. (1996a) O-18 Studies on Recharge of Phreatic Aquifers and Groundwater Flow-Paths of Mixing in the Delhi Area. *J. Hydrol.* (Neth.), **176,** 25.

Datta, P.S.; Deb, D.L.; and Tyagi, S.K. (1996b) Stable Isotope (O-18) Investigations on the Processes Controlling Fluoride Contamination of Groundwater. *J. Contam. Hydrol.,* **24,** 85.

Davidson, J.M., and Parsons, R. (1996) Remediating MTBE with Current and Emerging Technologies. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 15.

Davis, A.P. (1996) Washing of Zinc(II) from Contaminated Soil Column (Closure). *J. Environ. Eng.,* **122,** 883.

Davis, J.W., and Madsen, S. (1996) Factors Affecting the Biodegradation of Toluene in Soil. *Chemosphere* (G.B.), **33,** 107.

Dawson, C.N.; Vanduijn, C.J.; and Grundy, R.E. (1996) Large Time Asymptotics in Contaminant Transport in Porous Media. *SIAM J. Appl. Math.,* **56,** 965.

de Blanc, P.C.; Sepehnoori, K.; Speitel, G.E.; and McKinney, D.C. (1996) Investigation of Numerical Solution Techniques for Biodegradation Equations in a Groundwater Flow Model. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., 1, 161.

de Cecaritat, P., and Aamlid, D. (1995) Groundwater Acidification at Birkenes, Southern Norway: Comparing Trends of Chemical Composition of Precipitation, Throughfall, Soilwater and Groundwater. *Water, Air, Soil Pollut.* (Neth.), **85,** 1861.

de Jonge, H., and Mittelmeijer-Hazeleger, M.C. (1996) Adsorption of CO2 and n(2) on Soil Organic Matter: Nature of Porosity, Surface Area, and Diffusion Mechanisms. *Environ. Sci. Technol.,* **30,** 408.

Delin, G.N., and Landon, M.K. (1996) Multiport Well Design for Sampling of Ground Water at Closely Spaced Vertical Intervals. *Ground Water,* **34,** 1098.

de Llano, A.Y.; Bidoglio, G.; Avogadro, A.; Gibson, P.N.; and Romero, P.R. (1996) Redox Reactions and Transport of Selenium Through Fractured Granite. *J. Contam. Hydrol.,* **21,** 129.

Delshad, M.; Pope, G.A.; and Sepehrnoori, K. (1996) A Compositional Simulator for Modeling Surfactant Enhanced Aquifer Remediation. I. Formulation. *J. Contam. Hydrol.,* **23,** 303.

Demond, A.H.; Rathfelder, K.; and Abriola, L.M. (1996) Simulation of Organic Liquid Flow in Porous Media Using Estimated and Measured Transport Properties. *J. Contam. Hydrol.,* **22,** 223.

Deng, Y.W.; Stjernstrom, M.; and Banwart, S. (1996) Accumulation and Remobilization of Aqueous Chromium(VI) at Iron Oxide Surfaces: Application of a Thin-Film Continuous Flow-Through Reactor. *J. Contam. Hydrol.,* **21,** 141.

DePaoli, D.W.; Wilson, J.H.; and Thomas, C.O. (1996) Conceptual Design of Soil Venting Systems. *J. Environ. Eng.,* **122,** 399.

de Rosa, E.; Rubel, D.; Tudino, M.; Viale, A.; and Lombardo, R.J. (1996) The Leachate Composition of an Old Waste Dump Connected to Groundwater: Influence of the Reclamation Works. *Environ. Monit. Assessment,* **40,** 239.

Desimone, L.A., and Howes, B.L. (1996) Denitrification and Nitrogen Transport in a Coastal Aquifer Receiving Wastewater Discharge. *Environ. Sci. Technol.,* **30,** 1152.

Devlin, J.F. (1996) A Method to Assess Analytical Uncertainties Over Large Concentration Ranges with Reference to Volatile Organics in Water. *Ground Water Monit. Remed.,* **16,** 179.

Devlin, J.F., and Barker, J.F. (1996) Field Investigation of Nutrient Pulse Mixing in an In Situ Biostimulation Experiment. *Water Resour. Res.,* **32,** 2869.

Devlin, J.F., and Parker, B.L., (1996) Optimum Hydraulic Conductivity to Limit Contaminant Flux Through Cutoff Walls. *Ground Water,* **34,** 719.

Deziél, E.; Paquette, G.; Villemur, R.; Lepine, F.; and Bisaillon, J.G. (1996) Biosurfactant Production by a Soil Pseudomonas Strain Growing on Polycyclic Aromatic Hydrocarbons. *Appl. Environ. Microbiol.,* **62,** 1908.

Dodds, W.K.; Randel, C.A.; and Edler, C.C. (1996) Microcosms for Aquifer Research: Application to Colonization of Various Sized Particles by Ground-Water Microorganisms. *Ground Water,* **34,** 756.

Dolfing, J. (1996) Degradation of Monochlorinated and Nonchlorinated Aromatic Compounds Under Iron-Reducing Conditions. *Appl. Environ. Microbiol.,* **62,** 3554.

Donaldson, S.G., and Miller, G.C. (1996) Coupled Transport and Photodegradation of Napropamide in Soils Undergoing Evaporation from a Shallow Water Table. *Environ. Sci. Technol.,* **30,** 924.

Doong, R.A., and Chen, T.F. (1996) Anaerobic Degradation of 1,1,1-Trichloroethane with the Amendment of Different Substrate and Microbial Concentrations. *Chemosphere* (G.B.), **32,** 2003.

Doong, R.A., and Wu, S.C. (1996) Effect of Substrate Concentration on the Biotransformation of Carbon Tetrachloride and 1,1,1-Trichloroethane Under Anaerobic Condition. *Water Res.* (G.B.), **30,** 577.

Doong, R.A.; Wu, S.C.; and Chen, T.F. (1996) Anaerobic Biotransformation of Polychlorinated Methane and Ethene Under Various Redox Conditions. *Chemosphere* (G.B.), **32,** 377.

Douglas, G.S.; Bence, A.E.; Prince, R.C.; Mcmillen, S.J.; and Butler, E.L. (1996) Environmental Stability of Selected Petroleum Hydrocarbon Source and Weathering Ratios. *Environ. Sci. Technol.,* **30,** 2332.

Douthit, T.L.; Novick, N.J.; Payne, R.E.; Malander, M.W.; and Taylor, M.B. (1996) Evaluation of Intrinsic Bioremediation in Support of Risk-Based Corrective Action: Data From a New York Remediation by Natural Attenuation Demonstration Site. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 461.

Downey, D.C.; Benson, L.A.; and Frishmuth, R.A. (1996) Trends in Regulatory Acceptance of Risk-Based Cleanup Goals and Natural Attenuation for Site Closure. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 47.

Downey, D.C.; Guest, P.R.; and Ratz, J.W. (1995) Results of a Two-Year In Situ Bioventing Demonstration. *Environ. Progr.,* **14,** 121.

Downs, C.E. (1996) Multimedia Remediation Applications of Horizontal Wells. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 237.

Drucker, A.S., and Dijulio, S.S. (1996) Groundwater Cleanup by In Situ Air Sparging: Development of a Model and Application to Saturated Soil Column Experiments. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 55.

Duba, A.G.; Jackson, K.J.; Jovanovich, M.C.; Knapp, R.B.; and Taylor, R.T. (1996) TCE Remediation Using In Situ, Resting-State Bioaugmentation. *Environ. Sci. Technol.,* **30,** 1982.

Duetz, W.A.; Marques, S.; Wind, B.; Ramos, J.L.; and Vanandel, J.G. (1996) Catabolite Repression of the Toluene Degradation Pathway in Pseudomonas putida Harboring pWWO Under Various Conditions of Nutrient Limitation in Chemostat Culture. *Appl. Environ. Microbiol.,* **62,** 601.

Dullien, F.A.L., and Dong, M. (1996) Experimental Determination of the Flow Transport Coefficients in the Coupled Equations of Two-Phase Flow in Porous Media. *Transp. Porous Media,* **25,** 97.

Dykaar, B.B., and Kitanidis, P.K. (1996) Macrotransport of a Biologically Reacting Solute Through Porous Media. *Water Resour. Res.,* **32,** 307.

Edmondson, R.D.; Fontana, J.V.; and Jackson, G.L. (1996) Synchronous Scanning Ultraviolet Fluorescence as a Screening Method for Petroleum Based Hydrocarbon Products in Ground Water and Soils. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 709.

Eganhouse, R.P.; Dorsey, T.F.; Phinney, C.S.; and Westcott, A.M. (1996) Processes Affecting the Fate of Monoaromatic Hydrocarbons in an Aquifer Contaminated by Crude Oil. *Environ. Sci. Technol.,* **30,** 3304.

Ehret, J.F.; Allen, B.; and Maher, K.P. (1996) Installing Recovery Wells in a Low Yield Aquifer. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., 499.

Elberling, B. (1996) Gas Phase Diffusion Coefficient in Cemented Porous Media. *J. Hydrol.* (Neth.), **178,** 93.

Elejalde, C.; Herranz, M.; Romero, F.; and Legarda, F. (1996) Correlations Between Soil Parameters and Radionuclide Contents in Samples from Biscay (Spain). *Water, Air, Soil Pollut.* (Neth.), **89,** 23.

El-Fadel, M.; Findikakis, A.N.; and Leckie, J.O. (1995) Migration and Atmospheric Emission of Landfill Gas. *Haz. Waste Haz. Mater.,* **12,** 309.

Ellsworth, T.R.; Shouse, P.J.; Skaggs, T.H.; Jobes, J.A.; and Fargerlund, J. (1996) Solute Transport in Unsaturated Soil: Experimental Design, Parameter Estimation, and Model Discrimination. *Soil Sci. Soc. Am. J.,* **60,** 397.

Emekli, N.; Karahanoglu, N.; Yazicigil, H.; and Doyuran, V. (1996) Numerical Simulation of Saltwater Intrusion in a Groundwater Basin. *Water Environ. Res.,* **68,** 855.

Endres, A.L., and Greenhouse, J.P. (1996) Detection and Monitoring of Chlorinated Solvent Contamination by Thermal Neutron Logging. *Ground Water,* **34,** 283.

Engesgaard, P., and Traberg, R. (1996) Contaminant Transport at a Waste Residue Deposit. II. Geochemical Transport Modeling. *Water Resour. Res.,* **32,** 939.

Engesgaard, P.; Jensen, K.H.; Molson, J.; Frind, E.O.; and Olsen, H. (1996) Large-Scale Dispersion in a Sandy Aquifer: Simulation of Subsurface Transport of Environmental Tritium. *Water Resour. Res.,* **32,** 3253.

Entry, J.A.; Vance, N.C.; Hamilton, M.A.; Zabowski, D.; Watrud, L.S.; and Adriano, D.C. (1996) Phytoremediation of Soil Contaminated with Low Concentrations of Radionuclides. *Water, Air, Soil Pollut.* (Neth.), **88,** 167.

Eriksson, E., and Karltun, E. (1995) Modelling the Transport of Acidity in Soil Profiles with FRONT—A Dynamic Transport Model. *Water, Air, Soil Pollut.* (Neth.), **85,** 1789.

Errett, D.H.; Chin, Y.P.; Xu, Y.P.; and Yan, Y.J. (1996) The Sorption and Desorption Kinetics of Polycyclic Aromatic Hydrocarbons in Methanol/Water Mixtures. *Haz. Waste Haz. Mater.,* **13,** 177.

Essa, M.H.; Farooq, S.; and Nakhla, G.F. (1996) Simulation of In-Situ Bioremediation of Phenol Contaminated Sandy Aquifers. I. Effect of Sand Sizes. *Water, Air, Soil Pollut.* (Neth.), **87,** 267.

Essaid, H.I.; Bekins, B.A.; Godsy, E.M.; Warren, E.; Baedecker, M.J.; and Cozzarelli, I.M. (1995) Simulation of Aerobic and Anaerobic Biodegradation Processes at a Crude Oil Spill Site. *Water Resour. Res.,* **31,** 3309.

Ewen, J. (1996a) 'SAMP' Model for Water and Solute Movement in Unsaturated Porous Media Involving Thermodynamic Subsystems and Moving Packets. I. Theory. *J. Hydrol.* (Neth.), **182,** 175.

Ewen, J. (1996b) 'SAMP' Model for Water and Solute Movement in Unsaturated Porous Media Involving Thermodynamic Subsystems and Moving Packets. II. Design and Application. *J. Hydrol.* (Neth.), **182,** 195.

Ewing, R.E. (1996) Three-Phase Flow Formulations. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 411.

Ewing, R.E., and Wang, H. (1996) An Optimal-Order Estimate for Eulerian-Lagrangian Localized Adjoint Methods for Variable-Coefficient Advection-Reaction Problems. *SIAM J. Numer. Anal.,* **33,** 318.

Ezzedine, S., and Rubin, Y. (1996) A Geostatistical Approach to the Conditional Estimation of Spatially Distributed Solute Concentration and Notes on the Use of Tracer Data in the Inverse Problem. *Water Resour. Res.,* **32,** 853.

Falta, R.W. (1996) A Program for Analyzing Transient and Steady-State Soil Gas Pump Tests. *Ground Water,* **34,** 750.

Farooq, S.; Nakhla, G.F.; and Essa, M.H. (1996) Simulation of In-Situ Bioremediation of Phenol Contaminated Sandy Aquifers. II. Effect of Phenol Concentration. *Water, Air, Soil Pollut.* (Neth.), **87,** 283.

Fauré, M.H.; Sardin, M.; and Vitorge, P. (1996) Transport of Clay Particles and Radioelements in a Salinity Gradient: Experiments and Simulations. *J. Contam. Hydrol.,* **21,** 255.

Fedorak, P.M., and Coy, D.L. (1996) Biodegradation of Sulfolane in Soil and Groundwater Samples from a Sour Gas Plant Site. *Environ. Technol.,* **17,** 1093.

Feng, L.; Han, S.K.; and Wang, L.S. (1996a) Sorption of Phenylthioacetates on Natural Soil: Application of Partition-Adsorption Mechanism and Model. *Chemosphere* (G.B.), **33,** 2113.

Feng, L.; Han, S.K.; Wang, L.S.; Wang, Z.T.; and Zhang, Z. (1996b) Determination and Estimation of Partitioning Properties for Phenylthio-Carboxylates. *Chemosphere* (G.B.), **32,** 353.

Ferraresi, M., and Marinelli, A. (1996) An Extended Formulation of the Integrated Finite Difference Method for Groundwater Flow and Transport. *J. Hydrol.* (Neth.), **175,** 453.

Fiedler, H.; Lau, C.; Kjeller, L.O.; and Rappe, C. (1996) Patterns and Sources of Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans Found in Soil and Sediment Samples in Southern Mississippi. *Chemosphere* (G.B.), **32,** 421.

Field, M.S.; Wilhelm, R.G.; Quinlan, J.F.; and Aley, T.J. (1995) An Assessment of the Potential Adverse Properties of Fluorescent Tracer Dyes Used for Groundwater Tracing. *Environ. Monit. Assess.,* **38,** 75.

Fingerling, G.; Hertkorn, N.; and Parlar, H. (1996) Formation and Spectroscopic Investigation of Two Hexachlorobornanes from Six Environmentally Relevant Toxaphene Components by Reductive Dechlorination in Soil Under Anaerobic Conditions. *Environ. Sci. Technol.,* **30,** 2984.

Finke, P.A.; Wosten, J.H.M.; and Kroes, J.G. (1996) Comparing Two Approaches of Characterizing Soil Map Unit Behavior in Solute Transport. *Soil Sci. Soc. Am. J.,* **60,** 200.

Fiori, A. (1996) Finite Peclet Extensions of Dagan's Solutions to Transport in Anisotropic Heterogeneous Formations. *Water Resour. Res.,* **32,** 193.

Fitch, M.W.; Speitel, G.E.; and Georgiou, G. (1996) Degradation of Trichloroethylene by Methanol-Grown Cultures of Methylosinus Trichosporium OB3b PP358. *Appl. Environ. Microbiol.,* **62,** 1124.

Fitts, C.R. (1996) Uncertainty in Deterministic Groundwater Transport Models Due to the Assumption of Macrodispersive Mixing: Evidence from the Cape Cod (Massachusetts, USA) and Borden (Ontario, Canada) Tracer Tests. *J. Contam. Hydrol.,* **23,** 69.

Flury, M. (1996) Experimental Evidence of Transport of Pesticides Through Field Soils—A Review. *J. Environ. Qual.,* **25,** 25.

Folger, P.F.; Poeter, E.; Wanty, R.B.; Frishman, D.; and Day, W. (1996) Controls on Rn-222 Variations in a Fractured Crystalline Rock Aquifer Evaluated Using Aquifer Tests and Geophysical Logging. *Ground Water,* **34,** 250.

Follett, R.F. (1995) NLEAP Model Simulation of Climate and Management Effects on N Leaching for Corn Grown on Sandy Soil. *J. Contam. Hydrol.,* **20,** 241.

Fountain, J.C.; Starr, R.C.; Middleton, T.; Beikirch, M.; Taylor, C.; and Hodge, D. (1996) A Controlled Field Test of Surfactant-Enhanced Aquifer Remediation. *Ground Water,* **34,** 910.

Francis, A.J.; Joshitope, G.A.; and Dodge, C.J. (1996) Biodegradation of Nickel-Citrate and Modulation of Nickel Toxicity by Iron. *Environ. Sci. Technol.,* **30,** 562.

Francis, G.S. (1995) Management Practices for Minimising Nitrate Leaching After Ploughing Temporary Leguminous Pastures in Canterbury, New Zealand. *J. Contam. Hydrol.,* **20,** 313.

Freedman, D.L., and Herz, S.D. (1996) Use of Ethylene and Ethane as Primary Substrates for Aerobic Cometabolism of Vinyl Chloride. *Water Environ. Res.,* **68,** 320.

Freedman, Y.E.; Ronen, D.; and Long, G.L. (1996) Determination of Cu and Cd Content of Groundwater Colloids by Solid Sampling Graphite Furnace Atomic Absorption Spectrometry. *Environ. Sci. Technol.,* **30,** 2270.

Freijer, J.I. (1996) Mineralization of Hydrocarbons in Soils Under Decreasing Oxygen Availability. *J. Environ. Qual.,* **25,** 296.

Friedman, S.P., and Seaton, N.A. (1996) On the Transport Properties of Anisotropic Networks of Capillaries. *Water Resour. Res.,* **32,** 339.

Frieseke, R.W., and Christensen, E.R. (1996) Ground-Water Remediation with Granular Collection System. *J. Environ. Eng.,* **122,** 546.

Fry, V.A.; Istok, J.D.; and Oreilly, K.T. (1996) Effect of Trapped Gas on Dissolved Oxygen Transport—Implications for In Situ Bioremediation. *Ground Water,* **34,** 200.

Fuller, C.C.; Davis, J.A.; Coston, J.A.; and Dixon, E. (1996) Characterization of Metal Adsorption Variability in a Sand and Gravel Aquifer, Cape Cod, Massachusetts, USA. *J. Contam. Hydrol.,* **22,** 165.

Fullerton, S.K.; Babcock, D.B.; Herz, S.; and Rossello, S.J. (1996) Use of Leachability and Modeling Tools as a Basis for Selecting a Metals Site Remedy. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 17.

Gallagher, M.N.; Payne, R.E.; and Nainan, M.M. (1996) Replacing a Pump and Treat System with a Biosparging Cut-Off Wall. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 123.

Gallaher, K., and Mueller, T.C. (1996) Effect of Crop Presence on Persistence of Atrazine, Metribuzin, and Clomazone in Surface Soil. *Weed Sci.,* **44,** 698.

Gallo, C., and Manzini, G. (1996) Modeling Transport and Biodegradation of Nitrates Using a Mixed Finite Elements-Finite Volumes Approach. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 169.

Gallo, C.; Paniconi, C.; and Gambolati, G. (1996) Comparison of Solution Approaches for the Two-Domain Model of Nonequilibrium Transport in Porous Media. *Adv. Water Resour.,* **19,** 241.

Gan, J.; Becker, L.; Koskinen, W.C.; and Buhler, D.D. (1996) Degradation of Atrazine in Two Soils as a Function of Concentration. *J. Environ. Qual.,* **25,** 1064.

Gan, J.Y.; Yates, S.R.; Wang, D.; and Spencer, W.F. (1996) Effect of Soil Factors on Methyl Bromide Volatilization After Soil Application. *Environ. Sci. Technol.*, **30**, 1629.

Ganesan, R., and Salamon, N.J. (1996) Solution of the One-Dimensional Convection-Diffusion Equation by a Multilevel Petrov-Galerkin Method. *Int. J. Numerical Methods Eng.*, **39**, 2095.

Gao, C.; Govind, R.; and Tabak, H.H. (1996) Predicting Soil Sorption Coefficients of Organic Chemicals Using a Neural Network Model. *Environ. Toxicol. Chem.*, **15**, 1089.

Garfiás, J.; Herrera, I.; Andre, C.; and Llanos, H. (1996) Generalized Eulerian-Lagrangian Method of Cells for Contaminant Migration and Comparison with Other Methods. *Computat. Methods Water Resour. XI*, Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1**, 489.

Gaston, L.A.; Locke, M.A.; Wagner, S.C.; Zablotowicz, R.M.; and Reddy, K.N. (1996a) Sorption of Bentazon and Degradation Products in Two Mississippi Soils. *Weed Sci.*, **44**, 678.

Gaston, L.A.; Locke, M.A.; and Zablotowicz, R.M. (1996b) Sorption and Degradation of Bentazon in Conventional- and No-Till Dundee Soil. *J. Environ. Qual.*, **25**, 120.

Ge, S.M., and Liao, M.R. (1996) An Analytical Evaluation for Airflow to Inlet Wells in Vapor Extraction Systems Under Leaky Conditions. *Water Resour. Res.*, **32**, 743.

Ge, S.M., and Lu, N. (1996) A Semianalytical Solution of One-Dimensional Advective-Dispersive Solute Transport Under an Arbitrary Concentration Boundary Condition. *Ground Water*, **34**, 501.

Gelinas, Y.; Randall, H.; Robidoux, L.; and Schmit, J.P. (1996) Well Water Survey in Two Districts of Conakry (Republic of Guinea), and Comparison with the Piped City Water. *Water Res.* (G.B.), **30**, 2017.

Geng, Q.Z.; Girard, G.; and Ledoux, E. (1996) Modeling of Nitrogen Cycle and Nitrate Transfer in Regional Hydrogeologic Systems. *Ground Water*, **34**, 293.

Gerke, H.H., and van Genuchten, M.T. (1996) Macroscopic Representation of Structural Geometry for Simulating Water and Solute Movement in Dual-Porosity Media. *Adv. Water Resour.*, **19**, 343.

Gerlach, C.L. (1996) New Instrument Brings PAH Analysis to the Field. *Environ. Sci. Technol.*, **30**, A252.

Gerritse, R.G. (1996) Column- and Catchment-Scale Transport of Cadmium: Effect of Dissolved Organic Matter. *J. Contam. Hydrol.*, **22**, 145.

Ghoshal, S., and Luthy, R.G. (1996) Bioavailability of Hydrophobic Organic Compounds from Nonaqueous-Phase Liquids: The Biodegradation of Naphthalene from Coal Tar. *Environ. Toxicol. Chem.*, **15**, 1894.

Ghoshal, S.; Ramaswami, A.; and Luthy, R.G. (1996) Biodegradation of Naphthalene from Coal Tar and Heptamethylnonane in Mixed Batch Systems. *Environ. Sci. Technol.*, **30**, 1282.

Giambelluca, T.W.; Loague, K.; Green, R.E.; and Nullet, M.A. (1996) Uncertainty in Recharge Estimation: Impact on Groundwater Vulnerability Assessments for the Pearl Harbor Basin, O'ahu, Hawai'i, USA. *J. Contam. Hydrol.*, **23**, 85.

Gibson, T.L.; Abdul, A.S.; and Chalmer, P.D. (1996) Enhancement of Intrinsic Bioremediation by Oxygen Injection Under Natural Gradient Conditions. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 645.

Gieg, L.M.; Otter, A.; and Fedorak, P.M. (1996) Carbazole Degradation by Pseudomonas sp LD2: Metabolic Characteristics and the Identification of Some Metabolites. *Environ. Sci. Technol.*, **30**, 575.

Gimmi, T., and Fluhler, H. (1996) Flux and Resident Injection in Gaseous Advection Experiments. *Water Resour. Res.*, **32**, 1.

Goldstein, S.J.; Slemmons, A.K.; and Canavan, H.E. (1996) Energy-Dispersive X-Ray Fluorescence Methods for Environmental Characterization of Soils. *Environ. Sci. Technol.*, **30**, 2318.

Gomez-Lahoz, C.; Delgado, R.G.; Maroto, J.M.R.; and Wilson, D.J. (1996) Cleanup of Fractured Rock Aquifers. II. Effects of Matrix Diffusion and Nonaqueous Phase Liquid. *Environ. Monit. Assess.*, **43**, 153.

Gomis, V.; Boluda, N.; and Ruiz, F. (1996) Application of a Model for Simulating Transport of Reactive Multispecies Components to the Study of the Hydrochemistry of Salt Water Intrusions. *J. Contam. Hydrol.*, **22**, 67.

Gong, Y.; McCarthy, F.H.; Lewis, T.G.; and Stamatis, D.J. (1996) Impact of Two-Phase Desorption Kinetics on Human Health Risk Assessment and Hazardous Waste Cleanup. *Proc. 1996 Pet. Hydrocarbon Organ. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 239.

Gonullu, M.T. (1996) Modelling Dissolution of an Organic Mixture in the Subsurface. *Water Res.* (G.B.), **30**, 649.

Gonzalez, L.A., and Ririe, G.T. (1996) Analysis of Approaches to Evaluate Risk Related to Determining Metal Clean Up Levels in Reserve Pits. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 851.

Goode, D.J. (1996) Direct Simulation of Groundwater Age. *Water Resour. Res.*, **32**, 289.

Gorres, J., and Gold, A.J. (1996) Incorporating Spatial Variability into GIS to Estimate Nitrate Leaching at the Aquifer Scale. *J. Environ. Qual.*, **25**, 491.

Goss, K.U., and Eisenreich, S.J. (1996) Adsorption of VOCs from the Gas Phase to Different Minerals and a Mineral Mixture. *Environ. Sci. Technol.*, **30**, 2135.

Govi, M.; Sarti, A.; Dimartino, E.; Ciavatta, C.; and Rossi, N. (1996) Sorption and Desorption of Herbicides by Soil Humic Acid Fractions. *Soil Sci.*, **161**, 265.

Govindaraju, R.S.; Kavvas, M.L.; Jones, S.E.; and Rolston, D.E. (1996) Use of Green-Ampt Model for Analyzing One-Dimensional Convective Transport in Unsaturated Soils. *J. Hydrol.* (Neth.), **178**, 337.

Gray, A.L.; Browne, T.E.; Kelly, S.; and Moore, B.J. (1996) Respiration Testing for Bioventing and Biosparging Remediation of Petroleum Contaminated Soil and Ground Water. *Proc. 10th Natl. Outdoor Action. Conf.*, Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 303.

Greacen, J.; Block, R.N.; and Silvia, K. (1996a) Pilot Testing Aboveground Vapor Collection for Air Sparging. *Proc. 10th Natl. Outdoor Action. Conf.*, Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 395.

Greacen, J.; Morgan, D.; and Tezak, J. (1996b) Refinging Cleanup Standards Using Site-Specific Partitioning Coefficients. *Proc. 10th Natl Outdoor Action Conf.*, Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 531.

Grey, T.L.; Wehtje, G.R.; Hajek, B.F.; and Walker, R.H. (1996) Sorption and Mobility of Bentazon in Coastal Plain Soils. *Weed Sci.*, **44**, 166.

Grifoll, J., and Cohen, Y. (1996) Contaminant Migration in the Unsaturated Soil Zone: The Effect of Rainfall and Evapotranspiration. *J. Contam. Hydrol.*, **23**, 185.

Grimberg, S.J. (1996) Dissolution and Biodegradation Kinetics of Phenanthrene in the Presence of Nonionic Surfactants. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3**,.

Grimberg, S.J.; Miller, C.T.; and Aitken, M.D. (1996a) Surfactant-Enhanced Dissolution of Phenanthrene into Water for Laminar Flow Conditions. *Environ. Sci. Technol.*, **30**, 2967.

Grimberg, S.J.; Stringfellow, W.T.; and Aitken, M.D. (1996b) Quantifying the Biodegradation of Phenanthrene by Pseudomonas stutzeri P16 in the Presence of a Nonionic Surfactant. *Appl. Environ. Microbiol.*, **62**, 2387.

Grindrod, P., and Takase, H. (1996) Reactive Chemical Transport Within Engineered Barriers. *J. Contam. Hydrol.*, **21**, 283.

Grindrod, P.; Edwards, M.S.; Higgo, J.J.W.; and Williams, G.M. (1996) Analysis of Colloid and Tracer Breakthrough Curves. *J. Contam. Hydrol.*, **21**, 243.

Grolimund, D.; Borkovec, M.; Barmettler, K.; and Sticher, H. (1996) Colloid-Facilitated Transport of Strongly Sorbing Contaminants in Natural Porous Media: A Laboratory Column Study. *Environ. Sci. Technol.,* **30,** 3118.

Gron, C.; Wassenaar, L.; and Krog, M. (1996) Origin and Structures of Groundwater Humic Substances from Three Danish Aquifers. *Environ. Int.,* **22,** 519.

Gruiz, K., and Kriston, E. (1995) In Situ Bioremediation of Hydrocarbon in Soil. *J. Soil Contam.,* **4,** 163.

Guglielmi, Y., and Mudry, J. (1996) Estimation of Spatial and Temporal Variability of Recharge Fluxes to an Alluvial Aquifer in a Fore Land Area by Water Chemistry and Isotopes. *Ground Water,* **34,** 1017.

Guha, S., and Jaffè, P.R. (1996a) Biodegradation Kinetics of Phenanthrene Partitioned into the Micellar Phase of Nonionic Surfactants. *Environ. Sci. Technol.,* **30,** 605.

Guha, S., and Jaffè, P.R. (1996b) Bioavailability of Hydrophobic Compounds Partitioned into the Micellar Phase of Nonionic Surfactants. *Environ. Sci. Technol.,* **30,** 1382.

Guigard, S.E.; Stiver, W.H.; and Zytner, R.G. (1996a) Retention Capacities of Immiscible Chemicals in Unsaturated Soils. *Water Air Soil Pollut.* (Neth.), **89,** 277.

Guigard, S.; Stiver, W.H.; and Zytner, R.G. (1996b) The Infiltration and Movement of Immiscible Chemicals in Unsaturated Soil. *Environ. Technol.,* **17,** 1123.

Gunther, T.; Dornberger, U.; and Fritsche, W. (1996) Effects of Ryegrass on Biodegradation of Hydrocarbons in Soil. *Chemosphere,* **33,** 203.

Gupta, G., and Baummer, J. (1996) Biodegradation of Atrazine in Soil Using Poultry Litter. *J. Haz. Mater.,* **45,** 185.

Gupte, S.M.; Radcliffe, D.E.; Franklin, D.H.; West, L.T.; Tollner, E.W.; and Hendrix, P.F. (1996) Anion Transport in a Piedmont Ultisol. II. Local-Scale Parameters. *Soil Sci. Soc. Am. J.,* **60,** 762.

Gwo, J.P.; Jardine, P.M.; Wilson, G.V.; and Yeh, G.T. (1996) Using a Multiregion Model to Study the Effects of Advective and Diffusive Mass Transfer on Local Physical Nonequilibrium and Solute Mobility in a Structured Soil. *Water Resour. Res.,* **32,** 561.

Haby, P.A., and Crowley, D.E. (1996) Biodegradation of 3-Chlorobenzoate as Affected by Rhizodeposition and Selected Carbon Substrates. *J. Environ. Qual.,* **25,** 304.

Hackley, K.C.; Liu, C.L.; and Coleman, D.D. (1996) Environmental Isotope Characteristics of Landfill Leachates and Gases. *Ground Water,* **34,** 827.

Hadad, A.; Bensabat, J.; and Rubin, H. (1996) Simulation of Immiscible Multiphase Flow in Porous Media: A Focus on the Capillary Fringe of Oil-Contaminated Aquifers. *Transp. Porous Media,* **22,** 245.

Haderlein, S.B.; Weissmahr, K.W.; and Schwarzenbach, R.P. (1996) Specific Adsorption of Nitroaromatic: Explosives and Pesticides to Clay Minerals. *Environ. Sci. Technol.,* **30,** 612.

Hadermann, J., and Heer, W. (1996) The Grimsel (Switzerland) Migration Experiment: Integrating Field Experiments, Laboratory Investigations and Modelling. *J. Contam. Hydrol.,* **21,** 87.

Haidour, A., and Ramos, J.L. (1996) Identification of Products Resulting from the Biological Reduction of 2,4,6-Trinitrotoluene, 2,4-Dinitrotoluene, and 2,6-Dinitrotoluene by Pseudomonas sp. *Environ. Sci. Technol.,* **30,** 2365.

Haight, K.S.; Butler, W.A.; and Garon, K.P. (1996) Bioventing: Technology Selection Through Implementation. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 95.

Hamed, M.M.; Bedient, P.B.; and Conte, J.P. (1996) Numerical Stochastic Analysis of Groundwater Contaminant Transport and Plume Containment. *J. Contam. Hydrol.,* **24,** 1.

Hammill, T.B., and Crawford, R.L. (1996) Degradation of 2-sec-butyl-4,6-Dinitrophenol (Di-noseb) by Clostridium bifermentans KMR-1. *Appl. Environ. Microbiol.,* **62,** 1842.

Hapka, A., and Whang, J. (1996) In Situ Precipitation of an Iron Based Grout for Subsurface Containment. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex, **3,** 185.

Haran, B.S.; Popov, B.N.; Zheng, G.H.; and White, R.E. (1996) Development of a New Electrokinetic Technique for Decontamination of Hexavalent Chromium from Low Surface Charged Soils. *Environ. Progr.,* **15,** 166.

Hardisty, P.E., and Schroder, R.A. (1996) Fracture-Controlled Transport of MTBE. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 31.

Harman, J.; Robertson, W.D.; Cherry, J.A.; and Zanini, L. (1996) Impacts on a Sand Aquifer from an Old Septic System: Nitrate and Phosphate. *Ground Water,* **34,** 1105.

Harquail, S.B. (1996) Anatomy of a Complex Groundwater Monitoring Program. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 621.

Hart, S. (1996) In Situ Bioremediation: Defining the Limits. *Environ. Sci. Technol.,* **30,** A398.

Harter, T., and Yeh, T.C.J. (1996a) Stochastic Analysis of Solute Transport in Heterogeneous, Variably Saturated Soils. *Water Resour. Res.,* **32,** 1585.

Harter, T., and Yeh, T.C.J. (1996b) Conditional Stochastic Analysis of Solute Transport in Heterogeneous, Variably Saturated Soils. *Water Resour. Res.,* **32,** 1597–1609.

Hartz, M.J., and Overcamp, T.J. (1996) The Geometry of Nonwetting Liquids in the Unsaturated Zone. *Ground Water,* **34,** 837.

Hassanizadeh, S.M. (1996) On the Transient Non-Fickian Dispersion Theory. *Transp. Porous Media,* **23,** 107.

Hatfield, K.; Burris, D.R.; and Wolfe, N.L. (1996) Analytical Model for Heterogeneous Reactions in Mixed Porous Media. *J. Environ. Eng.,* **122,** 676.

Hathhorn, W.E. (1996) A Second Look at the Method of Random Walks. *Stoch. Hydrol. Hydraul.,* **10,** 319.

Hauschild, J.E.; Masai, E.; Sugiyama, K.; Hatta, T.; Kimbara, K.; Fukuda, M.; and Yano, K. (1996) Identification of an Alternative 2,3-Dihydroxybiphenyl 1,2-Dioxygenase in Rhodococcus sp Strain RHA1 and Cloning of the Gene. *Appl. Environ. Microbiol.,* **62,** 2940.

Hawari, J.; Paquet, L.; Zhou, E.; Halasz, A.; and Zilber, B. (1996) Enhanced Recovery of the Explosive Hexahydro-1,3,5-Trinitro-1,3,5-Triazine (RDX) from soil: Cyclodextrin Versus Anionic Surfactants. *Chemosphere,* **32,** 1929.

Hayden, N.J., and Van der Hoeven, E.J. (1996) Alcohol Flushing for Enhanced Removal of Coal Tar from Contaminated Soils. *Water Environ. Res.,* **68,** 1165.

Hayworth, J.S., and Burris, D.R. (1996) Modeling Cationic Surfactant Transport in Porous Media. *Ground Water,* **34,** 274.

He, Y.Q., and Sykes, J.F. (1996) On the Spatial-Temporal Averaging Method for Modeling Transport in Porous Media. *Transp. Porous Media,* **22,** 1.

Hedgcoxe, H.R.; Clubb, H.R.; and Pastene, A.J. (1996) Hydraulic Fracturing to Enhance Remediation. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 63.

Helton, J.C.; Bean, J.E.; Butcher, B.M.; Garner, J.W.; Schreiber, J.D.; Swift, P.N.; and Vaughn, P. (1996) Uncertainty and Sensitivity Analysis for Gas and Brine Migration at the Waste Isolation Pilot Plant: Permeable Shaft with Panel Seals. *J. Haz. Mater.,* **45,** 107.

Henry, E., and Herman, C.M. (1996) Use of a Biological Attenuation and Dispersion Model as a Screening Tool to Assess the Applicability of Site Closure or Passive Remediation of a Hydrocarbon Impacted Site. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl Ground Water Assoc., Dublin, Ohio, 261.

Herbert, R.B. (1996) Metal Retention by Iron Oxide Precipitation from Acidic Ground Water in Dalarna, Sweden. *Appl. Geochem.,* **11,** 229.

Herbst, B., and Wiesmann, U. (1996) Kinetics and Reaction Engineering

Aspects of the Biodegradation of Dichloromethane and Dichloroethane. *Water Res.*, **30,** 1069.

Hess, A.; Hohener, P.; Hunkeler, D.; and Zeyer, J. (1996) Bioremediation of a Diesel Fuel Contaminated Aquifer: Simulation Studies in Laboratory Aquifer Columns. *J. Contam. Hydrol.*, **23,** 329.

Hickey, W.J., and Paek, J. (1996) Ventilation Effects on Mineralization and Volatilization of Naphthalene in a Gasoline-Contaminated Subsurface Soil. *Chemosphere* (G.B.), **32,** 1655.

Hicks, P.J., and Grader, A.S. (1996) Simulation of Three-Phase Displacement Experiments. *Transp. Porous Media,* **24,** 221.

Hicks, R.T., and Rizvi, R. (1996) Do-Nothing Cleanups. *Civil Eng.*, **66,** 54.

Hilfer, R., and Oren, P.E. (1996) Dimensional Analysis of Pore Scale and Field Scale Immiscible Displacement. *Transp. Porous Media,* **22,** 53.

Hill, B.D.; Miller, J.J.; Chang, C.; and Rodvang, S.J. (1996) Seasonal Variation in Herbicide Levels Detected in Shallow Alberta Groundwater. *J. Environ. Sci. Health Part B Pestic. Food Contam. Agric. Wastes,* **31,** 883.

Hill, C.S., and Walker, R.D. (1996) Predicting Maximum Influent Contaminant Concentrations for Ground Water Recovery Wells. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 635.

Hinsby, K.; Mckay, L.D.; Jorgensen, P.; Lenczewski, M.; and Gerba, C.P. (1996) Fracture Aperture Measurements and Migration of Solutes, Viruses, and Immiscible Creosote in a Column of Clay-Rich Till. *Ground Water,* **34,** 1065.

Holm, P.E.; Andersen, B.B.H.; and Christensen, T.H. (1996) Cadmium Solubility in Aerobic Soils. *Soil Sci. Soc. Am. J.*, **60,** 775.

Holman, H.Y.N., and Javandel, I. (1996a) Evaluation of Transient Dissolution of Slightly Water-Soluble Compounds from a Light Nonaqueous Phase Liquid Pool. *Water Resour. Res.*, **32,** 915.

Holman, H.Y.N., and Javandel, I. (1996b) Evaluation of Transient Dissolution of Slightly Water-Soluble Compounds from a Light Nonaqueous Phase Liquid Pool (vol 32, pg 915, 1996). *Water Resour. Res.*, **32,** 1917.

Hölta, P.; Hakanen, M.; Hautojarvi, A.; Timonen, J.; and Vaatainen, K. (1996) The Effects of Matrix Diffusion on Radionuclide Migration in Rock Column Experiments. *J. Contam. Hydrol.*, **21,** 165.

Hong, J.H., and Pintauro, P.N. (1996) Selective Removal of Heavy Metals from Contaminated Kaolin by Chelators. *Water Air Soil Pollut.* (Neth.), **87,** 73.

Hong, S., and Smith, A.E. (1996) Abiotic and Biotic Degradation of Dithiopyr in Golf Course Greens. *J. Agric. Food Chem.*, **44,** 3393.

Horton, P.D., and Ihnen, S.M. (1996) The California Groundwater Purging Study for Petroleum Hydrocarbons. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 741.

Hossain, A., and Corapcioglu, M.Y. (1996) Modeling Primary Substrate Controlled Biotransformation and Transport of Halogenated Aliphatics in Porous Media. *Transp. Porous Media,* **24,** 203.

Hottenstein, C.S.; Rubio, F.M.; Herzog, D.P.; Fleeker, J.R.; and Lawruk, T.S. (1996) Determination of Trace Atrazine Levels in Water by a Sensitive Magnetic Particle-Based Enzyme Immunoassay. *J. Agric. Food Chem.*, **44,** 3576.

Howard, J.L., and Sledzinski, G. (1996) Geochemical Behavior of Lead in an Alfisol and an Utisol at High Levels of Contamination. *J. Soil Contam.*, **5,** 61.

Howard, K.W.F., and Mullings, E. (1996) Hydrochemical Analysis of Ground-Water Flow and Saline Incursion in the Clarendon Basin, Jamaica. *Ground Water,* **34,** 801.

Hsu, K.C.; Zhang, D.X.; and Neuman, S.P. (1996) Higher-Order Effects on Flow and Transport in Randomly Heterogeneous Porous Media. *Water Resour. Res.*, **32,** 571.

Hu, Q.H., and Brusseau, M.L. (1996) Transport of Rate-Limited Sorbing Solutes in an Aggregated Porous Medium: A Multiprocess Non-Ideality Approach. *J. Contam. Hydrol.*, **24,** 53.

Huang, C., and Mayer, A.S. (1996) The Role of Uncertainty in the Optimization of Groundwater Remediation Systems. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 359.

Huang, W.L.; Schlautman, M.A.; and Weber, W.J. (1996) A Distributed Reactivity Model for Sorption by Soils and Sediments. V. The Influence of Near-Surface Characteristics in Mineral Domains. *Environ. Sci. Technol.*, **30,** 2993.

Hughes, J.B., and Parkin, G.F. (1996a) Concentration Effects on Chlorinated Aliphatic Transformation Kinetics. *J. Environ. Eng.*, **122,** 92.

Hughes, J.B., and Parkin, G.F. (1996b) Individual Biotransformation Rates in Chlorinated Aliphatic Mixtures. *J. Environ. Eng.*, **122,** 99.

Hurst, R.W.; Davis, T.E.; and Chinn, B.D. (1996) The Lead Fingerprints of Gasoline Contamination. *Environ. Sci. Technol.*, **30,** A304.

Huwe, B., and Totsche, K.U. (1995) Deterministic and Stochastic Modelling of Water, Heat and Nitrogen Dynamics on Different Scales with WHNSIM. *J. Contam. Hydrol.*, **20,** 265.

Huyakorn, P.S.; Wu, Y.S.; and Park, N.S. (1996) Multiphase Approach to the Numerical Solution of a Sharp Interface Saltwater Intrusion Problem. *Water Resour. Res.*, **32,** 93.

Hyndman, D.W., and Gorelick, S.M. (1996) Estimating Lithologic and Transport Properties in Three Dimensions Using Seismic and Tracer Data: The Kesterson Aquifer. *Water Resour. Res.*, **32,** 2659.

Ibaraki, M., and Sudicky, E.A. (1995a) Colloid-Facilitated Contaminant Transport in Discretely Fractured Porous Media. I. Numerical Formulation and Sensitivity Analysis. *Water Resour. Res.*, **31,** 2945.

Ibaraki, M., and Sudicky, E.A. (1995b) Colloid-Facilitated Contaminant Transport in Discretely Fractured Porous Media. II. Fracture Network Examples. *Water Resour. Res.*, **31,** 2961.

Iben, I.E.T.; Edelstein, W.A.; Sheldon, R.B.; Shapiro, A.P.; Uzgiris, E.E.; Scatena, C.R.; Blaha, S.R.; Silverstein, W.B.; Brown, G.R.; Stegemeier, G.L.; and Vinegar, H.J. (1996) Thermal Blanket for In-Situ Remediation of Surficial Contamination: A Pilot Test. *Environ. Sci. Technol.*, **30,** 3144.

Idelsohn, S.R.; Heinrich, J.C.; and Onate, E. (1996) Petrov-Galerkin Methods for the Transient Advective-Diffusive Equation with Sharp Gradients. *Int. J. Numer. Methods Eng.*, **39,** 1455.

Idelsohn, S.; Nigro, N.; Storti, M.; and Buscaglia, G. (1996) A Petrov-Galerkin Formulation for Advection-Reaction-Diffusion Problems. *Comput. Meth. Appl. Mech. Eng.*, **136,** 27.

Iglesias-Jimenez, E.; Sanchez-Martin, M.J.; and Sanchez-Camazano, M. (1996) Pesticide Adsorption in a Soil-Water System in the Presence of Surfactants. *Chemosphere* (G.B.), **32,** 1771.

Imhoff, P.T., and Miller, C.T. (1996) Dissolution Fingering During the Solubilization of Non-Aqueous Phase Liquids in Saturated Porous Media. I. Model Predictions. *Water Resour. Res.*, **32,** 1919.

Imhoff, P.T.; Thyrum, G.P.; and Miller, C.T. (1996) Dissolution Fingering During the Solubilization of Nonaqueous Phase Liquids in Saturated Porous Media. II. Experimental Observations. *Water Resour. Res.*, **32,** 1929.

Indelman, P., and Rubin, Y. (1996) Solute Transport in Nonstationary Velocity Fields. *Water Resour. Res.*, **32,** 1259.

Inskeep, W.P.; Wraith, J.M.; Wilson, J.P.; Snyder, R.D.; Macur, R.E.; and Gaber, H.M. (1996) Input Parameter and Model Resolution Effects on Predictions of Solute Transport. *J. Environ. Qual.*, **25,** 453.

Ioannidis, M.A.; Chatzis, I.; and Dullien, F.A.L. (1996) Macroscopic Percolation Model of Immiscible Displacement: Effects of Buoyancy and Spatial Structure. *Water Resour. Res.*, **32,** 3297.

Iqbal, M.Z., and Krothe, N.C. (1996) Transport of Bromide and Other Inorganic Ions by Infiltrating Storm Water Beneath a Farmland Plot. *Ground Water,* **34,** 972.

Irwin, N.C.; Botz, M.M.; and Greenkorn, R.A. (1996) Experimental Investigation of Characteristic Length Scale in Periodic Heterogeneous Porous Media. *Transp. Porous Media,* **25,** 235.

Isensee, A.R., and Sadeghi, A.M. (1996) Effect of Tillage Reversal on Herbicide Leaching to Groundwater. *Soil Sci.*, **161,** 382.

Istok, J.D., and Rautman, C.A. (1996) Probabilistic Assessment of

Ground-Water Contamination. II. Results of Case Study. *Ground Water,* **34,** 1050.

Izadi, B.; King, B.; Westermann, D.; and Mccann, I. (1996) Modeling Transport of Bromide in Furrow-Irrigated Field. *J. Irrig. Drain.,* **122,** 90.

Jaekel, U.; Georgescu, A.; and Vereecken, H. (1996) Asymptotic Analysis of Nonlinear Equilibrium Solute Transport in Porous Media. *Water Resour. Res.,* **32,** 3093.

Jalajas, E.W.P.; Nyer, E.K.; and Nautiyal, D. (1996) Superfund Clean Up Strategy at the Tibbetts Road Site. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 371.

James, B.R. (1996) The Challenge of Remediating Chromium-Contaminated Soil. *Environ. Sci. Technol.,* **30,** A248.

James, B.R.; Gwo, J.P.; and Toran, L. (1996) Risk-Cost Decision Framework for Aquifer Remediation Design. *J. Water Resour. Plann. Manage. Div., Proc. Am. Soc. Civ. Eng.,* **122,** 414.

James, D.E.; Johnson, T.E.; and Kreamer, D.K. (1996) Interference of Avian Guano in Analyses of Fuel Contaminated Soils. *J. Environ. Eng.,* **122,** 74.

Jardine, K.; Smith, L.; and Clemo, T. (1996) Monitoring Networks in Fractured Rocks: A Decision Analysis Approach. *Ground Water,* **34,** 504.

Jayaweera, G.R., and Biggar, J.W. (1996) Role of Redox Potential in Chemical Transformations of Selenium in Soils. *Soil Sci. Soc. Am. J.,* **60,** 1056.

Jeng, C-Y.; Kremesec, V.J.; and Primack, H.S. (1996) Models of Hydrocarbon Vapor Diffusion Through Soil and Transport into Buildings. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 319.

Jensen, K.H.; Destouni, G.; and Sassner, M. (1996) Advection-Dispersion Analysis of Solute Transport in Undisturbed Soil Monoliths. *Ground Water,* **34,** 1090.

Jin, X.; Bailey, G.W.; Yu, Y.S.; and Lynch, A.T. (1996) Kinetics of Single and Multiple Metal Ion Sorption Processes on Humic Substances. *Soil Sci.,* **161,** 509.

Jin, Y., and Jury, W.A. (1996) Characterizing the Dependence of Gas Diffusion Coefficient on Soil Properties. *Soil Sci. Soc. Am. J.,* **60,** 66.

Johannesson, K.H.; Stetzenbach, K.J.; and Hodge, V.F. (1995) Speciation of the Rare Earth Element Neodymium in Groundwaters of the Nevada Test Site and Yucca Mountain and Implications for Actinide Solubility. *Appl. Geochem.,* **10,** 565.

Johannesson, K.H.; Stetzenbach, K.J.; Kreamer, D.K.; and Hodge, V.F. (1996) Multivariate Statistical Analysis of Arsenic and Selenium Concentrations in Groundwaters from South-Central Nevada and Death Valley, California. *J. Hydrol.* (Neth.), **178,** 181.

Johns, R.T., and Rivera, A. (1996) Dispersive Transport Dynamics in a Strongly Coupled Groundwater-Brine Flow System (Comment). *Water Resour. Res.,* **32,** 3405.

Johnson, A.C.; Haria, A.H.; Bhardwaj, C.L.; Williams, R.J.; and Walker, A. (1996) Preferential Flow Pathways and Their Capacity to Transport Isoproturon in a Structured Clay Soil. *Pestic. Sci.,* **48,** 225.

Johnson, B.D., and Hall, J.C. (1996) Fluroxypyr- and Triclopyr-Specific Enzyme-Linked Immunosorbent Assays: Development and Quantitation in Soil and Water. *J. Agric. Food Chem.,* **44,** 488.

Johnson, J., and Methvin, R. (1996) Management of a Dissolved Phase Hydrocarbon Plume Using a Passive Permeable ORC Oxygen Barrier. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 775.

Johnson, J.A.; Parcher, M.A.; Parker, J.C.; and Seaton, W.J. (1996) VOC Vapor Transport: Implications for Risk Assessment. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 307.

Johnson, P.R.; Sun, N.; and Elimelech, M. (1996) Colloid Transport in Geochemically Heterogeneous Porous Media: Modeling and Measurements. *Environ. Sci. Technol.,* **30,** 3284.

Johnson, T.M., and DePaolo, D.J. (1996) Reaction-Transport Models for Radiocarbon in Groundwater: The Effects of Longitudinal Dispersion and the Use of Sr Isotope Ratios to Correct for Water-Rock Interaction. *Water Resour. Res.,* **32,** 2203.

Johnson, W.P., and Logan, B.E. (1996) Enhanced Transport of Bacteria in Porous Media by Sediment-Phase and Aqueous-Phase Natural Organic Matter. *Water Res.* (G.B.), **30,** 923.

Johnson, W.P.; Amy, G.L.; and Chapra, S.C. (1996) Modeling of NOM-Facilitated PAH Transport Through Low-f(oc) Sediment (vol 121, pg 442, 1995). *J. Environ. Eng.,* **122,** 337.

Johnston, J.J.; Borden, R.C.; and Barlaz, M.A. (1996) Anaerobic Biodegradation of Alkylbenzenes and Trichloroethylene in Aquifer Sediment Down Gradient of a Sanitary Landfill. *J. Contam. Hydrol.,* **23,** 263.

Jones, I., and Lerner, D.N. (1995) Level-Determined Sampling in an Uncased Borehole. *J. Hydrol.* (Neth.), **171,** 291.

Jorgensen, D.G. (1996) The Ratio Method of Estimating Water Resistivity and TDS from Resistivity Logs. *Ground Water,* **34,** 519.

Joss, C.J. (1996) Quantifying Flow Across the Water Table in Air-Sparging Systems. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 619.

Kaleris, V.; Hadjitheodorou, C.; and Demetracopoulos, A.C. (1995) Numerical Simulation of Field Methods for Estimating Hydraulic Conductivity and Concentration Profiles. *J. Hydrol.* (Neth.), **171,** 319.

Kaluarachchi, J.J. (1996) Effect of Subsurface Heterogeneity on Free-Product Recovery from Unconfined Aquifers. *J. Contam. Hydrol.,* **22,** 19.

Kamau, P.A.; Ellsworth, T.R.; Boast, C.W.; and Simmons, F.W. (1996) Tillage and Cropping Effects on Preferential Flow and Solute Transport. *Soil Sci.,* **161,** 549.

Kang, S.H., and Oulman, C.S. (1996) Evaporation of Petroleum Products from Contaminated Soils. *J. Environ. Eng.,* **122,** 384.

Kaplan, D.I.; Cantrell, K.J.; Wietsma, T.W.; and Potter, M.A. (1996) Retention of Zero-Valent Iron Colloids by Sand Columns: Application to Chemical Barrier Formation. *J. Environ. Qual.,* **25,** 1086.

Kaplan, I.R.; Galperin, Y.; Alimi, H.; Lee, R.P.; and Lu, S.T. (1996) Patterns of Chemical Changes During Environmental Alteration of Hydrocarbon Fuels. *Ground Water Monit. Remed.,* **16,** 113.

Kapoor, A., and Viraraghavan, T.(1996) Permeable Barriers to Remove Benzene: Candidate Media Evaluation (Discussion). *J. Environ. Eng.,* **122,** 885.

Kapoor, V., and Kitanidis, P.K. (1996) Concentration Fluctuations and Dilution in Two-Dimensionally Periodic Heterogeneous Porous Media. *Transp. Porous Media,* **22,** 91.

Karatzas, G.P., and Pinder, G.F. (1996a) The Solution of Groundwater Quality Management Problems with a Nonconvex Feasible Region Using a Cutting Plane Optimization Technique. *Water Resour. Res.,* **32,** 1091.

Karatzas, G.P., and Pinder, G.F. (1996b) Combination of Pumping Wells and Drains for an Optimal Groundwater Remediation Design. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 367.

Karimi-Lotfabad, S.; Pickard, M.A.; and Gray, M.R. (1996) Reactions of Polynuclear Aromatic Hydrocarbons on Soil. *Environ. Sci. Technol.,* **30,** 1145.

Katz, L.E.; Humphrey, D.N.; Jankauskas, P.T.; and Demascio, F.A. (1996) Engineered Soils for Low-Level Radioactive Waste Disposal Facilities: Effects of Additives on the Adsorptive Behavior and Hydraulic Conductivity of Natural Soils. *Haz. Waste Haz. Mater.,* **13,** 283.

Kavanaugh, M.C. (1995) Cleanup of Contaminated Groundwater: A Major Policy Dilemma. *Environ. Prog.,* **14,** M3.

Kavvas, M.L., and Karakas, A. (1996) On the Stochastic Theory of Solute Transport by Unsteady and Steady Groundwater Flow in Heterogeneous Aquifers. *J. Hydrol.* (Neth.), **179,** 321.

Kavvas, M.L.; Chen, Z.Q.; Govindaraju, R.S.; Rolston, D.E.; Koos, T.;

Karakas, A.; Or, D.; Jones, S.; and Biggar, J. (1996) Probability Distribution of Solute Travel Time for Convective Transport in Field-Scale Soils Under Unsteady and Nonuniform Flows. *Water Resour. Res.*, **32,** 875.

Kazumi, J.; Haggblom, M.M.; and Young, L.Y. (1996) Degradation of Monochlorinated and Nonchlorinated Aromatic Compounds Under Iron-Reducing Conditions (Reply). *Appl. Environ. Microbiol.*, **62,** 3554.

Kedziorek, M.A.M., and Bourg, A.C.M. (1996) Acidification and Solubilisation of Heavy Metals from Single and Dual-Component Model Solids. *Appl. Geochem.*, **11,** 299.

Kehew, A.E.; Straw, W.T.; Steinmann, W.K.; Barrese, P.G.; Passarella, G.; and Peng, W.S. (1996) Ground-Water Quality and Flow in a Shallow Glaciofluvial Aquifer Impacted by Agricultural Contamination. *Ground Water,* **34,** 491.

Kelley, I., and Cerniglia, C.E. (1995) Degradation of a Mixture of High-Molecular-Weight Polycyclic Aromatic Hydrocarbons by a Mycobacterium Strain PYR-1. *J. Soil Contam.*, **4,** 77.

Kelly, L.L. (1996) SVE System Cost Analysis: Internal Combustion Engine Vs. GAC. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 563.

Kelly, W.R.; Hornberger, G.M.; Herman, J.S.; and Mills, A.L. (1996a) Kinetics of BTX Biodegradation and Mineralization in Batch and Column Systems. *J. Contam. Hydrol.*, **23,** 113.

Kelly, W.R.; Saliga, M.P.; Machesky, M.L.; and Freedman, D.L. (1996b) Biodegradation of BTEX Under Iron-Reducing Conditions in Batch Microcosms. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 161.

Kessavalou, A.; Doran, J.W.; Powers, W.L.; Kettler, T.A.; and Qian, J.H. (1996) Bromide and Nitrogen-15 Tracers of Nitrate Leaching Under Irrigated Corn in Central Nebraska. *J. Environ. Qual.*, **25,** 1008.

Khan, S.A.; Pope, G.A.; and Trangenstein, J.A. (1996) Micellar/Polymer Physical-Property Models for Contaminant Cleanup Problems and Enhanced Oil Recovery. *Transp. Porous Media,* **24,** 35.

Khan, Z.A.; Misra, B.M.; and Raghu, K. (1996) Thermodynamics of Interaction of Lindane on Silty Loam and Silty Clay Loam Indian Soils. *J. Environ. Sci. Health Part B Pestic. Food Contam. Agric. Wastes,* **31,** 1015.

Kiilerich, O., and Arvin, E. (1996) Ground Water Contamination from Creosote Sites. *Ground Water Monit. Remed.*, **16,** 112.

Kim, C.S.; Sandretto, C.; and Hostetler, J. (1996) Effects of Farmer Response to Nitrogen Fertilizer Management Practices on Groundwater Quality. *Water Resour. Res.*, **32,** 1411.

Kim, J.H.; Stenstrom, M.K.; and Harmon (1996) A Study of Fluid Flow and Mass Transformation in Immiscible Liquids. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 1.

Kim, S.H., and Corapcioglu, M.Y. (1996) A Kinetic Approach to Modeling Mobile Bacteria-Facilitated Groundwater Contaminant Transport. *Water Resour. Res.*, **32,** 321.

Kinniburgh, D.G., and Trafford, J.M. (1996) Unsaturated Zone Pore Water Chemistry and the Edge Effect in a Beech Forest in Southern England. *Water, Air, Soil Pollut.* (Neth.), **92,** 421.

Kinzelbach, W.; Vassolo, S.; and Li, G.-M. (1996) Stochastic Determination of Capture Zones of Wells. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 33.

Kirshner, M.; Pressly, N.C.; and Roth, R.J. (1996) In Situ Remediation of Jet in Soil and Ground Water by High Vacuum, Dual Phase Extraction. *Ground Water Monit. Remed.*, **16,** 73.

Kitanidis, P.K., and Shen, K.F. (1996) Geostatistical Interpolation of Chemical Concentration. *Adv. Water Resour.*, **19,** 369.

Knabner, P.; Totsche, K.U.; and Kogelknabner, I. (1996) The Modeling of Reactive Solute Transport with Sorption to Mobile and Immobile Sorbents. I. Experimental Evidence and Model Development. *Water Resour. Res.*, **32,** 1611.

Knaebel, D.B.; Federle, T.W.; Mcavoy, D.C.; and Vestal, J.R. (1996) Microbial Mineralization of Organic Compounds in an Acidic Agricultural Soil: Effects of Preadsorption to Various Soil Constituents. *Environ. Toxicol. Chem.*, **15,** 1865.

Knight, J.H. (1996) An Improved Approximation for Spherical Diffusion of Tritium in Relatively Dry Soil. *Water Resour. Res.*, **32,** 349.

Knox, R.C., and Canter, L.W. (1996) Prioritization of Ground Water Contaminants and Sources. *Water, Air, Soil Pollut.* (Neth.), **88,** 205.

Knutson, J.H., and Selker, J.S. (1996) Fiberglass Wick Sampler Effects on Measurements of Solute Transport in the Vadose Zone. *Soil Sci. Soc. Am. J.*, **60,** 420.

Kolpin, D.W.; Nations, B.K.; Goolsby, D.A.; and Thurman, E.M. (1996) Acetochlor in the Hydrologic System in the Midwestern United States, 1994. *Environ. Sci. Technol.*, **30,** 1459.

Komor, S.C., and Magner, J.A. (1996) Nitrate in Groundwater and Water Sources Used by Riparian Trees in an Agricultural Watershed: A Chemical and Isotopic Investigation in Southern Minnesota. *Water Resour. Res.*, **32,** 1039.

Kong, D., and Harmon, T.C. (1996) Using the Multiple Cell Balance Method to Solve the Problem of Two-Dimensional Groundwater Flow and Contaminant Transport with Nonequilibrium Sorption. *J. Contam. Hydrol.*, **23,** 285.

König, C. (1996) Density Dependent Groundwater Flow Coupled with a Hydrogeochemical Transport Model. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 101.

Korom, S.F.; Mcfarland, M.J.; and Sims, R.C. (1996) Reduced Sediments: A Factor in the Design of Subsurface Oxidant Delivery Systems. *Ground Water Monit. Remed.*, **16,** 100.

Koskinen, W.C.; Stone, D.M.; and Harris, A.R. (1996) Sorption of Hexazinone, Sulfometuron Methyl, and Tebuthiuron on Acid, Low Base Saturated Sands. *Chemosphere* (G.B.), **32,** 1681.

Kovalick, W.W., and Kingscott, J. (1996) Emerging Issues and Technology in Site Remediation. *Haz. Waste Haz. Mater.*, **13,** U2.

Krapac, I.G.; Roy, W.R.; Smyth, C.A.; and Barnhardt, M.L. (1995) Occurrence and Distribution of Pesticides in Soil at Agrichemical Facilities in Illinois. *J. Soil Contam.*, **4,** 209.

Krebs-Yuill, B.; Harwell, J.H.; Sabatini, D.A.; Quinston, G.E.; and Shoemaker, S.H. (1996) Economic Study of Surfactant-Enhanced Pump-and-Treat Remediation. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 31.

Kroening, D.E.; Snipes, D.S.; Brame, S.E.; Hodges, R.A.; Price, V.; and Temples, T.J. (1996) The Rehabilitation of Monitoring Wells Clogged by Calcite Precipitation and Drilling Mud. *Ground Water Monit. Remed.*, **16,** 114.

Kruger, E.L.; Zhu, B.L.; and Coats, J.R. (1996a) Relative Mobilities of Atrazine, Five Atrazine Degradates, Metolachlor, and Simazine in Soils of Iowa. *Environ. Toxicol. Chem.*, **15,** 691.

Kruger, E.L.; Rice, P.J.; Anhalt, J.C.; Anderson, T.A.; and Coats, J.R. (1996b) Use of Undisturbed Soil Columns Under Controlled Conditions to Study the Fate of [C-14]Deethylatrazine. *J. Agric. Food Chem.*, **44,** 1144.

Kruse, C.W.; Moldrup, P.; and Iversen, N. (1996) Modeling Diffusion and Reaction in Soils. 2. Atmospheric Methane Diffusion and Consumption in a Forest Soil. *Soil Sci.*, **161,** 355.

Kuehne, D.L. (1996) Numerical Modeling of the Two-Phase Vacuum Extraction Process. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 745.

Kueper, B.H., and Gerhard, J.I. (1996) Variability of Point Source Infiltration Rates for Two-Phase Flow in Heterogeneous Porous Media. *Water Resour. Res.*, **31,** 2971.

Kuo, C.C., and Papadopoulos, K.D. (1996) Electrokinetic: Movement of Settled Spherical Particles in Fine Capillaries. *Environ. Sci. Technol.*, **30,** 1176.

Kurek, E.; Kaczorowska, R.; Nadulska, I.; Ochal, M.; Puacz, E.; and

Patkowska, E. (1996) Retention of Cd by Soil Constituents Under Different Environmental Conditions. *Chemosphere* (G.B.), **33,** 277.

Labieniec, P.A.; Dzombak, D.A.; and Siegrist, R.L.(1996a) Risk Variability Due to Uniform Soil Remediation Goals. *J. Environ. Eng.,* **122,** 612.

Labieniec, P.A.; Dzombak, D.A.; and Siegrist, R.L. (1996b) SoilRisk: Risk Assessment Model for Organic Contaminants in Soil. *J. Environ. Eng.,* **122,** 388.

LaBolle, E.M.; Fogg, G.E.; and Tompson, A.F.B. (1996) Random-Walk Simulation of Transport in Heterogeneous Porous Media: Local Mass-Conservation Problem and Implementation Methods. *Water Resour. Res.,* **32,** 583.

Lalah, J.O., and Wandiga, S.O. (1996) Adsorption Desorption and Mobility of Carbofuran in Soil Samples from Kenya. *Bull. Environ. Contam. Toxicol.,* **56,** 575.

Landmeyer, J.E.; Vroblesky, D.A.; and Chapelle, F.H. (1996) Stable Carbon Isotope Evidence of Biodegradation Zonation in a Shallow Jet-Fuel Contaminated Aquifer. *Environ. Sci. Technol.,* **30,** 1120.

Laperche, V.; Traina, S.J.; Gaddam, P.; and Logan, T.J. (1996) Chemical and Mineralogical Characterizations of Pb in a Contaminated Soil: Reactions with Synthetic Apatite. *Environ. Sci. Technol.,* **30,** 3321.

La Salle, C.L.; Marlin, C.; Savoye, S.; and Fontes, J.C. (1996) Geochemistry and C-14 Dating of Groundwaters from Jurassic Aquifers of North Aquitaine Basin (France). *Appl. Geochem.,* **11,** 433.

Lasseux, D.; Quintard, M.; and Whitaker, S. (1996) Determination of Permeability Tensors for Two-Phase Flow in Homogeneous Porous Media: Theory. *Transp. Porous Media,* **24,** 107.

Laue, H.; Field, J.A.; and Cook, A.M. (1996) Bacterial Desulfonation of the Ethanesulfonate Metabolite of the Chloroacetanilide Herbicide Metazachlor. *Environ. Sci. Technol.,* **30,** 1129.

Lazarov, R.D.; Mishev, I.D.; and Vassilevski, P.S. (1996) Finite Volume Methods for Convection-Diffusion Problems. *SIAM J. Numer. Anal.,* **33,** 31.

Leahy, J.G.; Byrne, A.M.; and Olsen, R.H. (1996) Comparison of Factors Influencing Trichloroethylene Degradation by Toluene-Oxidizing Bacteria. *Appl. Environ. Microbiol.,* **62,** 825.

Lee, C.K.; Sun, C.C.; and Mei, C.C. (1996) Computation of Permeability and Dispersivities of Solute or Heat in Periodic Porous Media. *Int. J. Heat Mass Transfer,* **39,** 661.

Lee, L.S., and Rao, P.S.C. (1996) Impact of Several Water-Miscible Organic Solvents on Sorption of Benzoic Acid by Soil. *Environ. Sci. Technol.,* **30,** 1533.

Lee, S.Z.; Allen, H.E.; Huang, C.P.; Sparks, D.L.; Sanders, P.F.; and Peijnenburg, W.J.G.M. (1996) Predicting Soil-Water Partition Coefficients for Cadmium. *Environ. Sci. Technol.,* **30,** 3418.

Leethem, J.T.; Conti, E.; Hudson, T.S.; Shoemaker, S.H.; Pitre, M.P.; and Marley, M.C. (1996) Biosparging with Pure Oxygen into a Confined Aquifer. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 117.

Lefevre, F.; Sardin, M.; and Vitorge, P. (1996) Migration of Ca-45 and Sr-90 in a Clayey and Calcareous Sand: Calculation of Distribution Coefficients by Ion Exchange Theory and Validation by Column Experiments. *J. Contam. Hydrol.,* **21,** 175.

Lehmann, R.G., and Miller, J.R. (1996) Volatilization and Sorption of Dimethylsilanediol in Soil. *Environ. Toxicol. Chem.,* **15,** 1455.

Lehmann, R.G.; Frye, C.L.; Tolle, D.A.; and Zwick, T.C. (1996) Fate of Sludge-Applied Silicones in Agricultural Soil Microcosms. *Water, Air, Soil Pollut.* (Neth.), **87,** 231.

Leitao, T.E.; Loboferreira, J.P.; and Valocchi, A.J. (1996) Application of a Reactive Transport Model for Interpreting Non-Conservative Tracer Experiments: The Rio Maior Case-Study. *J. Contam. Hydrol.,* **24,** 167.

Lensing, H.J. (1996) Modelling of Microbially Mediated Processes in the Subsurface. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 177.

Lerner, D.N., and Teutsch, G. (1995) Recommendations for Level-Determined Sampling in Wells. *J. Hydrol.,* **171,** 355.

Lesage, S.; Brown, S.; and Millar, K. (1996) Vitamin B-12-Catalyzed Dechlorination of Perchloroethylene Present as Residual DNAPL. *Ground Water Monit. Remed.,* **16,** 76.

Li, C.W., and Yu, T.S. (1996) Conservative Characteristics-Based Schemes for Mass Transport (Closure). *J. Hydraul. Eng.,* **122,** 118.

Li, D.X., and Lundegard, P.D. (1996) Evaluation of Subsurface Oxygen Sensors for Remediation Monitoring. *Ground Water Monit. Remed.,* **16,** 106.

Li, J.; Smith, J.A.; and Winquist, A.S. (1996) Permeability of Earthen Liners Containing Organobentonite to Water and Two Organic Liquids. *Environ. Sci. Technol.,* **30,** 3089.

Li, J.H.; Langford, C.H.; and Gamble, D.S. (1996a) Atrazine Sorption by a Mineral Soil: Effects of Soil Size Fractions and Temperature. *J. Agric. Food Chem.,* **44,** 3680.

Li, J.H.; Langford, C.H.; and Gamble, D.S. (1996b) Atrazine Sorption by a Mineral Soil: Processes of Labile and Nonlabile Uptake. *J. Agric. Food Chem.,* **44,** 3672.

Li, Z.B., and Shuman, L.M. (1996a) Extractability of Zinc, Cadmium, and Nickel in Soils Amended with EDTA. *Soil Sci.,* **161,** 226.

Li, Z.B., and Shuman, L.M. (1996b) Heavy Metal Movement in Metal-Contaminated Soil Profiles. *Soil Sci.,* **161,** 656.

Li, Z.M.; Yu, J.W.; and Neretnieks, I. (1996) A New Approach to Electrokinetic Remediation of Soils Polluted by Heavy Metals. *J. Contam. Hydrol.,* **22,** 241.

Liao, Y.Y.; Wang, Z.T.; Chen, J.W.; Han, S.K.; Wang, L.S.; Lu, G.Y.; and Zhao, T.N. (1996) The Prediction of Soil Sorption Coefficients of Heterocyclic Nitrogen Compounds by Octanol Water Partition Coefficient, Water Solubility, and by Molecular Connectivity Indices. *Bull. Environ. Contam. Toxicol.,* **56,** 711.

Lieberman, J. (1996) Groundwater Arsenic: Making the Case for Reductive Dissolution. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 117.

Lièvremont, D.; Seiglemurandi, F.; and Benoitguyod, J.L. (1996) Effects of Culture Parameters on Pentachloronitrobenzene Removal by Sporothrix Cyanescens. *Chemosphere* (G.B.), **32,** 361.

Lin, T.F.; Vanloy, M.D.; and Nazaroff, W.W. (1996) Gas-Phase Transport and Sorption of Benzene in Soil. *Environ. Sci. Technol.,* **30,** 2178.

Linde, C.D.; Gee, S.J.; Goh, K.S.; Hsu, J.C.; Hammock, B.D.; Barry, T.A.; and Weaver, D.J. (1996) Regulatory Application of ELISA: Compliance Monitoring or Bromacil in Soil. *Bull. Environ. Contam. Toxicol.,* **57,** 264.

Lindhardt, B., and Christensen, T.H. (1996) Volatilisation of Aromatic Hydrocarbons from Soil. 2. Fluxes from Coal Tar Contaminated Soils Residing Below the Soil Surface. *Water, Air, Soil Pollut* (Neth.), **92,** 375.

Lindhardt, B.; Christensen, T.H.; and Andersen, L. (1996) Volatilisation of Aromatic Hydrocarbons from Soil. I. Fluxes from Coal Tar Contaminated Surface Soils. *Water, Air, Soil Pollut.* (Neth.), **89,** 129.

Lindquist, J.C.; Victor, W.R.; and Meyer, J.L. (1996) Development of Quantitative Soil Vapor Performance Standards for the Hassayampa Landfill Superfund Site Using Sesoil, a One-Dimensional Vadose Zone Transport Model. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 479.

Lineham, T.R.; Nash, P.J.; Rodwell, W.R.; Bolt, J.; Watkins, V.M.B.; Grainger, P.; Heath, M.J.; and Merefield, J.R. (1996) Gas Migration in Fractured Rock: Results and Modelling of a Helium Gas Injection Experiment at the Reskajeage Farm Test Site, SW England, United Kingdom. *J. Contam. Hydrol.,* **21,** 101.

Lipson, D.S., and McGuire, P.N. (1996) Demonstrating the Natural Attenuation of Chlorinated VOCs in Ground Water Using Spider Diagrams. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 759.

Litaor, M.I.; Barth, G.R.; and Zika, E.M. (1996) Fate and Transport of Plutonium-239+240 and Americium-241 in the Soil of Rocky Flats, Colorado. *J. Environ. Qual.,* **25,** 671.

Litaor, M.I., and Ibrahim, S.A. (1996) Plutonium Association with Selected Solid Phases in Soils of Rocky Flats, Colorado, Using Sequential Extraction Technique. *J. Environ. Qual.*, **25**, 1144.

Little, R.; Muller, E.; and Mackay, R. (1996) Modelling of Contaminant Migration in a Chalk Aquifer. *J. Hydrol.* (Neth.), **175**, 473.

Liu, B.; Allen, M.B.; Kojouharov, H.; and Chen, B. (1996) Finite-Element Solution of Reaction-Diffusion Equations with Advection. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1**, 3.

Liu, H.H., and Dane, J.H. (1996a) Two Approaches to Modeling Unstable Flow and Mixing of Variable Density Fluids in Porous Media. *Transp. Porous Media,* **23**, 219.

Liu, H.H., and Dane, J.H. (1996b) A Criterion for Gravitational Instability in Miscible Dense Plumes. *J. Contam. Hydrol.,* **23**, 233.

Liu, H.H., and Dane, J.H. (1996c) An Interpolation-Corrected Modified Method of Characteristics to Solve Advection-Dispersion Equations. *Adv. Water Resour.,* **19**, 359.

Liu, H.H., and Dane, J.H. (1996d) An Extended Transfer Function Model of Field-Scale Solute Transport: Model Development. *Soil Sci. Soc. Am. J.,* **60**, 986.

Liu, J.S.; Yu, J.W.; and Neretnieks, I. (1996) Transport Modelling in the Natural Analogue Study of the Cigar Lake Uranium Deposit (Saskatchewan, Canada). *J. Contam. Hydrol.,* **21**, 19.

Liu, S.P.; Yen, S.T.; and Kolpin, D.W. (1996a) Pesticides in Ground Water: Do Atrazine Metabolites Matter? *Water Resour. Bull.* (Urb.), **32**, 845.

Liu, S.P.; Yen, S.T.; and Kolpin, D.W. (1996b) Atrazine Concentrations in Near-Surface Aquifers: A Censored Regression Approach. *J. Environ. Qual.,* **25**, 992.

Lizanec, T., and Fahey, L. (1996) A Field Test of Visually Clear Casing for Subsurface Inspection. *Ground Water Monit. Remed.,* **16**, 76.

Lo, I.M.C. (1996) The Role of Organic Attenuation in Saturated Clay Barrier System. *Water Sci. Technol.* (G.B.), **33**, 145.

Loague, K.; Bernknopf, R.L.; Green, R.E.; and Giambelluca, T.W. (1996) Uncertainty of Groundwater Vulnerability Assessments for Agricultural Regions in Hawaii: Review. *J. Environ. Qual.,* **25**, 475.

Locke, M.A.; Gaston, L.A.; and Zablotowicz, R.M. (1996) Alachlor Biotransformation and Sorption in Soil from Two Soybean Tillage Systems. *J. Agric. Food Chem.,* **44**, 1128.

Loehr, R.C., and Webster, M.T. (1996a) Behavior of Fresh vs Aged Chemicals in Soil. *J. Soil Contam.,* **5**, 361.

Loehr, R.C., and Webster, M.T. (1996b) Performance of Long-Term, Field-Scale Bioremediation Process. *J. Haz. Mater.,* **50**, 105.

Loftis, J.C. (1996) Trends in Groundwater Quality. *Hydrol. Proc.,* **10**, 335.

Logan, J.D. (1996) Solute Transport in Porous Media with Scale-Dependent Dispersion and Periodic Boundary Conditions. *J. Hydrol.* (Neth.), **184**, 261.

Losonsky, G.; Beljin, M.S.; Liddle, R.L.; Shoemaker, S.H.; and Speake, R.C. (1996) Comparing Horizontal Groundwater Extraction Well Efficiencies at Hazardous Waste Sites—Implications for Well Planning and Development. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 183.

Lumsdon, D.G.; Evans, L.J.; and Bolton, K.A. (1995) The Influence of pH and Chloride on the Retention of Cadmium, Lead, Mercury, and Zinc by Soils. *J. Soil Contam.,* **4**, 137.

Lundegard, P.D., and Andersen, G. (1996) Multiphase Numerical Simulation of Air Sparging Performance. *Ground Water,* **34**, 451.

Lundegard, P.D.; Chaffee, B.; and LaBrecque, D. (1996) Effective Design of a Horizontal Air Sparing Well. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 135.

Lundin, L. (1995) Soil Water Chemistry Dependence on Water Pathways and Turnover. *Water Air Soil Pollut.* (Neth.), **85**, 1695.

Lundy, D.A., and Zimmerman, L.M. (1996) Assessing the Recoverability of LNAPL Plumes for Recovery System Conceptual Design. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 19.

Ma, L.W., and Selim, H.M. (1996) Solute Transport in Soils Under Conditions of Variable Flow Velocities. *Water Resour. Res.,* **32**, 3277.

Ma, Q.L.; Ahuja, L.R.; Wauchope, R.D.; Benjamin, J.G.; Burgoa, B. (1996) Comparison of Instantaneous Equilibrium and Equilibrium-Kinetic Sorption Models for Simulating Simultaneous Leaching and Runoff of Pesticides. *Soil Sci.,* **161**, 646.

Mabury, S.A., and Crosby, D.G. (1996) Pesticide Reactivity Toward Hydroxyl and its Relationship to Field Persistence. *J. Agric. Food Chem.,* **44**, 1920.

Maccagno, M.D.; Ross, S.D.; and Hardisty, P.E. (1996) Containment of a Dissolved-Phase Plume. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 221.

Mackay, A.A.; Chin, Y.P.; Macfarlane, J.K.; and Gschwend, P.M. (1996) Laboratory Assessment of BTEX Soil Flushing. *Environ. Sci. Technol.,* **30**, 3223.

Mackay, R., and Cooper, T.A. (1996) Contaminant Transport in Heterogeneous Porous Media: A Case Study I. Site Characterisation and Deterministic Modelling. *J. Hydrol.* (Neth.), **175**, 383.

Mackay, R.; Cooper, T.A.; Metcalfe, A.V.; and Oconnell, P.E. (1996) Contaminant Transport in Heterogeneous Porous Media: A Case Study II. Stochastic Modelling. *J. Hydrol.* (Neth.), **175**, 429.

Macleod, C.L.; Borcsik, M.P.; and Jaffe, P.R. (1996) Effect of Infiltrating Solutions on the Desorption of Mercury from Aquifer Sediments. *Environ. Technol.,* **17**, 465.

Madsen, E.L.; Thomas, C.T.; Wilson, M.S.; Sandoli, R.L.; and Bilotta, S.E. (1996) In Situ Dynamics of Aromatic Hydrocarbons and Bacteria Capable of AH Metabolism in a Coal Tar Waste-Contaminated Field Site. *Environ. Sci. Technol.,* **30**, 2412.

Magnico, P. (1996) Permeability Evolution Induced by the Precipitation of an Advected Solute: Effect of the Microscopic and the Macroscopic Scales Competition on the Clogging Mechanism. *Transp. Porous Media,* **24**, 341.

Mahesha, A. (1996a) Steady-State Effect of Freshwater Injection on Seawater Intrusion. *J. Irrig. Drain.,* **122**, 149.

Mahesha, A. (1996b) Transient Effect of Battery of Injection Wells on Seawater Intrusion. *J. Hydraul. Eng.,* **122**, 266.

Mahesha, A. (1996c) Control of Seawater Intrusion Through Injection-Extraction Well System. *J. Irrig. Drain.,* **122**, 314.

Mahesha, A., and Nagaraja, S.H. (1996) Effect of Natural Recharge on Sea Water Intrusion in Coastal Aquifers. *J. Hydrol.* (Neth.), **174**, 211.

Mallants, D.; Vanclooster, M.; and Feyen, J. (1996a) Transect Study on Solute Transport in a Macroporous Soil. *Hydrol. Proc.,* **10**, 55.

Mallants, D.; Vanclooster, M.; Toride, N.; Vanderborght, J.; Vangenuchten, M.T.; and Feyen, J. (1996b) Comparison of Three Methods to Calibrate TDR for Monitoring Solute Movement in Undisturbed Soil. *Soil Sci. Soc. Am. J.,* **60**, 747.

Mallawatantri, A.P., and Mulla, D.J. (1996) Uncertainties in Leaching Risk Assessments Due to Field Averaged Transfer Function Parameters. *Soil Sci. Soc. Am. J.,* **60**, 722.

Mallawatantri, A.P.; Mcconkey, B.G.; and Mulla, D.J. (1996) Characterization of Pesticide Sorption and Degradation in Macropore Linings and Soil Horizons of Thatuna Silt Loam. *J. Environ. Qual.,* **25**, 227.

Malmstrom, M.; Banwart, S.; Lewenhagen, J.; Duro, L.; and Bruno, J. (1996) The Dissolution of Biotite and Chlorite at 25 Degrees C in the Near-Neutral pH Region. *J. Contam. Hydrol.,* **21**, 201.

Manceau, A.; Boisset, M.C.; Sarret, G.; Hazemann, R.L.; Mench, M.; Cambier, P.; and Prost, R. (1996) Direct Determination of Lead Speciation in Contaminated Soils by EXAFS Spectroscopy. *Environ. Sci. Technol.,* **30**, 1540.

Manning, B.A., and Goldberg, S. (1996) Modeling Competitive Adsorption of Arsenate with Phosphate and Molybdate on Oxide Minerals. *Soil Sci. Soc. Am. J.,* **60**, 121.

Mannings, S.; Smith, S.; and Bell, J.N.B. (1996) Effect of Acid Deposition on Soil Acidification and Metal Mobilisation. *Appl. Geochem.*, **11**, 139.

Manoranjan, V.S., and Stauffer, T.B. (1996) Exact Solution for Contaminant Transport with Kinetic Langmuir Sorption. *Water Resour. Res.*, **32**, 749.

Mansell, R.S.; Rhue, R.D.; Ouyang, Y.; and Bloom, S.A. (1996) Microemulsion-Mediated Removal of Residual Gasoline from Soil Columns. *J. Soil Contam.*, **5**, 309.

Marinelli, F., and Durnford, D.S. (1996) LNAPL Thickness in Monitoring Wells Considering Hysteresis and Entrapment. *Ground Water*, **34**, 405.

Mariner, P.E.; Holzmer, F.J.; Jackson, R.E.; Meinardus, H.W.; and Wolf, F.G. (1996) Effects of High pH on Arsenic Mobility in a Shallow Sandy Aquifer and on Aquifer Permeability Along the Adjacent Shoreline, Commencement Bay Superfund Site, Tacoma, Washington. *Environ. Sci. Technol.*, **30**, 1645.

Marks, B.J.; El Sururi, S.E.; Chute, S.; and Lee, K. (1996) Sensitivity Analysis for Vapor Transport Properties in the ASTM RBCA. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 353.

Marryott, R.A. (1996) Optimal Ground-Water Remediation Design Using Multiple Control Technologies. *Ground Water*, **34**, 425.

Mars, A.E.; Houwing, J.; Dolfing, J.; and Janssen, D.B. (1996) Degradation of Toluene and Trichloroethylene by Burkholderia Cepacia G4 in Growth-Limited Fed-Batch Culture. *Appl. Environ. Microbiol.*, **62**, 886.

Martens, D.A., and Frankenberger, W.T. (1995) Enhanced Degradation of Polycyclic Aromatic Hydrocarbons in Soil Treated with an Advanced Oxidative Process—Fenton's Reagent. *J. Soil Contam.*, **4**, 175.

Martin, M.J.; Logan, B.E.; Johnson, W.P.; Jewett, D.G.; and Arnold, R.G. (1996) Scaling Bacterial Filtration Rates in Different Sized Porous Media. *J. Environ. Eng.*, **122**, 407.

Maskall, J.; Whitehead, K.; Gee, C.; and Thornton, I. (1996) Long-Term Migration of Metals at Historical Smelting Sites. *Appl. Geochem.*, **11**, 43.

Mason, A.R., and Kueper, B.H. (1996) Numerical Simulation of Surfactant-Enhanced Solubilization of Pooled DNAPL. *Environ. Sci. Technol.*, **30**, 3205.

Matanga, G.B. (1996) Stream and Pseudopotential Functions in Visualizing Groundwater Flow and Transport Processes. *Water Resour. Res.*, **32**, 953.

Mathieu, R., and Bariac, T. (1996) An Isotopic Study (H-2 and O-18) of Water Movements in Clayey Soils Under a Semiarid Climate. *Water Resour. Res.*, **32**, 779.

Matus, V.; Vasquez, M.; Vicente, M.; and Gonzalez, B. (1996) Microbial Mineralization of 2,4,5-Trichlorophenol in Soil. *Environ. Sci. Technol.*, **30**, 1472.

Mayer, A.S., and Miller, C.T. (1996) The Influence of Mass Transfer Characteristics and Porous Media Heterogeneity on Nonaqueous Phase Dissolution. *Water Resour. Res.*, **32**, 1551.

Mayotte, T.J.; Dybas, M.J.; and Criddle, C.S. (1996) Bench-Scale Evaluation of Bioaugmentation to Remediate Carbon Tetrachloride-Contaminated Aquifer Materials. *Ground Water*, **34**, 358.

Mazurek, M.; Alexander, W.R.; and Mackenzie, A.B. (1996) Contaminant Retardation in Fractured Shales: Matrix Diffusion and Redox Front Entrapment. *J. Contam. Hydrol.*, **21**, 71.

McAllister, P. (1996) Application of Screening Model Approaches for Evaluation of BTEX Natural Attenuation in Groundwater. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 481.

McCall, W. (1996) Electrical Conductivity Logging to Determine Control of Hydrocarbon Flow Paths in Alluvial Sediments. *Proc. 10th Natl. Outdoor Action. Conf.*, Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 461.

McCarthy, J.F.; Gu, B.; Liang, L.; Maspla, J.; Williams, T.M.; and Yeh, T.C.J. (1996) Field Tracer Tests on the Mobility of Natural Organic Matter in a Sandy Aquifer. *Water Resour. Res.*, **32**, 1223.

McCarty, P.L.; Goltz, M.; Hopkins, G.; and Allan, J. (1996) In-Situ Biodegradation of Chlorinated Solvent Contaminants in Groundwater. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3**, 217.

McCaulou, D.R.; Jewett, D.G.; and Huling, S.G. (1996) Compatibility of NAPLs and Other Organic Compounds with Materials Used in Well Construction, Sampling, and Remediation. *Ground Water Monit. Remed.*, **16**, 125.

McClay, K.; Fox, B.G.; and Steffan, R.J. (1996) Chloroform Mineralization by Toluene-Oxidizing Bacteria. *Appl. Environ. Microbiol.*, **62**, 2716.

McClure, P.D., and Sleep, B.E. (1996) Simulation of Bioventing for Soil and Ground-Water Remediation. *J. Environ. Eng.*, **122**, 1003.

McCray, J.E., and Falta, R.W. (1996) Defining the Air Sparging Radius of Influence for Ground-Water Remediation. *J. Contam. Hydrol.*, **24**, 25.

McFarland, M.J.; Beck, M.; Harper, S.; and Deshmuck, K. (1996) Anoxic Treatment of Trifluoralin-Contaminated Soil. *J. Haz. Mater.*, **50**, 129.

McGrath, W.A., and Pinder, G.F. (1996) Sampling Network Design for Delineating Groundwater Contaminant Plumes. *Computat. Meth. Water Resour. XI*, Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **3**, 185.

McKay, D.J., and Acomb, L.J. (1996) Neutron Moisture Probe Measurements of Fluid Displacement During In Situ Air Sparging. *Ground Water Monit. Remed.*, **16**, 86.

McKenna, E.A.; Youngren, S.H.; Baker, S.R.; Schroeder, J.R.; Piccin, T.B.; Weisman, W.H.; and Long, C. (1995) Evaluation of the Total Petroleum Hydrocarbon (TPH) Standard for JP-4 Jet Fuel. *J. Soil Contam.*, **4**, 355.

McKinney, D.C., and Lin, M.D. (1996) Pump and Treat Ground-Water Remediation System Optimization. *J. Water Resour. Plann. Manage. Div., Proc. Am. Soc. Civ. Eng.*, **122**, 128.

Medina, A., and Carrera, J. (1996) Coupled Estimation of Flow and Solute Transport Parameters. *Water Resour. Res.*, **32**, 3063.

Medina, M.A.; Jacobs, T.L.; Lin, W.C.; and Lin, K.C. (1996) Ground Water Solute Transport, Optimal Remediation Planning, and Decision Making Under Uncertainty. *Water Resour. Bull.* (Urb.), **32**, 1.

Meeussen, J.C.L.; Scheidegger, A.; Hiemstra, T.; Vanriemsdijk, W.H.; and Borkovec, M. (1996) Predicting Multicomponent Adsorption and Transport of Fluoride at Variable pH in a Goethite-Silica Sand System. *Environ. Sci. Technol.*, **30**, 481.

Meijerink, A.M.J. (1996) Remote Sensing Applications to Hydrology: Groundwater. *Hydrol. Sci. J.*, **41**, 549.

Mersie, W., and Seybold, C. (1996) Adsorption and Desorption of Atrazine, Deethylatrazine, Deisopropylatrazine, and Hydroxyatrazine on Levy Wetland Soil. *J. Agric. Food Chem.*, **44**, 1925.

Meshalkina, J.L.; Stein, A.; and Makarov, O.A. (1996) Spatial Variability of Soil Contamination Around a Sulphureous Acid Producing Factory in Russia. *Water, Air, Soil Pollut.* (Neth.), **92**, 289.

Mester, K.G., and Kosson, D.S. (1996) Anaerobic Biodegradation of Toluene Under Denitrifying Conditions in Contaminated Groundwater and Soil. *J. Haz. Mater.*, **45**, 219.

Metzger, D.; Kinzelbach, H.; and Kinzelbach, W. (1996) Effective Dispersion of a Solute Cloud in a Chemically Heterogeneous Porous Medium: Comparison of Two Ensemble-Averaging Procedures. *Water Resour. Res.*, **32**, 3311.

Metzger, L.O.Y.; Munierlamy, C.; Chone, T.; Belgy, M.J.; Andreux, F.; and Vedy, J.C. (1996) Fate of a Sulfonylurea Herbicide in an Alluvial Soil, as Shown by Experimental Degradation of Pyrimidine-2-C-14-Labeled Rimsulfuron. *Chemosphere* (G.B.), **33**, 625.

Meyer, E.W., and Bardsley, D.S. (1996) Site Characterization, Application and Operation of Horizontal Wells for Ground Water Remediation. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 791.

Middeldorp, P.J.M.; Jaspers, M.; Zehnder, A.J.B.; and Schraa, G. (1996) Biotransformation of Alpha-, Beta-, Gamma-, and Delta-Hexachlorocyclohexane Under Methanogenic Conditions. *Environ. Sci. Technol.,* **30,** 2345.

Miettinen, I.T.; Vartiainen, T.; and Martikainen, P.J. (1996) Bacterial Enzyme Activities in Ground Water During Bank Filtration of Lake Water. *Water Res.* (G.B.), **30,** 2495.

Migaud, M.E.; Chee-Sanford, J.C.; Tiedje, J.M.; and Frost, J.W. (1996) Benzylfumaric, Benzylmaleic, and Z- and E-Phenylitaconic Acids: Synthesis, Characterization, and Correlation with a Metabolite Generated by Azoarcus Tolulyticus Tol-4 During Anaerobic Toluene Degradation. *Appl. Environ. Microbiol.,* **62,** 974.

Mills, D.; Downs, L.; and Williams, R. (1996) Design, Construction, and Operation of a Cutoff Trench for Groundwater Containment. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 547.

Mills, W.B.; Johnson, K.M.; Liu, S.; Loh, J.Y.; and Lew, C.S. (1996) Multimedia Risk-Based Soil Cleanup at a Gasoline-Contaminated Site Using Vapor Extraction. *Ground Water Monit. Remed.,* **16,** 168.

Minsker, B.S., and Shoemaker, C.A. (1996) Differentiating a Finite Element Biodegradation Simulation Model for Optimal Control. *Water Resour. Res.,* **32,** 187.

Miralles-Wilhelm, F., and Gelhar, L.W. (1996) Stochastic Analysis of Sorption Macrokinetics in Heterogeneous Aquifers. *Water Resour. Res.,* **32,** 1541.

Mitchell, J.A., and Cain, R.B. (1996) Rapid Onset of the Accelerated Degradation of Dicarboximide Fungicides in a UK Soil with a Long History of Agrochemical Exclusion. *Pestic. Sci.,* **48,** 1.

Miyamoto, K., and Urano, K. (1996) Reaction Rates and Intermediates of Chlorinated Organic Compounds in Water and Soil. *Chemosphere* (G.B.), **32,** 2399.

Moench, A.F. (1996) Convergent Radial Dispersion: A Laplace Transform Solution for Aquifer Tracer Testing. *Water Resour. Res.,* **32,** 1475.

Moldrup, P.; Kruse, C.W.; Rolston, D.E.; and Yamaguchi, T. (1996a) Modeling Diffusion and Reaction in Soils. III. Predicting Gas Diffusivity from the Campbell Soil-Water Retention Model. *Soil Sci.,* **161,** 366.

Moldrup, P.; Kruse, C.W.; Yamaguchi, T.; and Rolston, D.E. (1996b) Modeling Diffusion and Reaction in Soils. I. A Diffusion and Reaction Corrected Finite Difference Calculation Scheme. *Soil Sci.,* **161,** 347.

Moline, G.R.; Beauchamp, J.J.; and Wright, T. (1996) Determining an Optimal Sampling Frequency for Measuring Bulk Temporal Changes in Ground-Water Quality. *Ground Water,* **34,** 579.

Montoto, M.; Menager, M.T.; Rodriguezrey, A.; Menendez, B.; Martineznistal, A.; and Fernandezmerayo, N. (1996) Uranium Transfer Phenomena in Rock Matrix: Petrophysical and Geochemical Study of El Berrocal Experimental Site, Spain. *J. Contam. Hydrol.,* **21,** 35.

Moore, A.; Revell, S.; and Norland, B. (1996) Calibration of Models of Vapor Transport into Buildings. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 339.

Moore, J.W., and Claypool, J.E. (1995) Optimizing Remedial Action Implementation at the C and R Battery Company Superfund Site. *Environ. Prog.,* **14,** 75.

Mora, A.; Comejo, J.; Revilla, E.; and Hermosin, M.C. (1996) Persistence and Degradation of Carbofuran in Spanish Soil Suspensions. *Chemosphere* (G.B.), **32,** 1585.

Morris, D.E.; Allen, P.G.; Berg, J.M.; Chisholmbrause, C.J.; Conradson, S.D.; Donohoe, R.J.; Hess, N.J.; Musgrave, J.A.; and Tait, C.D. (1996) Speciation of Uranium in Fernald Soils by Molecular Spectroscopic Methods: Characterization of Untreated Soils. *Environ. Sci. Technol.,* **30,** 2322.

Morton, L.S., and Evans, C.V. (1996) Soil Radioactivity and the Soil Survey: Field Data Collection for Series Interpretations. *Soil Sci. Soc. Am. J.,* **60,** 531.

Moseley, W.A., and Dhir, V.K. (1996) Capillary Pressure-Saturation Relations in Porous Media Including the Effect of Wettability. *J. Hydrol.* (Neth.), **178,** 33.

Moulin, V., and Moulin, C. (1995) Fate of Actinides in the Presence of Humic Substances Under Conditions Relevant to Nuclear Waste Disposal. *Appl. Geochem.,* **10,** 573.

Moutoux, D.E.; Benson, L.A.; Swanson, M.A.; Wiedemeier, T.H.; Lenhart, J.; Wilson, J.T.; and Hansen, J.E. (1996) Estimating the Changing Rate of Anaerobic Reductive Dechlorination of Chlorinated Aliphatic Hydrocarbons in the Presence of Petroleum Hydrocarbons. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 399.

Moyer, E.E.; Ostendorf, D.W.; Richards, R.J.; and Goodwin, S. (1996) Petroleum Hydrocarbon Bioventing Kinetics Determined in Soil Core, Microcosm and Tubing Cluster Studies. *Ground Water Monit. Remed.,* **16,** 141.

Mulbry, W.W.; Delvalle, P.L.; and Karns, J.S. (1996) Biodegradation of the Organophosphate Insecticide Coumaphos in Highly Contaminated Soils and in Liquid Wastes. *Pestic. Sci.,* **48,** 149.

Mulla, D.J.; Perillo, C.A.; and Cogger, C.G. (1996) A Site-Specific Farm-Scale GIS Approach for Reducing Groundwater Contamination by Pesticides. *J. Environ. Qual.,* **25,** 419.

Muller, M., and Kordel, W. (1996) Comparison of Screening Methods for the Estimation of Adsorption Coefficients on Soil. *Chemosphere,* **32,** 2493.

Munakata-Marr, J.; Mccarty, P.L.; Shields, M.S.; Reagin, M.; and Francesconi, S.C. (1996) Enhancement of Trichloroethylene Degradation in Aquifer Microcosms Bioaugmented with Wild Type and Genetically Altered Burkholderia (Pseudomonas) cepacia G4 and PR1. *Environ. Sci. Technol.,* **30,** 2045.

Muñoz, J.F.; Rengifo, P.; and Irarrazaval, M. (1996) Mathematical Modelation of Simultaneous Transport of Reactive Solutes: Application to Bioremediation and Acid Leaching of Copper Tailings. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 375.

Murphy, E.M.; Ginn, T.R.; and Phillips, J.L. (1996) Geochemical Estimates of Paleorecharge in the Pasco Basin: Evaluation of the Chloride Mass Balance Technique. *Water Resour. Res.,* **32,** 2853.

Mushtaq, M.; Feely, W.F.; Syintsakos, L.R.; and Wislocki, P.G. (1996) Immobility of Emamectin Benzoate in Soils. *J. Agric. Food Chem.,* **44,** 940.

Nelson, E.C.; Ghoshal, S.; Edwards, J.C.; Marsh, G.X.; and Luthy, R.G. (1996) Chemical Characterization of Coal Tar-Water Interfacial Films. *Environ. Sci. Technol.,* **30,** 1014.

Nelson, N.T., and Brusseau, M.L. (1996) Field Study of the Partitioning Tracer Method for Detection of Dense Nonaqueous Phase Liquid in a Trichloroethene-Contaminated Aquifer. *Environ. Sci. Technol.,* **30,** 2859.

Nemeth, T. (1995) Nitrogen in Hungarian soils—Nitrogen Management Relation to Groundwater Protection. *J. Contam. Hydrol.,* **20,** 185.

Neuman, S.P., and Chen, G.L. (1996) On Instability During Immiscible Displacement in Fractures and Porous Media. *Water Resour. Res.,* **32,** 1891.

Neumann, K., and Dreiss, S. (1995) Strontium 87 Strontium 86 Ratios as Tracers in Groundwater and Surface Waters in Mono Basin, California. *Water Resour. Res.,* **31,** 3183.

Newcomer, D.R.; Hall, S.H.; and Vermeul, V.R. (1996) Use of Improved Hydrologic Testing and Borehole Geophysical Logging Methods for Aquifer Characterization. *Ground Water Monit. Remed.,* **16,** 67.

Newell, C.J.; McLeod, R.K.; and Gonzales, J.R. (1996) How Far? How Long? The Bioscreen Natural Attenuation Decision Support System. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 807.

Ng, C.O., and Mei, C.C. (1996) Aggregate Diffusion Model Applied to Soil Vapor Extraction in Unidirectional and Radial Flows. *Water Resour. Res.,* **32,** 1289.

Nguyen, H. (1996) A Petrov-Gaerkin Finite Element Scheme for One-Dimensional Water Flow and Solute Transport Processes in the Unsaturated Zone. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 559.

Nielsen, P.H.; Christensen, T.H.; Albrechtsen, H.J.; and Gillham, R.W. (1996) Performance of the In Situ Microcosm Technique for Measuring the Degradation of Organic Chemicals in Aquifers. *Ground Water Monit. Remed.,* **16,** 130.

Nilsen, S., and Espedal, M.S. (1996) Wavelet Upscaling Based on Piecewise Bilinear Approximation of the Permeability Field. *Transp. Porous Media,* **23,** 125.

Nilsson, B.; Jakobsen, R.; and Andersen, L.J. (1995a) Development and Testing of Active Ground-Water Samplers. *J. Hydrol.* (Neth.), **171,** 223.

Nilsson, B.; Luckner, L.; and Schirmer, M. (1995b) Field Trials of Active and Multi-Port Sock Samplers in Gravel-Packed Wells. *J. Hydrol.* (Neth.), **171,** 259.

Nivas, B.T.; Sabatini, D.A.; Shiau, B.J.; and Harwell, J.H. (1996) Surfactant Enhanced Remediation of Subsurface Chromium Contamination. *Water Res.* (G.B.), **30,** 511.

Niven, R.K., and Khalili, N. (1996) Washing of Zinc(II) from Contaminated Soil Column (Discussion). *J. Environ. Eng.,* **122,** 881.

Noblet, J.A.; Smith, L.A.; and Suffet, I.H. (1996) Influence of Natural Dissolved Organic Matter, Temperature, and Mixing on the Abiotic Hydrolysis of Triazine and Organophosphate Pesticides. *J. Agric. Food Chem.,* **44,** 3685.

Noborio, K.; Mcinnes, K.J.; and Heilman, J.L. (1996a) Two-Dimensional Model for Water, Heat, and Solute Transport in Furrow-Irrigated Soil. I. Theory. *Soil Sci. Soc. Am. J.,* **60,** 1001.

Noborio, K.; Mcinnes, K.J.; and Heilman, J.L. (1996b) Two-Dimensional Model for Water, Heat, and Solute Transport in Furrow-Irrigated Soil. II. Field Evaluation. *Soil Sci. Soc. Am. J.,* **60,** 1010.

Noguera, D.R., and Freedman, D.L. (1996) Reduction and Acetylation of 2,4-Dinitrotoluene by a Pseudomonas aeruginosa Strain. *Appl. Environ. Microbiol.,* **62,** 2257.

Nolan, J.G. (1996) Caution Against the Inappropriate Use of Analytical Fate and Transport Models to Estimate the Age and Risk of Petroleum Product Releases. *Ground Water Monit. Remed.,* **16,** 184.

Nordqvist, A.W.; Tsang, Y.W.; Tsang, C.F.; Dverstorp, B.; and Andersson, J. (1996) Effects of High Variance of Fracture Transmissivity on Transport and Sorption at Different Scales in a Discrete Model for Fractured Rocks. *J. Contam. Hydrol.,* **22,** 39.

Norkus, R.G.; Maurer, J.; Schultz, N.A.; Stuart, J.D.; Robbins, G.A.; and Bristol, R.D. (1996) Field Examination of Ground Water Quality as an Indicator of Microbiological Activity at Gasoline Contaminated Sites. *Chemosphere* (G.B.), **33,** 421.

Norris, R.D.; Dupont, R.R.; and Gorder, K. (1996) Selection of Remedial Strategies Based on Modeling of Plume Dynamics. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 823.

Novak, C.F. (1996) Development of the FMT Chemical Transport Simulator: Coupling Aqueous Density and Mineral Volume Fraction to Phase Compositions. *J. Contam. Hydrol.,* **21,** 297.

Novakowski, K.S., and van der Kamp, G. (1996) The Radial Diffusion Method. II. A Semianalytical Model for the Determination of Effective Diffusion Coefficients, Porosity, Arid Adsorption. *Water Resour. Res.,* **32,** 1823.

Nowack, B.; Lutzenkirchen, T.; Behra, P.; and Sigg, L. (1996) Modeling the Adsorption of Metal-EDTA Complexes Onto Oxides. *Environ. Sci. Technol.,* **30,** 2397.

Nuck, B.A., and Federle, T.W. (1996) Batch Test for Assessing the Mineralization of C-14-Radiolabeled Compounds Under Realistic Anaerobic Conditions. *Environ. Sci. Technol.,* **30,** 3597.

Oakley, D., and Korte, N.E. (1996) Nickel and Chromium in Ground Water Samples as Influenced by Well Construction and Sampling Methods. *Ground Water Monit. Remed.,* **16,** 93.

O'Brien, R.; Keller, C.K.; and Smith, J.L. (1996) Multiple Tracers of Shallow Ground-Water Flow and Recharge in Hilly Loess. *Ground Water,* **34,** 675.

O'Connor, K.; Duetz, W.; Wind, B.; and Dobson, A.D.W. (1996) The Effect of Nutrient Limitation on Styrene Metabolism in Pseudomonas putida CA-3. *Appl. Environ. Microbiol.,* **62,** 3594.

O'Connor, O.A., and Young, L.Y. (1996) Effects of Six Different Functional Groups and Their Position on the Bacterial Metabolism of Monosubstituted Phenols Under Anaerobic Conditions. *Environ. Sci. Technol.,* **30,** 1419.

Oetting, G.C.; Banner, J.L.; and Sharp, J.M. (1996) Regional Controls on the Geochemical Evolution of Saline Groundwaters in the Edwards Aquifer, Central Texas. *J. Hydrol.* (Neth.), **181,** 251.

Okuda, I.; McBride, J.F.; Gleyzer, S.N.; and Miller, C.T. (1996) Physicochemical Transport Processes Affecting the Removal of Residual DNAPL by Nonionic Surfactant Solutions. *Environ. Sci. Technol.,* **30,** 1852.

Oldenburg, C.M., and Pruess, K. (1996) Mixing with First-Order Decay in Variable-Velocity Porous Media Flow. *Transp. Porous Media,* **22,** 161.

Oldenburg, C.M.; Pruess, K.; and Travis, B.J. (1996) Dispersive Transport Dynamics in a Strongly Coupled Groundwater-Brine Flow System (Reply). *Water Resour. Res.,* **32,** 3411.

Olesen, T.; Moldrup, P.; Henriksen, K.; and Petersen, L.W. (1996) Modeling Diffusion and Reaction in Soils. IV. New Models for Predicting Ion Diffusivity. *Soil Sci.,* **161,** 633.

Olivella, S.; Carrera, J.; Gens, A.; and Alonso, E.E. (1996) Porosity Variations in Saline Media Caused by Temperature Gradients Coupled to Multiphase Flow and Dissolution/Precipitation. *Transp. Porous Media,* **25,** 1.

Ollila, P.W. (1996) Evaluating Natural Attentuation with Spreadsheet Analytical Fate and Transport Models. *Ground Water Monit. Remed.,* **16,** 69.

Olmos, F.; Chinesta, F.; and Torres, R. (1996) Finite Element Resolution of Convection-Diffusion Equations with Interior and Boundary Layers. *Int. J. Numerical Methods Fluids,* **22,** 643.

Oltean, C., and Buès, M.A. (1996) Two Two-Dimensional Simulation Codes for Modeling Salt Intrusion in Aquifers. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 717.

Oostrom, M.; Hofstee, C.; Dane, J.H.; and White, M.D. (1996) Simulation of a Quantitative Multi-Fluid Flow Experiment. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 449.

Oremland, R.S.; Lonergan, D.J.; Culbertson, C.W.; and Lovley, D.R. (1996) Microbial Degradation of Hydrochlorofluorocarbons (CHCl2F and CHCl2CF3) in Soils and Sediments. *Appl. Environ. Microbiol.,* **62,** 1818.

Oster, H.; Sonntag, C.; and Munnich, K.O. (1996) Groundwater Age Dating with Chlorofluorocarbons. *Water Resour. Res.,* **32,** 2989.

Ou, Z.Q.; Yediler, A.; He, Y.W.; Jia, L.Q.; Kettrup, A.; and Sun, T.H. (1996) Adsorption of Linear Alkylbenzene Sulfonate (LAS) on Soils. *Chemosphere,* **32,** 827.

Ouyang, Y.; Mansell, R.S.; and Rhue, R.D. (1996a) A Microemulsification Approach for Removing Organolead and Gasoline from Contaminated Soil. *J. Haz. Mater.,* **46,** 23.

Ouyang, Y.; Shinde, D.; Mansell, R.S.; and Harris, W. (1996b) Colloid-Enhanced Transport of Chemicals in Subsurface Environments: A Review. *Crit. Rev. Environ. Sci. Technol.,* **26,** 189.

Overby, R., and Pedlar, B. (1996) Horizontal Well Application for Dual-Phase Extraction. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 253.

Paillère, H.; Boxho, J.; Degrez, G.; and Deconinck, H. (1996) Multidimensional Upwind Residual Distribution Schemes for the Convection-Diffusion Equation. *Int. J. Numerical Methods Fluids,* **23,** 923.

Pakrou, N., and Dillon, P. (1995) Preferential Flow, Nitrogen Transformations and N-15 Balance Under Urine-Affected Areas of Irrigated and Non-Irrigated Clover-Based Pastures. *J. Contam. Hydrol.*, **20,** 329.

Pantani, O.; Pusino, A.; Calamai, L.; Gessa, C.; and Fusi, P. (1996) Adsorption and Degradation of Rimsulfuron on Al Hectorite. *J. Agric. Food Chem.*, **44,** 3412.

Papiernik, T.D.; Widmer, S.K.; and Spalding, R.F. (1996) Effect of Various Materials in Multilevel Samplers on Monitoring Commonly Occurring Agrichemicals in Ground Water. *Ground Water Monit. Remed.*, **16,** 80.

Park, N. (1996) Closed-Form Solutions for Steady State Density-Dependent Flow and Transport in a Vertical Soil Column. *Water Resour. Res.*, **32,** 1317.

Parmentier, P.P., and Klemovich, R.M. (1996) A New Direction in Remediation. *Civil Eng.*, **66,** 55.

Pasquarell, G.C., and Boyer, D.G. (1996) Herbicides in Karst Groundwater in Southeast West Virginia. *J. Environ. Qual.*, **25,** 755.

Pasti-Grigsby, M.B.; Lewis, T.A.; Crawford, D.L.; and Crawford, R.L. (1996) Transformation of 2,4,6-Trinitrotoluene (TNT) by Actinomycetes Isolated from TNT-Contaminated and Uncontaminated Environments. *Appl. Environ. Microbiol.*, **62,** 1120.

Patterson, C.G., and Runnells, D.D. (1996) A Field Test of Electromigration as a Method for Remediating Sulfate from Shallow Ground Water. *Ground Water Monit. Remed.*, **16,** 63.

Paunov, V.N.; Angelopoulos, A.; and Burganos, V.N. (1996) Lattice-Boltzmann Simulation of Ideal and Nonideal Immiscible Two-Phase Flow in Porous Media. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 457.

Pawell, A., and Krannich, K.D. (1996) Dissolution Effects in Transport in Porous Media. *SIAM J. Appl. Math.*, **56,** 89.

Pearcy, E.C.; Prikryl, J.D.; and Leslie, B.W. (1995) Uranium Transport Through Fractured Silicic Tuff and Relative Retention in Areas with Distinct Fracture Characteristics. *Appl. Geochem.*, **10,** 685.

Pearson, R.J.; Inskeep, W.P.; Wraith, J.M.; Comford, S.D.; and Gaber, H.M. (1996a) Observed and Simulated Solute Transport Under Varying Water Regimes. I. Bromide and Pentafluorobenzoic acid. *J. Environ. Qual.*, **25,** 646.

Pearson, R.J.; Inskeep, W.P.; Wraith, J.M.; Gaber, H.M.; and Comfort, S.D. (1996b) Observed and Simulated Solute Transport under Varying Wafer Regimes. II. 2,6-Difluorobenzoic Acid and Dicamba. *J. Environ. Qual.*, **25,** 654.

Pedit, J.A., and Miller, C.T. (1996) A Distributed Reactivity Model for Sorption by Soils and Sediments. IV. Intraparticle Heterogeneity and Phase Distribution Relationships Under Nonequilibrium Conditions (Comment). *Environ. Sci. Technol.*, **30,** 3128.

Pelmulder, S.D.; Yeh, W.W.G.; and Kastenberg, W.E. (1996) Regional Scale Framework for Modeling Water Resources and Health Risk Problems. *Water Resour. Res.*, **32,** 1851.

Pennell, K.D.; Pope, G.A.; and Abriola, L.M. (1996) Influence of Viscous and Buoyancy Forces on the Mobilization of Residual Tetrachloroethylene During Surfactant Flushing. *Environ. Sci. Technol.*, **30,** 1328.

Pereira, G.G.; Pinczewski, W.V.; Chan, D.Y.C.; Paterson, L.; and Oren, P.E. (1996) Pore-Scale Network Model for Drainage-Dominated Three-Phase Flow in Porous Media. *Transp. Porous Media,* **24,** 167.

Perkovich, B.S.; Anderson, T.A.; Kruger, E.L.; and Coats, J.R. (1996) Enhanced Mineralization of [C-14]Atrazine in Kochia Scoparia Rhizospheric Soil from a Pesticide-Contaminated Site. *Pestic. Sci.*, **46,** 391.

Petersen, L.W.; Elfarhan, Y.H.; Moldrup, P.; Rolston, D.E.; and Yamaguchi, T. (1996) Transient Diffusion, Adsorption, and Emission of Volatile Organic Vapors in Soils with Fluctuating Low Water Contents. *J. Environ. Qual.*, **25,** 1054.

Petitjeans, P., and Maxworthy, T. (1996) Miscible Displacements in Capillary Tubes. I. Experiments. *J. Fluid Mech.*, **326,** 37.

Peyton, B.M. (1996) Improved Biomass Distribution Using Pulsed Injections of Electron Donor and Acceptor. *Water Res.* (G.B.), **30,** 756.

Philip, J.R. (1996) Some Exact Solutions of Convection-Diffusion and Diffusion Equations (Reply). *Water Resour. Res.*, **32,** 489.

Phillips, F.M.; Rogers, D.B.; Dreiss, S.J.; Jannik, N.O.; and Elmore, D. (1995) Chlorine 36 in Great Basin Waters: Revisited. *Water Resour. Res.*, **31,** 3195.

Phillips, I., and Chapple, L. (1995) Assessment of a Heavy Metals-Contaminated Site Using Sequential Extraction, TCLP, and Risk Assessment Techniques. *J. Soil Contam.*, **4,** 311.

Piatt, J.J.; Backhus, D.A.; Capel, P.D.; and Eisenreich, S.J. (1996) Temperature-Dependent Sorption of Naphthalene, Phenanthrene and Pyrone to Low Organic Carbon Aquifer Sediments. *Environ. Sci. Technol.*, **30,** 751.

Pieuchot, M.; Perringanier, C.; Portal, J.M.; and Schiavon, M. (1996) Study on the Mineralization and Degradation of Isoproturon in Three Soils. *Chemosphere,* **33,** 467.

Piggott, A.R., and Novakowski, K.S. (1996) Determination of Solution Criteria for a Semianalytical Model of Solute Transport. *Comput. Geosci.*, **22,** 441.

Piggott, J.H., and Cawlfield, J.D. (1996) Probabilistic Sensitivity Analysis for One-Dimensional Contaminant Transport in the Vadose Zone. *J. Contam. Hydrol.*, **24,** 97.

Piontek, K.; Maloney, T.; and Miller, T. (1996) Evaluation of Sampling and Analytical Methods for Measuring Indicators of Intrinsic Bioremediation. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 207.

Pistiner, A., and Shapiro, M. (1996) A Model of Groundwater Pollution from an Underground Source. *Water Resour. Res.*, **32,** 2311.

Pivetz, B.E.; Kelsey, J.W.; Steenhuis, T.S.; and Alexander, M. (1996) A Procedure to Calculate Biodegradation During Preferential Flow Through Heterogeneous Soil Columns. *Soil Sci. Soc. Am. J.*, **60,** 381.

Porter, L.K. (1995) Depleted N-15 Carryover, Leaching and Uptake for Three Years of Irrigated Corn. *J. Contam. Hydrol.*, **20,** 209.

Potter, T.L. (1996) Analysis of Petroleum-Contaminated Water by GC/FID with Direct Aqueous Injection. *Ground Water Monit. Remed.*, **16,** 157.

Poulsen, T.G.; Massmann, J.W.; and Moldrup, P. (1996) Effects of Vapor Extraction on Contaminant Flux to Atmosphere and Ground Water. *J. Environ. Eng.*, **122,** 700.

Powers, S.E.; Anckner, W.H.; and Seacord, T.F. (1996) Wettability of NAPL-Contaminated Sands. *J. Environ. Eng.*, **122,** 889.

Prakash, A. (1996) Desorption of Soil Contaminants Due to Rainwater Infiltration. *J. Hydraul. Eng.*, **122,** 523.

Pruess, K. (1996) A Fickian Diffusion Model for the Spreading of Liquid Plumes Infiltrating in Heterogeneous Media. *Transp. Porous Media,* **24,** 1.

Ptak, T., and Schmid, G. (1996) Dual-Tracer Transport Experiments in a Physically and Chemically Heterogeneous Porous Aquifer: Effective Transport Parameters and Spatial Variability. *J. Hydrol.* (Neth.), **183,** 117.

Purdy, C.B.; Helz, G.R.; Mignerey, A.C.; Kubik, P.W.; Elmore, D.; Sharma, P.; and Hemmick, T. (1996) Aquia Aquifer Dissolved Cl- and Cl-36/Cl: Implications for Flow Velocities. *Water Resour. Res.*, **32,** 1163.

Pusino, A.; Petretto, S.; and Gessa, C. (1996) Montmorillonite Surface-Catalyzed Hydrolysis of Fenoxaprop-Ethyl. *J. Agric. Food Chem.*, **44,** 1150.

Qiao, X.W.; Ma, L.P.; and Hummel, H.E. (1996) Persistence of Atrazine and Occurrence of Its Primary Metabolites in Three Soils. *J. Agric. Food Chem.*, **44,** 2846.

Quanrud, D.M.; Arnold, R.G.; Wilson, L.G.; and Conklin, M.H. (1996a) Effect of Soil Type on Water Quality Improvement During Soil Aquifer Treatment. *Water Sci. Technol.* (G.B.), **33,** 419.

Quanrud, D.M.; Arnold, R.G.; Wilson, L.G.; Gordon, H.J.; Graham, D.W.; and Amy, G.L. (1996b) Fate of Organics during Column Studies of Soil Aquifer Treatment. *J. Environ. Eng.*, **122,** 314.

Rabbani, M.G. (1996) Direct Formulation Finite Element Method for Two-Dimensional Ground-Water Pollution Modelling with a Comparison with Conventional Finite Element Method. *Int. J. Numerical Methods Eng.*, **39,** 2575.

Race, K.C., and Phillips, I.M. (1996) Streamlining the Cleanup Process and Achieving Regulatory Closure for Two Industrial Sites in Massachusetts. *Proc. 10th Natl. Outdoor Action. Conf.*, Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 159.

Racke, K.D.; Steele, K.P.; Yoder, R.N.; Dick, W.A.; and Avidov, E. (1996) Factors Affecting the Hydrolytic Degradation of Chlorpyrifos in Soil. *J. Agric. Food Chem.*, **44,** 1582.

Radcliffe, D.E.; Tillotson, P.M.; Hendrix, P.F.; West, L.T.; Box, J.E.; and Tollner, E.W. (1996) Anion Transport in a Piedmont Ultisol. I. Field-Scale Parameters. *Soil Sci. Soc. Am. J.*, **60,** 755.

Radenkova-Yaneva, M.; Kostakeva, E.; and Toshev, D. (1995) Contaminant Migration from Sanitary Landfill Leachate Through Soil Monoliths. *Water Sci. Technol.* (G.B.), **32,** 215.

Rae, J.E., and Malik, S.A. (1996) The Determination of Iodine in Geochemical Samples: The Use of Pyrohydrolytic Decomposition. *Chemosphere,* **33,** 2121.

Ragab, R.; Cooper, D.M.; Harris, G.L.; and Catt, J.A. (1996) Simulating Nitrate Leaching Under Winter Wheat Grown on a Structured Clay Soil Considering Bypass Flow. *J. Hydrol.* (Neth.), **182,** 157.

Rajaram, H. (1996) Taylor Dispersion Analysis of the Influence of Matrix Diffusion on Solute Transport in Fractures. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 279.

Rao, K.S. (1996) Finite Element Digital Model for Longitudinal Dispersion of Pollutant in Porous Media. *Water Sci. Technol.* (G.B.), **33,** 79.

Rashed, M.; Awad, S.R.; Salam, M.A.; and Smidt, E. (1995) Monitoring of Groundwater in Gabal el Asfar Wastewater Irrigated Area (Greater Cairo). *Water Sci. Technol.* (G.B.), **32,** 163.

Rashidi, M.; Peurrung, L.; Tompson, A.F.B.; and Kulp, T.J. (1996) Experimental Analysis of Pore-Scale Flow and Transport in Porous Media. *Adv. Water Resour.*, **19,** 163.

Rathfelder, K.M.; Lang, J.R.; and Abriola, L.M. (1996) Mathematical Modeling of Rate-Limited Transport and Biotransformation in the Vadose Zone. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 135.

Rautman, C.A., and Istok, J.D. (1996) Probabilistic Assessment of Ground-Water Contamination. I. Geostatistical Framework. *Ground Water,* **34,** 899.

Ray, A.B.; Ma, J.Z.; and Borst, M. (1995) Adsorption of Surfactant on Clays. *Haz. Waste Haz. Mater.*, **12,** 357.

Ray, C., and Schock, S.C. (1996) Comparability of Large-Scale Studies of Agricultural Chemical Contamination of Rural Private Wells. *Ground Water Monit. Remed.*, **16,** 92.

Rebhun, M.; Desmedt, F.; and Rwetabula, J. (1996) Dissolved Humic Substances for Remediation of Sites Contaminated by Organic Pollutants. Binding-Desorption model predictions. *Water Res.* (G.B.), **30,** 2027.

Reddi, L.N., and Wu, H. (1996) Mechanisms Involved in Vibratory Destabilization of NAPL Ganglia in Sands. *J. Environ. Eng.*, **122,** 1115.

Reddy, H.L., and Ford, R.M. (1996) Analysis of Biodegradation and Bacterial Transport: Comparison of Models with Kinetic and Equilibrium Bacterial Adsorption. *J. Contam. Hydrol.*, **22,** 271.

Reed, B.E.; Moore, R.E.; and Cline, S.R. (1995) Soil Flushing of a Sandy Loam Contaminated with Pb(II), $PbSO_4$(s), $PbCO_3$(3), or Pb-Naphthalene: Column Results. *J. Soil Contam.*, **4,** 243.

Reed, B.E.; Carriere, P.C.; and Moore, R. (1996a) Flushing of a Pb(II) Contaminated Soil Using HCl, EDTA, and CaCl2. *J. Environ. Eng.*, **122,** 48.

Reed, B.E.; Carriere, P.C.; Thompson, J.C.; and Hatfield, J.H. (1996b) Electronic (EK) Remediation of a Contaminated Soil at Several Pb Concentrations and Applied Voltages. *J. Soil Contam.*, **5,** 95.

Reeves, P.C., and Celia, M.A. (1996) A Functional Relationship Between Capillary Pressure, Saturation, and Interfacial Area as Revealed by a Pore-Scale Network Model. *Water Resour. Res.*, **32,** 2345.

Remde, A., and Debus, R. (1996) Biodegradability of Fluorinated Surfactants Under Aerobic and Anaerobic Conditions. *Chemosphere* (G.B.), **32,** 1563.

Remenda, V.H.; Vanderkamp, G.; and Cherry, J.A. (1996) Use of Vertical Profiles of Delta O-18 to Constrain Estimates of Hydraulic Conductivity in a Thick, Unfractured Aquitard. *Water Resour. Res.*, **32,** 2979.

Ren, G.L.; Izadi, B.; King, B.; and Dowding, E. (1996) Preferential Transport of Bromide in Undisturbed Cores Under Different Irrigation Methods. *Soil Sci.*, **161,** 214.

Resnick, S.M., and Gibson, D.T. (1996) Regio- and Stereospecific Oxidation of Fluorene, Dibenzofuran, and Dibenzothiophene by Naphthalene Dioxygenase from Pseudomonas sp Strain NCIB 9816-4. *Appl. Environ. Microbiol.*, **62,** 4073.

Revesz, K.; Coplen, T.B.; Baedecker, M.J.; Glynn, P.D.; and Hult, M. (1995) Methane Production and Consumption Monitored by Stable H and C Isotope Ratios at a Crude Oil Spill Site, Bemidji, Minnesota. *Appl. Geochem.*, **10,** 505.

Rhode, D.R. (1996) Quality Assurance in Environmental Data Interpretation—RCRA and Superfund Programs. *Proc. 10th Natl. Outdoor Action. Conf.*, Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 131.

Rice, P.J.; Anderson, T.A.; Cink, J.H.; and Coats, J.R. (1996) The Influence of Soil Environmental Variables on the Degradation and Volatility of Methyl Bromide in Soil. *Environ. Toxicol. Chem.*, **15,** 1723.

Richards, R.P.; Baker, D.B.; Creamer, N.L.; Kramer, J.W.; Ewing, D.E.; Merryfield, B.J.; and Wallrabenstein, L.K. (1996a) Well Water Quality, Well Vulnerability, and Agricultural Contamination in the Midwestern United States. *J. Environ. Qual.*, **25,** 389.

Richards, R.P.; Baker, D.B.; Creamer, N.L.; Kramer, J.W.; Ewing, D.E.; Merryfield, B.J.; and Wallrabenstein, L.K. (1996b) Well Water Quality, Well Vulnerability, and Agricultural Contamination in the Midwestern United States. *J. Environ. Qual.*, **25,** 930.

Rijnaarts, H.H.M.; Norde, W.; Bouwer, E.J.; Lyklema, J.; and Zehnder, A.J.B. (1996a) Bacterial Deposition in Porous Media Related to the Clean Bed Collision Efficiency and to Substratum Blocking by Attached Cells. *Environ. Sci. Technol.*, **30,** 2869.

Rijnaarts, H.H.M.; Norde, W.; Bouwer, E.J.; Lyklema, J.; and Zehnder, A.J.B. (1996b) Bacterial Deposition in Porous Media: Effects of Cell-Coating, Substratum Hydrophobicity, and Electrolyte Concentration. *Environ. Sci. Technol.*, **30,** 2877.

Rimmer, A.; Parlange, J.Y.; Steenhuis, T.S.; Darnault, C.; and Condit, W. (1996) Wetting and Nonwetting Fluid Displacements in Porous Media. *Transp. Porous Media,* **25,** 205.

Ritz, S.M., and Weston, R.F. (1996) Natural Attenuation of Petroleum Hydrocarbons and Chlorinated Solvents in Groundwater: A State Policy Overview. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 415.

Rixey, W.G. (1996) The Long-Term Dissolution Characteristics of a Residually Trapped BTX Mixture in Soil. *Haz. Waste Haz. Mater.*, **13,** 197.

Rixey, W.G., and Garg, S. (1996) An Assessment of the Finite Leaching Characteristics of Contaminated Soils and Oily Wastes. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.*, Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 273.

Rizzo, D.M., and Dougherty, D.E. (1996a) Solving Groundwater Inverse Problems Using Artificial Neural Networks. *Computat. Meth. Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 313.

Rizzo, D.M., and Dougherty, D.E. (1996b) Design Optimization for

Multiple Management Period Groundwater Remediation. *Water Resour. Res.,* **32,** 2549.

Robertson, B.K., and Alexander, M. (1996) Mitigating Toxicity to Permit Bioremediation of Constituents of Nonaqueous Phase Liquids. *Environ. Sci. Technol.,* **30,** 2066.

Rochette, E.A., and Koskinen, W.C. (1996) Supercritical Carbon Dioxide for Determining Atrazine Sorption by Field-Moist Soils. *Soil Sci. Soc. Am. J.,* **60,** 453.

Rockhold, M.L.; Rossi, R.E.; and Hills, R.G. (1996) Application of Similar Media Scaling and Conditional Simulation for Modeling Water Flow and Tritium Transport at the Las Cruces Trench Site. *Water Resour. Res.,* **32,** 595.

Rogers, D.B., and Dreiss, S.J. (1995a) Saline Groundwater in Mono Basin, California. I. Distribution. *Water Resour. Res.,* **31,** 3131.

Rogers, D.B., and Dreiss, S.J. (1995b) Saline Groundwater in Mono Basin, California. II. Long-Term Control of Lake Salinity by Groundwater. *Water Resour. Res.,* **31,** 3151.

Rogers, D.T.; Doxtader, S.K.; Copeland, C.; and Metcalf, M. (1996) Evaluation of Intrinsic Bioremediation of Gasoline-Contaminated Groundwater in Glacial and Postglacial-Generated Sediments. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 323.

Romine, M.F., and Brockman, F.J. (1996) Recruitment and Expression of Toluene/Trichloroethylene Biodegradation Genes in Bacteria Native to Deep-Subsurface Sediments. *Appl. Environ. Microbiol.,* **62,** 2647.

Romkens, P.F.; Bril, J.; and Salomons, W. (1996) Interaction Between Ca2+ and Dissolved Organic Carbon: Implications for Metal Mobilization. *Appl. Geochem.,* **11,** 109.

Ronen, D.; Yechieli, Y.; and Shatkay, M. (1996) Characterization of Water and Solute Transport in the Unsaturated Zone of a Hypersaline Environment. *Water Resour. Res.,* **32,** 3267.

Ronen, Z.; Bollag, J.M.; Hsu, C.H.; and Young, J.C. (1996) Feasibility of Bioremediation of a Ground Water Polluted with Alkylpyridines. *Ground Water,* **34,** 194.

Rose, T.P.; Davisson, M.L.; and Criss, R.E. (1996) Isotope Hydrology of Voluminous Cold Springs in Fractured Rock From an Active Volcanic Region, Northeastern California. *J. Hydrol.* (Neth.), **179,** 207.

Roth, K., and Hammel, K. (1996) Transport of Conservative Chemical Through an Unsaturated Two-Dimensional Miller-Similar Medium with Steady State Flow. *Water Resour. Res.,* **32,** 1653.

Rouse, J.D.; Sabatini, D.A.; Brown, R.E.; and Harwell, J.H. (1996) Evaluation of Ethoxylated Alkylsulfate Surfactants for Use in Subsurface Remediation. *Water Environ. Res.,* **68,** 162.

Rozycki, A. (1996) Analysis of a Marine Intrusion by Parameters Derived from Salt-Water Conductivity. *Ground Water,* **34,** 1076.

Rubin, H., and Buddemeier, R.W. (1996a) A Top Specified Boundary Layer (TSBL) Approximation Approach for the Simulation of Groundwater Contamination Processes. *J. Contam. Hydrol.,* **22,** 123.

Rubin, H., and Buddemeier, R.W. (1996b) Transverse Dispersion of Contaminants in Fractured Permeable Formations. *J. Hydrol.* (Neth.), **176,** 133.

Rubin, H.; Bodarwe, H.; Forkel, C.; and Kongeter, J. (1996a) Contaminant Transport in Fractured Permeable Formations. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 287.

Rubin, H.; Soliman, A.M.; Birkholzer, J.; and Rouve, G. (1996b) Transport of a Tracer Slug in a Fractured Permeable Formation. *J. Hydrol.* (Neth.), **176,** 153.

Rudolph, D.L.; Kachanoski, R.G.; Celia, M.A.; Leblanc, D.R.; and Stevens, J.H. (1996) Infiltration and Solute Transport Experiments in Unsaturated Sand and Gravel, Cape Cod, Massachusetts: Experimental Design and Overview of Results. *Water Resour. Res.,* **32,** 519.

Russell, K.T., and Rabideau, A.J. (1996) Performance of an Air Sparging System for Removal of Volatile Organic Compounds from Groundwater. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 77.

Russo, D. (1996) Stochastic Analysis of Mass Flux of Sorptive Solutes in Unsaturated Heterogeneous Anisotropic Porous Formations. *Water Resour. Res.,* **32,** 3243.

Rutherford, K.W., and Johnson, P.C. (1996) Effects of Process Control Changes on Aquifer Oxygenation Rates During In Situ Air Sparging in Homogeneous Aquifers. *Ground Water Monit. Remed.,* **16,** 132.

Ryan, R.G., and Dhir, V.K. (1996) The Effect of Interfacial Tension on Hydrocarbon Entrapment and Mobilization Near a Dynamic Water Table. *J. Soil Contam.,* **5,** 9.

Rytwo, G.; Nir, S.; and Margulies, L. (1996) Adsorption and Interactions of Diquat and Paraquat with Montmorillonite. *Soil Sci. Soc. Am. J.,* **60,** 601.

Saaf, F.; Tapia, R.A.; Bryant, S.; and Wheeler, M.F. (1996) Computing General Chemical Equilibria with an Interior-Point Method. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 201.

Saaltink, M.W.; Carrera, J.; and Ayora, C. (1996) On the Numerical Formulation of Reactive TrAnsport Problems. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 123.

Sacan, M.T., and Balcioglu, I.A. (1996) Prediction of the Soil Sorption Coefficient of Organic Pollutants by the Characteristic Root Index Model. *Chemosphere* (G.B.), **32,** 1993.

Sadeghi, A.M., and Isensee, A.R. (1996) Impact of Reversing Tillage Practices on Movement and Dissipation of Atrazine in Soil. *Soil Sci.,* **161,** 390.

Sadeghi, A.M.; Isensee, A.R.; and Shirmohammadi, A. (1995) Atrazine Movement in Soil: Comparison of Field Observations and PRZM Simulations. *J. Soil Contam.,* **4,** 151.

Sadiq, M., and Alam, I. (1996) Arsenic Chemistry in a Groundwater Aquifer from the Eastern Province of Saudi Arabia. *Water Air Soil Pollut.* (Neth.), **89,** 67.

Sadler, L.Y., and Donald, C.S. (1996) Effects of Organic Liquids on the Permeability of Selma Chalk. *Haz. Waste Haz. Mater.,* **13,** 351.

Saeed, I.A.M.; Harkin, J.M.; and Rouse, D.I. (1996) Leaching of Methyl Isothiocyanate in Plainfield Sand Chemigated with Metam-Sodium. *Pestic. Sci.,* **46,** 375.

Saiers, J.E., and Hornberger, G.M. (1996a) Migration of Cs-137 Through Quartz Sand: Experimental Results and Modeling Approaches. *J. Contam. Hydrol.,* **22,** 255.

Saiers, J.E., and Hornberger, G.M. (1996b) The Role of Colloidal Kaolinite in the Transport of Cesium Through Laboratory Sand Columns. *Water Resour. Res.,* **32,** 33.

Saiers, J.E., and Hornberger, G.M. (1996c) Modeling Bacteria-Facilitated Transport of DDT. *Water Resour. Res.,* **32,** 1455.

Sale, T.C., and Applegate, D.H. (1996) Oil Recovery at a Former Wood-Treating Facility. *Water Environ. Res.,* **68,** 1116.

Salim, I.A.; Miller, C.J.; and Howard, J.L. (1996) Sorption Isotherm-Sequential Extraction Analysis of Heavy Metal Retention in Landfill Liners. *Soil Sci. Soc. Am. J.,* **60,** 107.

Sanders, P.F. (1995) Calculation of Soil Cleanup Criteria for Volatile Organic Compounds as Controlled by the Soil-to-Groundwater Pathway: Comparison of Four Unsaturated Soil Zone Leaching Models. *J. Soil Contam.,* **4,** 1.

Sandoli, R.L.; Ghiorse, W.C.; and Madsen, E.L. (1996) Regulation of Microbial Phenanthrene Mineralization in Sediment Samples by Sorbent-Sorbate Contact Time, Inocula and Gamma Irradiation-Induced Sterilization Artifacts. *Environ. Toxicol. Chem.,* **15,** 1901.

Sanford, W.E.; Shropshire, R.G.; and Solomon, D.K. (1996) Dissolved Gas Tracers in Ground-Water: Simplified Injection, Sampling, and Analysis. *Water Resour. Res.,* **32,** 1635.

Sätmark, B.; Albinsson, Y.; and Liang, L. (1996) Chemical Effects of Goethite Colloid on the Transport of Radionuclides Through a Quartz-Packed Column. *J. Contam. Hydrol.,* **21,** 231.

Saunders, J.A., and Toran, L.E. (1995) Modeling of Radionuclide and

Heavy Metal Sorption Around Low- and High-pH Waste Disposal Sites at Oak Ridge, Tennessee. *Appl. Geochem.*, **10,** 673.

Sawicki, A. (1996) Modeling Pumping of Saline Water from Two-Layer Aquifer. *J. Hydraul. Eng.*, **122,** 341.

Sawyer, G.M. (1996) Determination of Gasoline Range, Diesel Range, and Mineral Oil Range Organics in Soils and Water by Flame Ionization Gas Chromatography. *J. Soil Contam.*, **5,** 261.

Schaal, W., and Cox, C.L. (1996) Increased Yield from a Shallow Aquifer Using Enhanced Vacuum Recovery. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 515.

Schade, W., and Bublitz, J. (1996) On-Site Laser Probe for the Detection of Petroleum Products in Water and Soil. *Environ. Sci. Technol.*, **30,** 1451.

Schafer, D.C. (1996) Determining 3D Capture Zones in Homogeneous, Anisotropic Aquifers. *Ground Water,* **34,** 628.

Schafer, W., and Kinzelbach, W.K.H. (1996) Transport of Reactive Species in Heterogeneous Porous Media. *J. Hydrol.* (Neth.), **183,** 151.

Schaffner, I.R.; Hawkins, E.F.; and Wieck, J.M. (1996) Screening Study of Chlorinated Aliphatic Hydrocarbon Intrinsic Bioremediation at a Southern New Hampshire Site. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 339.

Schepers, J.S.; Varvel, G.E.; and Watts, D.G. (1995) Nitrogen and Water Management Strategies to Reduce Nitrate Leaching Under Irrigated Maize. *J. Contam. Hydrol.*, **20,** 227.

Schilling, K.E., and Hoyle, B.L. (1996) Tracer Test to Evaluate Dilution of Ground Water from Lost Circulation. *Ground Water Monit. Remed.*, **16,** 124.

Schima, S.; Labrecque, D.J.; and Lundegard, P.D. (1996) Monitoring Air Sparging Using Resistivity Tomography. *Ground Water Monit. Remed.*, **16,** 131.

Schirmer, M.; Jones, I.; Teutsch, G.; and Lerner, D.N. (1995) Development and Testing of Multiport Sock Samplers for Groundwater. *J. Hydrol.* (Neth.), **171,** 239.

Schleussinger, A.; Ohlmeier, B.; Reiss, I.; and Schulz, S. (1996) Moisture Effects on the Cleanup of PAH-Contaminated Soil with Dense Carbon Dioxide. *Environ. Sci. Technol.*, **30,** 3199.

Schlüter, K.; Alstad, J.; and Seip, H.M. (1995a) Mercury Translocation in and Evaporation from Soil. I. Soil Lysimeter Experiments with ^{203}Jg-Radiolabeled Compounds. *J. Soil Contam.*, **4,** 327.

Schlüter, K.; Seip, H.M.; and Alstad, J. (1995b) Mercury Translocation in and Evaporation from Soil. II. Evaporation of Mercury from Podzolized Soil Profiles Treated with $HgCl_2$ and CH_3HgCl. *J. Soil Contam.*, **4,** 269.

Schmidt, G.W. (1996) Forensic Geochemistry for Hydrocarbon Releases. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 549.

Schramke, J.A.; Murphy, E.M.; and Wood, B.D. (1996) The Use of Geochemical Mass-Balance and Mixing Models to Determine Groundwater Sources. *Appl. Geochem.*, **11,** 523.

Schulthess, C.P., and Dey, D.K. (1996) Estimation of Langmuir Constants Using Linear and Nonlinear Least Squares Regression Analyses. *Soil Sci. Soc. Am. J.*, **60,** 433.

Scrivner, N.C.; Butler, P.B.; and Karmazyn, J. (1996) Modeling: An Excellent Solution for Remediation. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 43.

Seaman, J.C.; Bertsch, P.M.; Korom, S.F.; and Miller, W.P. (1996) Physicochemical Controls on Nonconservative Anion Migration in Coarse-Textured Alluvial Sediments. *Ground Water,* **34,** 778.

Selifonov, S.A.; Grifoll, M.; Eaton, R.W.; and Chapman, P.J. (1996) Oxidation of Naphthenoaromatic and Methyl-Substituted Aromatic Compounds by Naphthalene 1,2-Dioxygenase. *Appl. Environ. Microbiol.*, **62,** 507.

Serlin, C.L., and Kaplan, L.M. (1996) Field Comparison of Micropurge and Traditional Ground Water Sampling for Volatile Organic Compounds. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 177.

Serrano, S.E. (1996) The Form of the Dispersion Equation Under Recharge and Variable Velocity, and Its Analytical Solution (Reply). *Water Resour. Res.*, **32,** 2967.

Seta, A.K., and Karathanasis, A.D. (1996) Colloid-Facilitated Transport of Metolachlor Through Intact Soil Columns. *J. Environ. Sci. Health Part B Pestic. Food Contam. Agric. Wastes,* **31,** 949.

Sexton, B.T.; Moncrief, J.F.; Rosen, C.J.; Gupta, S.C.; and Cheng, H.H. (1996) Optimizing Nitrogen and Irrigation Inputs for Corn Based on Nitrate Leaching and Yield on a Coarse-Textured Soil. *J. Environ. Qual.*, **25,** 982.

Shaffer, M.J.; Wylie, B.K.; and Hall, M.D. (1995) Identification and Mitigation of Nitrate Leaching Hot Spots Using NLEAP-GIS Technology. *J. Contam. Hydrol.*, **20,** 253.

Shah, F.H.; Hadim, H.A.; and Korfiatis, G.P. (1995) Laboratory Studies of Air Stripping of VOC-Contaminated Soils. *J. Soil Contam.*, **4,** 93.

Shanableh, A., and Kharabsheh, A. (1996) Stabilization of Cd, Ni and Pb in Soil Using Natural Zeolite. *J. Haz. Mater.*, **45,** 207.

Shapiro, A.A., and Stenby, E.H. (1996) On the Nonequilibrium Segregation State of a Two-Phase Mixture in a Porous Column. *Transp. Porous Media,* **23,** 83.

Sharma, P.K., and McCarty, P.L. (1996) Isolation and Characterization of a Facultatively Aerobic Bacterium that Reductively Dehalogenates Tetrachloroethene to Cis-1,2-Dichloroethene. *Appl. Environ. Microbiol.*, **62,** 761.

Shati, M.R.; Ronen, D.; and Mandelbaum, R. (1996) Method for In Situ Study of Bacterial Activity in Aquifers. *Environ. Sci. Technol.*, **30,** 2646.

She, Y.; Sleep, B.; and Mackay, D., (1995) A Fugacity Model for Soil Vapor Extraction. *J. Soil Contam.*, **4,** 227.

Shen, H.; Pritchard, P.H.; and Sewell, G.W. (1996) Microbial Reduction of Cr(VI) During Anaerobic Degradation of Benzoate. *Environ. Sci. Technol.*, **30,** 1667.

Shen, J., and Bartha, R. (1996a) Priming Effect of Substrate Addition in Soil-Based Biodegradation Tests. *Appl. Environ. Microbiol.*, **62,** 1428.

Shen, J., and Bartha, R. (1996b) Metabolic Efficiency and Turnover of Soil Microbial Communities in Biodegradation Tests. *Appl. Environ. Microbiol.*, **62,** 2411.

Sheng, G.Y.; Xu, S.H.; and Boyd, S.A. (1996) Mechanism(s) Controlling Sorption of Neutral Organic Contaminants by Surfactant-Derived and Natural Organic Matter. *Environ. Sci. Technol.*, **30,** 1553.

Sheppard, S.C., and Evenden, W.G. (1996) Retention of Inorganic Carbon-14 by Isotopic Exchange in Soils. *J. Environ. Qual.*, **25,** 1153.

Shih, E.H.H., and Griffin, D.E. (1996) Multiphase Extraction (Bioslurping) of JP-4 Impacted Soil and Groundwater Kanto Plain, Japan. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 379.

Shipitalo, M.J., and Edwards, W.M. (1996) Effects of Initial Water Content on Macropore/Matrix Flow and Transport of Surface-applied Chemicals. *J. Environ. Qual.*, **25,** 662.

Shurtliff, M.M.; Parkin, G.F.; Weathers, L.J.; and Gibson, D.T. (1996) Biotransformation of Trichloroethylene by a Phenol-Induced Mixed Culture. *J. Environ. Eng.*, **122,** 581.

Sidle, W.C., and Lee, P.Y. (1996) Uranium Contamination in the Great Miami Aquifer at the Fernald Environmental Management Project, Fernald, Ohio. *Ground Water,* **34,** 876.

Siegel, P.; Blaschke, A.P.; and Acker, P. (1996) Inverse Problem Applied to Groundwater Flow and Transport Equations Using a Downscaling Parameterization. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 321.

Silliman, S.E. (1996) The Importance of the Third Dimension on Transport Through Saturated Porous Media: Case Study Based on Transport of Particles. *J. Hydrol.* (Neth.), **179,** 181.

Sim, Y., and Chrysikopoulos, C.V. (1996a) One-Dimensional Virus

Transport in Porous Media with Time-Dependent Inactivation Rate Coefficients. *Water Resour. Res.,* **32,** 2607.

Sim, Y., and Chrysikopoulos, C.V. (1996b) Analytical Models for One-Dimensional Virus Transport in Saturated Porous Media. *Water Resour. Res.,* **32,** 1473.

Simon, R.D., and Cooper, G.A. (1996) Cryogenic Drilling: A New Drilling Method for Environmental Remediation. *Ground Water Monit. Remed.,* **16,** 79.

Simons, G.A., (1996) Extension of the "Pore Tree" Model to Describe Transport in Soil. *Ground Water,* **34,** 683.

Sims, R.; Lawless, T.A.; Alexander, J.L.; Bennett, D.G.; and Read, D. (1996) Uranium Migration Through Intact Sandstone: Effect of Pollutant Concentration and the Reversibility of Uptake. *J. Contam. Hydrol.,* **21,** 215.

Singh, G.; Vangenuchten, M.T.; Spencer, W.F.; Cliath, M.M.; and Yates, S.R. (1996) Measured and Predicted Transport of Two S-Triazine Herbicides Through Soil Columns. *Water, Air, Soil Pollut.* (Neth.), **86,** 137.

Skaggs, R.L.; Vail, L.W.; and Mays, L.W. (1996) Enhanced Annealing Applied to Design of Groundwater Restoration Systems. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex, 3.

Skaggs, T.H., and Barry, D.A. (1996) Sensitivity Methods for Time-Continuous, Spatially Discrete Groundwater Contaminant Transport Models. *Water Resour. Res.,* **32,** 2409.

Skouras, E.D.; Paraskeva, C.A.; Burganos, V.N.; and Payatakes, A.C. (1996) Simulation of Particle Deposition and Loss of Permeability During Flow of Aqueous Suspensions in Underground Formations. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 245.

Smith, J.A.; Tisdale, A.K.; and Cho, H.J. (1996) Quantification of Natural Vapor Fluxes of Trichloroethene in the Unsaturated Zone at Picatinny Arsenal, New Jersey. *Environ. Sci. Technol.,* **30,** 2243.

Smith, R.L.; Garabedian, S.P.; and Brooks, M.H. (1996) Comparison of Denitrification Activity Measurements in Groundwater Using Cores and Natural-Gradient Tracer Tests. *Environ. Sci. Technol.,* **30,** 3448.

Soerens, T.S., and Sabatini, D.A. (1996) Interpretation of Sorption Studies for Compound Isomers or Mixtures. *Ground Water,* **34,** 605.

Solomon, D.K.; Hunt, A.; and Poreda, R.J. (1996) Source of Radiogenic Helium 4 in Shallow Aquifers: Implications for Dating Young Groundwater. *Water Resour. Res.,* **32,** 1805.

Sommeijer, B.P., and Kok, J. (1995) Implementation and Performance of the Time Integration of a 3D Numerical Transport Model. *Int. J. Numerical Methods Fluids,* **20,** 213.

Sonnenborg, T.O.; Engesgaard, P.; and Rosbjerg, D. (1996) Contaminant Transport at a Waste Residue Deposit. 1. Inverse Flow and Nonreactive Transport Modeling. *Water Resour. Res.,* **32,** 925.

Sophocleous, M.; Stadnyk, N.G.; and Stotts, M. (1996) Modeling Impact of Small Kansas Landfills on Underlying Aquifers. *J. Environ. Eng.,* **122,** 1067.

Sorek, S. (1996) A Model for Solute Transport Following an Abrupt Pressure Impact in Saturated Porous Media. *Transp. Porous Media,* **22,** 271.

Soukup, W.G. P.G., C.G.W.P., and Scheuing, L.E. (1996) A Comparison of NAPL Field Screening Techniques at Three Hazardous Waste Sites. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 51.

Speake, R.; Losonsky, G.; and Beljin, M. (1996) Animation of Horizontal Well Hydraulics. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 863.

Squillace, P.J.; Zogorski, J.S.; Wilber, W.G.; and Price, C.V. (1996) Preliminary Assessment of the Occurrence and Possible Sources of MTBE in Groundwater in the United States, 1993–1994. *Environ. Sci. Technol.,* **30,** 1721.

Srivastava, R., and Brusseau, M.L. (1996) Nonideal Transport of Reactive Solutes in Heterogeneous Porous Media. I. Numerical Model Development and Moments Analysis. *J. Contam. Hydrol.,* **24,** 117.

Stallard, W.M.; Wu, K.C.; Shi, N.; and Corapcioglu, M.Y. (1996) Two-Dimensional Hydraulics of Recirculating Ground-Water Remediation Wells in Unconfined Aquifers. *J. Environ. Eng.,* **122,** 692.

Starr, J.L.; Sadeghi, A.M.; Parkin, T.B.; and Meisinger, J.J. (1996) A Tracer Test to Determine the Fate of Nitrate in Shallow Groundwater. *J. Environ. Qual.,* **25,** 917.

Starr, R.I.; Timm, R.W.; Doxtader, K.G.; Hurlbut, D.B.; Volz, S.A.; and Goodall, M. (1996) Sorption and Aerobic Biodegradation of Strychnine Alkaloid in Various Soil Systems. *J. Agric. Food Chem.,* **44,** 1603.

Starrett, S.K.; Christians, N.E.; and Alaustin, T. (1996) Movement of Pesticides Under Two Irrigation Regimes Applied to Turfgrass. *J. Environ. Qual.,* **25,** 566.

Stenhouse, M.J.; Merceron, T.; and Demartinville, E.S. (1996) Provision of Diffusion Coefficients for Argillaceous Media in Support of Preliminary Safety Assessment Within the French HLW Disposal Programme. *J. Contam. Hydrol.,* **21,** 351.

Sternberg, S.P.K.; Cushman, J.H.; and Greenkorn, R.A. (1996) Laboratory Observation of Nonlocal Dispersion. *Transp. Porous Media,* **23,** 135.

Stockmaier, M.; Kreuzig, R.; and Bahadir, M. (1996) Investigations on the Behaviour of Fenpropimorph and Its Metabolite Fenpropimorphic Acid in Soils. *Pestic. Sci.,* **46,** 361.

Stollenwerk, K.G. (1996) Simulation of Phosphate Transport in Sewage-Contaminated Ground-Water, Cape Cod, Massachusetts. *Appl. Geochem.,* **11,** 317.

Stout, S.A., and Lundegard, P.D. (1996) Intrinsic Biodegradation of Diesel Fuel as Revealed by Vertical Heterogeneities in an Interval of Free Product. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 495.

Su, J.J., and Kafkewitz, D. (1996) Toluene and Xylene Degradation by a Denitrifying Strain of Xanthomonas maltophilia with Limited or No Oxygen. *Chemosphere* (G.B.), **32,** 1843.

Su, N.H. (1995) Development of the Fokker-Planck Equation and Its Solutions for Modeling Transport of Conservative and Reactive Solutes in Physically Heterogeneous Media. *Water Resour. Res.,* **31,** 3025.

Su, N.H. (1996a) The Form of the Dispersion Equation Under Recharge and Variable Velocity, and Its Analytical Solution (Comment). *Water Resour. Res.,* **32,** 2965.

Su, N.H. (1996b) Development of the Fokker-Planck Equation and Its Solutions for Modeling Transport of Conservative and Reactive Solutes in Physically Heterogeneous Media. *Water Resour. Res.,* **32,** 1915.

Sukhija, B.S.; Reddy, D.V.; Nagabhushanam, P.; Hussain, S.; Giri, V.Y.; and Patil, D.J. (1996a) Environmental and Injected Tracers Methodology to Estimate Direct Precipitation Recharge to a Confined Aquifer. *J. Hydrol.* (Neth.), **177,** 77.

Sukhija, B.S.; Varma, V.N.; Nagabhushanam, P.; and Reddy, D.V. (1996b) Differentiation of Palaeomarine and Modern Seawater Intruded Salinities in Coastal Groundwaters (of Karaikal and Tanjavur, India) Based on Inorganic Chemistry, Organic Biomarker Fingerprints and Radiocarbon Dating. *J. Hydrol.* (Neth.), **174,** 173.

Suksi, J.; Ruskeeniemi, T.; and Saarinen, L. (1996) Selective Extractions in Uranium Migration Studies—Findings from a Natural Analogue Study at Palmottu, Southern Finland. *J. Contam. Hydrol.,* **21,** 47.

Sun, S.B., and Jaffe, P.R. (1996) Sorption of Phenanthrone from Water Onto Alumina Coated with Dianionic Surfactants. *Environ. Sci. Technol.,* **30,** 2906.

Sun, Y.H.; Davert, M.W.; and Yeh, W.W.G. (1996) Soil Vapor Extraction System Design by Combinatorial Optimization. *Water Resour. Res.,* **32,** 1863.

Sundaram, K.M.S. (1996) Leaching, Mobility and Persistence of Tebufenozide in Columns Packed with Forest Litter and Soil. *J. Environ. Sci. Health Part B Pestic. Food Contam. Agric. Wastes,* **31,** 1215.

Suzuki, T.; Yaguchi, K.; Nishima, T.; and Suga, T. (1996) Degradation of Terbutol in Soils from Turfgrass and Drainage on Golf Courses. *J. Agric. Food Chem.*, **44,** 1599.

Swedberg, S. (1995) Regional Groundwater Monitoring and Examples of Acidification Trends in the Province of Goteborg and Bohus, Southwestern Sweden. *Water, Air, Soil Pollut.* (Neth.), **85,** 1843.

Sweed, H.G.; Bedient, P.B.; and Hutchins, S.R. (1996) Surface Application System for In Situ Ground-Water Bioremediation: Site Characterization and Modeling. *Ground Water,* **34,** 211.

Swindoll, C.M., and Troy, M.A. (1996) Demonstrating Intrinsic Bioremediation Potential of Chlorinated Aliphatic Hydrocarbons. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 383.

Szabo, Z.; Rice, D.E.; Plummer, L.N.; Busenberg, E.; and Drenkard, S. (1996) Age Dating of Shallow Groundwater with Chlorofluorocarbons, Tritium Helium 3, and Flow Path Analysis, Southern New Jersey Coastal Plain. *Water Resour. Res.,* **32,** 1023.

Taer, A.D.; Farrell, R.F.; and Ford, B. (1996) Use of the Cone Penetrometer and Laser-Induced Fluorescence in an Oil Field Site Characterization. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 257.

Tagami, K., and Uchida, S. (1996) Microbial Role in Immobilization of Technetium in Soil Under Waterlogged Conditions. *Chemosphere* (G.B.), **33,** 217.

Tegen, I., and Dorr, H. (1996) Mobilization of Cesium in Organic Rich Soils: Correlation with Production of Dissolved Organic Carbon. *Water, Air, Soil Pollut.* (Neth.), **88,** 133.

ten Hulscher, T.E.M., and Cornelissen, G. (1996) Effect of Temperature on Sorption Equilibrium and Sorption Kinetics of Organic Micropollutants—A Review. *Chemosphere* (G.B.), **32,** 609.

Teso, R.R.; Poe, M.P.; Younglove, T.; and Mccool, P.M. (1996) Use of Logistic Regression and GIS Modeling to Predict Groundwater Vulnerability to Pesticides. *J. Environ. Qual.,* **25,** 425.

Testa, S.M. (1996) Considerations and Methodology in Using Natural Attenuation as a Remedial Strategy. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 283.

Thai, L.T.; Jahan, K.; Ahmed, T.; and Maier, W.J. (1996) Solubilization and Biodegradation of Octadecane in the Presence of Nonionic Surfactants. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3,** 205.

Therrien, R., and Sudicky, E.A. (1996) Three-Dimensional Analysis of Variably-Saturated Flow and Solute Transport in Discretely-Fractured Porous Media. *J. Contam. Hydrol.,* **23,** 1.

Thibaud-Erkey, C.; Guo, Y.; Erkey, C.; and Akgerman, A. (1996) Mathematical Modeling of Adsorption and Desorption of Volatile Contaminants from Soil: Influence of Isotherm Shape on Adsorption and Desorption Profiles. *Environ. Sci. Technol.,* **30,** 2127.

Thompson, J.L. (1996) Radionuclide Sorption on Well Construction Materials. *Ground Water Monit. Remed.,* **16,** 163.

Thurman, E.M.; Goolsby, D.A.; Aga, D.S.; Pomes, M.L.; and Meyer, M.T. (1996) Occurrence of Alachlor and Its Sulfonated Metabolite in Rivers and Reservoirs of the Midwestern United States: The Importance of Sulfonation in the Transport of Chloroacetanilide Herbicides. *Environ. Sci. Technol.,* **30,** 569.

Ticknor, K.V.; Vilks, P.; and Vandergraaf, T.T. (1996) The Effect of Fulvic Acid on the Sorption of Actinides and Fission Products on Granite and Selected Minerals. *Appl. Geochem.,* **11,** 555.

Tim, U.S. (1996) Coupling Vadose Zone Models with GIS: Emerging Trends and Potential Bottlenecks. *J. Environ. Qual.,* **25,** 535.

Tim, U.S.; Jain, D.; and Liao, H.H. (1996) Interactive Modeling of Ground-Water Vulnerability Within a Geographic Information System Environment. *Ground Water,* **34,** 618.

Tompson, A.F.B.; Schafer, A.L.; and Smith, R.W. (1996) Impacts of Physical and Chemical Heterogeneity on Cocontaminant Transport in a Sandy Porous Medium. *Water Resour. Res.,* **32,** 801.

Toride, N., and Leij, F.J. (1996a) Convective Dispersive Stream Tube Model for Field-Scale Solute Transport. I. Moment Analysis. *Soil Sci. Soc. Am. J.,* **60,** 342.

Toride, N., and Leij, F.J. (1996b) Convective Dispersive Stream Tube Model for Field-Scale Solute Transport. II. Examples and Calibration. *Soil Sci. Soc. Am. J.,* **60,** 352.

Totsche, K.U.; Knabner, P.; and Kogelknabner, I. (1996) The Modeling of Reactive Solute Transport with Sorption to Mobile and Immobile Sorbents. II. Model Discussion and Numerical Simulation. *Water Resour. Res.,* **32,** 1623.

Toulhoat, P.T.; Gallien, J.P.; Louvat, D.; Moulin, V.; Lhenoret, P.; Guerin, P.; Ledoux, E.; Gurban, I.; Smellie, J.A.T.; and Winberg, A. (1996) Preliminary Studies of Groundwater Flow and Migration of Uranium Isotopes Around the Oklo Natural Reactors (Gabon). *J. Contam. Hydrol.,* **21,** 3.

Tros, M.E.; Schraa, G.; and Zehnder, A.J.B. (1996) Transformation of Low Concentrations of 3-Chlorobenzoate by Pseudomonas sp Strain B13: Kinetics and Residual Concentrations. *Appl. Environ. Microbiol.,* **62,** 437.

Tsang, Y.W.; Tsang, C.F.; Hale, F.V.; and Dverstorp, B. (1996) Tracer Transport in a Stochastic Continuum Model of Fractured Media. *Water Resour. Res.,* **32,** 3077.

Tsihrintzis, V.A.; Fuentes, H.R.; and Gadipudi, R.K. (1996) Modeling Prevention Alternatives for Nonpoint Source Pollution at a Wellfield in Florida. *Water Resour. Bull.* (Urb.), **32,** 317.

Turner, D.R., and Sassman, S.A. (1996) Approaches to Sorption Modeling for High-Level Waste Performance Assessment. *J. Contam. Hydrol.,* **21,** 311.

Tyler, S.W.; Chapman, J.B.; Conrad, S.H.; Hammermeister, D.P.; Blout, D.O.; Miller, J.J.; Sully, M.J.; and Ginanni, J.M. (1996) Soil-Water Flux in the Southern Great Basin, United States: Temporal and Spatial Variations Over the Last 120 000 Years. *Water Resour. Res.,* **32,** 1481.

Ukrainczyk, L., and Ajwa, H.A. (1996) Primisulfuron Sorption on Minerals and Soils. *Soil Sci. Soc. Am. J.,* **60,** 460.

Ukrainczyk, L., and Smith, K.A. (1996) Solid State N-15 NMR Study of Pyridine Adsorption on Clay Minerals. *Environ. Sci. Technol.,* **30,** 3167.

Unger, A.J.A.; Forsyth, P.A.; and Sudicky, E.A. (1996) Variable Spatial and Temporal Weighting Schemes for Use in Multi Phase Compositional Problems. *Adv. Water Resour.,* **19,** 1.

Unger, D.R.; Lam, T.T.; Schaefer, C.E.; and Kosson, D.S. (1996) Predicting the Effect of Moisture on Vapor-Phase Sorption of Volatile Organic Compounds to Soils. *Environ. Sci. Technol.,* **30,** 1081.

Vag, J.E.; Wang, H.; and Dahle, H.K. (1996) Eulerian-Lagrangian Localized Adjoint Methods for Systems of Nonlinear Advective-Diffusive-Reactive Transport Equations. *Adv. Water Resour.,* **19,** 297.

Valdes, J.A. (1996) Natural Attenuation in New Jersey: Two Case Histories. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 355.

Vanderglas, B.R.; Benson, L.A.; Downey, D.C.; and Taffinder, S.A. (1996) Obtaining Regulatory Acceptance of Risk-Based Remediation of Fuel-Contaminated Soils and Groundwater. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 883.

Vandergraaf, T.T.; Drew, D.J.; and Masuda, S. (1996) Radionuclide Migration Experiments in a Natural Fracture in a Quarried Block of Granite. *J. Contam. Hydrol.,* **21,** 153.

van der Kamp, G.; Vanstempvoort, D.R.; and Wassenaar, L.I. (1996) The Radial Diffusion Method. 1. Using Intact Cores to Determine Isotopic Composition, Chemistry, and Effective Porosities for Groundwater in Aquitards. *Water Resour. Res.,* **32,** 1815.

Van der Kwaak, J.E., and Sudicky, E.A. (1996) Dissolution of Non-Aqueous-Phase Liquids and Aqueous-Phase Contaminant Transport in Discretely-Fractured Porous Media. *J. Contam. Hydrol.,* **23,** 45.

Van der Zanden, A.J.J., and Schoenmakers, A.M.E. (1996) The Influence of Sorption Isotherms on the Drying of Porous Materials. *Int. J. Heat Mass Transfer,* **39,** 2319.

van Dijke, M.I.J., and van der Zee, S.E.A.T.M. (1996) Analytical Description of LNAPL Redistribution with Entrapment. *Computat. Methods Water Resour. XI,* Cancun, Mex., Natl. Ground Water Assoc., Dublin, Ohio, **1,** 391.

Van Hoof, P.L., and Jafvert, C.T. (1996) Reductive Dechlorination of Chlorobenzenes in Surfactant-Amended Sediment Slurries. *Environ. Toxicol. Chem.,* **15,** 1914.

Van Kemenade, I.; Anderson, W.A.; Scharer, J.M.; and Mooyoung, M. (1995) Bioremediation Enhancement of Phenanthrene Contaminated Soils by Chemical Pre-Oxidation. *Haz. Waste Haz. Mater.,* **12,** 345.

Van Kooten, J.J.A. (1996) A Method to Solve the Advection-Dispersion Equation with a Kinetic Adsorption Isotherm. *Adv. Water Resour.,* **19,** 193.

Van Warmerdam, E.M.; Frape, S.K.; Aravena, R.; Drimmie, R.J.; Flatt, H.; and Cherry, J.A. (1995) Stable Chlorine and Carbon Isotope Measurements of Selected Chlorinated Organic Solvents. *Appl. Geochem.,* **10,** 547.

Veeh, R.H.; Inskeep, W.P.; and Camper, A.K. (1996) Soil Depth and Temperature Effects on Microbial Degradation of 2,4-D. *J. Environ. Qual.,* **25,** 5.

Vengosh, A., and Keren, R. (1996) Chemical Modifications of Groundwater Contaminated by Recharge of Treated Sewage Effluent. *J. Contam. Hydrol.,* **23,** 347.

Verce, M.F., and Freedman, D.L. (1996) Ethene Promoted Cometabolism in Vinyl Chloride. Paper presented at 69th Annu. Water Environ. Fed. Tech. Exposition Conf., Dallas, Tex., **3** 173.

Verma, A.K., and Eswaran, V. (1996) Overlapping Control Volume Approach for Convection-Diffusion Problems. *Int. J. Numerical Methods Fluids,* **23,** 865.

Vicari, A.; Zimdahl, R.L.; Cranmer, B.K.; and Dinelli, G. (1996) Primisulfuron and Rimsulfuron Degradation in Aqueous Solution and Adsorption in Six Colorado Soils. *Weed Sci.,* **44,** 672.

Vilks, P., and Bachinski, D.B. (1996a) Characterization of Organics in Whiteshell Research Area Groundwater and the Implications for Radionuclide Transport. *Appl. Geochem.,* **11,** 387.

Vilks, P., and Bachinski, D.B. (1996b) Colloid and Suspended Particle Migration Experiments in a Granite Fracture. *J. Contam. Hydrol.,* **21,** 269.

Vink, J.P.M., and van der Zee, S.E.A.T.M. (1996) Some Physicochemical and Environmental Factors Affecting Transformation Rates and Sorption of the Herbicide Metamitron in Soil. *Pestic. Sci.,* **46,** 113.

Vogele, T.J., and Nitao, J. (1996) Field-Scale Simulation of a Soil Vapoir Extraction (SVE) System. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 209.

Vogeler, I.; Clothier, B.E.; Green, S.R.; Scotter, D.R.; and Tillman, R.W. (1996) Characterizing Water and Solute Movement by Time Domain Reflectometry and Disk Permeametry. *Soil Sci. Soc. Am. J.,* **60,** 5.

Von Gunten, H.R.; Surbeck, H.; and Rossler, E. (1996) Uranium Series Disequilibrium and High Thorium and Radium Enrichments in Karst Formations. *Environ. Sci. Technol.,* **30,** 1268.

Voudrias, E.A., and Assaf, K.S. (1996) Theoretical Evaluation of Dissolution and Biochemical Reduction of TNT for Phytoremediation of Contaminated Sediments. *J. Contam. Hydrol.,* **23,** 245.

Voznakova, Z.; Podehradska, J.; and Kohlickova, M. (1996) Determination of Nitrophenols in Soil. *Chemosphere* (G.B.), **33,** 285.

Vroblesky, D.A.; Bradley, P.M.; and Chapelle, F.H. (1996a) Influence of Electron Donor on the Minimum Sulfate Concentration Required for Sulfate Reduction in a Petroleum Hydrocarbon-Contaminated Aquifer. *Environ. Sci. Technol.,* **30,** 1377.

Vroblesky, D.A.; Rhodes, L.C.; Robertson, J.F.; and Harrigan, J.A. (1996b) Locating VOC Contamination in a Fractured-Rock Aquifer at the Ground-Water/Surface-Water Interface Using Passive Vapor Collectors. *Ground Water,* **34,** 223.

Wade, A.; Wallace, G.W.; Siegwald, S.F.; Lee, W.A.; and McKinney, K.C. (1996) Performance Comparison Between a Horizontal and a Vertical Air Sparging Well: A Full-Scale One-Year Pilot Study. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 189.

Wagenet, R.J., and Hutson, J.L. (1996) Scale-Dependency of Solute Transport Modeling/GIS Applications. *J. Environ. Qual.,* **25,** 499.

Wagner, S.C.; Zablotowicz, R.M.; Gaston, L.A.; Locke, M.A.; and Kinsella, J. (1996) Bentazon Degradation in Soil: Influence of Tillage and History of Bentazon Application. *J. Agric. Food Chem.,* **44,** 1593.

Walton, J.C., and Anker, C.B. (1996) Secondary Effects of Soil Venting and Potential Low-Cost Enhancements. *Ground Water Monit. Remed.,* **16,** 91.

Walworth, J.L., and Reynolds, C.M. (1995) Bioremediation of a Petroleum Contaminated Cryic Soil: Effects of Phosphorus, Nitrogen, and Temperature. *J. Soil Contam.,* **4,** 299.

Wang, C.T., and Yeh, H.D. (1996) Some Exact Solutions of Convection-Diffusion and Diffusion Equations (Comment). *Water Resour. Res.,* **32,** 487.

Wang, C.Y., and Cheng, P. (1996) A Multiphase Mixture Model for Multiphase, Multicomponent Transport in Capillary Porous Media. I. Model Development. *Int. J. Heat Mass Transfer,* **39,** 3607.

Wang, E.X., and Benoit, G. (1996) Mechanisms Controlling the Mobility of Lead in the Spodosols of a Northern Hardwood Forest Ecosystem. *Environ. Sci. Technol.,* **30,** 2211.

Wang, M.K.; Wang, S.L.; and Wang, W.M. (1996) Rapid Estimation of Cation-Exchange Capacities of Soils and Clays with Methylene Blue Exchange. *Soil Sci. Soc. Am. J.,* **60,** 138.

Wardell, L.J. (1995) Potential for Bioremediation of Fuel-Contaminated Soil in Antartica. *J. Soil Contam.,* **4,** 111.

Washington, J.W. (1996) Gas Partitioning of Dissolved Volatile Organic Compounds in the Vadose Zone: Principles, Temperature Effects and Literature Review. *Ground Water,* **34,** 709.

Watkins, M.L.; Sieber, E.; and Schulze, M.E. (1996) Calibration of NAPL Field Screening Methodologies for Inclusion in a Comprehensive NAPL Investigation at a Superfund Site in New Jersey. *Proc. 10th Natl. Outdoor Action. Conf.,* Las Vegas, Nev., Natl. Ground Water Assoc., Dublin, Ohio, 35.

Wauters, J.; Elsen, A.; and Cremers, A. (1996a) Prediction of Solid/Liquid Distribution Coefficients of Radiocaesium in Soils and Sediments. III. A Quantitative Test of a K-D Predictive Equation. *Appl. Geochem.,* **11,** 601.

Wauters, J.; Elsen, A.; Cremers, A.; Konoplev, A.V.; Bulgakov, A.A.; and Comans, R.N.J. (1996b) Prediction of Solid/Liquid Distribution Coefficients of Radiocaesium in Soils and Sediments. I. A Simplified Procedure for the Solid Phase Characterisation. *Appl. Geochem.,* **11,** 589.

Wauters, J.; Vidal, M.; Elsen, A.; and Cremers, A. (1996c) Prediction of Solid/Liquid Distribution Coefficients of Radiocaesium in Soils and Sediments. II. A New Procedure for Solid Phase Speciation of Radiocaesium. *Appl. Geochem.,* **11,** 595.

Weber, E.J. (1996) Iron-Mediated Reductive Transformations: Investigation of Reaction Mechanism. *Environ. Sci. Technol.,* **30,** 716.

Weber, W.J., and Huang, W.L. (1996a) A Distributed Reactivity Model for Sorption by Soils and Sediments. 4. Intraparticle Heterogeneity and Phase-Distribution Relationships Under Nonequilibrium Conditions. *Environ. Sci. Technol.,* **30,** 881.

Weber, W.J., and Huang, W.L. (1996b) A Distributed Reactivity Model for Sorption by Soils and Sediments. IV. Intraparticle Heterogeneity and Phase-Distribution Relationships Under Nonequilibrium Conditions (Response). *Environ. Sci. Technol.,* **30,** 3130.

Weed, D.A.J., and Kanwar, R.S. (1996) Nitrate and Water Present in and Flowing from Root-Zone Soil. *J. Environ. Qual.,* **25,** 709.

Weisbrod, N.; Ronen, D.; and Nativ, R. (1996) New Method for Sampling Groundwater Colloids Under Natural Gradient Flow Conditions. *Environ. Sci. Technol.,* **30,** 3094.

Welch, A.H.; Szabo, Z.; Parkhurst, D.L.; Vanmetre, P.C.; and Mullin, A.H. (1995) Gross-Beta Activity in Ground Water: Natural Sources and Artifacts of Sampling and Laboratory Analysis. *Appl. Geochem.,* **10,** 491.

Wels, C.; Smith, L.; and Vandergraaf, T.T. (1996) Influence of Specific Surface Area on Transport of Sorbing Solutes in Fractures: An Experimental Analysis. *Water Resour. Res.,* **32,** 1943.

Wen, X.H., and Kung, C.S. (1996) Implementation of the Constant Displacement Scheme in Random Walk. *Comput. Geosci.,* **22,** 369.

Wendland, E., and Schmid, G. (1996) Symmetrical Streamline Stabilization (S) for High Advective Transport Processes. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 569.

Werkheiser, W.O., and Anderson, S.J. (1996) Effect of Soil Properties and Surfactant on Primisulfuron Sorption. *J. Environ. Qual.,* **25,** 809.

West, R.J., and Gonsior, S.J. (1996) Biodegradation of Triethanolamine. *Environ. Toxicol. Chem.,* **15,** 472.

White, J.C., and Alexander, M. (1996) Reduced Biodegradability of Desorption-Resistant Fractions of Polycyclic Aromatic Hydrocarbons in Soil and Aquifer Solids. *Environ. Toxicol. Chem.,* **15,** 1973.

Wiedemeier, T.H.; Swanson, M.A.; Wilson, J.T.; Kampbell, D.H.; Miller, R.N.; and Hansen, J.E. (1996) Approximation of Biodegradation Rate Constants for Monoaromatic Hydrocarbons (BTEX) in Ground Water. *Ground Water Monit. Remed.,* **16,** 186.

Wiesner, M.R.; Grant, M.C.; and Hutchins, S.R. (1996) Reduced Permeability in Groundwater Remediation Systems: Role of Mobilized Colloids and Injected Chemicals. *Environ. Sci. Technol.,* **30,** 3184.

Wilcke, W.; Zech, W.; and Kobza, J. (1996) PAH-Pools in Soils Along a PAH-Deposition Gradient. *Environ. Pollut.* (G.B.), **92,** 307.

Wilhelm, S.R.; Schiff, S.L.; and Robertson, W.D. (1996) Biogeochemical Evolution of Domestic Waste Water in Septic Systems. II. Application of Conceptual Model in Sandy Aquifers. *Ground Water,* **34,** 853.

Wilkes, H.; Wittich, R.M.; Timmis, K.N.; Fortnagel, P.; and Francke, W. (1996) Degradation of Chlorinated Dibenzofurans and Dibenzo-p-Dioxins by Sphingomonas sp Strain RW1. *Appl. Environ. Microbiol.,* **62,** 367.

Williams, K.; Martinez, A.; Daugherty, S.; and Lundegard, P.D. (1996) Ground Water Sampling—A Pilot Study of the Effects of Well Purging. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 191.

Wilson, J.P.; Inskeep, W.P.; Wraith, J.M.; and Snyder, R.D. (1996) GIS-Based Solute Transport Modeling Applications: Scale Effects of Soil and Climate Data Input. *J. Environ. Qual.,* **25,** 445.

Wilson, M.S., and Madsen, E.L. (1996) Field Extraction of a Transient Intermediary Metabolite Indicative of Real Time In Situ Naphthalene Biodegradation. *Environ. Sci. Technol.,* **30,** 2099.

Wilson, R.D., and Mackay, D.M. (1996a) Passive Release Wells for In-Situ Remediation of Contaminant Plumes. *Proc. 1996 Pet. Hydrocarbon Org. Chem. Ground Water Conf.,* Houston, Tex., Natl. Ground Water Assoc., Dublin, Ohio, 151.

Wilson, R.D., and Mackay, D.M. (1996b) SF6 as a Conservative Tracer in Saturated Media with High Intragranular Porosity or High Organic Carbon Content. *Ground Water,* **34,** 241.

Wilson, S.C.; Duckham, C.; and Jones, K.C. (1996) Quantification of Volatile Organic Compound Losses from Sludge Amended Soil: A Pilot Scale Study. *Chemosphere* (G.B.), **33,** 1261.

Woldt, W.; Dahab, M.; Bogardi, I.; and Dou, C. (1996) Management of Diffuse Pollution in Groundwater Under Imprecise Conditions Using Fuzzy Models. *Water Sci. Technol.* (G.B.), **33,** 249.

Wolf, S.A., and Nowak, P.J. (1996) A Regulatory Approach to Atrazine Management: Evaluation of Wisconsin's Groundwater Protection Strategy. *J. Soil Water Conserv.,* **51,** 94.

Wolkersdorfer, C. (1996) Hydrogeochemical Investigations of an Abandoned Uranium Mine in the Erzgebirge/Germany. *Appl. Geochem.,* **11,** 237.

Wolt, J.D.; Smith, J.K.; Sims, J.K.; and Duebelbeis, D.O. (1996) Products and Kinetics of Cloransulam-Methyl Aerobic Soil Metabolism. *J. Agric. Food Chem.,* **44,** 324.

Wood, W.W., and Sanford, W.E. (1995) Eolian Transport, Saline Lake Basins, and Groundwater Solutes. *Water Resour. Res.,* **31,** 3121.

Woodbury, A.D., and Ulrych, T.J. (1996) Minimum Relative Entropy Inversion: Theory and Application to Recovering the Release History of a Groundwater Contaminant. *Water Resour. Res.,* **32,** 2671.

Wu, J.; Xue, Y.; and Zhang, Z. (1996) A Study on the Numerical Simulation of Ca, Na and Mg Transfer in Aquifer During Sea Water Intrusion. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 219.

Wu, Q.J.; Ward, A.D.; and Workman, S.R. (1996) Using GIS in Simulation of Nitrate Leaching from Heterogeneous Unsaturated Soils. *J. Environ. Qual.,* **25,** 526.

Wu, Y.S.; Forsyth, P.A.; and Jiang, H. (1996) A Consistent Approach for Applying Numerical Boundary Conditions for Multiphase Subsurface Flow. *J. Contam. Hydrol.,* **23,** 157.

Wu, Y.-S., and Pruess, K. (1996) A Numerical Method for Simulating Non-Newtonian Fluid Flow and Displacement in Porous Media. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 109.

Xing, B.S., and Pignatello, J.J. (1996) Time-Dependent Isotherm Shape of Organic Compounds in Soil Organic Matter: Implications for Sorption Mechanism. *Environ. Toxicol. Chem.,* **15,** 1282.

Xing, B.S.; Pignatello, J.J.; and Gigliotti, B. (1996) Competitive Sorption Between Atrazine and Other Organic Compounds in Soils and Model Sorbents. *Environ. Sci. Technol.,* **30,** 2432.

Xu, L.L., and Brusseau, M.L. (1996) Semianalytical Solution for Solute Transport in Porous Media with Multiple Spatially Variable Reaction Processes. *Water Resour. Res.,* **32,** 1985.

Xu, M.J., and Eckstein, Y. (1996) Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale (Reply). *Ground Water,* **34,** 578.

Xue, Y.; Wu, J.; Xie, C.; Zhang, Z.; and Zhang, Y. (1996) Modeling Contaminant Transport in a System of Leaky Aquifers. *Computat. Meth. Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 227.

Yamaguchi, T.; Moldrup, P.; Rolston, D.E.; Ito, S.; and Teranishi, S. (1996) Nitrification in Porous Media During Rapid, Unsaturated Water Flow. *Water Res.* (G.B.), **30,** 531.

Yang, G.X.; Erickson, L.E.; and Fan, L.T. (1996) A Bench-Scale Study on Biodegradation and Volatilization of Ethylbenzoate in Aquifers. *J. Haz. Mater.,* **50,** 169.

Yang, J.Z.; Zhang, R.; and Wu, J.Q. (1996a) An Analytical Solution of Macrodispersivity for Adsorbing Solute Transport in Unsaturated Soils. *Water Resour. Res.,* **32,** 355.

Yang, J.Z.; Zhang, R.D.; Wu, J.Q.; and Allen, M.B. (1996b) Stochastic Analysis of Adsorbing Solute Transport in Two-Dimensional Unsaturated Soils. *Water Resour. Res.,* **32,** 2747.

Yasuda, H.; Ambe, S.; and Uchida, S. (1996) Distribution Coefficients of Platinum Group Metals Between Soil Solid and Liquid Phases. *Environ. Technol.,* **17,** 1151.

Yeh, G.-T.; Cheng, H.-P.; Cheng, J.-R.; Short, T.E.; and Enfield, C. (1996a) An Adaptive Local Grid Refinement to Solve Nonlinear Transport Problems with Moving Fronts. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 577.

Yeh, G.-T.; Salvage, K.; and Choi, W. (1996b) Reactive Chemical Transport Controlled by Both Equilibrium and Kinetic Reactions. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **2,** 585.

Yen, S.T.; Liu, S.P.; and Kolpin, D.W. (1996) Analysis of Nitrate in Near-Surface Aquifers in the Midcontinental United States: An Application of the Inverse Hyperbolic Sine Tobit Model. *Water Resour. Res.,* **32,** 3003.

Yeom, I.T.; Ghosh, M.M.; and Cox, C.D. (1996a) Kinetic Aspects of Surfactant Solubilization of Soil-Bound Polycyclic Aromatic Hydrocarbons. *Environ. Sci. Technol.,* **30,** 1589.

Yeom, I.T.; Ghosh, M.M.; Cox, C.D.; and Robinson, K.G. (1996b)

Micellar Solubilization of Polynuclear Aromatic Hydrocarbons in Coal Tar-Contaminated Soils. *Environ. Sci. Technol.,* **30,** 2104.

Yiacoumi, S., and Rao, A.V. (1996) Organic Solute Uptake from Aqueous Solutions by Soil: A New Diffusion Model. *Water Resour. Res.,* **32,** 431.

Yonezawa, C.; Tanaka, T.; and Kamioka, H. (1996) Water-Rock Reactions During Gamma-Ray Irradiation. *Appl. Geochem.,* **11,** 461.

Yoon, J.-H., and Shoemaker, C.A. (1996) Applications of SALQR and Evolutionary Algorithms to Optimization of Groundwater Bioremediation. *Computat. Methods Water Resour. XI,* Cancun, Mexico, Computational Mechanics Publications, Southampton, U.K., **1,** 383.

You, C.N., and Liu, J.C. (1996) Desorptive Behavior of Chlorophenols in Contaminated Soils. *Water Sci. Technol.* (G.B.), **33,** 263.

You, G.R.; Sayles, G.D.; Kupferle, M.J.; Kim, I.S.; and Bishop, P.L. (1996) Anaerobic DDT Biotransformation: Enhancement by Application of Surfactants and Low Oxidation Reduction Potential. *Chemosphere,* **32,** 2269.

Yu, S.C.T. (1995) Transport and Fate of Chlorinated Hydrocarbons in the Vadose Zone—A Literature Review with Discussions on Regulatory Implications. *J. Soil Contam.,* **4,** 25.

Yu, Y.S.; Bailey, G.W.; and Jin, X.C. (1996) Application of a Lumped, Nonlinear Kinetics Model to Metal Sorption on Humic Substances. *J. Environ. Qual.,* **25,** 552.

Zaidel, J.; Russo, D.; and Feldman, G. (1996) Theoretical Analysis of the Impact of Vapor Transport on the NAPL Distribution in Dry Soils. *Adv. Water Resour.,* **19,** 145.

Zegeling, P.A. (1996) Numerical Solution of Advection-Dispersion Models Using Dynamically-Moving Adaptive Grids. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 593.

Zhang, D., and Zhang, Y.-K. (1996) Higher-Order Velocity Covariance and Its Effect on Advective Transport in Three-Dimensional Heterogeneous Anisotropic Media. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 689.

Zhang, D.X., and Neuman, S.P. (1996a) Head and Velocity Covariances Under Quasi-Steady State Flow and Their Effects on Advective Transport. *Water Resour. Res.,* **32,** 77.

Zhang, D.X., and Neuman, S.P. (1996b) Effect of Local Dispersion on Solute Transport in Randomly Heterogeneous Media. *Water Resour. Res.,* **32,** 2715.

Zhang, R.; Hamerlinck, J.D.; Gloss, S.P.; and Munn, L. (1996a) Determination of Nonpoint-Source Pollution Using GIS and Numerical Models. *J. Environ. Qual.,* **25,** 411.

Zhang, R.; Yang, J.; and Ye, Z. (1996b) Solute Transport Through the Vadose Zone: A Field Study and Stochastic Analyses. *Soil Sci.,* **161,** 270.

Zhang, Y.K., and Chi, J.A. (1995) An Evaluation of Nonlinearity in Spatial Second Moments of Ensemble Mean Concentration in Heterogeneous Porous Media. *Water Resour. Res.,* **31,** 2991.

Zhang, Y.K.; Zhang, D.X.; and Lin, J. (1996) Nonergodic Solute Transport in Three-Dimensional Heterogeneous Isotropic Aquifers. *Water Resour. Res.,* **32,** 2955.

Zhao, H.T.; Jaynes, W.F.; and Vance, G.F. (1996) Sorption of the Ionizable Organic Compound, Dicamba (3,6-Dichloro-2-Methoxy Benzoic Acid), by Organo-Clays. *Chemosphere* (G.B.), **33,** 2089.

Zhao, X., and Sykes, J.F. (1996) Macroscopic Scale Solute Transfer in Groundwater Using the Lattice Boltzmann Equation. *Computat. Methods Water Resour. XI,* Cancun, Mex., Computational Mechanics Publications, Southampton, U.K., **1,** 235.

Zhen, C.Q., and Uber, J.G. (1996) Reliability of Remediation Designs in Presence of Modeling Error. *J. Water Resour. Plann. Manage. Div., Proc. Am. Soc. Civ. Eng.,* **122,** 253.

Zijl, W. (1996) The Symmetry Approximation for Nonsymmetric Permeability Tensors and Its Consequences for Mass Transport. *Transp. Porous Media,* **22,** 121.

Zlotnik, V.A., and Logan, J.D. (1996) Boundary Conditions for Convergent Radial Tracer Tests and Effect of Well Bore Mixing Volume. *Water Resour. Res.,* **32,** 2323.

Zoppou, C., and Roberts, S. (1996) Conservative Characteristics-Based Schemes for Mass Transport (Discussion). *J. Hydraul. Eng.,* **122,** 117.

Zou, S.M.; Xia, J.H.; and Koussis, A.D. (1996) Analytical Solutions to Non-Fickian Subsurface Dispersion in Uniform Groundwater Flow. *J. Hydrol.* (Neth.), **179,** 237.

Zurmühl, T., and Durner, W. (1996) Modeling Transient Water and Solute Transport in a Biporous Soil. *Water Resour. Res.,* **32,** 819.

Nonpoint sources

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Nonpoint source (NPS) pollution originates from diffuse land areas that intermittently contribute pollutants to surface and groundwater. This article is a review of 1996 literature on several aspects of NPS pollution, including policy, economics, and management issues; effects and extent of pollutants in surface water and groundwater; pollution controls; and modeling and monitoring.

Several publications addressed the broad topic of NPS pollution. The *Watershed '96 Technical Conference Proceedings* focused on a wide variety of water-quality topics presented at the conference, including various methods of controlling agricultural and urban NPS pollution (Tetra Tech, Inc., 1996). Proceedings of a conference on physical, chemical, and biological aspects of watershed-restoration management included papers on hydrological processes, restoration planning and management, and restoration in forested, agricultural, and urban settings (McDonnell *et al.* [Eds.], 1996). A geographic information systems (GIS) and water resources conference proceedings included papers addressing database issues, water quality, groundwater, stormwater, and watershed studies (Hallam *et al.* [Eds.], 1996). Nutrient management topics were covered in papers published in the proceedings of the Fourth Annual Fertilizer Research and Education Program Conference (Cady *et al.* [Eds.], 1996). The proceedings of the Water Environment Federation's annual conference included several papers on stormwater, its control, and its effects on receiving water (Water Environment Federation, 1996). Hornsby *et al.* (1996) published a book presenting data on pesticide properties in the environment.

Gannon *et al.* (1996) presented issues related to reauthorization of the Clean Water Act and recommended a coordinated national approach to controlling agricultural NPS pollution that mandates basin-scale, water-quality-based state programs that target critical areas and employ systems of best management practices (BMPs). Schell (1996) discussed the regulatory implications of a U.S. Court of Appeals decision concerning one of New York's largest dairy farms and the environmental risks posed by large industrialized agricultural operations. Brady