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Natural Treatment and On-Site Processes

Kevin D. White

Joel Gerard Burken

Missouri University of Science and Technology, burken@mst.edu

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Methanogenic Sediments from a Petroleum-Contaminated Aquifer. *Appl. Environ. Microbiol.*, **64**, 5, 1937.

Weiner, J.M., and Lovley, D.R. (1998b) Anaerobic Benzene Degradation in Petroleum-Contaminated Aquifer Sediments After Inoculation with a Benzene-Oxidizing Enrichment. *Appl. Environ. Microbiol.*, **64**, 2, 775.

Westlund, A.D.; Hagland, E.; and Rothman, M. (1998) Foaming in Anaerobic Digesters Caused by *Microthrix parvicella*. *Water Sci. Technol.* (G.B.), **37**, 4–5, 51.

Wickman, T.L. (1998) A Physical and Genetic Map of the Chromosome of the Sulfate-Reducing Bacterium *Desulfovibrio desulfuricans* G20. Ph.D. thesis, Univ. Mo., Columbia.

Wiemann, M.; Schenk, H.; and Hegemann, W. (1998) Anaerobic Treatment of Tannery Wastewater with Simultaneous Sulphide Elimination. *Water Res.* (G.B.), **32**, 774.

Wilson, F.; Yu, H.; Tay, J.H.; and Gu, G. (1998) Empirical Model for Predicting the Organic Concentration of Anaerobic Filter Effluents. *Water Environ. Res.*, **70**, 1061.

Wischnak, C.; Loeffler, F.E.; Li, J.; Urbance, J.W.; and Mueller, R. (1998) *Psedomonas* sp. Strain 273, an Aerobic Alpha, Omega,-Dichloroalkane Degrading Bacterium. *Appl. Environ. Microbiol.*, **64**, 9, 3507.

Wiseman, C.; Biskovich, V.; Garber, R.; Tielbaard, M.; and Martin, W.T. (1998) Anaerobic Treatment of Kraft Foul Condensates. *TAPPI Proc. Environ. Conf. Exhibition*, Vancouver, Can.

Witzgall, R.A.; Volpe, G.J.; and Haug, R.T. (1998) Digester Evaluation. *Water Environ. Technol.*, **10**, 5, 59.

Wu, Q.; Sowers, K.R.; and May, H.D. (1998) Microbial Reductive Dechlorination of Aroclor 1260 in Anaerobic Slurries of Estuarine Sediments. *Appl. Environ. Microbiol.*, **64**, 3, 1052.

Yang, P.Y., and Gan, C. (1998) On-Farm Swine Waste Management System in Hawaii. *Bioresour. Technol.*, **65**, 1–2, 21.

Yang, X.; Tian, S.; Zheng, Y.; Zhang, W.; Liu, M.; and Wang, H. (1998) Study on Immobilized Methanosarcinas-Formation of Anaerobic Granular Sludge (in Chinese). *China Environ. Sci.* (China), **18**, 4, 1000.

Yao, J., and He, M. (1998) Effect on the Aerobic Biodegradability After Anaerobic Acidification of Organic Pollutants in Coke-Plant Wastewater (in Chinese). *China Environ. Sci.* (China), **18**, 3, 276.

Yui, H.; Wilson, F.; and Tay, J.H. (1998) Kinetic Analysis of an Anaerobic Filter Treating Soybean Wastewater. *Water Res.* (G.B.), **32**, 3341.

Zhang, H. (1998) Biotransformation of Tetrachloroethene: The Role of Acclimation and Reactor Configuration. Ph.D. thesis, Vanderbilt Univ., Nashville, Tenn.

Zhang, M.; Tay, J.H.; Qian, Y.; and Gu, X.S. (1998) Coke Plant Wastewater Treatment by Fixed Biofilm System for COD and NH_3–N Removal. *Water Res.* (G.B.), **32**, 519.

Zhao, H.W.; Mavinic, D.S.; Oldham, W.K.; and Koch, F.A. (1998) Pre-Denitrification with Methanol in Single-Sludge Biological Nutrient Removal Processes Treating Domestic Sewage. *Proc. Water Environ. Fed. 71st Annu. Conf. Exposition*, Orlando, Fla.

Zhao, Y.; Xu, J.; Chen, M.; and Xu, X. (1998) Population and Distribution of Microorganisms in Upflow Anaerobic Sludge Bed (in Chinese). *J. Zhejiang Agric. Univ.* (China), **24**, 1, 11.

Zheng, J.; Graff, R.A.; Fillos, J.; and Rinard, I. (1998) Incorporation of Rapid Thermal Conditioning into a Wastewater Treatment Plant. *Fuel Process. Technol.* (Neth.), **56**, 3, 183.

Zheng, P.; Li, J.; Fang, Z.; Xu, X.; and Yu, X. (1998) Biodegradability of Chloromycetin Wastewater (in Chinese). *J. Zhejiang Agric. Univ.* (China), **24**, 1, 5.

Zhou, G.M., and Fang, H.H.P. (1998) Competition Between Methanogenesis and Sulfidogenesis in Anaerobic Wastewater Treatment. *Water Sci. Technol.* (G.B.), **38**, 8–9, 317.

Zhou, J.; Yang, P.; and Fang, Z. (1998) Treating Straw KP Wastewater in an Anaerobic Fluidized Bed Reactor (in Chinese). *Trans. China Pulp Paper* (China), **13**, 53.

Zitomer, D.H. (1998) Stoichiometry of Combined Aerobic and Methanogenic COD Transformation. *Water Res.* (G.B.), **32**, 669.

Zitomer, D.H., and Shrout, J. (1998b) Fluidized Bed Reactors Under Limited Aeration: Methanogen Activity and Low Alkalinity Requirements. *Proc. Water Environ. Fed. 71st Annu. Conf. Exposition*, Orlando, Fla.

Zitomer, D.H., and Shrout, J.D. (1998a) Feasibility and Benefits of Methanogenesis Under Oxygen-Limited Conditions. *Water Manage.*, **18**, 2, 107.

Natural Treatment and On-Site Processes

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Natural treatment systems are divided into several categories: land-treatment systems, wetland systems (free water surface, subsurface flow, and vertical flow systems), aquatic systems (ponds and floating aquatic plant systems), on-site and small community systems, and phytoremediation.

LAND TREATMENT SYSTEMS

Nutrient simulations of a wastewater land treatment system were investigated by Dukes and Ritter (1998) using the groundwater loading effects of agricultural management systems model. A total of 33 best management practices (BMPs) were simulated. The effectiveness of each BMP, nitrogen leaching into the root zone, and harvested market value of each crop were used to make operating recommendations. Hawkins et al. (1998) described the use of vegetative filter strips to treat the effluent from a swine waste anaerobic lagoon system. Mass-balance estimates suggest that the vegetative strips are an excellent treatment system for lagoon effluents, but nitrate leaching may be a long-term concern. The use of riparian buffer systems (overland flow) to assimilate nitrogen from swine lagoon effluent was studied by Hubbard et al. (1998). Three vegetative buffer treatments (combinations of grass and native riparian zone vegetation, and grass/maidencane) were evaluated and found to be effective at assimilating nitrogen.

WETLAND SYSTEMS

General. Design considerations and applications for wetland treatment of high-nitrate wastewaters were described by Baker (1998). Emerging applications including the renovation of nitrate-contaminated aquifers, denitrification of nitrified wastewater effluent, and treatment of irrigation return flows were identified. The role of large macrophytes in wetland systems was defined as substrate for the attachment of microorganisms responsible for organic pollutant removal, substrate aeration by root release of oxygen, and direct pollutant uptake (Williams et al., 1998). A water balance determination found that transpiration rates of *Scirpus acutus* can be greater than two to four times the measured pan evaporation rates. The capital and operation and maintenance costs of both free water surface and subsurface flow wetland systems were presented by Crites and Ogden (1998). Construction costs averaged $18 200/ha for free water surface systems and between $32 000 and $160 000/ha for subsurface flow systems. Operating costs ranged from $0.026 to $0.08/m^3 for free water surface systems and from $0.01 to $0.02/m^3 for subsurface flow systems. Ingersoll and Baker (1998) investigated the effect of hydraulic loading and carbon addition on nitrate removal in wetland microcosms. It was found that the C:N ratio was highly predictive of nitrate removal efficiency; however, as nitrate removal efficiency increased, chloroform formation potential in the effluent also increased. Nitrogen abatement costs associated with the use of constructed wetlands as part of a nonpoint source management strategy was evaluated by Bystrom (1998). Establishing a link between abatement costs and nitrogen load, analyses revealed that wetland systems have the capacity to provide low-cost nitrogen removal. Abatement costs using wetlands are compared to costs associated with changing land-use patterns and reducing nitrogen fertilizers.

Chu et al. (1998) used a tide-tank system to simulate a mangrove wetland and its capacity to remove nutrients and metals from wastewater. Using a synthetic wastewater, nutrient removal approached 98% and metal removal was nearly 96%, suggesting that mangrove ecosystems have inherent physical, chemical, and biological properties for adsorption and utilization of nutrients and heavy metals. Biological selenium volatilization in wetland systems was found to be significant, accounting for 10 to 30% of total selenium removal (Hansen et al., 1998). Average rates of selenium volatilization from highly vegetated areas were as high as 190 g Se/m^2·d. The availability, uptake, and phytotoxicity of arsenic in wetland vegetation was studied by Carbonell et al. (1998). Targeting *Spartina alterniflora,* experiments using four arsenic chemical forms showed that arsenic levels of 0.2 mg/L caused no toxic effects for this marsh grass. Root and shoot arsenic concentrations significantly increased with increasing arsenic application rates. Phytotoxicity to monomethyl arsonic acid was suggested as a cause for reduced concentrations of several essential macro- and micronutrients in vegetative tissue.

Bacterivorous activity of ciliate organisms isolated from constructed wetlands treating wastewater was measured by quantifying grazing rates upon fluorescently-labelled bacteria (FLB), specifically *Escherichia coli* (Decamp and Warren, 1998). The highest mean grazing rates were observed for *Paramecium* spp. at 1.85 FLB/cell·min. Although the results suggest that ciliates are capable of all observed *E. coli* removal from wastewaters treated via constructed wetlands, other processes are likely involved in both pathogenic and indicator bacteria removal. Kang et al. (1998) studied enzyme activity in constructed wetlands and hypothesize that soil enzyme activity is lower in wetland sediment than in adjacent upland areas. Results suggest that the enzymatic approach is a valuable method to assess decomposition in wetland sediments and that the characteristically low enzyme activities in wetland sediments may be important in the water quality amelioration function.

Municipal wastewater sludge was proposed as a suitable substrate for wetland creation after evaluating three designs (Sawhill and Ferguson, 1998). Traditional concerns about land application of biosolids (i.e., the mobility of nitrogen, metals, and pathogens) were shown to be effectively addressed in wetland systems. The use of wastewater sludge for wetland substrate suggests an integrated solution to rising landfill costs and wetland mitigation/mine reclamation needs. Steevens et al. (1998) performed toxicological evaluations on wetland habitats created as a result of agricultural runoff. Bioassays found that pore water inhibited bacterial bioluminescence but no significant mortality was found in the whole sediment *Hyalella azteca* toxicity test. These results demonstrate the importance of multiple toxicity bioassays when conducting a toxicological evaluation of contaminated sediments. Phosphorus adsorption capacities of soils, two industrial byproducts and a clinoptilolite material (zeolite) were examined for their potential use as substrates to remove phosphorus in constructed wetlands (Sakadevan and Bavor, 1998). Blast furnace slag was found to have the highest P adsorption capacity at 44.2 g P/kg slag. Multiple regression showed that P adsorption is more closely related to a combination of both oxalate extractable Fe and Al than extractable Fe or Al alone. Results suggest that the selected industrial byproducts and adsorptive materials may be used alone or in combination with soils to improve the P-removal performance of constructed wetlands.

The use of constructed wetlands for metal removal in urban runoff was described by Scholes et al. (1998). Two wetland treatment systems receiving urban runoff were sampled bimonthly and showed significant metal removal variability. Reeds were found to bioaccumulate metals and uptake was found to be greatest in the roots. Tilley and Brown (1998) described a quantitative method suitable for planning wetland stormwater treatment using simple zero-order kinetics (uptake rates) and nutrient loading conditions. At several scales (>1000, 100 to 1000, and 10 to 100 ha), wetland area needed to treat nitrogen, phosphorus, suspended sediment, and biochemical oxygen demand (BOD) in runoff were calculated. The methodology was deemed useful for feasibility analysis and may facilitate basin-scale stormwater management planning in urban watersheds. The mechanisms of lead removal in a wetland receiving industrial stormwater runoff was investigated by Nu Hoai et al. (1998). Lead removal was primarily attributed to sedimentary processes, adsorption of lead on exchange sites, and lead bound to the carbonate and oxidizable phases. Cole (1998) generally discussed efforts now underway to document the specific treatment mechanisms and ultimate pollutant fate in wetland systems. U.S. policy and regulations that promote and retard wetland technology are also discussed.

Free Water Surface Constructed Wetlands. The influence of temperature on treatment efficiency of a two-celled free water surface (FWS) wetland system treating poultry lagoon effluent was studied by Hill and Payton (1998). Three parallel systems, one planted with *Sagittaria* (10% fill), one planted with *Phragmites australis* and *Scirpus* spp. (5% fill), and one control (no vegetation) showed that mass removal of several common pollutants (BOD, nitrogen, phosphorus, etc.) was not correlated to temperature. However, treatment efficiency did correlate to temperature for ammonia, nitrate, total phosphorus, and orthophosphorus in one series. Polprasert et al. (1998) investigated organic removal in tropical wetland systems, specifically assessing the importance of biofilm bacteria in the overall kinetics of organic matter chemical oxygen demand (COD) removal. A kinetic model incorporating the activities of both biofilm and suspended bacteria, dispersion number, and hydraulic retention time was found to satisfactorily predict COD removal efficiencies in FWS wetland systems treating domestic wastewater. The removal of hydrocarbons from wastewater in a *Typha latifolia* wetland was investigated by Salmon et al. (1998). The development of aerobic heterotrophic bacteria (10^6 cells/mL) and hydrocarbon-utilizing bacteria (10^5 bac/mL) was indicated to be responsible for hydrocarbon degradation. A comparative system with floating plants (*Lemna minor*) showed lower hydrocarbon removal performance. A 0.39-ha wetland, designed with nine cells (including two anaerobic cells to stimulate dissimilatory sulfate reduction), was evaluated for its effect on water quality of a low-order acid mine drainage stream (Mitsch and Wise, 1998). Study emphasis was on the uptake and fate of selected metals and the accuracy of a simulation model. Acidity and pH showed little improvement despite the anoxic drain, however iron and aluminum removals were significant.

Subsurface Flow Constructed Wetlands. Three subsurface flow (SF) wetlands sized to accommodate wastewater from a three-bedroom home were constructed with length width ratios of 4:1, 10:1, and 30:1 and evaluated for performance (Bounds et al., 1998). Over a 2-year period, no significant difference between systems due to L:W was observed, except for sulfide discharge amounts. Stress tests such as "wash day," "10-day vacation," "power failure," and changing of plant species all failed to reduce treatment efficiency. Laouali et al. (1998) monitored nutrient removal in an experimental reed bed located in Montreal Canada. Nitrification–denitrification was identified as the main mechanism responsible for nitrogen removal, while precipitation and adsorption accounted for most phosphorus removal. The design, construction, and maintenance of reed bed wetland systems to polish lagoon effluent was described by Gschloessl et al. (1998). Removals of chlorophyll and suspended solids, and the buffering of pH and temperature are detailed. Relationships between pollutant mass loading and removal were studied in a series of five pilot-scale wetlands in year 4 and 5 of their operation (Tanner et al., 1998b). Removal efficiencies for BOD, total nitrogen, ammonia nitrogen, total phosphorus, and fecal coliform were found to follow seasonal patterns and varied inversely with mass loadings. Removal rates were modeled using a simple plug-flow, first-order approach accounting for removal down to nonzero background concentrations. Suspended solids and total phosphorus removal declined over time. The accumulation of organic matter in a series of gravel bed wetlands treating farm dairy wastewater at varying loading rates (21 to 72 mm/d) was described by Tanner et al. (1998a). Mean accumulations of organic matter in the wetland systems after 5 years of operation ranged between 6.8 and 14.9 kg/m^2, increasing with loading rate. Annual accumulation rates in the first 2 years were 1.2 to 2-fold higher than in subsequent years. The effective void space in the substrata was found to be markedly reduced in the highest loaded wetland, with hydraulic retention time reduced to approximately 50% of its theoretical value. Badkoubi et al., (1998) evaluated a reed bed wetland system to determine surface area requirements per person in an arid region to achieve acceptable effluent quality. Minimum land requirements were determined to be 1 to 2 m^2 per population equivalent to reduce BOD by 90% and fecal coliform by 99%. In a separate study, reed beds were evaluated in a hot, arid climate for organic load removal and parasitical load (helminth eggs) removal (Mandi et al., 1998). Pollutant load reductions corresponded best to periods of high plant growth.

Vertical Flow Constructed Wetlands. Rate studies of orthophosphate removal from wastewater in vertical upflow wetlands was found to occur simultaneously via three removal processes (Lantzke et al., 1998). In order of decreasing rate, these processes were defined as reversible sorption to gravel substratum, reversible conversion to complex phosphorus compounds, and irreversible uptake by plant roots. The relevance of the defined mechanisms to total wetland assimilative capacity and effluent quality were also evaluated. Parkes et al. (1998) investigated the use of vertical flow reed beds to treat pig pen washwater following lagoon treatment. Biochemical oxygen demand removal averaged between 61 and 65%, and was best described by an inverse logarithmic function of hydraulic load. Ponding was problematic and efficient nitrification was not achieved.

AQUATIC SYSTEMS

Ponds. A review of the control processes in waste stabilization ponds was performed by Hosetti and Frost (1998). Pond management is described in terms of microflora, chemistry, retention time, and treatment efficiency. The integration of pond systems with membrane filter systems for future water supply protection was discussed. Roche (1998) evaluated the growth potential of *Daphnia magna* straus in waste stabilization ponds treating dairy wastewater. Each of two ponds in series were investigated, with the performance generally being superior in the second pond. Pond effluent was shown to have potential as a growth medium for *D. magna.* Two-dimensional computational fluid dynamic (CFD) models were compared to experimental residence time distributions in ponds by Wood et al. (1998). The models had difficulty representing the three-dimensional experimental inlet, suggesting that two-dimensional CFD models cannot be used a priori to adequately describe hydrodynamic patterns in waste stabilization ponds. Bahlaoui et al. (1998) described the effects of several environmental factors on bacterial populations and community dynamics in high-rate oxidation ponds. Fecal coliform and fecal streptococci distributions showed seasonal cycles, with low summer and high winter abundances being correlated to solar radiation, temperature, pH, and chlorophyll *a* concentration. Results suggest that fecal-indicator bacteria are controlled by different processes in the high-rate pond than are the *Aeromonas* spp. and aerobic heterotrophic bacteria. A series of eight ponds used for sedimentation, aeration, and then fish culturing was found to be effective as a combination wastewater treatment/fish culturing system (Liang et al., 1998). Treatment ponds were found to play an important role in removing pollutants (organic matter, nutrients, and pathogenic bacteria), and algal promotion, while fish culture ponds demonstrated an ability to remove phosphorus and nitrite. Fecal coliform concentration averages in the fish ponds (6.35×10^{-3} cells/100 mL) were within World Health Organization guidelines. Flere and Zhang (1998) discussed the feasibility of using the sulfur/limestone autotrophic denitrification (SLAD) process as an in situ method for remediation of nitrate-contaminated surface waters. Using both mixed (aerobic) and unmixed (anoxic) bench-scale pond systems with 30-day hydraulic retention times (HRTs), the application of SLAD ponds under unmixed (anoxic) conditions was found to be feasible for nitrate removal, while minimizing sulfate production. An integrated pond system consisting of duckweed and algae ponds was investigated for duckweed production and for further treatment of anaerobically treated domestic wastewater by van der Steen et al. (1998). The system of 10 ponds in series produced duckweed at a rate between 2.7 and 16.4 g/m^2·d. Production was found to be most related to organic compounds in the water. Ammonia removal was categorized by volatilization and denitrification (73%), duckweed uptake (18%), sedimentation (8%), and nitrification (3%). Using chemical and biological data on a high-rate algal pond system, Mihalyfalvy et al. (1998) describe a special flow pattern that improves the efficiency of waste treatment. The simplicity, low cost, and ability to remove BOD with algal-produced oxygen is discussed in conjunction with phosphorus chemistry. A comparison of several dispersion equations with the results of dye tracer experiments on more than 30 existing ponds was performed to determine which pond characteristics best influence flow pattern (Nameche and Vasel, 1998). Results suggest several new dispersion prediction formulas that relate Peclet number values to aerator power input and pond shape (L:W and length-to-depth ratios).

Floating Aquatic Plant Systems. The potential of duckweed (*Lemna minor* L.) to accumulate Cd, Cr, Cu, Ni, Pb, and Se from wastewater was investigated by Zayed, Gowthaman, and Terry (1998). Duckweed was found to be a good accumulator of Cd, Se, and Cu, but a poor accumulator of Ni and Pb. Korner et al. (1998) performed laboratory experiments on duckweed-covered domestic sewage to determine whether the removal of organic material is enhanced by the presence of duckweed. Chemical oxygen demand removal was found to be significantly faster in the presence of duckweed. The enhanced degradation of organic material was explained through both additional oxygen supply and additional surface for bacterial growth. An integrated kinetic model for water hyacinth ponds showed the significance of both the suspended and biofilm bacteria, and flow hydraulics (based on dispersion number) in the reduction of organic matter (Polprasert and Khatiwada, 1998). The model effectively predicts BOD removal in full-scale hyacinth pond systems treating anaerobic pond effluent. Design guidelines and operating strategies to improve performance are also discussed.

Solar Aquatic Systems. The factors limiting the acceptance and use of solar aquatic systems for wastewater treatment were discussed by Stephens (1998). For increased acceptance of this technology, it was suggested that tangible environmental benefits, standardization of design, increased public awareness, and increased ecological education must be exhibited. Costa-Pierce (1998) investigated the feasibility of using integrated aquaculture–wetland ecosystems (AWE) for food production and nitrogen removal from tertiary treated wastewater. The system accomplished food production and almost complete nitrogen removal from wastewater. The concept of using tertiary-treated wastewater for aquatic food production may be attractive in the periurban areas of megacities, both for fish markets and to stem the growing discharges of wastewater that are causing coastal pollution.

ON-SITE AND SMALL COMMUNITY SYSTEMS

General. A mathematical model was described by Lee et al. (1998) that predicts the fate and transport of household chemicals in septic systems. Model simulations were found to be in good agreement with field data for laundry detergent builders tartrate monosuccinate (TMS) and tartrate dissuccinate (TDS). Sensitivity analysis showed little change in model predictions when the distribution coefficient and biodegradation rate constants were varied by 10%. Braida et al. (1998) assessed the fate of absorbable organic halide (AOX) formed from the use of household bleach during laundering in septic systems. AOX from unbleached laundry wash water was compared to AOX from the use of sodium hypochlorite in bleached laundry wash water in terms of removal. The fate and chemical effects of olestra, a noncaloric fat replacer, in septic tanks found that high olestra loadings had no effect on system operation or performance (McAvoy et al., 1998). Only 3 to 6% of the total olestra added was recovered in septic tank effluent. Yost and Lingireddy (1998) detailed a hydraulic study of septic tanks that contained a pump vault and pump inside the tank. Results (presented in terms of Reynolds numbers) suggest that pumps can be placed inside septic tanks without negatively affecting performance, thus eliminating the need for external dosing chambers.

Small Treatment Systems. The effects of hydraulic and organic loading rates, and seasonal variation on the performance of overland flow/wetland treatment system for pond effluent in a small town was evaluated by Surampalli et al. (1998). Results of the study showed that the combined system provided excellent treatment for BOD, total suspended solids (TSS), and ammonia-nitrogen. House et al. (1998) described design criteria for constructed wetlands treating wastewater flows of 37 850 L/d or less. Variations in cell depth, vegetation, and substrate media were correlated to treatment performance with respect to BOD, TSS, ammonia, and total phosphorus removal. Design recommendations for on-site wastewater treatment using constructed wetlands were also defined by White and Shirk (1998). Based on more than 2 years of performance data, shallow systems (less than 0.45 m in depth) with HRTs of 2 days or more are effective for BOD, TSS, and fecal coliform removal. It was recommended that in-ground disposal be designed based on soil type. Stein et al. (1988) described a study to develop process-based design approaches for constructed wetlands in cold climates. Macrophytic plants were shown to have a significant influence on mass removal of organic carbon, nitrogen, phosphorus, and sulfate. The influence of wastewater solids on the hydraulic properties of subsurface flow wetlands was conducted using laboratory experiments (Sun et al., 1998). The addition of sawdust to pea gravel was used to evaluate hydraulic conductivity and head loss. Results indicated that Darcy's law calculations fit the laminar region well but did not fit the transition nor turbulent regions of flow data in systems where organic solids significantly affected head loss. Venhuizen (1998) reviewed the use of sand filter/drip irrigation technology for on-site wastewater management and water reuse potential in semiarid areas. Water savings (up to 70% during the peak irrigation season) and system costs are described. Media variations in intermittent sand filters was discussed by Weaver et al. (1998). Sand, recycled crushed glass, limestone, polyethylene pellets, and open-cell foam were evaluated for their capacity to achieve effective wastewater treatment. A number of alternative medias were shown to be effective, suggesting that designers take advantage of locally available materials. Vanlandingham and Gross (1998) studied the effects of filter size and hydraulic loading on virus removal in sand filters. Preferential flow paths were shown to exist along filter walls, suggesting care in hydraulic loading design. Larger diameter filters proved to be more efficient virus removers, suggesting that small diameter laboratory filters may underestimate treatment capacity in full-scale systems. Peat biofiltration systems at individual residences were evaluated after 5 years of operation (O'Driscoll et al., 1998). Biochemical oxygen demand, TSS, and fecal coliform removals exceed 90% and although ammonia-nitrogen removals declined somewhat over time, nitrate removal was enhanced. Good performance has been achieved with little maintenance.

In-Ground Disposal. Keys et al. (1998) developed a mass-balance model to predict system life and loading rates of gravel wastewater infiltration systems on a sand soil. The functional life of the system was predicted using multiple linear regression analysis of ponding depths of wastewater versus time. The matted sidewall of infiltration trenches was found to be most efficient for movement of wastewater into the soil. Various trench designs were compared by Loudon et al. (1998) for their ability to accept either septic tank effluent or highly treated sand filter effluent in a slowly permeable clay loam soil. Soil acceptance rates through trench bottoms were found to be 7 to 12 times greater for trenches receiving sand filter effluent than for trenches receiving septic tank effluent. A high school septic system and the associated waste-impacted unconfined sand and gravel aquifer were instrumented to establish viral transport rates, transport distances, and concentrations (DeBorde et al., 1998). Enteroviruses were found in only two of eight assays of septic tank effluent and were below detection in eight groundwater samples. Virus transport was found to travel at the same rate as a bromide tracer (1 to 2.9 m/d) and the presence of virus was observed for more than 9 months. Baker et al. (1998) used batch and column studies to develop permeable reactive mixtures of silica sand, crushed limestone, and metal oxides to remove phosphorus from on-site wastewater effluent. Iron/calcium oxides produced from steel manufacturing, and fine grained activated aluminum oxide outperformed other materials tested during the study. The structure of biofilms in wastewater infiltration systems were described by Pell et al. (1998). Principal components analysis indicated that a diverse bacterial population was present and that the ability to ferment sugars, ammonify, and grow on nutrient broth were best at explaining microbial structure.

PHYTOREMEDIATION

There are a number of articles that appear offering a general overview of phytoremediation topics and issues. Some articles overview the different subsets within phytoremediation and some of the latest breakthroughs in each (Flathman and Lanza, 1998, and Salt et al., 1998). One review article looked specifically at the biotechnology challenges and opportunities that exist in the field of phytoremediation (Vickers and Lemaux, 1998). The multidiscipline research conducted at the University of Washington is overviewed in one article. The primary focus of their work is organic compounds (MTBE and TCE) remediation utilizing hybrid poplars (Newman et al., 1998). The potential of phytoremediation in the marketplace and a review of current applications is the focus of another review (Glass, 1998). These articles act to give a good introduction to phytoremediation and narration of recent advancements.

Organic Contaminants. Adsorption to the roots and subsequent uptake and/or degradation may be significant in phytoremediation of lipophilic organic compounds. Freundlich isotherms described the adsorption of napthalene on the roots of fescue and alfalfa, revealing that alfalfa with a greater lipid content in the roots and a greater affinity for napthalene (Schwab et al., 1998). In other studies to determine contaminant fate in phytoremediation applications, the uptake of 12 organic compounds was tested in hydroponic reactors with hybrid poplars. Predictive relationships for the uptake and fate were developed, and volatilization of contaminants was discovered and quantified (Burken and Schnoor, 1998). In laboratory tests, *Potamogeton crispus* plants were capable of removing significant amounts of phenol from both industrial waste and hydroponic solution. Toxicity was observed in the experiments (Hafez et al., 1998).

In greenhouse studies, the genetic variability among alfalfa genotypes for agronomic performance in and phytoremediation of crude oil contaminated soils. Genetic variability was present for all traits but not on all evaluations dates. The results indicate that overall agronomic performance is reduced in contaminated soil, and variability exists among genotypes for growth in and for phytoremediation of contaminated soils (Wiltse et al., 1998). Phytoremediation was also evaluated for potential use at manufactured gas plants contaminated with polyaromatic hydrocarbons (PAHs). Using both alfalfa and switch grass, a 57% reduction in total PAH concentration was observed in 6 months. A final polishing step with alfalfa further decreased PAH concentrations by 15% (Pradhan, 1998).

In a 24-week, bench-scale study, diesel range organics decreased by 40 to 90%, and agronomic assessment indicated conditions were favorable for willow tree growth. Phytoremediation utilizing willow trees was implemented as a remediation for the site, and the trees have exhibited fair to excellent growth over the first season (Carman et al., 1998a). The willows displayed some stress when planted in the hotspots of high contamination, although a fertilizing scheme has overcome most of this problem, and the project is continuing into its third year (Carman et al., 1998b). Lin and Mendelssohn (1998) examined the effects of nutrient additions and phytoremediation, utilizing marsh sods on oil contamination in wetlands. Growth was significantly higher at all oil levels up to 250 mg/g than in uncontaminated soil, with or without nutrients. Results suggest that vegetative transplants implemented with nutrients can simultaneously restore oil-contaminated wetlands and accelerate oil degradation.

Trinitrotoluene (TNT) has been studied at detail in hopes of engineering a new remediation tool. It has been found to translocate only slightly in hybrid poplars but was transformed by and adsorbed tightly to roots. Transformation products included 4-amino-2,6-dinitrotoluene, 2-amino-4,6-dinitrotoluene, and a number of unidentified compounds, as well as nonextractable fractions (Thompson, Rames, and Schnoor, 1998). Other research on 11 different species found similar metabolite production and binding, which resulted in decreased soil concentrations. Toxicity testing revealed that *Phaseolus vulgaris* was the most tolerant species tested, growing in soils with TNT levels up to 500 mg/kg soil. (Scheidemann et al., 1998). The toxicity effects of TNT on hybrid poplars have also been evaluated. In hydroponic studies, aqueous concentrations of 5 mg/L and higher caused depressed transpiration rates and subsequently leaf chlorosis and abscission. Similar results were also observed in pilot-scale greenhouse tests (Thompson, Ramer, Guffex, and Schnoor, 1998). Germination of switchgrass and bromegrass seeds exposed to TNT and subsequent growth revealed a difference in tolerance. Switchgrass germination was relatively unaffected by concentrations up to 60 mg/L and root growth was unaffected up to 15 mg/L, whereas bromegrass showed detriment at 7.5 mg/L. Visual analysis via microscopy supported the effects morphologically (Peterson et al., 1998). The majority of studies infer that decreased contaminant concentrations indicate decreased toxicity. One study utilizing solid-phase Microtox testing did not show any benefit with respect to soil toxicity, but results indicated that the solid-phase method may not be suitable for tracking relatively small decreases in soil contaminants (Harvey and Pradhan, 1998).

Wetland plants have also been proposed to remediate nitroaromatic (TNT, RDX, and HMX) contaminated water. Degradation products have been identified and a number of enzymatic pathways have been investigated. (Medina et al., 1998). Batch studies indicate that RDX degradation was slower than that for TNT. The HMX removal rates were reasonable but required a lag phase (Rivera et al., 1998). In other research, the ability of Eurasian watermilfoil to transform TNT was tested in batch studies. Rapid disappearance of TNT was observed and reduced degradation products were detected. However, the majority of the added TNT could not be recovered from the plant biomass (Pavlostathis et al., 1998).

Planting of sunflower, Timothy grass, or red clover was found to increase the microbial mineralization of 2,4,5-trichlorophenoxyacetic acid. Soils with initially low organic matter, K, and P gained the most benefit of the plants, while differences in plant species used produced only minor effects (Boyle and Shann, 1998). Research in the Kuwaiti desert has revealed that the rhizosphere effect (increased microbial populations) was much more pronounced in oil-polluted soils than in clean soils. Findings indicate that rhizosphere was densely populated with hydrocarbon-utilizing bacteria that can contribute to detoxification and bioremediation of the oily soil around the roots (Radwan et al., 1998). Plant-specific effects on the rhizosphere populations were studied for high phenolic-containing oregano varieties to evaluate the potential accelerated degradation of polymeric dyes and aromatic compounds. Peroxidase activity was increased, and steromicroscopic observations revealed that the dyes were sequestered within the growing axis of the roots (Zheng et al., 1998).

The rich microbial community that exists as a biofilm on roots was investigated for microbial diversity and to evaluate the transmission of plasmids for enzymatic, degradation pathways. Results from transmission electron microscopy and PCR techniques revealed a morphologically diverse population and the transmission and harbouring of catabolic plasmids (Sarand et al., 1998). In other research, specific plant/microbe interactions were shown to enhance the degradation of 2-chlorobenzoic acid (Siciliano and Germida, 1998b). Degradation was specific to plant species and bacterial inocula. The specific inocula also proved to decrease phytotoxicity (Siciliano and Germida, 1998c). It was also shown that inoculating the rhizosphere with degradative root-colonizing microbes could alter the root-associated microbial community. Through the use of fatty acid methyl ester profiles, a change in the substrate utilization was detected in the inoculated meadow brome (Siciliano and Germida, 1998a). The use of recombinant microbes to increase the degradative potential of the rhizosphere populations has also been evaluated. *Pseudomonas fluorescens* were taken from wheat rhizosphere, the *tomA*$^+$ gene for TCE degradation was cloned into the chromosome, and the resulting recombinant strain was used to coat wheat seeds. In microcosm studies, the resulting plant/microbe combination degraded 63% of the initial TCE as compared to 9% degradation in microcosms containing wheat inoculated with the wild-type strain (Yee et al., 1998).

Aberdeen Proving Grounds is the site of an extensively evaluated full-scale phytoremediation project, which is using hybrid poplar trees to remediation volatile chlorinated compounds. Results indicate that the VOCs can be taken up by the trees and metabolized or transpired to the atmosphere. A drawdown of the groundwater and an increase in the nematode populations at the site, are further indicators that the phytoremediation is successfully proceeding (Compton et al., 1998). Another field-scale remediation effort for chlorinated volatile compounds (TCE) is underway in Fort Worth, Texas. Initial results do not show a significant effect of the planted trees, but there is evidence of increased degradation near native cottonwoods. This increased degradation suggests that the trees can induce reducing environments that are advantageous for the reduction of chlorinated volatile compounds (Lee, Jones, et al., 1998).

Siliciano et al. (1998) report the presence of an enzyme in Dahurian wild rye that degrades 2-chlorobenzoic acid (2CBA). They also found that the rye inoculated with two *Pseudomonas* strains decreased 2CBA by 46%. Hybrid poplar cells have been shown to degrade TCE to trichloroethanol, di- and trichloroacetic acid. While whole plant studies revealed that 70 to 90% of the TCE was volatilized in the laboratory, while less than 5% was volatilized in greenhouse and field studies (Gordon et al., 1998).

Chang and Corapcioglu (1998) present a model for subsurface bioremediation of nonvolatile hydrocarbons. It investigates properties that might be dominating the processes of degradation and uptake from the vadose zone. A related model has been proposed to evaluate the phytoremediation of hydrocarbon contaminated land (Corapcioglu et al., 1998). The model is proposed to identify dominant parameters and optimize data-collecting efforts.

Inorganic Contaminants. The use of phytoremediation has been evaluated as a method to reduce the volume of water needing treatment after pumping the brackish water from deep petroleum walls. Results indicate that economic volume reduction is possible and that a beneficial use of biomass generated (cattle feed) can result as well (Settle et al., 1998). Similar land application was tested for treating nickel and high nitrate remaining after a VOC stripping process to treat groundwater. The limpograss foliage at this Florida site will result in 5.5 tons hay/a that can be sold as cattle feed (Glanders and Lundquist, 1998). In Minneapolis, Minnesota, the site of an anhydrous ammonium spill is being treated using a pump-and-treat system to irrigate alfalfa with the NH_4- and NO_3-contaminated water. The application was unique as it utilized a type of alfalfa that requires high nitrogen and transpires more water than does normal varieties. The site is expected to be closed in 3 years at much lower costs than had been spent on previous attempts to remediate the site (Elsenheimer, 1998). A survey of soils enriched with sulfur either naturally or by human activities revealed that a surplus of sulfur is mostly accompanied with a surplus of other chemical elements, which may phytoremediation because these cooccurring elements are more toxic to plants than sulfur (Ernst, 1998).

Boyd and Martens (1998) compared the hyperaccumulation of nickel in brassica plants that had been growing in high-Ni soils and those that had grown in low-Ni soils. The hyperaccumulation trait was found to be constitutive in the brassica regardless of the Ni content in the native soil. In another hyperaccumulation study, the screening of 22 plants revealed that oat and barley tolerated high Cd, Cu, and Zn concentrations and accumulated elevated levels of these metals. A hydroponic study comparing the grasses to Indian mustard (*Brassica juncea*) indicated that, while Zn levels were higher in the Indian mustard, the grasses were more tolerant. The authors suggest that barley has phytoremediation potential equal to or greater than *B. juncea* (Ebbs and Kochian, 1998).

The wetland plant duckweed was tested for accumulation of numerous trace metals. The duckweed was found to be a good accumulator Cd, Cu, and Se; a moderate accumulator of Cr; and a poor accumulator of Ni and Pb when exposed to each individually. Toxicity was observed at high levels for each metal, with the descending order of damage being Cu $>$ Se $>$ Pb $>$ Cd $>$ Ni $>$ Cr (Zayed, Gowthaman, and Terry, 1998). Tissue cultures of *Amoracia rusticana L.* were found to bioaccumulate metals. The highest rate was found for Hg^{+2}, Fe^{+2}, Fe^{+3}, and Cu^{+2} (Soudel et al., 1998).

Burd et al. (1998) found that inoculating canola seeds with the plant growth-promoting bacterium *Kluyvera ascorbata* SUD 165 partially protected the plants from Ni toxicity when grown in high levels of Ni. However, the bacterium did not influence the uptake or storage of Ni, possibly reflecting the ability of the microbes to lower the level of stress ethylene induced by the nickel.

Goldsmith (1998) discusses the potential and costs of remediating lead contaminated riverine sediments with wetland species. In studies with terrestrial plants, Xiong (1998) found that in lab studies *Brassica pekinensis* can compare to hyperaccumulators already discovered. The ability and mechanisms to hyperaccumulate metals is of great interest. The hyperaccumulation of Pb and Zn in lichens was found to result from a reactive mechanism of organic acid production, whereas metallo-tolerance was achieved through passive complexation reactions (Sarrat et al., 1998).

Metals uptake by the hyperaccumulator *Thalaspi caerulescens* has been investigated in many research studies. The uptake of Cd, Zn, Pb, and Mn was investigated in pilot studies. The final metal content of the plants was strongly related to the plant-available fraction as measured by ammonium acetate extraction (Robinson et al., 1998). The use of organic acids was tested to increase the mobility and accumulation of uranium in two brassica species. Shoot U concentrations were shown to increase by up to 1000 times when citric acid was used to mobilizing agent (Huang et al., 1998). Similar findings were also revealed by Ebbs et al. (1998) in the study of U uptake by red beet. Citric acid was the only soil amendment that proved effective at increasing uptake, as accumulation increased by a factor of 14.

Cesium and strontium were translocated through switchgrass that was grown in three different growth media. Growth of above ground biomass was not effected by the radionuclides (Entry and Watrud, 1998). Research into the use of NH_4NO_3 to increase accumulation of ^{137}Cs revealed no increased accumulation in the shoots of any plants tested. Researchers proposed that the NH_4NO_3 solution quickly percolated below the rhizosphere, making the ^{137}Cs unavailable for uptake (Lasat et al., 1998).

Banuelos heads research into selenium management using phytoremediation techniques. Research has investigated the potential of using *Brassica* species to accumulate Se when grown in soil containing high SeO_3^{2-} and SeO_4^{2-} levels. The most promising plant in field studies was canola, which was limited to the top 30 cm of soil (Banuelos et al., 1998b). In field studies the uptake of Se was approximately 50% of the observed uptake in greenhouse studies. Such relationships for greenhouse/field studies may prove to be valuable as field-scale implementation expands (Banuelos et al., 1998a). Others have shown that plant exposed to SeO_4 accumulate more Se than those exposed to selenomethanine than SeO_3. Reduction of SeO_4 to SeO_3 appears to be the rate-limiting step in the volatilization of Se compounds by plants (Desouza et al., 1998, and Zayed, Lytle, and Terry, 1998). Selenium remediation and volatilization has also been found to be significant in *Populus tremula x alba.* Volatilization rates were 230-fold higher from selenomethionine compared to selenite and 1.5-fold higher from selenite than selenate (Pilonsmits et al., 1998).

Research at the University of Georgia has focused on the phytoremediation of mercury-contaminated soils. Transgenic tobacco and yellow poplar plants have been generated using the bacterial *mer A* gene. The transgenic plants can convert Hg(II) taken up from soil to the much less toxic Hg(0), which is volatilized from the leaf tissues. The transgenic yellow poplar plantlets released elemental Hg at approximately 10 times the levels of untransformed plantlets. The process of generating the transgenic plants may be applicable for generating other transgenic plants for phytoremediation purposes (Heaton et al., 1998, Rugh, Gragson, et al., 1998, and Rugh, Senecoff, et al., 1998). In research with chromium in wetland plants, water hyacinth accumulated nontoxic Cr(III) in roots and shoots when supplied with Cr(IV) in nutrient solution. The reduction appeared to occur in the fine lateral roots followed by translocation of the Cr(IV) to the leaf tissues (Lytle et al., 1998).

Phytoremediation techniques have also been proposed for use as landfill covers. A comparison of the performance expectations and a cost comparison of traditional and vegetative caps is presented (Beath, 1998). The ability of certain hybrid poplar species to transpire leachate and tolerate heavy metals has been investigated. Research concluded that *P. alba x P. gladulosa* and *P. euroamericana* had a greater adsorptive capacity than other poplars (Lee and Woo, 1998).

Analytical techniques to monitor heavy metals uptake are also being developed. Measurement of chlorophyll fluorescence induction kinetics was carried out during phytoremediation field experiments to monitor heavy-metal uptake. Good correlation was observed between this parameter and accompanied heavy-metal concentration (Richter et al., 1998).

Kevin D. White is an associate professor of civil engineering at the University of South Alabama. Joel G. Burken is an assistant professor of civil engineering at the University of Missouri–Rolla. Correspondence should be addressed to Kevin D. White, Department of Civil Engineering, University of South Alabama, Mobile, AL 36688.

REFERENCES

Badkoubi, A.; Ganjidoust, H.; Ghaderi, A.; and Rajabi, A. (1998) Performance of a Subsurface Constructed Wetland in Iran. *Water Sci. Technol.* (G.B.), **38**, 1, 345.

Bahlaoui, M.A.; Baleux, B.; and Frouji, M.A. (1998) Effect of Environmental Factors on Bacterial Populations and Community Dynamics in High Rate Oxidation Ponds. *Water Environ. Res.*, **70**, 1186.

Baker, L.A. (1998) Design Considerations and Applications for Wetland Treatment of High-Nitrate Waters. *Water Sci. Technol.* (G.B.), **38**, 1, 389.

Baker, M.J.; Blowes, D.W.; and Ptacek, C.J. (1998) Laboratory Development of Permeable Reactive Mixtures for the Removal of Phosphorus from Onsite Wastewater Disposal Systems. *Environ. Sci. Technol.*, **32**, 15, 2308.

Banuelos, G.; Ajwa, H.; Wu, L.; and Zambrzuski, S. (1998a) Is Phytoremediation Up to the Selenium Challenge? *Soil Groundwater Cleanup*, 6.

Banuelos, G.; Ajwa, H.; Wu, L.; and Zambrzuski, S. (1998b) Selenium Accumulation by *Brassica napus* Grown in Se-Laden Soil From Different Depths of Kesterson Reservoir. *J. Soil Contam.*, **7**, 481.

Beath, J.M. (1998) Phytoremediation Proposed as Surface Impoundment Cap. *Haz. Waste Consultant*, 12.

Bounds, H.C.; Collins, J.; Liu, Z.; Qin, Z.; and Sasek, T.A. (1998) Effects of Length-Width Ration and Stress on Rock-Plant Filter Operation. *Small Flows J.*, **4**, 1, 4.

Boyd, R., and Martens, S. (1998) Nickel Hyperaccumulation by *Thlaspi montanum* var. *montanum* (Brassicae): A Constitutive Trait. *Am. J. Bot.*, **85**, 259.

Boyle, J., and Shann, J. (1998) The Influence of Planting and Soil Characteristics on Mineralization of 2,4,5-T in Rhizosphere Soil. *J. Environ. Qual.*, **27**, 704.

Braida, W.; Ong, S.K.; Smith, W.L.; and McCabe, J.W. (1998) Fate of Adsorbable Organic Halides from Bleached Laundering in Septic Tank Systems. *Environ. Toxicol. Chem.*, **17**, 3, 398.

Burd, G.; Dixon, D.; and Glick, B. (1998) A Plant Growth-Promoting Bacterium That Decreases Nickel Toxicity in Seedlings. *Appl. Environ. Microbiol.*, **64**, 3663.

Burken, J.G., and Schnoor, J.L. (1998) Predictive Relationships for Uptake of Organic Contaminants by Hybrid Poplar Trees. *Environ. Sci. Technol.*, **32**, 3379.

Bystrom, O. (1998) The Nitrogen Abatement Cost in Wetlands. *Ecol. Econ.*, **26**, 321.

Carbonell, A.A.; Aarabi, M.A.; DeLaune, R.D.; Gambrell, R.P.; and Patrick, W.H. (1998) Arsenic in Wetland Vegetation: Availability, Phytotoxicity, Uptake, and Effects on Plant Growth and Nutrition. *Sci. Total Environ.*, **217**, 189.

Carman, E.; Crossman, T.; and Gatliff, E. (1998a) Phytoremediation of No. 2 Fuel-Oil Contaminated Soil. *J. Soil Contam.*, **7**, 455.

Carman, E.; Crossman, T.; and Gatliff, E. (1998b) Trees Stimulate Remediation at Fuel Oil Contaminated Site. *Soil Groundwater Cleanup*, 40.

Chang, Y., and Corapcioglu, M. (1998) Plant-Enhanced Subsurface Bioremediation of Nonvolatile Hydrocarbons. *J. Environ. Eng.*, **124**, 162.

Chu, H.Y.; Chen, N.C.; Yeung, M.C.; Tam, N.F.Y.; and Wong, Y.S. (1998) Tide-Tank System Simulating Mangrove Wetland for Removal of Nutrients and Heavy Metals from Wastewater. *Water Sci. Technol.* (G.B.), **38**, 1, 361.

Cole, S. (1998) Emergence of Treatment Wetlands, *Environ. Sci. Technol.*, **32**, 9, 218a.

Compton, H.R.; Harosi, D.M.; Hirsch, S.R.; and Wrobel, J.G. (1998) Pilot-Scale Use of Trees To Address VOC Contamination *Proc. First Int. Conf. Remed. Chlorinated Recalcitrant Compounds*, Monterey, Calif., **4**, 245.

Corapcioglu, M.; Rhykerd, R.; Munster, C.; Drew, M.; Sung, K.; and Chang, Y. (1998) Modeling Phytoremediation of Land Contaminated by Hydrocarbons. *Proc. First Int. Conf. Remed. Chlorinated Recalcitrant Compounds*, Monterey, Calif., **4**, 239.

Costa-Pierce, B.A. (1998) Preliminary Investigation of an Integrated Aquaculture-Wetland Ecosystem Using Tertiary-Treated Municipal Wastewater in Los Angeles County, California. *Ecol. Eng.*, **10**, 341.

Crites, R.W., and Ogden, M. (1998) Costs of Constructed Wetland Systems. *Proc. Water Environ. Fed. 71st Annu. Conf. Exposition*, Orlando, Fla., **7**, 293.

DeBorde, D.C.; Woessner, W.W.; Lauerman, B.; and Ball, P.N. (1998) Virus Occurrence and Transport in a School Septic System and Unconfined Aquifer. *Ground Water*, **36**, 5, 825.

Decamp, O., and Warren, A. (1998) Bacterivory in Ciliates Isolated from Constructed Wetlands (Reed Beds) Used for Wastewater Treatment. *Water Res.* (G.B.), **32**, 1989.

Desouza, M.; Pilonsmits, E.; Lytle, C.; Hwang, S.; Tai, J.; Honma, T.; Yeh, L.; and Terry, N. (1998) Rate-Limiting Steps in Selenium Assimilation and Volatilization by Indian Mustard. *Plant Physiol.*, **117**, 1487.

Dukes, M.D.; and Ritter, W.F. (1998) Modeling BMPs To Optimize Municipal Wastewater Land Treatment System. *J. Environ. Eng.*, **124**, 12, 1178.

Ebbs, S.; Brady, D.; and Kochian, L. (1998) Role of Uranium Speciation in the Uptake and Translocation of Uranium by Plants. *J. Exp. Biol.*, **49**, 1183.

Ebbs, S., and Kochian, L. (1998) Phytoextraction of Zinc by Oat (*Avena sativa*), Barley (*Hordeum vulgare*), and Indian Mustard (*Brassica juncea*). *Environ. Sci. Technol.*, **32**, 802.

Elsenheimer, D. (1998) System Using Alfalfa Reduces Contamination at Railway Site. *Soil Groundwater Cleanup*, 11.

Entry, J., and Watrud, L. (1998) Potential Remediation of Cs-137 and Sr-90 Contaminated Soil by Accumulation in Alamo Switchgrass. *Water, Air, Soil Pollut.* (Neth.), **104**, 339.

Ernst, W. (1998) Sulfur Metabolism in Higher Plants: Potential for Phytoremediation. *Biodegradation*, **9**, 311.

Flathman, P., and Lanza, G. (1998) Phytoremediation: Current Views on an Emerging Green Technology. *J. Soil Contam.*, **7**, 415.

Flere, J.M., and Zhang, T.C. (1998) Sulfur-Based Autotrophic Denitrification Pond Systems for in-situ Remediation of Nitrate-Contaminated Surface Water. *Water Sci. Technol.* (G.B.), **38**, 1, 15.

Glanders, G., and Lundquist, J. (1998) Phytoremediation of Groundwater at Avesta Sheffield Pipe. *Iron Steel Eng.*, **75**, 39.

Glass, D. (1998) An Overview of the Phytoremediation Market—Growth Potential. *Haz. Waste Consultant*, **16**, A7.

Goldsmith, W. (1998) Lead-Contaminated Sediments Prove Susceptible to Phytoremediation. *Soil Groundwater Cleanup*, 15.

Gordon, M.; Choe, N.; Duffy, J.; Ekuan, G.; Heilman, P.; Muiznieks, I.; Ruszaj, M.; Shurtleff, B.B.; Strand, S.; and Wilmoth, J.; et al. (1998) Phytoremediation of Trichloroethylene with Hybrid Poplars. *Environ. Health Perspect.*, **106**, 1001.

Gschloessl, T.; Steinmann, C.; Schleypen, P.; and Melzer, A. (1998) Constructed Wetlands for Effluent Polishing of Lagoons. *Water Res.* (G.B.), **32**, 2639.

Hafez, N.; Abdalla, S.; and Ramadan, Y. (1998) Accumulation of Phenol by *Potamogeton crispus* from Aqueous Industrial Waste. *Bull. Environ. Contam. Toxicol.*, **60**, 944.

Hansen, D.; Duda, P.J.; Zayed, A.; and Terry, N. (1998) Selenium Removal by Constructed Wetlands: Role of Biological Volatilization. *Environ. Sci. Technol.*, **32**, 5, 591.

Harvey, G., and Pradhan, S. (1998) Relationship Between Contaminant Loss and Toxicity During Phytoremediation Using Solid-Phase Microtox Tests. *Bull. Environ. Contam. Toxicol.*, **61**, 419.

Hawkins, G.L.; Hill, D.T.; Rochester, E.W.; and Wood, C.W. (1998) Evaluation of Vegetative Filter Strips for Swine Lagoon Wastewater. *Trans. Am. Soc. Agric. Eng.*, **41**, 3, 639.

Heaton, A.; Rugh, C.; Wang, N.; and Meagher, R. (1998) Phytoremediation of Mercury- and Methylmercury-Polluted Soils Using Genetically Engineered Plants. *J. Soil Contam.*, **7**, 497.

Hill, D.T., and Payton, J.D. (1998) Influence of Temperature on Treatment Efficiency of Constructed Wetlands. *Trans. Am. Soc. Agric. Eng.*, **41**, 2, 393.

Hosetti, B., and Frost, S. (1998) Review of the Control of Biological Waste Treatment in Stabilization Ponds. *Crit. Rev. Environ. Sci. Technol.*, **28**, 2, 193.

House, C.H.; Spooner, J.; Broome, S.W.; and Rubin, A.R. (1998) Evaluation of Cell Depth, Substrate, and Vegetation for Domestic Wastewater Treatment by Constructed Wetlands. *Proc. Water Environ. Fed. 71st Annu. Conf. Exposition*, Orlando, Fla., **4**, 463.

Huang, J.; Blaylock, M.; Kapulnik, Y.; and Ensley, B. (1998) Phytoremediation of Uranium-Contaminated Soils: Role of Organic Acids in Triggering Uranium Hyperaccumulation in Plants. *Environ. Sci. Technol.*, **32**, 2004.

Hubbard, R.K.; Newton, G.L.; Davis, J.G.; Lowrance, R.; Vellidis, G.; and Dove, C.R. (1998) Nitrogen Assimilation by Riparian Buffer Systems Receiving Swine Lagoon Wastewater. *Trans. Am. Soc. Agric. Eng.*, **41**, 5, 1295.

Ingersoll, T.L., and Baker, L.A. (1998) Nitrate Removal in Wetland Microcosms. *Water Res.* (G.B.), **32**, 677.

Kang, H.; Freeman, C.; Lee, D.; and Mitsch, W.J. (1998) Enzyme Activities in Constructed Wetlands: Implication for Water Quality Amelioration. *Hydrobiologia*, **368**, 231.

Keys, J.R.; Tyler, E.J.; and Converse, J.C. (1998) Predicting Life for Wastewater Absorption Systems. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 167.

Korner, S.; Lyatuu, G.B.; and Vermaat, J.E. (1998) Influence of *Lemna gibba* L. on the Degradation of Organic Material in Duckweed-Covered Domestic Wastewater. *Water Res.* (G.B.), **32**, 3092.

Lantzke, I.R.; Heritage, A.D.; Pistillo, G.; and Mitchell, D.S. (1998) Phosphorus Removal Rates in Bucket Size Planted Wetlands with a Vertical Hydraulic Flow. *Water Res.* (G.B.), **32**, 1280.

Laouali, G.; Brisson, J.; Dumont, L.; and Vincent, G. (1998) Nitrogen and Phosphorus Removal in a Subsurface-Flow Reed Bed. *Water Qual. Res. J. Can.*, **33**, 2, 319.

Lasat, M.; Fuhrman, M.; Ebbs, S.; Cornish, J.; and Kochian, L. (1998) Phytoremediation of a Radiocesium-Contaminated Soil: Evaluation of Cesium-137 Bioaccumulation in the Shoots of Three Plant Species. *J. Environ. Qual.*, **27**, 165.

Lee, D., and Woo, S. (1998) Status of Waste Generation, Disposal Ways and Poplar Species as a Landfill Cover in South Korea. *Environ. Forest Sci.*, **54**, 83.

Lee, R.; Jones, S.; Kuniansky, E.; Harvey, G.; and Eberts, S. (1998) Phreatophyte Influence on Reductive Dechlorination in Shallow Aquifer Containing PCE. *Proc. First Int. Conf. Remed. Chlorinated Recalcitrant Compounds*, Monterey, Calif., **4**, 263.

Lee, S.; McAvoy, D.C.; Szydlik, J.; and Schnoor, J.L. (1998) Modeling the Fate and Transport of Household Chemicals in Septic Tanks. *Ground Water*, **36**, 1, 123.

Liang, Y.; Cheung, R.Y.H.; Everitt, S.; and Wong, M.H. (1998) Reclamation of Wastewater for Polyculture of Freshwater Fish: Wastewater Treatment in Ponds. *Water Res.* (G.B.), **32**, 1864.

Lin, Q., and Mendelssohn, I. (1998) The Combined Effects of Phytoremediation and Biostimulation in Enhancing Habitat Restoration and Oil

Degradation of Petroleum Contaminated Wetlands. *Ecol. Eng.*, **10**, 263.

Loudon, T.L.; Salthouse, G.S.; and Mokma, D.L. (1998) Wastewater Quality and Trench System Design Effects on Soil Acceptance Rates. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 186.

Lytle, C.; Lytle, F.; Yang, N.; Qian, J.; Hansen, D.; Zyed, A.; and Terry, N. (1998) Reduction of Cr(VI) to Cr(III) by Wetland Plants—Potential for in-situ Heavy Metal Detoxification. *Environ. Sci. Technol.*, **32**, 3087.

Mandi, L.; Bouhoum, K.; and Ouazzani, N. (1998) Application of Constructed Wetlands for Domestic Wastewater Treatment in an Arid Climate. *Water Sci. Technol.* (G.B.), **38**, 1, 379.

McAvoy, D.C.; Greff, J.A.; Webb, D.R.; and Allgood, G.S. (1998) Effects of Olestra on Organic and Solids Removal in Septic Tanks. *Ground Water Monitor. Remed.*, **18**, 4, 131.

Medina, V.; Rivera, R.; Larson, S.; and McCutcheon, S. (1998) Phytoreactors Show Promise in Treating Munitions Contaminants. *Soil Groundwater Cleanup*, 19.

Mihalyfalvy, E.; Johnston, H.T.; Garrett, M.K.; Fallowfield, H.J.; and Cromar, N.J. (1998) Improved Mixing of High Rate Algal Ponds. *Water Res.* (G.B.), **32**, 1334.

Mitsch, W.J., and Wise, K.M. (1998) Water Quality, Fate of Metals, and Predictive Model Validation of a Constructed Wetland Treating Acid Mine Drainage. *Water Res.* (G.B.), **32**, 1888.

Nameche, T., and Vasel, J.L. (1998) Hydrodynamic Studies and Modelization for Aerated Lagoons and Waste Stabilization Ponds. *Water Res.* (G.B.), **32**, 3039.

Newman, L.; Doty, S.; Gery, K.; Heilman, P.; Muiznieks, I.; Shang, T.; Siemieniec, S.; Strand, S.; Wang, X.; and Wilson, A.; et al. (1998) Phytoremediation of Organic Contaminants: A Review of Phytoremediation Research at the University of Washington. *J. Soil Contam.*, **7**, 531.

Nu Hoai, V.N.; Farrah, H.E.; Lawrance, G.A.; and Orr, G.L. (1998) Efficiency of a Small Artificial Wetland with an Industrial Urban Catchment. *Sci. Total Environ.*, **214**, 221.

O'Driscoll, J.P.; White, K.D.; Salter, D.W.; and Garner, L. (1998) Long Term Performance of Peat Biofilters for Onsite Wastewater Treatment. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 530.

Parkes, M.E.; McBride, A.D.; and Waalkens, A. (1998) Treatment of Dilute Piggery Effluent with Vertical Flow Reed Beds. *J. Environ. Qual.*, **27**, 4, 783.

Pavlostathis, S.; Comstock, K.; Jacobson, M.; and Saunders, F. (1998) Transformation of 2,4,6-Trinitrotoluene by the Aquatic Plant *Myriophyllum spicatum. Environ. Toxicol. Chem.*, **17**, 2266.

Pell, M.; Stenberg, B.; and Hallin, S. (1998) Bacterial Structure of Biofilms in Wastewater Infiltration Systems. *Water Sci. Technol.* (G.B.), **37**, 4–5, 203.

Peterson, M.; Horst, G.; Shea, P.; and Comfort, S. (1998) Germination and Seeding Development of Switchgrass and Smooth Bromegrass Exposed to 2,4,6-Trinitrotoluene. *Environ. Pollut.*, **99**, 53.

Pilonsmits, E.; Desouza, M.; Lytle, C.; Shang, C.; Lugo, T.; and Terry, N. (1998) Selenium Volatilization and Assimilation by Hybrid Poplar (*Populus tremula x Alba*). *J. Exp. Bot.*, **49**, 1889.

Polprasert, C., and Khatiwada, N.R. (1998) An Integrated Kinetic Model for Water Hyacinth Ponds Used for Wastewater Treatment. *Water Res.* (G.B.), **32**, 179.

Polprasert, C.; Khatiwada, N.R.; and Bhurtel, J. (1998) A Model for Organic Matter Removal in Free Water Surface Constructed Wetlands. *Water Sci. Technol.* (G.B.), **38**, 1, 369.

Pradhan, S. (1998) Potential of Phytoremediation for Treatment of PAHs in Soil at MGP Sites. *J. Soil Contam.*, **7**, 467.

Radwan, S.; Al-Awadhi, H.; Sorkhoh, N.; and El-Nemr, I. (1998) Rhizospheric Hydrocarbon-Utilizing Microorganisms as Potential Contributors to Phytoremediation for the Oily Kuwaiti Desert. *Microbiol. Res.*, **153**, 247.

Richter, P.; Barocsi, A.; Csintalan, Z.; Kuperberg, M.; and Szdzuj, J. (1998) Monitoring Soil Phytoremediation by a Portable Chlorophyl. *Field Analyt. Chem. Technol.*, **2**, 241.

Rivera, R.; Medina, V.; Larson, S.; and McCutcheon, S. (1998) Phytotreatment of TNT-Contaminated Groundwater. *J. Soil Contam.*, **7**, 511.

Robinson, B.H.; Leblanc, M.; Petit, D.; Brooks, R.R.; Kirkman, J.H.; and Greg, P.E.H. (1998) The Potential of *Thalaspi caerulescens* for Phytoremediation of Contaminated Soil. *Plant Soil*, **203**, 47.

Rugh, C.; Gragson, G.; Meagher, R.; and Merkle, S. (1998) Toxic Mercury Reduction and Remediation Using Transgenic Plants with Modified Bacterial Gene. *HortScience*, **33**, 618.

Rugh, C.; Senecoff, J.; Meagher, R.; and Merkle, S. (1998) Development of Transgenic Yellow Poplar for Mercury Phytoremediation. *Nature Biotechnol.*, **16**, 925.

Sakadevan, K., and Bavor, H.J. (1998) Phosphate Adsorption Characteristics of Soils, Slags, and Zeolites To Be Used as Substrates in Constructed Wetland Systems. *Water Res.* (G.B.), **32**, 393.

Salmon, C.; Crabos, J.L.; Sambuco, J.P.; Bessiere, J.M.; Basseres, A.; Caumette, P.; and Baccou, J.C. (1998) Artificial Wetland Performances in the Purification Efficiency of Hydrocarbon Wastewater. *Air Soil Pollut.*, **104**, 3–4, 313.

Salt, D.; Smith, R.; and Raskin, I. (1998) Phytoremediation. *Ann. Rev. Plant Physiol. Plant Molec. Biol.*, **49**, 643.

Sarand, I.; Timonen, S.; Nurmiaho-Lassila, E.; Koivula, T.; Haahtela, K.; Romantschuk, M.; and Sen, R. (1998) Microbial Biofilms and Catabolic Plasmid Harbouring Degradative Fluorescent Pseudomonads in Scots Pine Mycorrhizospheres Developed on Petroleum Contaminated Soil. *FEMS Microbiol. Ecol.*, **27**, 115.

Sarrat, G.; Manceau, A.; Cuny, D.; Vanhaluwyn, C.; Deruelle, S.; Hazeman, J.; Soldo, Y.; Eybertberard, L.; and Menthonnex, J. (1998) Mechanisms of Lichen Resistance to Metallic Pollution. *Environ. Sci. Technol.*, **32**, 3325.

Sawhill, R.B., and Ferguson, B.K. (1998) The Potential for Recycling Municipal Sewage Sludge as a Substrate for Wetland Creation. *Land. Urban Plann.*, **42**, 123.

Scheidemann, P.; Klunk, A.; Sens, C.; and Werner, D. (1998) Species Dependent Uptake and Tolerance of Nitroaromatic Compounds by Higher Plants. *J. Plant Physiol.*, **152**, 242.

Scholes, L.; Shutes, R.B.E.; Revitt, D.M.; Forshaw, M.; and Purchase, D. (1998) Treatment of Metals in Urban Runoff by Constructed Wetlands. *Sci. Total Environ.*, **214**, 1–3, 211.

Schwab, A.; Al-Assi, A.; and Banks, M. (1998) Adsorption of Napthalene onto Plant Roots. *J. Environ. Qual.*, **27**, 220.

Settle, T.; Mollock, G.; Hinchman, R.; and Negri, M. (1998) Engineering the Use of Green Plants To Reduce Produced Water Disposal Volume. *SPE Permian Basin Oil Gas Recovery Conf.*, Midland, Tex., 127.

Siciliano, S., and Germida, J. (1998b) Degradation of Chlorinated Benzoic Acid Mixtured by Plant-Bacteria Associations. *Environ. Toxicol. Chem.*, **17**, 728.

Siciliano, S., and Germida, J. (1998c) Mechanisms of Phytoremediation: Biochemical and Ecological Interactions Between Plants and Bacteria. *Environ. Rev.*, **6**, 65.

Siciliano, S., and Germida, J. (1998a) Biolog Analysis and Fatty Acid Methyl Ester Profiles Indicate That Pseudomonad Inoculants That Promote Phytoremediation at the Root-Associated Microbial Community of *Bromus biebersteinii. Soil Biol. Biochem.*, **30**, 1717.

Siciliano, S.; Goldie, H.; and Germida, J. (1998) Enzymatic Activity in Root Exudates of Dahurian Wild Rye (*Elymus dauricus*) That Degrades 2-Chlorobenzoic Acid. *J. Agric. Food Chem.*, **46**, 5.

Soudel, P.; Podlipna, R.; Lipavska, H.; and Vanek, T. (1998) Bioaccumulation of Heavy Metals by Hair-Root Cultures of *Armoracia rusticana* L. (I.). *Pharm. Pharmacol. Lett.*, **8**, 57.

Steevens, J.A.; Vansal, S.S.; Kallies, K.W.; Knight, S.S.; Cooper, C.M.; and Benson, W.H. (1998) Toxicological Evaluation of Constructed Wetland Habitat Sediments Utilizing Hyalella Azteca 10-Day Sediment Test and Bacteriological Bioluminescence. *Chemosphere* (G.B.), **36**, 3167.

Stein, O.R.; Biederman, J.A.; and Hook, P.B. (1998) Performance of Model Constructed Wetlands for Wastewater Treatment. *Proc. 8th*

Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 202.

Stephens, J.C. (1998) Factors Limiting the Acceptance and Use of Innovative Environmental Technologies: A Case Study of the Solar Aquatics System (SAS) Technology for Wastewater Treatment. *J. Environ. Syst.*, **26**, 2, 163.

Sun, X.; Thompson, A.L.; Hjelmfelt, A.T.; and Sievers, D.M. (1998) Influence of Solids on Hydraulic Properties of Submerged Flow Wetlands. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 211.

Surampalli, R.Y.; Banerji, S.K.; McAllister, D.; and Clarkson, R. (1998) Evaluation of Overland Flow and Wetland Wastewater Treatment System Following a Waste Stabilization Pond. *Proc. Water Environ. Fed. 71st Annu. Conf. Exposition*, Orlando, Fla., **7**, 245.

Tanner, C.C.; Sukias, J.P.S.; and Upsdell, M.P. (1998a) Organic Matter Accumulation During Maturation of Gravel-Bed Constructed Wetlands Treating Farm Dairy Wastewaters. *Water Res.* (G.B.), **32**, 3046.

Tanner, C.C.; Sukias, J.P.S.; and Upsdell, M.P. (1998b) Relationships Between Loading Rates and Pollutant Removal During Maturation of Gravel Bed Constructed Wetlands. *J. Environ. Qual.*, **27**, 2, 448.

Thompson, P.L.; Ramer, L.A.; and Schnoor, J.L. (1998) Uptake and Transformation of TNT by Hybrid Poplars. *Environ. Sci. Technol.*, **32**, 975.

Thompson, P.; Ramer, L.; Guffey, A.; and Schnoor, J. (1998) Decreased Transpiration in Poplar Trees Exposed to 2,4,6-Trinitrotoluene. *Environ. Toxicol. Chem.*, **17**, 902.

Tilley, D.R., and Brown, M.T. (1998) Wetland Networks for Stormwater Management in Subtropical Urban Watersheds. *Ecol. Eng.*, **10**, 131.

van der Steen, P.; Brenner, A.; and Oron, G. (1998) An Integrated Duckweed and Algae Pond System for Nitrogen Removal and Renovation. *Water Sci. Technol.* (G.B.), **38**, 1, 335.

Vanlandingham, D.S., and Gross, M.A. (1998) Contaminant Distribution in Intermittent Sand Filters. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 380.

Venhuizen, D. (1998) Sand Filter/Drip Irrigation Systems Solve Water Resources Problems. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 356.

Vickers, K., and Lemaux, P. (1998) Biotechnology and the Environment: Challenges and Opportunities. *HortScience*, **33**, 609.

Weaver, C.P.; Gaddy, B.S.; and Ball, H.L. (1998) Effects of Media Variations on Intermittent Sand Filter Performance. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 363.

White, K.D., and Shirk, C.M. (1998) Performance and Design Recommendations for On-Site Wastewater Treatment Using Constructed Wetlands. *Proc. 8th Natl. Symp. Individual Small Community Sewage Syst.*, Am. Soc. Agric. Eng., Orlando, Fla., 195.

Williams, C.; Perry, M.W.; Post, R.; and Dombeck, G. (1998) The Significant Effects of Large Macrophytes in a Constructed Wetlands. *Proc. Water Environ. Fed. 71st Annu. Conf. Exposition*, Orlando, Fla., **4**, 479.

Wiltse, C.; Rooney, W.; Schwab, A.; and Banks, M. (1998) Greenhouse Evaluation of Agronomic and Crude Oil-Phytoremediation Potential Among Alfalfa Genotypes. *J. Environ. Qual.*, **27**, 169.

Wood, M.G.; Howes, T.; Keller, J.; and Johns, M.R. (1998) Two Dimensional Computational Fluid Dynamic Models for Waste Stabilization Ponds. *Water Res.* (G.B.), **32**, 958.

Xiong, Z. (1998) Lead Uptake and Effects on Seed Germination and Plant Growth in a Pb Hyperaccumulator *Brassica pekinensis*. *Bull. Environ. Contam. Toxicol.*, **60**, 285.

Yee, D.C.; Maynard, J.A.; and Wood, T.K. (1998) Rhizoremediation of Trichloroethylene by a Recombinant, Root-Colonizing *Pseudomonas fluorescens* Strain Expressing Toluene *ortho*-Monooxygenase Constitutively. *Appl. Environ. Microbiol.*, **64**, 112.

Yost, S.A., and Lingireddy, S. (1998) Hydraulic Performance of Vaulted Pumps Placed in Septic Tanks Used with On-Site Wastewater Systems. *Appl. Eng. Agric.*, **14**, 3, 275.

Zayed, A.; Gowthaman, S.; and Terry, N. (1998) Phytoaccumulation of Trace Elements by Wetland Plants: I. Duckweed. *J. Environ. Qual.*, **27**, 715.

Zayed, A.; Lytle, C.; and Terry, N. (1998) Accumulation and Volatilization of Different Chemical Species of Selenium by Plants. *Planta* (Ger.), **206**, 284.

Zheng, Z.; Pinkman, J.; and Shetty, K. (1998) Identification of Polymeric Dye-Tolerant Oregano (*Origanum vulgare*) Clonal Lines by Quantifying Total Phenolics and Peroxidase Activity. *J. Agric. Food Chem.*, **46**, 4441.

Disinfection and Antimicrobial Processes

Jih-Fen Kuo, Lori Yamashita

GENERAL

Regulations and Policies. The U.S. Environmental Protection Agency (U.S. EPA) is in the process of responding to the requirements imposed by the Safe Drinking Water Act Amendments of 1996. The pace of regulatory activity has been dramatically accelerated to meet the new requirements and regulatory schedules. New rules have been mandated, including those cover microorganisms, disinfection byproducts (DBPs), and groundwater disinfection. New contaminants for regulation will be identified using a listing process through which the agency will decide whether candidate contaminants warrant regulation (Pontius, 1998b). In July 1997, large water utilities using surface water began an 18-month monitoring program for Cryptosporidium under the Information Collection Rule (ICR). These data are being reported to U.S. EPA and would be used for development of future rules for microorganisms and DBPs (Allgeier et al., 1998, and Pontius, 1998a).

Health Risk. Transmission of waterborne diseases is now controlled in most developed countries but a residual level of both epidemic and endemic diseases can still be observed. To control waterborne outbreaks many countries are proposing treatment goals that would achieve a significant reduction in the risk to the population without increasing the risks of cancer due to DBPs. Reliance on continuous measurement of physicochemical parameters such as disinfectant residual and contact time, turbidity, and particulate measurement in real-time are proposed solutions (Payment and Hartemann, 1998). Clancy and Fricker (1998) noted that Cryptosporidium has become a focus of regulatory agencies in the United States and the United Kingdom, following reports of the outbreak of waterborne cryptosporidiosis. The prospects of controlling this pathogen in drinking water are not clear. To combat this problem, water suppliers are using a combination of chemicals and UV light.

Recent epidemiological studies conducted in Finland have re-