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Environmental Restoration – Expedient Methods and Technologies: A User Guide with Case Studies

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19980618 171

March 1998

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IDA Paper P-3383
Log: H 97-003880

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PREFACE

This document was compiled by the Institute for Defense Analyses (IDA) in support of a NATO Pilot Study for the Committee on the Challenges of Modern Society entitled, "Reuse of Former Military Lands." The study was co-chaired by the Principal Assistant, Deputy Under Secretary of Defense for Environmental Security. Originally, its focus was as a guide to methods that may be useful to NATO member nations and Cooperation Partners who desire to convert disused military sites to civilian use, but it has a wider use in the assistance it can give to any planning for site environmental and economic restoration. Dr. Joel E. Tumarkin was the project leader; Mr. John F. Kreis was the task leader for this effort.

The case studies collected in this volume are presented according to the type of pollution that is the object of remediation plans. Wherever possible, we included more than one site illustration for each major problem type, with a description of the problem to be resolved, the anticipated cost (if available), and the actual cost (if known). Also included are discussions of technical problems that have been encountered, source documents containing information that might be useful, and appropriate sites on the World Wide Web that may give summaries of information. One section is devoted to new technologies that may soon be available; an appendix discusses technology applications that are deemed impractical because of high cost, difficulty of use, or other factors. Also included is a listing of sources of technology delivery systems. As additional information becomes available, this document will be updated.

Two previous studies, IDA Document D-1936, "Sources of Financial Assistance for the Restoration of Former Military Lands" and the "Project Prospectus for Environmental Restoration," are companion pieces to this volume. All three have been prepared as guides that complement one another for planning site restoration and conversion work.

Several agencies offered information and assistance in this document's preparation. Of particular help were the staffs of the U.S. Army Corps of Engineers,

District Office, Omaha, Nebraska; the U.S. Air Force's Center for Environmental Excellence; the U.S. Naval Space and Naval Warfare Systems Center, Port Hueneme, California; the Naval Command, Control, and Ocean Surveillance Center, San Diego, California; the Naval Environmental Leadership Program, San Diego, California and Mayport (Jacksonville), Florida; and the Office of the Staff Civil Engineer, NAS North Island, San Diego, California.

The authors also appreciate the work of this paper's reviewers, Dr. Ivan Oelrich, our colleague at the Institute for Defense Analyses; Captain James Campbell, U.S. Navy, Naval Research Laboratory; and Dr. Aldis Valkirs and Dr. Sabine Apitz, of the Naval Research and Development Center, San Diego, California. Ms. Barbara Capps prepared the manuscript for publication through several versions; Ms. Patricia Phillips edited the document. Both spent considerable time on the project, and their effort made the final product possible. The authors very much appreciate their contributions.

Although we have attempted to include the best examples of specific methodologies or technologies, we cannot guarantee the completeness or correctness of such information. Questions regarding the cases cited should be referred to the respective agencies that performed the original study or work.

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APPENDICES

EXECUTIVE SUMMARY

This report summarizes the availability of remediation technologies and processes for projects having limited budgets. Relevant case studies of sites in the U.S. Department of Defense and other U.S. agencies are included. Only fuel hydrocarbon, chlorinated hydrocarbon, and heavy metal contamination restoration technologies are covered.

Each section contains case studies of contamination, the extent, the media in which it was found (soil, ground water, or sediment), the final cost of remediation (if available), and the success of the technology or methodology used in the project.

Certain field-proven technologies are excluded because of expense. Exclusion from this document does not imply that the technology is not valuable; rather, we believe that it may exceed available budgets. We have identified a number of these technologies in Appendix B.

A. DESIGN DRIVERS

Technology designs for the remediation of fuels, chlorinated solvents, and heavy metals are driven by three factors: the density and chemistry of the compound, where it is located as a contaminant, and if microorganisms can use it either as a nutrient or an electron acceptor.

1. Fuels

Field-ready technologies for cleanup are well characterized for fuel contaminants such as aviation fuels, gasoline, diesel, and kerosene, [light non-aqueous phase liquids (LNAPLs)]. Technologies include soil venting or soil vapor extraction, bioventing, air sparging, separate phase recovery including bioslurping, and natural attenuation.

For fuels, bioventing and biosparging are least expensive. Natural attenuation, which would seem to be least expensive, costs about the same as bioventing and biosparging because of the monitoring required. Separate phase recovery is expensive because of pumping costs; soil venting is expensive because of having to remediate the fuel vapor recovered from the contaminated area.

A unique technology for large pools of subsurface free-product gasoline uses an internal combustion engine. An automotive engine, modified for this purpose, runs on the vapors from a subsurface gasoline spill. The limiting factor for this treatment is that vapor concentration has to be in the 200,000 parts per million (ppm) range before extraction and be maintained at 40,000 ppm to keep the engine running.

2. Chlorinated Hydrocarbons

Chlorinated solvents present two main problems: they are difficult to remove, and they sink below water because of their density. For this reason, they are also called dense non-aqueous phase liquids (DNAPLs). Sources of DNAPL contamination in the subsurface can rarely be located with precision, due mainly to the great cost of locating the pockets and layers that DNAPLs form in the saturated zone below the ground water, or in the vadose zone. Therefore, treatment of chlorinated solvents in the subsurface is generally limited to plume remediation. The plume may be in or below the ground water, or vapors from the spill may emerge from the ground water or from the pool of contaminant in the vadose zone.

At present, natural attenuation in soils and ground water and passive barrier walls for chlorinated solvents in ground water are the two field-ready approaches that are potentially of greater use because they are less expensive than other solvent cleanup methods. Dual-phase recovery followed by chlorinated solvent destruction at the surface is mentioned because it is in field use, but it is expensive.

3. Heavy Metals

The techniques used to remediate heavy metals vary. Generally, if the soil is contaminated, it is left where it is when it is not a threat to life or health. If it *is* a threat (because it is contaminated with potentially toxic metals such as lead, zinc, chromium, cadmium, or mercury), then it is dug, hauled, solidified, placed in a landfill, permanently flooded, covered by a cap, or contained by a slurry wall. If the choice is made to remove heavy metal contaminated soil or sediment to a landfill, then other issues about landfill placement, design, and maintenance arise. If water is contaminated with heavy metals, it must be treated or use must stop. Some progress has been made in the remediation of heavy metal-contaminated water in the mining industry, but the technology is not consistent.

Heavy metal-contaminated sediments are another special case. However, the options for working with them are to cover them up where they are, dig them up, or leave them alone.

B. RISK-BASED CORRECTIVE ACTION

The underlying principle of risk-based correction action is the creation of an appropriate cleanup standard that includes (but is not limited to) such factors as target populations at risk as well as the fate, transport, and toxicity of constituents.

For example, at petroleum release sites, a four-step strategy may be proposed, beginning with negotiating a realistic cleanup standard to BTEX, instead of total petroleum hydrocarbons, followed by assessment of the natural attenuation capacity of the ground water. The next step is to recover any free product using bioslurper equipment, which can then be used for other projects if needed. For the soils, the final step is to remove the source by soil vapor extraction or bioventing.

In the heavily regulated area of environmental issues in the United States, changes to standards take time. To move to a risk-based corrective action stance would be possible, but can require changes to many laws and many people's minds.

Using risk-based corrective action (RBCA) and risk-based assessment may be a wise move because, thus far, such standards tend to save money on cleanup efforts. Specific cost savings as well as additional voluntary compliance with standards and speedier cleanups have been reported.

However, we do not know what effect these contaminants truly have. Thoughtful persons have indicated that eco-receptors may need to have standards in the parts per trillion (ppt). Continued exposure to many contaminants especially affects the unborn, and harmful effects are observed in animals and plants. Some of the suspected effects of continued exposure to endocrine imitators are decreased growth rate, feminization of males, overfeminization of females, accelerated or increased rates of breast, thyroid, and testicular cancer, and difficulties with metabolic rates.

C. EMERGING TECHNOLOGIES

The following technologies are included in this document because they are inexpensive or effective, and they are close to being field proven and ready: enhanced co-metabolism, surfactants, two phytoremediation technologies, and passive barrier walls to treat heavy metal-contaminated ground water. A potential substitute for activated charcoal or zeolites is also mentioned. Researchers estimate that these technologies will be field-ready in 1999 or 2000.

D. TREATMENT SUMMARY MATRIX

Table 1 summarizes the findings for the major types of contamination covered by this document. The table is intended for use as a quick reference guide for readers wishing to find specific problems and related treatments.

E. FURTHER INFORMATION

Brief summaries of technologies not considered in this document are in one appendix, while other appendixes have information on sources of environmental technology implementation, models, a remediation matrix, landfill information, heavy metal in sediment detection technologies, and useful World Wide Web sites.

Table 1. Summary of Findings and Index to the Cases

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Fuel Hydrocarbon	Ground Water	Drinking Water	Natural Attenuation	III:23-27	1. Naval Weapons Station, Seal Beach, CA. *In-situ* anaerobic degradation of petroleum hydrocarbons by native ground water microorganisms at a site contaminated with leaded and unleaded fuel. No cost data. 2. Columbus AFB, Ohio. Investigation of natural attenuation processes associated with fuel hydrocarbons through a large-scale field experiment, consisting of a natural-gradient, shallow, unconfined aquifer in the saturated zone. No cost data.
Fuel Hydrocarbon	Soil: Vadose Zone	Drinking Water, Air	Bioslurping, or Vacuum Enhanced Free Product Recovery	III:27-33	1. Naval Air Station, Fallon, Nevada. Bioslurping of JP-5 jet fuel floating on ground water table, removing free product and bioventing the vadose zone. System installed for approximately $30,000. 2. Naval Radar Site #3, Hofn, Iceland. Plume from leaking diesel fuel tanks treated via bioslurping, about one-fourth acre. Costs included a bioventing effort for two other fuel-contaminated sites. Installation $65,000 and $99,000 for completion without cost breakdowns. 3. Diego Garcia Island, Indian Ocean. Bioslurper system to recover JP-5 jet fuel leak of 160,000 gallons. As of March 1997, a total of 35,000 gal useable fuel recovered. Installation cost, $133,000; yearly maintenance, $20,000.
Fuel Hydrocarbon	Soil or Water	Drinking Water, Air	Dual Phase Recovery	III:33-39	1. Hill Air Force Base, Ogden, Utah. Soil vapor extraction, then bioventing. About 27,000 gal JP-5 spill from failure of automatic overflow device, contaminating the vadose zone. Total capital cost, $335,000; annual operating cost, $132,000. 2. Naval Air Station, Lemoore, California. Thermal enhancement using steam injection for pump-and-treat, and soil vapor extraction. Hydrocarbon sites. Demonstrations: cost estimated to be $200/ton of contaminated soil. 3. Amoco Petroleum Pipeline, Constantine, Michigan. Pipeline leak with an estimated 350,000 to 2 million gallons of gasoline, fuel oil, and kerosene in subsurface, about 6 acres, thickness 2 feet. Total capital costs for ground water recovery and treatment: $297,000, with annual cost $475,000. For air sparging capital cost, $375,000; no cost data for annual. 4. Luke Air Force Base, Arizona. Fire-fighting training pits contaminated with petroleum, oil and lubricant wastes and JP-5. Site cleaned to required standards with soil vapor extraction and thermal oxidizer. Capital costs, $297,000; annual operating costs, $210,000.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Fuel Hydrocarbon	Vadose zone of soil	Air, Water	Bioventing	IV: 41-46	1. Hill Air Force Base, Site 280, Ogden, Utah. Lowintensity bioventing system installed to remediate JP-4 jet fuel. Soil gas TPH of 11,200 mg/kg reduced to 2,600 mg/kg as of November 1992. Capital cost, $115,000; annual cost, $24,000 for each of 4 years. 2. Hill Air Force Base, Site 914, Ogden, Utah. Demonstration of soil vapor extraction followed by bioventing of 25,000 gal JP-4 jet fuel spill. Estimated 110,000 pounds of fuel volatilized, 90,000 pounds biodegraded in 9 months. No cost data. 3. Kelly Air Force Base, Texas. Remediation of fire training pits contaminated with petroleum, oils, and lubricants and fuels fires by one air injection well. Radius of oxygen influence was 50 feet, remediating 30,000 cubic yards of soil. Total cost for 1-year pilot testing and full-scale system upgrade, $115,000. 4. Lowry Air Force Base, Denver, Colorado. Underground storage tanks leaked heating oil. After excavating for landfarming to depth of 35-40 feet, bioventing chosen for residuals in soil at bottom of excavation. Total capital cost, $29,000; estimated annual costs, $39,000. 5. U.S. Coast Guard Support Center, Kodiak, Alaska. Demonstration of bioventing at remote, cold site. Leak from tank of diesel and JP-5 jet fuel. Soil temperatures averaged 6 °C, biodegradation rate of 1,300 mg fuel per kg soil per year. System installation and 1-year operation was $69,000.
Fuel Hydrocarbon	Ground Water, Soil	Drinking Water, Air	Internal Combustion Engine	IV: 46-48	1. Patrick Air Force Base, Florida. Vadose zone soil contaminated with gasoline at an active-base service station was treated using a gasoline internal combustion engine. Soil gas survey results ranged from 38,000 ppmv to 100,000 ppmv. Total operating costs were approximately $100,000, including engine purchase of $73,650.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Fuel Hydrocarbon	Soil	Air, Water	Composting: Landfarming and Biopiles	IV: 48-55	1. Lowry Air Force Base, Denver, Colorado. About 5,400 cubic yards of soil contaminated with an estimated 10,500 gallons of heating oil was landfarmed; ammonium nitrate nutrients added on a one-time basis. After 20 months, regulatory levels were not yet reached. Total capital cost $104,000; annual costs estimated at $19,000. 2. Seymour Johnson Air Force Base. Approximately 550 tons of fuel-contaminated soil from various places on the base were treated each time in a reusable cell. Turkey manure from local farmer and compost from the base were amendments. Treatment costs averaged $5.00 per ton. 3. Marine Corps Base Twentynine Palms, California. Heap pile bioremediation demonstration for 1,500 cubic yards of fuel-contaminated soil (JP-5 jet fuel and diesel, mainly). Purpose was to determine optimal conditions as well as clean the pile. Estimated cleanup costs $40/cubic yard. 4. Scott Lumber Company Superfund Site, Alton, Missouri. Creosote/diesel fuel mixture contaminated soil. About 15,961 tons of soil were treated in land treatment unit. Total costs were $4,047,000, including $1,292,000 for 3 years of contractor time and $254,000 for laboratory analyses. 5. Brown Wood Preserving Superfund Site, Live Oak, Florida. Creosote used to pressure treat lumber in cylinders, water from cylinders discharged to a lagoon, contaminating soil. About 8,100 cubic yards of contaminated soil were landfarmed in 3 lifts. Total cost was $565,400. 6. Naval Air Station, North Island, San Diego, California. A bioremediation treatment facility constructed to treat only petroleum hydrocarbon contaminated soils. Cost savings are given: for 1,000 tons of soil, about $30,000 saved compared to thermal desorption, and $100,000 compared to landfill disposal. 7. US Naval Station, Mayport, Florida. Clean up about 1,000 cubic yards of concrete in a detention pond covered with solidified oily petroleum hydrocarbons and 100 cubic yards of contaminated soil. Pressure washing followed by application of a proprietary mixture of microbes did not remediate the surface.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Chlorinated Solvents	Ground Water	Drinking Water	Natural Attenuation	VI: 61-66	1. Dover Air Force Base, Delaware: Groundwater Remediation Field Laboratory. U.S. facility for researchers to conduct carefully planned releases of chlorinated solvents into a natural aquifer and thus test different cleanup methods. Information only. 2. Edwards Air Force Base, California. Enhanced natural attenuation, the full-scale demonstration successfully demonstrated trichloroethylene (TCE) biodegradation in contaminated ground water. TCE concentrations of 1,000 to 1,400 mg/L fell 85%. No cost data. 3. National Priorities List Site at St. Joseph, Michigan. TCE in groundwater at 10 to 100 mg/L from waste lagoons or disposal of TCE into dry wells at the site. Natural *anaerobic degradation* of the TCE was occurring because transformation products and levels of ethene and methane were present. No cost data. 4. Fort Wainright, Alaska. Investigation of natural attenuation in extreme environment is occurring in a chlorinated hydrocarbon contaminated active ground-water and surface-water system. No cost data *or contamination data, but* this is one of the few sites for natural attenuation of chlorinated solvents.
Chlorinated Solvents	Ground Water	Drinking water	Passive Barrier Walls	VI:1 66-73	1. Moffett Field Airfield and Naval Air Station, Mountain View, California. A 50-foot long by 10-foot wide by 22-foot thick iron permeable reactive wall was installed across a TCE and PCE contamination plume. TCE of 1,000 mg/L reduced to non-detectable levels in first 2 feet of the cell. Report due March 1998. 2. Canadian Forces Base, Borden, Ontario, Canada. Permeable reaction using an iron-based catalyst intercepted a VOC contaminated plume to pilot test the wall's ability to degrade halogenated organic compounds. TCE 250 mg/L, PCE 43 mg/L reduced by 95% and 91% respectively. No cost data. 3. Demonstration sites: Canadian Forces Base, Bordon, Ontario, Canada. -- General Electric, Sunnyvale, California. -- Industrial Facility, New York State. -- Semiconductor Manufacturing Facility, New Jersey. -- Massachusetts Military Reserve, Falmouth, Massachusetts. -- Coast Guard Air Station, Elizabeth City, North Carolina. Each of these sites uses some form of a reactive barrier wall and has generally *been successful in treating chlorinated solvents.*

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Chlorinated Solvents	Ground Water	Drinking Water	Dual Phase Recovery	VI: 73-79	1. Rocky Mountain Arsenal Superfund Site, Commerce City, Colorado. Soil vapor extraction to remove halogenated volatile organic compounds from the vadose zone, pilot scale was sufficient to clean the site, removing 70 pounds of TCE. Total cost was $183,000. 2. Fairchild Semiconductor Corporation Superfund Site, San Jose, California. Organic solvents in an underground storage tank leaked about 60,000 gallons of TCA, DCE, PCE, Freon, and IPA. Soil vapor extraction with vapor treatment by dehumidification and granular activated carbon. Capital costs were $2,100,000 and 18 months of operation costs were $1,800.000. A slurry wall was also installed and water from aquifer was removed, which accelerated vapor removal from the soil. 3. Verona Well Field Superfund Site, Battle Creek, Michigan. Primary contaminants were PCE, TCA, acetone, and toluene, as well as LNAPLs, with estimated 3,900 pounds in ground water and 1,700 pounds in soil. Soil vapor extraction followed by carbon adsorption and then catalytic oxidation. 10,000 pounds of VOCs removed from ground water, 45,000 pounds from soil. Total cost was $2,085,000. 4. Savannah River Site, Aiken, South Carolina. A 64,000-cubic-foot site with about 600 pounds of DNAPL was treated by incremental injection of 4,200 gallons of hydrogen peroxide along with ferrous sulfate. Post-treatment DNAPL quantity dropped from 593 pounds to 36 pounds. No cost data.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Chlorinated Solvents	Ground Water	Drinking Water, Air	Air Stripping	,VI: 79-86	1. Furrow-irrigated Corn Field in Hastings, Nebraska. Ground water was pumped and used in a spray irrigation system, volatilizing most of the contaminants of ethylene dibromide, TCE, TCA, and carbon tetrachloride. Data showed most volatilization occurred in first 2 meters. No cost data. 2. Orange County Water District, Irvine, California. TCE removal via both sprinkler and drip irrigation system. TCE concentrations 0.018 mg/L reduced 42% in drip irrigation, 97% in sprinkler system. No cost data. 3. Fort Lewis Logistics Center, Fort Lewis, Washington. TCE and DCE contaminated ground water plume was extracted and air stripped in a tower. Operation began August 1995 and cleanup to drinking water standards is expected in 30 to 40 years. No cost data. 4. Treatment Facility D, Lawrence Livermore National Laboratory, California. Air stripping was chosen to treat volatile organic compounds in the ground water, and ion exchange to treat the chromium. The ion-exchange system effectively removed hexavalent chromium. No data on VOCs. No cost data. 5. A/M Area, Savannah River Site, Aiken, South Carolina. Soil and ground water contaminated with VOCs (especially PCE, TCE, and TCA) remediated using *in situ* air stripping with a horizontal well. Such a method costs 60% of conventional methods. Well installation, $170,000; annual labor, $63,000; total consumables, $158,000; total equipment costs, $254,000.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Chlorinated Solvents	Soil	Drinking Water, Air	Soil Vapor Extraction and Vapor Destruction	VII: 87-92	1. Sacramento Army Depot Superfund Site, Sacramento, California. Leaks from storage tanks contaminated soil with ethylbenzene, butanone, PCE and xylenes. Freon was unexpectedly encountered during cleanup. Soil vapor extraction removed 2,300 pounds of VOCs for a total cost of $556,000, but for non-freon components, it was only $290,000. 2. Verona Well Field Superfund Site, Battle Creek, Michigan. Primary contaminants were PCE, TCA, acetone, and toluene, as well as LNAPLs, with estimated 3,900 pounds in ground water and 1,700 pounds in soil. Soil vapor extraction followed by carbon adsorption and then catalytic oxidation. 10,000 pounds of VOCs removed from ground water, 45,000 pounds from soil. Total cost was $2,085,000. 3. Luke Air Force Base, Arizona. Fire-fighting training pits contaminated with petroleum, oil, and lubricant wastes and JP-5. Site cleaned to required standards with soil vapor extraction and thermal oxidizer. Capital costs, 297,000; annual operating costs, $210,000. 4. Naval Air Station Site 11, North Island, San Diego, California. A pilot-scale system on soil vapor extraction removed VOCs from ground water and soil, combining air sparging, SVE, and catalytic oxidation to destroy contaminants. No cost data.
Chlorinated Solvents	Surface Soil	Air, Water	Excavation, Slurry-Phase Treatment, and Landfilling	VII: 92-95	1. French Limited Superfund Site, Crosby, Texas. An estimated 70 million gallons of petrochemical wasters were deposited in an unlined lagoon, main contaminants were benzo(a)pyrene, vinyl chloride, benzene, arsenic, PCBs, VOCs, pentachlorophenol, SVOCs, and metals. Slurry-phase treatment in the lagoon in 2 cells with 17 million gallons each. Soils were landfilled. Total costs were about $49,000,000, with $26,900,000 for activities directly attributed to treatment.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Chlorinated Solvents	Surface Soil	Air, Water	Thermal Desorption	VII: 95-103	1. Pristine, Inc. Superfund Site, Reading, Ohio. Thermal desorption using a mobile Anaerobic Thermal Processor (rotary kiln desorber) treated about 12,800 tons of VOC, SVOC, PAH, and pesticide contaminated soil. No cost data. 2. Department of Energy, Savannah River, Georgia. Six electrodes to send electrical current through TCE and PCE contaminated soil, creating heat through resistive heating to 100 °C. Contamination was reduced from 100-200 ppm to less than 1 ppm. No cost data. 3. Department of Energy, Savannah River, Georgia. TCE and PCE contaminants in soil *in situ* were treated using radio frequency heating, to demonstrate effectiveness of this method. More than 170 kg of chlorinated solvents were extracted from sediments. No cost data. 4. Undescribed AT&T Site in the Midwest. TCE and TCA contaminated soil was treated *in situ* with steam injection. At outer fringes of zone, enhanced biotransformation with injected nutrient slurry was used. More than 18,000 pounds of solvent have been removed. No cost data. 5. U.S. Naval Station, Mayport, Florida. Estimated 250,000 gallons of bilge water and several thousand gallons waste oil were under sludge drying beds. Excavated soil was treated in a thermal desorber at 600-700 °F, about 2,400 tons of soil treated. Off-gases treated in thermal oxidizer. No cost data.
Heavy Metals	Ground Water	Drinking Water	Surface Treatment	IX: 109-111	1. Electro-Coatings, Inc., Cedar Rapids, Iowa. Chromium, cadmium, nickel, & zinc from plating operations contaminated ground water, primarily hexavalent chromium. Chosen containment remedy: ground water is pumped with discharge to the sanitary sewer with ongoing ground water monitoring. No cost data.
Heavy Metals	Ground Water	Drinking Water	Phytoremediation	IX: 112-117	Phytoextraction, Phytostabilization, Rhizofiltration
Heavy Metals	Subsurface or Surface Soil	Groundwater, Plant Uptake, Drinking water	Landfilling with or without Solidification	X: 119-122	1. E.I. Dupont De Nemours & Company, Inc., Site Near West Point, New York. Ground water and soils contaminated with heavy metals including cadmium and lead. Stabilization and solidification of soil and monitoring of ground water were remediation methods. Site closed 1995. No cost data. 2. Bunker Hill Superfund Site, Kellogg, Idaho. In a small section of a 21 square mile complex, 1.5 million cubic yards of contaminated soil, mine tailings and other materials were excavated and landfilled. No cost data, but it is in the millions of dollars. Work is ongoing.

Contaminant	Media	Threat	Restoration Technology	Chapter & Page Number	Cases
Heavy Metals	Surface or Subsurface Soils	Drinking Water, Plants	Solidification, Stabilization	X: 123-131	1. Parsons Superfund Site, Grand Ledge, Michigan. Full-scale soil *in situ* vitrification system with electricity heating was used to treat soils and sediments contaminated with pesticides, heavy metals, and dioxins. Melt cells were 16 feet by 26 feet by 26 feet, require a year to cool. No actual costs: cost ceiling was $1,763,000. 2. Pristine, Inc., Superfund Site, Reading, Ohio. About 12,800 tons of soil contaminated with mixed wastes, including heavy metals, was treated in an Anaerobic Thermal Processor. Soil contaminant concentrations were below cleanup levels. No cost data. 3. Landfill Cut, Naval Air Station, North Island, San Diego. Ash-like materials on exposed face held arsenic and lead contaminants. The slope was regraded, capped, and covered with native plants. The area's drainage was improved. Total costs were $262,000. 4. Big River Mine Tailings, Desloge, Missouri. Heavy rains caused about 50,000 cubic yards of lead-contaminated mine tailing to slump into the Big River. In-place stabilization of the pile has begun; revegetating the area, capping the pile, and revegetating the cap are planned. No cost data. 5. Former Scrap Metal Processing Yard, Port of Los Angeles, California. About 100,000 tons of heavy metal-contaminated soil were treated with polysilicate technology in a processing system. Soil was backfilled on the site. No cost data.
Heavy Metals	Sediments	Surface waters, sediments	dredge, haul, and treat	X: 132-140	1. Buffalo River Sediments, New York. Mixed waste of PAHs, PCBs, and heavy metals from city and industry discharge pollute river sediments. First, thermal desorption treated PAHs & PCBs, then that soil was mixed with cement for solidification/stabilization of heavy metals. No cost data. 2. Old Navy Dump/Manchester Superfund Site, Manchester, Washington. A tidal lagoon was used as landfill. Shallow groundwater flow and tidal flow in and out of area of landfill debris transport PCBs and dissolved metals into Clam Bay. Four alternative treatments cost $0, $3.5 million, $5 million, and $47 million.
Heavy Metals	Sediments	Surface water, sediments	In-situ capping	X: 140-143	1. Eagle Harbor Superfund Site, Near Bainbridge Island, Washington. Clean dredged material is being used to confine sediments contaminated with creosote and mercury. Periodic monitoring of the cap for an initial period of 10 years is covered. No cost data.

I. INTRODUCTION

A. BACKGROUND AND ORGANIZATION

This document summarizes proven and emerging technologies for the environmental restoration of former military lands in Central European nations. Only fuel hydrocarbon, chlorinated hydrocarbon, and heavy metal contamination restoration technologies are included.

Our specific purpose with this document is to present cases of technologies used at U.S. Army, Navy, and Air Force bases, with a few cases from the Department of Energy (DOE) and the Environmental Protection Agency (EPA), to resolve specific areas of contamination. In each Chapter, we illustrate examples of contamination, the extent, the media in which they were found (soil, sand, clay, water, sediment, etc.), the anticipated cost of remediation, the final cost of remediation (if available), and the success of the technology in the project. By providing this information, it is our hope that others may be able to use it to better prepare their own plans to resolve similar problems.

Certain field-proven technologies are excluded because of expense. For example, soil washing to remove heavy metals and pump and treat technologies for chlorinated solvents have been somewhat successful but are quite costly. Exclusion from this document does not imply that the technology is not valuable, but that it may exceed available budgets.[1]

Throughout this document, we refer to relative expense or cost of remediation technologies. Please see Appendix H, which is a simplified graph that shows approximate relative cost of 10 technologies. In general, this graph summarizes our assessment of relative cost. Relative cost is also based on our experiences, our knowledge after reviewing dozens of case studies, on conversations with knowledgeable

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[1] Technologically sophisticated processes are not addressed in this study because of high cost, which includes the engineering, materials, and potential training for personnel to install and operate these systems. A significant number of such technologies are listed in Appendix B.

partners, and on the content of documents including: the "Treatment Technologies Applications Matrix for Base Closure Activities, the California Base Closure Environmental Committee – Technology Matching Process Action Team," and the "Remediation Technologies Screening Matrix and Reference Guide," EPA/542/B-94/013, NTIS PB95-104782, October 1994.

This document is organized in Chapters by contaminant, then by technology process and location in the subsurface.[2]

B. EFFECTS OF DENSITY, CHEMISTRY, LOCATION, AND MICROORGANISM METABOLISM OF CONTAMINANTS ON REMEDIATION TECHNOLOGIES

Three factors drive technology designs for the remediation of fuels, chlorinated solvents, and heavy metals: the density and chemistry of the compound, where it is located as a contaminant, and if microorganisms can use it as either a nutrient or an electron acceptor.

Density and Chemistry. Fuels, also known as light non-aqueous phase liquids (LNAPLs), are less dense than water, and thus float on water and vaporize to some extent. Gasoline vaporizes well; diesel and jet fuels, less well; others, such as lubricants and polycyclic aromatic hydrocarbons, not at all. Chlorinated solvents (also called chlorinated hydrocarbons) are grouped in dense non-aqueous phase liquids (DNAPLs). These are not as volatile as fuels and are more dense than water, causing them to sink below or into ground water. Heavy metals exist as ions or in compounds and are in different valence states. These valence states, or species of metals (also termed speciation), critically affect the threat or non-threat to life and health.

Location. Contaminants can be in water (in surface water, on the ground water table, dissolved in the ground water) or in soil zones [in surface soil, in subsurface soil that is not saturated with water (vadose zone), or in subsurface soil that is saturated with water (saturated zone)]. The saturated zone contains the ground water. However, ground

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[2] See also (1) *Remediation Technologies for Typical Contaminants and Media Types at Navy Sites*, Naval Facilities Engineering Service Center, 17 Jan 1997, Draft Final; (2) *Road Map to Understanding Innovative Technology Options for Brownfields, Investigation and Cleanup*, EPA 542-B-97-002 (brownfields are industrial sites that are being remediated); (3) *Completed North American Innovative Remediation Technology Demonstration Projects*, EPA 542-B-96-002, August 1996.

water can be pumped out of the saturated zone, leaving contaminants in the soil of the saturated zone and dissolved in the remaining water.

Microorganism Metabolism of Contaminants. Microorganisms that degrade fuel hydrocarbons are everywhere. Some researchers speculate that this is due to the presence of crude oil deposits and seeps worldwide. Regardless of their origin, such microorganisims can be used effectively as restoration agents. The rate of biodegradation depends on the water solubility of the fuel components and the type of electron acceptor present. The water-soluble components of fuel, benzene, toluene, ethylbenzene, and meta-, ortho-, and para-xylenes (BTEX), and straight chain alkanes are rapidly degraded under aerobic conditions, whereas polycyclic aromatic hydrocarbons are degraded less rapidly or not at all. Anaerobic degradation of BTEX occurs slowly.

Microbial degradation of chlorinated solvents is problematic and does not readily occur using chlorinated solvents as a primary source of microbial energy. Chlorinated solvents under anaerobic conditions may be reductively de-chlorinated, and under aerobic conditions, enzyme systems in operation on other chemicals often also happen to degrade chlorinated solvents in a process termed co-metabolism. Microorganisms that reductively dechlorinate and co-metabolize are everywhere, but the processes are slow. Reductive dechlorination occurs under sulfate-reducing and methanogenic conditions, which is the path of least favorable yield of energy to a microorganism. Co-metabolism of chlorinated hydrocarbons is slow, as the organisms apparently derive no growth-linked or energy-conserving benefit from the process.

Microbial degradation of heavy metals does not occur, but bioprocesses can change the valence state of (or species) metals, affecting the bioavailability of the metal.

II. GENERAL COMMENTS ON FUELS

Field ready technologies are well characterized for cleanup of fuel contaminants such as aviation fuels, gasoline, diesel, and kerosene, which are light non-aqueous phase liquids (LNAPLs). These technologies include soil venting or soil vapor extraction, bioventing, air sparging, separate phase recovery including bioslurping, and natural attenuation.

Bioventing and biosparging are the least costly. Natural attenuation, which intuitively may seem to be the least expensive, costs about the same as bioventing and biosparging because of the monitoring required. Separate phase recovery is expensive due to pumping costs: soil venting is expensive due to recovery of fuel from the vapor phase.

The U.S. Air Force collected information on bioventing treatment, and published it in a report titled, *Bioventing Performance and Cost Results From Multiple Air Force Test Sites*. This report gives general cost ranges for treating both a small amount (500 cubic yards) and a large amount (20,000 cubic yards) of soil. These costs are as follows:

Cleanup Technique	500 Yd^3 (Dollars/Yard)	20,000 Yd^3 (Dollars/Yard)
Soil Vapor Extraction	110	12
Excavation and Landfill	64	29
Landfarming	51	11
Bioventing	58	4

Clearly, economies of scale can be achieved by treating larger amounts of contaminated soil. This indicates that combining cleanup projects located near to one another might result in significant cost advantages.

A colorless synthetic gasoline additive, methyl tertiary butyl ether (MTBE) deserves mention. It moves through soil very quickly and is not easily biodegraded, thus it finds its way into shallow ground water basins faster than other components of gasoline.[1] It is not found in jet fuels. MTBE was first added to gasoline in the United States in 1979 to prevent engine knocking. Beginning in 1992, U.S. Federal Law required the use of oxygenated gasoline for winter driving in cities that exceeded air quality standards for carbon monoxide. Although the law does not require the use of MTBE specifically, it has become the oxygenate of choice because of its high octane rating, low production cost, and ability to readily mix with other gasoline components. It was detected in ground water in the early 1990s and has been found in both ground water and surface water supplies since then, typically entering ground water as a result of leaking underground storage tanks or pipelines or from a spill. Lawrence Livermore Laboratories is currently researching MTBE in the same way benzene was researched in the study by David Rice and others.

A. DOCUMENTATION

1997 Bioremediation Symposium Proceedings (Five book set), edited by Bruce C. Alleman and Andrea Leeson. Copies from Battelle Press, 505 King Avenue, Columbus, Ohio 43201 USA. 1-800-451-3543.

"Bioventing Performance and Cost Results From Multiple Air Force Test Sites, Technology Demonstration Final Technical Memorandum," June 1996, Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, Texas.

Colborn, Theo, Dianne Dumanoski, and John Peterson Meyers. *Our Stolen Future*. Dutton, New York, 1996.

Cooney, Catherine M. "California struggles with presence of MTBE in public drinking water wells." *Environmental Science and Technology*. Vol. 31, No. 6. 1997.

Stanners D. and P. Bourdeau, Editors. *Europe's Environment: The Dobris Assessment..* European Environmental Agency. Office for Official Publications of the European Communities, Luxembourg, 1995.

Hinchee, Robert A., Jeffrey A. Kittel, H. James Reisinger. *Applied Bioremediation of Petroleum Hydrocarbons*. Sixth book in a series of ten books from the Third International In Situ and On-Site Bioreclamation Symposium, San Diego, California. Copies from Battelle Press, 505 King Avenue, Columbus, Ohio 43201 USA. 1-800-451-3543.

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[1] For this reason, some researchers have proposed using MTBE as a tracer for plume migration of gasoline contamination.

Leclair, Vincent. "MTBE water contamination raises health concern, research questions." Environmental Science and Technology Vol. 31, No. 4, 1997.

"Remediation Handbook for POL-Contaminated Sites," HQ USAF/CE, December 1993.

"Remediation Technologies Screening Matrix and Reference Guide," DoD Environmental Technology Transfer Committee, Second Edition, October 1994.

"Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites With Volatile Organic Compounds in Soils," U.S. EPA, September 1993.

Rice, David, *et al.*, *Recommendations to Improve the Clean Up Process for California's Leaking Underground Fuel Tanks.* UCRL-AR-121762. Oct. 16, 1995. Produced for the California Environmental Protection Department, Environmental Restoration Division, by the University of California Lawrence Livermore National Laboratory. Submitted to the California State Water Resource Control Board and the Senate Bill 1764 Leaking Underground Fuel Tank Advisory Committee. Obtain copies from the California State Water Control Board, (916) 227-4313.

Tarradella, Joseph, Gabriel Bitton, and Dominique Rossel. *Soil Ecotoxicology*. Lewis Publishers, Boca Raton, Florida, 1997.

Testa, Stephen M. *The Reuse and Recycling of Contaminated Soil.* Lewis Publishers, Boca Raton, Florida, 1997.

B. WORLD WIDE WEB SITE(S)

http://www.acwanet.com/legislation/regulatory/mtbe.html (Specific to MTBE)

http://www.calepa.ca.gov/epa-hot.htm (Briefing paper on MTBE by the California Environmental Protection Agency)

http://www.mrd.usace.army.mil/mrded-h/mrded-h.html (U.S. Army Corps of Engineers Hazardous, Toxic, Radioactive Waste Center of Expertise)

http://www.usgs.gov (U.S. Geological Survey)

III. FUELS IN GROUND WATER

A. NATURAL ATTENUATION

The simplest way to remediate fuel components in ground water is natural attenuation, defined by the United States Environmental Protection Agency (USEPA) as "the biodegradation, diffusion, dilution, sorption, volatilization and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility or volume to levels that are protective of human health and the environment."[1]

Cleanup of ground water contamination from fuels focuses on the components of fuel that readily dissolve in water: benzene, toluene, ethylbenzene and the xylenes (ortho-, meta- and para-), abbreviated as BTEX. Although other fuel components remain in the subsurface, they have very low solubility in water and are not targets for remediation since they are not believed to be health hazards. Because BTEX components dissolve in ground water, they are more easily biodegraded: biodegradation is one of the aspects included in natural attenuation. Therefore, the one major means of remediating fuel components in ground water is natural attenuation.

Data from a California study of 1,500 leaking underground fuel tanks (LUFTs), and a Texas study of data from 605 such tanks, have shown that 85 - 90 percent of all ground water plumes, regardless of whether the source of the contamination was removed or not, extended no greater than 300 feet. The rate of BTEX fuel components dissolving into the water was matched within that 300 feet by the rate of biodegradation. The few ground water plumes that were greater than 300 feet generally were in fractured, limestone, or sandy media. The EPA is preparing a guidance document, "Monitored Natural Attenuation," which states that if ground water is the receptor and there are no human receptors within 300 feet, one should allow natural attenuation with monitoring.

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[1] United States Environmental Protection Agency, World Wide Web page, http://www.epa.gov.

Some remediation efforts suggest, or require, that the source of the fuel contamination be removed, based on the assumption that removal of the source will accelerate remediation. These data suggest such removal may be moot for fuel contamination. If source removal is indicated, however, a pump and treat system would be appropriate. The significance of these data is that microorganisms degrade the water-soluble components of fuels within reasonably short distances in most cases. The fuel components that are not water soluble are not a health concern.

If a site can be naturally attenuated, it must still be monitored. Monitoring wells, no matter what the plume length, are required to ensure the remediation is continuing and that the plume is not spreading. Seasonal variables can change some situations. This is critical in the case of drinking water wells that may be affected by dissolved hydrocarbons.

Accurate and real-time measurement of microbial activity and hydrocarbon concentration is difficult and costly. However, some measurement is required both for site characterization and monitoring. Therefore, in order to lower costs, site characterization and monitoring are usually done in the laboratory with samples collected in the field.

1. Example Site(s)

Site 1. Naval Weapons Station (NWS), Seal Beach, California. Unleaded fuel from underground storage tank. *In-situ* anaerobic degradation of petroleum hydrocarbons is being done by native ground water microorganisms at an NWS Seal Beach site contaminated with leaded and unleaded gasoline. At this site, gasoline from a leaking underground storage tank spread radially through the shallow subsoil a distance of 150 - 300 feet from the source.

Approximately 160,000 square feet (ft^2) of soil in a zone 1 - 2 feet thick above the water table is contaminated. The process being used for remediation involves placement of a number of small-diameter recirculation and monitoring wells in a plot at the site. Nutrients are added to optimize degradation rates. Nine extraction and injection wells are used to draw samples. Native microorganisms in the ground water are degrading the pollutant.

Early field data are promising, demonstrating remediation of toluene, ethylbenzene and xylenes within the first few weeks of experimentation. It is expected that once the toluene, ethylbenzene, and xylenes are depleted, benzene will disappear as well. The costs associated with this method are expected to be less than one-tenth the cost of using a pump-and-treat technology.

The costs were not given.

Site 2. A shallow unconfined aquifer at Columbus AFB, Ohio. Natural attenuation processes associated with fuel-related hydrocarbon compounds will be investigated through a large-scale field experiment at the Columbus Groundwater Research (CGR) facility at Columbus Air Force Base, site of the previous MADE-2 study. The field study will consist of a natural-gradient experiment primarily aimed at a mechanistic understanding of natural attenuation processes. The study will be initiated by emplacing an immobile, nonaqueous-phase hydrocarbon source within the saturated zone of the aquifer. The intent is to create a source resembling a zone of residual product contamination. Transport and attenuation of the dissolved hydrocarbon contaminants derived from the residual source will be periodically monitored in three dimensions as these compounds migrate under natural ground water flow conditions.

The overall transport behavior of each hydrocarbon will be characterized through spatial moments and time-series analyses of the concentration measurements. Microbiological and geochemical assays of the ground water and aquifer material will be conducted before and during the natural-gradient experiment. These data will provide identification and numbers of the microorganisms responsible for hydrocarbon degradation, leading to a better understanding of the dominant biodegradative processes. Data will also be evaluated to identify the principal geochemical indicators of the biodegradation, such as dissolved oxygen, dissolved carbon dioxide, redox couples, and pH. In conjunction with the field study, a method for obtaining *in situ* measurements of biodegradation rates will be evaluated through direct comparisons with the rates estimated from the natural-gradient experiment.

The research project will be carried out in two phases. Phase I will consist of the field experiment. Final analysis and interpretation of field and laboratory studies will be completed in Phase II along with preparation of the project report.

No experimental data or cost data were available.

2. Documentation

"An Analysis of Ground-Water Information Contained in the Bioremediation Field Search System (BFSS), from Ground-Water Remediation Case Studies from EPA's Bioremediation Field Search System (BFSS)." Version 2.0 of EPA's BFSS database lists 153 sites where *in situ* ground water treatment, via bioremediation, has occurred, is occurring, or is planned. This document provides a summary of information on the treatment techniques identified for use, types of contaminants, the metabolic requirements of microorganisms, and amendments used to facilitate bioremediation processes at these sites.

American Society for Testing and Materials (ASTM) Draft Guide for Remediation by Natural Attenuation at Petroleum Release Sites. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428. (610) 832-9565. e-mail: service @local.astm.org

Symposium on Intrinsic Bioremediation of Ground Water, Hyatt Regency Denver, Colorado, 30 August to 1 September 1994. EPA/540/R-94/515.

Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater, Vol. I and Vol. II. Todd Wiedemeier, John T. Wilson, Donald H. Kampbell, Ross N. Miller and Jerry E. Hansen. Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, San Antonio, Texas.

"Intrinsic Bioremediation of Petroleum Hydrocarbons." June 1996. Technical Report TM-2185-ENV. Naval Facilities Engineering Service Center, 1100 23rd Street, Port Hueneme, California 93043.

3. World Wide Web Site(s)

- http://www.gwrtac.org/ Ground Water Remediation Technologies Analysis Center (GWRTAC) focuses on innovative ground water remediation technologies as compared to the standard "pump and treat" approach. Many of the remedial activities summarized within GWRTAC are *in situ* technologies requiring no ground water extraction. However, means of enhancing pump and treat and selected types of *ex situ* technologies are also addressed. GWRTAC includes those remediation technologies which, through design or application, improve ground water quality and are essential to ground water cleanup.
- http://www.gwrtac.org/html/tech_misc.html#BFSS (Specific to the Bioremediation Field Search System).
- http://cayuga.nfesc.navy.mil/cc/projects/anaerobe.htm (Specific to Naval Weapons Station Seal Beach site).

- http://www.ra.utk.edu/ceb/proj19.htm (Specific to the Columbus AFB)
- http://ci.mond.org/9703/970314.html (Excellent article on Intrinsic Bioremediation and the considerations required)
- http://www.uwin.siv.edu (Database of international water research compiled by the Water Resources Scientific Information Center of the US Geological Survey. The research covers from 1967 to October 1993, with more than 265,000 abastracts and citations that are key-word searchable.)

4. Models

BIOSCREEN is an easy-to-use computer screening tool for simulating the natural attenuation of dissolved hydrocarbons at petroleum release sites. See "The BIOSCREEN Computer Tool" by Charles J. Newell, R. Kevin McLeod, and James R. Gonzales in: Symposium on Natural Attenuation of Chlorinated Organics in Ground Water, EPA 540/R-96/509.

The Bioscreen user's guide and computer software, since they are in the public domain, can be obtained at no charge from the EPA World Wide Web site at http://www.epa.gov/ada/bioscreen.html (Bioscreen simulates remediation through natural attenuation (RNA) in a Microsoft® Excel spreadsheet format and is based on the Domenico analytical solute transport model).

RT3D - a new (fall 1997) general-purpose, three-dimensional multispecies reactive transport model for use of accelerated bioremediation, bioventing, and natural attenuation.

B. BIOSLURPING

Vacuum enhanced free product recovery, or bioslurping is a recent *in situ* treatment development that teams vacuum-assisted free-product recovery with bioventing. Bioslurping thus simultaneously recovers free-product fuel from the water table and capillary fringe while promoting aerobic bioremediation in the vadose zone of subsurface soils. This is accomplished through use of a vacuum that removes free fuel and vapor while venting the soils to stimulate contaminant biodegradation. Biodegradation is further assisted by the decrease in fuel volume and increase in contaminant accessibility.

The U.S. Air Force (USAF) has documents from an initiative to examine bioslurping and data required to determine if this is an appropriate technology for a site.

Bioslurping involves the simultaneous application of vacuum enhanced extraction/recovery, vapor extraction, and bioventing to address LNAPL contamination. Vacuum extraction/recovery is used to remove free product along with some ground water; vapor extraction is used to remove high volatility vapors from the vadose zone; and bioventing is used to enhance aerobic biodegradation in the vadose zone and capillary fringe.

The Navy has a manual that delineates the best practices for bioslurping, listed in the documentation section below.

Testing to determine if bioslurping will be effective at a site is necessary. Some sites that seem identical have very different bioslurping results, and no single factor seems to be an indicator of success or failure. At present, the USAF uses an adjustable, trailer-mounted device to test for free-product skimming, bioslurping, or pump drawdown.

Bioslurping consists of an enclosed well casing, inside of which an inner, smaller-diameter adjustable-length tube is inserted like a straw. The tube, connected to a vacuum pump, is then lowered into the LNAPL layer, and pumping begins to remove free product along with some ground water (vacuum-enhanced extraction/recovery). The vacuum-induced negative pressure zone in the well promotes LNAPL flow toward the well and also draws LNAPL trapped in small pore spaces above the water table. When the LNAPL level declines slightly in response to pumping, the slurp tube begins to draw in and extract vapors (vapor extraction). This removal of vapors promotes air movement through the unsaturated zone, increasing oxygen content and enhancing aerobic bioremediation (bioventing). When mounding, due to the introduced vacuum, causes a slight rise in the water table, the slurp cycles back to removing LNAPL and ground water. This cycling minimizes water table fluctuations, reducing "smearing" associated with other recovery techniques.

Liquid (product and ground water) removed through the slurp tube is sent to an oil/water separator and can be stored or processed for reuse. Vapors are sent to a liquid vapor separator. Above ground, water and vapor treatment systems may also be included, if required. In some cases, if there is regulatory acceptance, system design modifications have allowed discharge of ground water and vapor extracted via bioslurping without treatment. Results of field tests of bioslurping systems have shown that LNAPL and vapor recovery are directly correlated with the degree of vacuum. A comparison of bioslurping to conventional methods of LNAPL recovery reported that bioslurping achieved greater recovery rates than either skimming or dual-pump methods.

Bioslurping technology installed on existing wells is often more effective than other methods of free-product recovery. Product and air move horizontally through the geologic formation, minimizing the amount of water removed (as opposed to traditional pump-and-treat methods for ground water cleanup). It is more economical than other LNAPL recovery and treatment technologies since less ground water is extracted and the vapor and ground water may not require treatment. Biofouling of well screens can occur, and fuel contamination in the saturated zone may remain, but may then be naturally attenuated. Once free product is removed, the equipment can be used for other technologies such as pump drawdown, soil vapor extraction (SVE), or bioventing, depending on site needs and requirements.

The radius of influence with bioslurping compared to pump draw-down is noteworthy. Pump draw-down is a way to create a "slope" of ground water by removing water from below the ground water table, creating a depression. For fuel products that float on the ground water table, free product moves into the depression and, in theory, is more easily removed. Two drawbacks are that this creates a smear zone where the contaminant may be forced deeper into the subsurface than before, and more water must be pumped to the surface for treatment than with bioslurping. Further, the radius of influence for pump draw-down is not large. Depending on soil porosity, this radius may be only 1 foot. Bioslurping has been shown to have a radius of influence of 20 feet under similar conditions.

1. Example Site(s)

Site 1. Naval Air Station, Fallon, Nevada. Bioslurping is being conducted at NAS Fallon, Nevada, and will be initiated at MCAS Kaneohe Bay, Hawaii. Both sites have extensive subsurface plumes of JP-5 jet fuel. The action of the bioslurper system cycles between removing liquid (free fuel and/or ground water) and soil gas. Since a cone of depression is not required to remove free product, a bioslurper system can be adjusted to remove minimal ground water. The exerted vacuum tends to pull fuel effectively from a large area of the water table and soil formations where other free-product removal methods usually fail.

Soil at the bioslurping site at NAS Fallon consists of loose sand to approximately 5 feet, followed by alternating layers of varying thicknesses of clay, sandy/silty clay, clayey/silty sand, and sand. Ground water generally is encountered 5 - 10 feet below the ground surface and is approximately 9 feet below the bioslurping site. Apparent free-product thicknesses are up to 2 feet. The recovered liquid is separated in an oil-water separator. Vapor discharge to the air, averaging 5 pounds/day, meets Nevada regulatory requirements without capture. The bioslurping system, which was started in January 1993, has removed an average of 24 gallons of fuel per day during operation, with maximal removal rates of 60 gallons/day. Ground water removal has averaged 0.46 gallons/minute, or 180,000 gallons in the first year. With operation at 75 percent of the time, the total estimated mass of hydrocarbons removed was 47,272 pounds or 6,500 gallons. An estimated 45,859 pounds was liquid free phase, 157 pounds aqueous phase, and 1,256 pounds gaseous phase.

This work was done in a small area of a large plume. At Fallon, the amount of free product being recovered is diminishing. Estimating the cost of this particular application of bioslurping is difficult; however, the project manager estimates that installation of most bioslurping projects would be $30,000 - $35,000, depending on factors such as the pump/blower itself. Maintenance of the system would be approximately $75,000/year. Most bioslurping projects are ended after 2 years, depending on rate of free-product recovery, which, in turn, depends on factors such as soil porosity, amount of free product present, and the pump.

The estimated cost to install this system was $30,000. More may be spent on a site depending on the pump itself, and other factors.

Site 2. Naval Radar Site #3, Hofn, Iceland. A plume from leaking diesel fuel tanks was treated with bioslurping technology. The plume covered approximately one-fourth acre. These diesel tanks were unable to be buried subsurface, so soil was mounded over them on the surface. Since the site was small, installation of the bioslurping system was simple. A 7.5 horse-power liquid ring pump was used. The above-ground buried tanks were then removed, and the bioslurping system reinstalled. Most of the remediation occurred after the tanks were removed, and a total removal of product was not given. Included in the bioslurping effort was a bioventing effort for 2 other fuel-contaminated sites. Therefore, the cost given for installation of the system of $65,000 and of $99,000 for completion was not strictly due to bioslurping, and cost breakdowns were not included.

Site 3. Indian Ocean Island of Diego Garcia, JP-5 Fuel Leak. In 1991 a leak in a section of an 18-inch-diameter JP-5 fuel line was discovered, and the spill exceeded

160,000 gallons. Hydrogeology of the site is a fragmented coral matrix with fresh water overlying more dense salt waster. Depth to water is less than 10 feet. Tidal action results in twice daily water table movement of about 2 feet. Remediation studies have identified natural attenuation processes that are containing and destroying the fuel contamination. Evidence of natural attenuation processes includes historical records of contaminant concentrations, geochemical data, and direct microbiological evidence: oxygen consumption, methanogenesis, and sulfate reduction. There was a large area of free-phase fuel. This fuel was recovered using vacuum-enhanced product-recovery technology, or bioslurping. The first bioslurper system was installed in March 1996 and recovered 2,000 gallons of JP-5 fuel during the first month of operation. Six extraction wells were used. Fuel recovery continued at a rate of about 1,000 gallons/month. A second bioslurper and 10 additional extraction wells were installed in January 1997. Fuel recovery increased to 8,000 gallons in January and has remained at about 5,000 gallons/month since then.

Bioslurping suction also biovents the vadose zone soils, resulting in aerobic degradation of fuel contamination. Additional fuel degradation was occurring as a result of the tidal-driven natural bioventing process. Vadose zone soil gas measurements determined that oxygen increased as the tide dropped and methane, along with carbon dioxide, increased as the tide rose. The remediation plan is to continue to use the bioslurper to remove the recoverable free-phase fuel and allow the natural bioventing process and other natural attenuation processes to complete the remediation.

Diego Garcia is part of the British Indian Ocean Territory. The climate is tropical with an average annual rainfall of 107 inches. The surface elevation is typically less than 10 feet above sea level. All personnel on the island are supporting U.S. and British military activities.

The most expensive costs were the 2 liquid ring pump skids, which cost $9,000 each. The total cost for both bioslurpers, piping, connectors, well-installation material, on-island support, travel to Diego Garcia to supervise installation and gather water samples has totaled $133,000 up to approximately March 1997. Cost to operate and maintain the bioslurper system is less than $20,000 per year. In a little more than 1 year, 35,000 gallons of useable fuel have been recovered.

The current array of recovery wells covers about 60 percent of the free-phase fuel. In August 1997, plans were to install 12 more recovery wells to complete the coverage. The bioslurping system will operate until no further fuel is recoverable; then it will be converted to full-phase bioventing until soil gas tests indicate that aerobic degradation has been completed. That is expected to require about 2 years.

2. Documentation

Wickramanayake, G.B., J.A. Kittel, M.C. Place, R. Hoeppel, A. Walker, E. Drescher, J.T. Gibbs. "Best Practices Manual for Bioslurping." Technical Memorandum TM-2191-ENV. Naval Facilities Engineering Service Center, Code 40, 1100 23rd Ave., Port Hueneme, California 93043, 1996.

Blake, Steven.. "Application of Vacuum Dewatering Techniques to Hydrocarbon Remediation." *The Proceedings of Petroleum Hydrocarbons and Organic Chemical in Ground Water: Prevention, Detection, and Restoration*. October 31-November 2, 1990. Houston, Texas. The Association of Ground Water Scientists and Engineers and The American Petroleum Institute.

"Intrinsic Bioremediation of Petroleum Hydrocarbons." June 1996. Technical Report TM-2185-ENV. Naval Facilities Engineering Service Center, 1100 23rd Street, Port Hueneme, California 93043.

Kampbell, Donald H., Jerry E. Hansen, Mano K. Husain. "Natural Attenuation and Bioslurping at Diego Garcia." 1997. Triservices Environmental Conference, St. Louis, Missouri.

"Test Plan and Technical Protocol for Bioslurping." AFCEE Technology Transfer Division, 3207 North Road, Brooks AFB, Texas 78235. Draft, circa July 1995. The draft is the current version as of April 1997.

"Test Plan and Technical Protocol for a Field Treatability Test for POL Free Product Recovery: Evaluating The Feasibility of Traditional and Bioslurping Technologies." Draft Document, AFCEE Technology Transfer Division, 3207 North Road, Brooks AFB, Texas 78235, January 1995.

Hinchee, Robert A., Jeffrey A. Kittel, H. James Reisinger. *Applied Bioremediation of Petroleum Hydrocarbons*. Sixth book in a series of ten books from the Third International In Situ and On-Site Bioreclamation Symposium, San Diego, CA. Copies from Battelle Press, 505 King Avenue, Columbus, Ohio 43201 USA. 1-800-451-3543.

"UST Corrective Action Technologies: Engineering Design of Free Product Recovery Systems." Jack C. Parker, Dan W. Waddill, and Jeffrey A. Johnson. EPA/600/R-96/031. National Risk Management Research Laboratory, Office of Research and Development, US EPA, Cincinnati, Ohio 45268.

Kittel, J.A., Andrea Leeson, R. E. Hinchee, R. E. Miller and P. E. Haas. "Results of a Multi-Site Field Treatability Test for Bioslurping: A comparison of LNAPL Rates Using Vacuum-Enhanced Recovery

(Bioslurping), Passive Skimming, and Pump Drawdown Recovery Techniques." U.S. Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas, date not given.

3. World Wide Web Site(s)

- http://www.frtr.gov. (Some sources of technology implementation have information about bioslurping at their Web sites.)
- http://cayuga.nfesc.navy.mil/cc/projects/bioslurp.htm (Specific to Site 1 at NAS Fallon.)
- http://www.uwin.siv.edu (Data base of international water research compiled by the Water Resources Scientific Information Center of the U.S. Geological Survey. The research covers from 1967 to October 1993, with more than 265,000 abastracts and citations that are key-word searchable.)

C. DUAL-PHASE RECOVERY, INCLUDING SOIL VAPOR EXTRACTION

Whenever a technology treats two media, such as air and water or soil and water, the system is considered to be dual phase. For instance, if the first requirement is to treat contaminated water, the first step is to remove subsurface water and then extract the vapors from the water once it is above ground. This technology is also sometimes called multi-phase, particularly if more than two phases are being treated. For instance, a matrix of soil and water may be treated by removing vapors. This technology had its first patents issued in the 1800s. Hundreds of applications of this technology exist.

In some cases where it is not prudent or possible to blow air into the subsurface, vapors may be extracted through wells and treated above ground. In some cases, a slow enough vacuum extraction may draw vapors through the subsurface at a rate that matches the period of time required for bioremediation. Above-ground treatment costs will vary depending on the above-ground treatment method, concentration of vapors, and total volume to be remediated. Vapors may be captured in beds of activated carbon, if activated carbon is available and there are places available to which the carbon is taken for regeneration. Other options are to run the vapors through a biofilter, which is essentially an above-ground small bioventing system, or to use a regenerative resin system such as the Purus PADRE.® A third option is to burn vapors in some sort of furnace or engine. See the following section on internal combustion engine use as an example of this last option.

1. Example Site(s)

Site 1. Hill Air Force Base, Site 914. This was a demonstration of SVE followed by bioventing. SVE was conducted for 9 months. When the system was operated in the bioventing mode for an additional 9 months, more than $54,000 was saved in off-gas treatment costs. In January 1985, an estimated 27,000 gallons of JP-4 jet fuel were spilled when an automatic overflow device failed. Total petroleum hydrocarbons (TPH, includes BTEX) in untreated soil ranged from less than 20 to 10,200 milligrams per kilogram (mg/kg), with the average soil TPH concentration of 411 mg/kg. The contaminated soil was estimated at 5,000 cubic yards over a spill area of 13,500 square feet. The area with the 10,000 mg/kg JP-4 concentration contour was approximately 100 by 150 feet. The formation consisted of mixed sands and gravels with occasional clay lenses. Air permeability ranged from 4.7 to 7.8 darcies.

The required cleanup goal from Utah Department of Health was 38.1 mg/kg TPH. This was achieved with the average TPH soil concentrations in treated soil reduced to less than 6 mg/kg. A total of 211,000 pounds of TPH was removed in approximately 2 years of operation with the removal rate of 20 - 400 pounds/day.

This site was one of the early applications of the sequential use of SVE followed by bioventing and was conducted from October 1988 to December 1990. The SVE system included 7 vent wells located in the areas of highest contamination, 31 monitoring wells, and a catalytic incinerator. The typical air flow rate through the vent wells was 700 actual cubic feet per minute (acfm) with a maximum of 1,500 acfm. In addition, a plastic liner was installed over part of the spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface. Within a year, the SVE system reduced hydrocarbons in the soil to levels ranging from 33 to 101 mg/kg. Further reduction of the hydrocarbon concentration in the soil, to below the specified TPH limit, was achieved by using bioventing for 15 months. Bioventing was done with 4 vent wells on the southern perimeter of the spill area, the same 31 monitoring wells used in the SVE system, and 3 neutron access probes for soil-moisture monitoring. Vent wells were approximately 50 feet deep with 4-inch diameter polyvinyl chloride (PVC) casings, screened from 10 to 50 feet below ground surface. The monitoring wells ranged in depth from 6 to 55 feet with 1-inch PVC casings, screened from 10 to 50 feet below ground surface. Because hydrocarbon concentrations were less than 50 mg/L in the extracted vapors, the catalytic incinerator was not required for this phase. The air flow was 250 acfm. Biodegradation was enhanced by injecting oxygen, moisture (to maintain soil moisture at 6-12 percent), and nutrients in the C:N:P ratio of 100:10:10.

The total capital cost for this application was $335,000, and the total annual operating costs were $132,000. Oxygen depletion was found to be a more accurate estimator of biodegradation rate than carbon dioxide formation because carbon dioxide disappears into biomass and into reactions with soil particles as well as being soluble in water. These factors limited the usefulness of carbon dioxide formation as a process control parameter.

Site 2. Steam Injection Vacuum Extraction (SIVE) at NAS Lemoore, California. The goal of this project is to develop a cost-effective *in situ* treatment to remediate hydrocarbon-contaminated sites and to recover valuable fuel for reuse. This *in situ* technology is a thermal enhancement to pump-and-treat and soil vapor extraction. Steam injection is used to enhance the desorption, mobilization, and transport of hydrocarbon contaminants to the subsurface for collection and treatment.

The design criteria for SIVE removal at NAS Lemoore recovery technology will be developed from the technology demonstration. There are many fuel contamination sites with shallow ground water tables or stratified clay layers in the subsurface. This project will also explore and develop the design criteria for using innovative horizontal wells combined with SIVE technology. Remediation costs are estimated to be $200/ton of contaminated soil.

Site 3. Amoco Petroleum Pipeline, Constantine, Michigan. The Amoco Corporation owns and operates a liquid petroleum product pipeline that traverses the Constantine site. As a result of a pipeline leak, discovered in June 1987, an estimated 350,000 - 2,000,000 gallons of gasoline, fuel oil, and kerosene were released to the subsurface. Contaminants of concern were BTEX and MTBE. Free product was present in an approximate 6-acre area at an average apparent thickness of 2 feet. Beginning in October 1988, a ground water pump-and-treat system, consisting of 4 extraction wells and granular activated carbon (GAC) vessels, was used to recover free product and treat the contaminated ground water, to depths up to 28 feet below ground surface (bgs) with extraction rates of 50 and 100 gallons per minute (gpm). Recovered free product was stored in above ground tanks. Approximately 775 million gallons of ground water were treated between 1988 and 1993. GAC proved to be inefficient in removing MTBE when compared to BTEX. The porosity at the site was 30 to 40 percent, and the hydraulic conductivity was 0.0002 - 0.0004 cm/sec.

In situ air sparging of the saturated zone was subsequently added and began operating in February 1994, with 30 2-inch-diameter air sparging wells installed to depths of 25 - 30 feet with 3-foot screens and two 300 scfm blowers. Through December 1993, ground water extraction with GAC had recovered an estimated 118,000 pounds of free product and reduced the observed apparent thickness of the free product layer to less than 0.01 feet. MTBE concentrations were reduced; BTEX concentrations near the source of contamination, however, remained relatively constant. No full-scale performance data were available for the air sparging system at the time of this report.

Between October 1987 and December 1993, 118,000 gallons of free product were recovered. The rate of free-product recovery decreased to 20 - 25 gallons per month as in late 1993. The free product has been hydraulically contained and the observed apparent thickness of free product has been reduced to less than 0.01 feet. Concentrations of BTEX in extracted ground water have remained relatively constant; MTBE concentrations have decreased, and the treated effluent from GAC have generally met State Pollution Discharge Elimination System (SPDES) discharge limits of benzene (5 ~g/L), total BTEX (20 ~g/L), MTBE (380 ~g/L), pH (6.5-9.0). For the *in situ* air sparing, the pilot testing indicated a radius of influence of 65-150 feet per single well.

The total capital costs were about $297,000 for the ground water recovery and treatment system (including well construction, pumps, system installation, engineering), and $375,000 for the air sparging system, including 3 months of initial operations and testing. The approximate annual operating costs were about $475,000 for the ground water recovery and treatment system. Annual costs were not available for the air sparging system.

Site 4. Luke Air Force Base, Arizona. North Fire Training Area. Routine fire training exercises were conducted at Luke Air Force Base in Arizona between 1963 and 1990, using petroleum, oil, and lubricant (POL) wastes, and JP-4 fuel. Fire training pits 3 and 4 were used since 1973. During site investigations conducted between 1981 and 1989, soil at these pits were determined to be contaminated with TPH (151 to 1,380 mg/kg TPH), methyl ethyl ketone (MEK, concentration not given), benzene (0.2 to 16 mg/kg), toluene (10 to 183 mg/kg), ethylbenzene (21 to 84 mg/kg), and xylenes (69 to 336 mg/kg). One soil vapor extraction well was installed in each of the 2 fire pits, with 35-foot screens to depths of up to 57 feet. Cleanup goals were established for TPH and BTEX in soil based on Arizona Action Levels (AALs) — TPH at 100 mg/kg and BTEX at 412 mg/kg.

The soil consisted of permeable silty sands, very permeable, clean, well-graded to poorly graded sands, and permeable to low permeability inorganic silts. The moisture content was 10 percent with permeability of top soils ranging from 1 x 10 [Sup -4] to 3 x 10 [Sup-3] cm/sec, and porosity ranging from 36 to 46 percent.

A full-scale cleanup of the soil in the 2 pits using SVE was conducted from October 1991 until December 1992. A thermal oxidizer was used for destruction of organic vapors extracted from the soil. The full-scale system, which used the thermal oxidizer, removed 12,000 pounds of contaminants in 30 weeks of operation. The removal rate remained at 40 pounds/day after 30 weeks of operation. TPH and BTEX levels were below the AALs after 5 months of operation, with TPH and benzene were reported as not detected in March 1992. Soil gas concentration reductions achieved in 6 months for 8 constituents ranged from 72 to 96 percent (benzene). Results of sampling in November 1992 showed ethylbenzene, toluene, and xylenes as not detected. System downtime was about 1 percent during this period. After a temporary shutdown period, an attempt to restart the system caused a malfunction in the thermal oxidizer and the destruction of the burner. As of December 1992, future activities at the site were pending.

The total cost of this treatment application was $507,185. Capital costs were $297,017 (including site preparation, site work, startup, engineering, pipes, buildings, permitting, and regulatory). Annual operating costs were $210,168 (including labor, laboratory charges, monitoring, fuel, electricity, maintenance, and disposal of residuals).

Site investigation underestimated the amount of contamination at the site. A pilot-scale study was conducted at Luke before implementing the full-scale system. The pilot-scale system used vapor-phase granular-activated carbon to treat extracted soil gas. Because of unexpectedly high concentrations of volatile organic constituents, the carbon supply was exhausted after 2 days of operation, and the study was ended. In discussing remediation of sites contaminated with JP-4 jet fuel, the report includes a discussion of the relative benefits of using SVE and bioventing techniques.

2. Documentation

Marks, Peter J., Walther J. Wujcik, and Amy F. Lonear. *Remediation Technologies Screening Matrix and Reference Guide*, Second Edition. National Technical Information Service TEL: (703) 487-4650. Document number NTIS-PB95-104782.

Johnson, Richard L., Duane A. Graves, and Chi-yuan Fan. *Assessing UST Corrective Action Technologies: Diagnostic Evaluation of In situ SVE-Based System Performance.* National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. March 1996.

Beljin, Milovan, Roy Chaudet, Duane Graves, Jeff Schubert and Joe Tyburski. *Assessing UST Corrective Action Technologies: In situ-Based Systems for Free Product Recovery and Residual Hydrocarbon Removal.* National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. EPA/600/R-96/042.

"A Performance and Cost Evaluation of Purus Padre® (Regenerative Resin System for the Treatment of Hydrocarbon Vapors from Fuel-Contaminated Soils)." Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, Texas. April 1995.

"A Performance and Cost Evaluation of Ultrox D-TOX® UV/Oxidation System for the Treatment of Hydrocarbon Vapors from Fuel-Contaminated Soils." Draft. Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, Texas. July 1996.

Pedersen, Tom A. and James T. Curtis. *Soil Vapor Extraction Technology, Reference Handbook.* EPA/540/2-91/003. Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. EPA, Cincinnati, Ohio 45268

Soil Vapor Extraction and Bioventing. U.S. Army Corps of Engineers, Engineering Manual. EM 1110-1-4001, 30 November 1995.

Hinchee, Robert E., Ross N. Miller, and Paul C. Johnson. *In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes.* Battelle Press, Columbus, Ohio, 1995. Second in a series of ten books from the Third In Situ and On-Site Bioreclamation Internation Symposium, San Diego, California. Copies available from Battle Press, 505 King Avenue, Columbus, Ohio 43201. 1-800-451-3543.

3. World Wide Web Site(s)

- http://www.frtr.gov.
- http://cayuga.nfesc.navy.mil/cc/projects/sive.htm (Specific to Site 1, Hill Air Force Base.)
- http://www.frtr.gov/abstracts/00000011.html (Specific to Site 3, Amoco Petroleum Pipeline.)
- http://www.frtr.gov/matrix/top_page.html (Specific for the Remediation Technologies Screening Matrix and Reference Guide.)

- http://www.crcpress.com/jour/sss/arts/340030.htm (Article 340030: "Estimation of Effective Cleanup Radius for Soil-Vapor Extraction Systems" by David H. Bass)
- http://www.seas.ucla.edu/~yhsun/sves_0.html (Soil Vapor Extraction System Design by William W-G. Yeh)
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center
- http://em-50.em.doe.gov/BEST/Integration_Technologies/section4.6.html
- http://denix.cecer.army.mil/denix/Public/Library/Remedy/Hill914/hill91401.html (Specific to the Hill AFB site)
- http://www.uwin.siv.edu (Database of international water research compiled by the Water Resources Scientific Information Center of the U.S. Geological Survey. The research covers from 1967 to October 1993, with more than 265,000 abstracts and citations that are key-word searchable.)
- http://earth.agu.org/revgeophys/rathfe01/rathfe01.html ("Soil vapor extraction and bioventing: Applications, limitations, and future research directions." K. Rathfelder, J.R. Lang, and L.M. Abriola, Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor)

4. Models

VENT2D & VENT3D: Models of SVE at sites with finite-difference of multi-compound vapor transport and phase distribution. URL: http://www.hydro.unr.edu/homepages/benson/brochure/v2dbroch.html

IV. FUELS IN SOIL

A. BIOVENTING OF FUELS IN THE VADOSE ZONE

Blowing air into the vadose zone provides oxygen to microorganisms, accelerating their degradation of fuel vapors in this zone. *Principles and Practices of Bioventing,* Vols. I and II, listed in the Documentation section below, contains thorough and complete implementation of this technology.

Three parameters are tested before bioventing is started: air permeability of the unsaturated zone, air vent (well) radius of influence, and *in situ* respiration. Air permeability, or a soil's capacity for fluid or air flow, and radius of influence, or the maximum distance from the air extraction or injection well where measurable vacuum or pressure (soil gas movement) exists, are measured at the same time. The most favored field test method is probably the modified field drawdown method. It involves the injection or extraction of air at a constant rate from a single venting well while measuring the pressure and vacuum changes over time at several monitoring points in the soil away from the venting well.

The *in situ* respiration test consists of placing narrowly screened soil gas monitoring points into both the unsaturated zone fuel-contaminated and uncontaminated soils and venting these soils with air containing an inert tracer gas for a given period of time. Venting an uncontaminated soil yields background information for comparison to the contaminated area. In a typical experiment, therefore, 2 monitoring point locations, the test location and a background control location, are used. A cluster of 3 to 4 probes are placed in the contaminated soil. Inert gas (1 to 3 percent) is added to the air and is injected for about 24 hours. The air provides oxygen to the soil, while the inert gas measurements provide diffusion data. The background control location measures the rate of natural respiration. Measurements of carbon dioxide and oxygen concentrations in the soil gas are taken before air and inert gas injection. After the air and inert gas injection is turned off, readings of carbon dioxide and oxygen concentrations are taken, at first every 2 hours, then at 4 and 8 hour intervals until the oxygen concentration of the soil gas is about 5 percent.

Since the radius of influence is often 30-100 feet, one bioventing well can sometimes encompass one spill, depending on the size of the spill. Some of the sites that the USAF tested were remediated because the radius of influence included the entire spill, both horizontally and vertically.

Bioventing does not work well in very tight soils, smear zones, or very dry soils, such as in the southwestern United States.

Typical full-scale bioventing cost for a system of 4 air injection wells drilled to a depth of 15 feet is $92,300, with costs as follows: Site Visit and Planning $5,000; Work Plan, $5,000; Pilot Testing, $27,000; Regulatory Approval, $3,000; Full-Scale Construction, $27,500; 2 Years of Monitoring, $8,500; 2 Years of Power, $2,800; and Soil Sampling for 2 Years, $13,500.

1. Example Site(s)

Site 1. Hill Air Force Base, Ogden, Utah, Site 280. Soil was contaminated with JP-4 jet fuel. Contaminants: TPH (includes BTEX) concentration in soil was as high as 5,050 mg/kg, and soil gas TPH measured as high as 11,200 ppm.

A low intensity bioventing system installed at the site consisted of 1 injection well (100 foot depth) and 10 monitoring wells (varying depths). Air flow rate on the blower discharge ranged from 20 to 117 cubic feet (ft^3) per minute (at a discharge pressure of 2 inches of mercury) to optimize air flow rates while eliminating volatilization. As of November 1992, soil gas TPH concentrations had been reduced from 11,200 mg/kg to below 2,600 mg/kg. Estimates of the mass of contaminants removed have not yet been reported.

The estimated total capital cost was $115,000. The total annual operating cost, estimated over 4 years, was $24,000, including labor, electricity, laboratory charges, maintenance, and monitoring, but excluding final site characterization. During this test, three items of interest were noted: biodegradation was enhanced by maintaining adequate soil oxygen, moisture, and nutrient levels; estimates of biodegradation were more accurate if oxygen depletion were used instead of carbon dioxide formation; and air flow rates can be optimized to low levels ranging from 40 to 67 acfm.

Site 2. Hill Air Force Base, Ogden, Utah, Site 914. This was a demonstration of SVE followed by bioventing at a 25,000-gallon JP-4 jet fuel spill site. SVE was conducted for 9 months. When the system was operated in the bioventing mode for an additional 9 months, more than $54,000 was saved in off-gas treatment costs. Based on data gathered during extraction of oxygen, carbon dioxide, and hydrocarbon concentrations, an estimated 110,000 pounds of fuel were volatilized, and 90,000 pounds were biodegraded during the total 18-month demonstration. Initial soil samples showed a JP-4 concentration as high as 20,000 mg/kg, with the average being about 400 mg/kg. A 98 percent reduction in fuel contamination, to less than 5 mg/kg, was achieved during the 18-month demonstration.

Site 3. Kelly Air Force Base, Texas, Site FC-2. Fire training exercises were conducted here from the 1950s to 1981. Several times each year, waste petroleum, oils and lubricants (POL) and fuel fires were set and extinguished around a simulated airplane at the site. No containment system was used to prevent direct infiltration of POL and fuel into the soils, which are gravely clay. Ground water depth is 15-19 feet below the ground surface.

A single air injection well and four vapor monitoring points were installed in December 1992. An air injection rate of approximately 10 scfm produced a radius of oxygen influence of at least 50 feet. Average initial biodegradation rate of 2,750 mg of fuel per kg of soil per year was estimated based on initial, 6-month, and 1-year test results. Several soil and soil gas samples were collected after 1 year of bioventing treatment. Because of low concentrations of BTEX remaining in these soils, they are no longer a source of significant ground water contamination. Based on these results, a full-scale system of 6 vent wells was installed at the site to complete the remediation of an estimated 30,000 cubic yards of contaminated soil.

The total cost of the initial 1-year pilot testing and full-scale system upgrade was $115,000, or $3.80 per cubic yard. The cost includes Work Plans and Regulatory Approval, $5,000; Design, $9,000; Equipment Cost, $3,500; Installation, $62,500; 1-Year Maintenance and Monitoring, $9,000; and Reporting and Profit, $26,000.

Site 4. Lowry Air Force Base, Denver, Colorado, Underground Storage Tanks. As a result of a leak of heating oil from an underground storage tank (UST) at Lowry Air Force Base in Denver, Colorado, soil was contaminated with TPH and BTEX. Following excavation of contaminated soil to a depth of 35 - 40 feet below ground level (excavated for landfarming), soil sampling from the bottom of the excavation indicated that total recoverable petroleum hydrocarbon (TRPH) concentrations of 15 - 14,000 mg/kg remained in the soils. BTEX concentrations in soil samples were lower than cleanup criteria.

A bioventing system, consisting of 6 bioventing piping manifolds (each consisting of two 10-foot diameter screens, placed in the excavation at right angles, that is, in a horizontal plane, and surrounded with a 1 - 2 foot layer of pea gravel), was installed at the bottom of the excavation. The system began operating in August 1992. The soil was aerated to maintain an oxygen concentration greater than 14 percent and a CO_2 concentration less than 4 percent.

The bioventing of the contaminated soil at this site was ongoing as of April 1994. The target cleanup levels for the soil were TPH to less than 500 mg/kg; TRPH to less than 500 mg/kg; and BTEX to less than 100 mg/kg. The cleanup is being conducted under the authority of the Colorado Department of Health Underground Storage Tank Program. While no TPH, TRPH, or BTEX data were available at the time of this report, the bioventing system was found to have maintained adequate O_2 and CO_2 levels in the soil.

The total capital cost for this application was $28,650 (including equipment, site work, engineering, and project management). Estimated annual operating costs are $32,875 (including electricity, maintenance, and laboratory charges). It was noted during this application that key operating parameters for bioventing are soil moisture, oxygen content, and carbon dioxide content and that more frequent and better reported respiration test results would provide a more complete picture of the progress of the bioventing process and would indicate when final soil samples should be collected. No estimates have been made of the quantity of soil treated or hydrocarbon product degraded at the time of this report. The soil was moist, firm, sandy clay in the top 10-15 feet, and medium to coarse-grained sand in next 15-80 feet.

Site 5. U.S. Coast Guard Support Center, Kodiak, Alaska, Site 6B-Fuel Farm (Tank 191). This site was selected to demonstrate the technology at a remote northern facility. Tank 191 was an underground storage tank installed in the early 1940s, made of concrete and steel; it had a 567,000-gallon storage capacity. Used for the storage of diesel and JP-5 jet fuel, the tank was abandoned in 1978 because of significant leakage.

In August 1994, 1 air injection vent well and 2 vapor monitoring points were installed in the sand and gravel fill surrounding the tank. An air injection flow rate of 26 scfm produced a radius of oxygen influence of 90 feet in soils surrounding the tank. Ground water depth was approximately 15 feet bgs during system installation. Approximately 4,500 cubic yards (yd^3) were treated by this pilot system.

Although soil temperatures at the site averaged only 6 °C, an average biodegradation rate of 1,300 mg of fuel/kg of soil per year was estimated based on initial, 6-month, and 1-year respiration test results.

Soil and soil gas samples were collected before pilot testing and after 1 year of extended testing. Diesel-range total extractable petroleum hydrocarbons (TEPH) were reduced more than 80 percent on average during the 1-year test, and single year total BTEX concentrations in soil measured less than 0.5 mg/kg, making the site a good candidate for risk-based closure.

The total cost of the system installation for 1 year of pilot testing was \$69,000, or \$15.30/yd^3. This cost is approximately 25 percent higher than the average cost of a bioventing system installation and 1 year of testing in the continental United States. Additional costs are mainly due to higher transportation and drilling costs in this remote location. The cost includes Work Plans and Regulatory Approval, \$7,200; Mobilization and Site Preparation, \$11,300; Installation, \$29,700; 1-Year Maintenance and Monitoring, \$11,100; and Reporting and Profit, \$9,700.

2. Documentation

Leeson, Andrea and Robert E. Hinchee, *et al. Principles and Practices of Bioventing*: Volume I: Bioventing Principles. Battelle Memorial Institute for the U.S. Air Force and U.S. Environmental Protection Agency, 29 September 1996.

Leeson, Andrea and Robert E. Hinchee, *et al. Principles and Practices of Bioventing*: Volume II: Bioventing Design. Battelle Memorial Institute for the U.S. Air Force and U.S. Environmental Protection Agency, 29 September 1996.

"Test Plan and Technical Protocol for a Field Treatability Test for Bioventing." Environmental Service Office, Air Force Center for Environmental Excellence, Brooks AFB, San Antonio, Texas, May 1992.

"Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing – Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential." Environmental Service Office, Air Force Center for Environmental Excellence, Brooks AFB, San Antonio, Texas, February 1994.

"Bioventing Performance and Cost Results From Multiple Air Force Test Sites," Technology Demonstration Final Technical Memorandum, June 1996, Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks AFB, Texas.

U.S. Army Corps of Engineers. *Soil Vapor Extraction and Bioventing.* Engineer Manual. EM 1110-1-4001, 30 November 1995.

Hinchee, R. and others. *Handbook of Bioremediation..* Lewis Publishers, Boca Raton, Florida, 1994.

"Intrinsic Bioremediation of Petroleum Hydrocarbons." June 1996. Technical Report TM-2185-ENV. Naval Facilities Engineering Service Center, 1100 23rd Street, Port Hueneme, California 93043.

Hinchee, Robert E., Ross N. Miller, and Paul C. Johnson. *In Situ Aeration: Air Sparging, Bioventing, and Related Remediation Processes.* Battelle Press, Columbus, Ohio. 1995. Second in a series of ten books from the Third In Situ and On-Site Bioreclamation International Symposium, San Diego, California. Copies available from Battle Press, 505 King Avenue, Columbus, Ohio 43201. 1-800-451-3543.

3. World Wide Web Site(s)

- http://www.frtr.gov
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center, TEL: (703) 908-2138

4. Models

RT3D — a new (fall 1997) general-purpose, three-dimensional multispecies reactive transport model for use of accelerated bioremediation, bioventing, and natural attenuation.

B. USING AN INTERNAL COMBUSTION ENGINE FOR FUELS IN THE VADOSE ZONE

One company in the United States has modified 8-cylinder internal combustion engines to burn vapors from subsurface fuel spills. The main limitation is that the vapor concentration has to be in the 200,000 ppm range before extraction and be maintained at about 40,000 ppm for engine function. In other words, a large amount of fuel has to be present for this system to work. However, it works very effectively for a cost of cents per pound as opposed to dollars per pound. When the system first begins, the gasses in the soil will be both oxygen and carbon dioxide, with a much higher concentration of carbon dioxide than in air. For this reason, the engines will probably use auxiliary fuel at startup. Note that this system is *not designed* to remove or treat chlorinated vapors from soil, as they can produce an off-gas air stream containing hydrochloric acid vapor and other corrosive and toxic vapors.

1. Example Site(s)

Site 1. Patrick Air Force Base, Florida, active Base Exchange Service Station. Vadose zone soil contaminated with gasoline was treated using a gasoline-burning internal combustion engine along with an onboard computer system that monitored engine performance and advanced emission controls. The vapors were extracted directly by the intake manifold vacuum of the engine (up to 18 inches of mercury) and the vapors ran the engine. Vapor Recovery (VR) Systems of Anaheim, California, developed the system used. Supplemental fuel (propane or natural gas) was used as makeup to provide smooth operation of the engine if extracted soil gas vapor varied. The computer regulated fuel requirements by maintaining an acceptable air-fuel ratio.

The soil had an average water table depth of approximately 5 feet bgs. Contamination existed from previous unleaded gasoline leaks from underground storage tanks. The total volume of the contamination zone was not reported. The initial soil gas survey results ranged from 38,000 parts per million by volume (ppmv) to 100,000 ppmv. A horizontal vent well (HVW) was installed at 4 feet bgs as part of a bioventing pilot test also occurring at the site. The HVW was placed in the center of the highest total volatile hydrocarbon readings obtained during the initial soil gas survey. The HVW used 4-inch, Schedule 40 PVC pipe with 30 feet of 0.03-inch slotted well screen. The entire length of the screened interval was placed within the contaminated soil area. The study area at this site was paved, which significantly reduced or eliminated the potential for short-circuiting and increased the area of influence for air injection or soil vapor extraction through the HVW.

Because initial soil vapor concentrations at this site were very high, there were concerns about potential vapor migration with injected air. SVE was required to significantly reduce soil vapor concentrations before bioventing with air injection could be implemented. Several emission control technologies were evaluated and that offered by VR Systems was chosen.

VR Systems offered three models: the V2C at 140 cubic inch (in^3) displacement, the V3 at 460 in^3, and the V4 at 920 in^3, (using two V3 engines). The maximum hydrocarbon destruction rates were 15, 55, and 110 pounds/hour for the V2C, V3, and V4, respectively. All 3 require the soil gas hydrocarbon concentration to be 40,000 ppm.

The internal combustion engine model V3 was chosen and ran for a total of 13 weeks. The first 2 days were used to test the operating parameters. The average flow rate during this period was 150 scfm at an average engine speed of 1,790 revolutions per minute (rpm). Purchase of the V3 was $73,450 in 1994, while rental per month was $6,235. The decision to rent or purchase would be based on the estimated length of remediation. Shipping to and from the site 500 miles from vendor via commercial carrier was $1,000 total. Daily maximum supplemental fuel cost @ 2,000 rpm engine speed was $70. Monthly maintenance service was $220. During the initial 2 days of time optimizing the system, the daily operating cost was $325.

The cost per kilogram of total volatile hydrocarbons (TVH) destroyed per day ranged from $0.83 at the beginning of the test to $15.40 at the end of the 13th week; cost of BTEX destroyed ranged from $97 to $550 per kilogram per day over the same period. Cost per day increased slowly over time because the engine parts began to wear, reducing efficiency of combustion, not because vapor concentration decreased. Note that the BTEX cost is artificially high because the BTEX concentration, normally 20 percent in an unweathered gasoline spill, was only 5 percent at this site, because of age and natural weathering. During the extended test, an average influent flow rate of 80 scfm was achieved.

All internal combustion engine units require routine maintenance; this may add to the cost. The relative humidity of the extracted air stream must be less than 95 percent or be noncondensing to maintain combustion.

2. Documentation

"A Performance and Cost Evaluation of Internal Combustion Engines for the Destruction of Hydrocarbon Vapors from Fuel-Contaminated Soils." Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas. December 1994.

3. World Wide Web Site(s)

- http://www.frtr.gov.

C. COMPOSTING WITH LANDFARMING AND BIOPILES FOR FUELS IN SURFACE SOIL

Composting means gathering organic material in one place with the right proportions of matter, moisture, and possibly amendments to speed the microbial and fungal degradation of that matter. Landfarming and creating biopiles are two technologies that utilize composting. They have in common that:

- The contaminated soil is gathered in one place on the surface, and

- That microbiological activity is promoted with some form of aeration and amendments, including moisture.

Landfarming uses plowing equipment attached to a tractor to turn, and thus aerate, contaminated soil mixed with amendments such as wood chips or fertilizer. The soil is usually trucked into the area from a contaminated place and turned by the tractor several times a month. The area is lined, preferably with a clay or plastic liner, to prevent migration of contaminants. Volatiles escaping to the air have been of concern, and some landfarming operations have been done inside a plastic tent to capture volatiles. Usually, this technology is used for heavier hydrocarbons from which volatiles are absent.

Biopiles are constructed of contaminated soil and are laid on top of perforated pipes (usually PVC in a grid no more than about 3 feet between pipes), which are on top of an impermeable liner of concrete or plastic. The pile is usually built 8 to 10 feet high, about 20 feet wide, and any length to accommodate the volume of soil to be treated. As piles are created with earthmoving equipment, fertilizer is added after determining the nutrient quality of the soil; sprinklers or drip irrigation hose is installed. A blower sucks air through the perforated pipe, drawing air down through the pile. Checks on soil moisture, nutrient needs, and hydrocarbon disappearance are made throughout the life of the pile until the contamination is below the standard required. Leachate is collected and usually recycled onto the pile. Some piles are covered with tarpaulins if weather conditions such as too much rain, wind, or cold temperatures warrant.

Advantages to landfarming or biopiles are the simple technology and the low costs. Biopiles have remediated diesel and jet fuel contaminated soils in 3 months. Landfarming can require more or less time than this, depending on weather, level of initial contamination, frequency of soil turning, and amendments, but the general length of time to be expected is months rather than years.

1. Example Site(s)

Site 1. Underground Storage Tanks Land Treatment, Lowry Air Force Base, Denver, Colorado. An estimated 10,500 gallons of heating oil leaked from an underground tank, contaminating soil with TPH and BTEX. The underground storage tanks were removed and the contaminated soil excavated to a depth of 35-40 feet bgs. Land treatment, or land farming, was selected for the excavated soil. Treatment of about 5,400 cubic yards (yd^3) began in July 1992 and was ongoing at the time of the report published in March 1995. For the land treatment, ammonium nitrate nutrients were added in a one-time application, the soil was tilled twice a month, and the soil moisture kept between 10-15 percent by weight. The target cleanup levels for the soil were TPH to less than 500 mg/kg; TRPH to less than 500 mg/kg; and BTEX to less than 100 mg/kg. The TEPH samples in September 1993 showed levels in the range of 1,300-1,700 mg/kg. These data appear to indicate that land farming will be effective, though no projections for a completion date were available.

Total capital cost was $104,257 including $76,000 for pilot testing. The estimated annual operating costs are $18,640. Credibility of the land treatment soil assessment would have been improved if an adequate random sampling program had been used for sample collection.[1]

Site 2. Seymour Johnson Air Force Base provided a second example for land farming treatment by composting. Base engineers implemented a means to clean petroleum-contaminated soil using an abandoned taxiway and three key ingredients: contaminant soil, compost, and a few loads of turkey manure. The contaminated soil came from a variety of sources including UST excavation projects, spills from jet engine fueling, and rare events such as plane crashes. Contaminants included gasoline, diesel, fuel oils (No. 1, 2, 5, and 6), jet fuels, aviation gasoline (AVGAS), fog oil, kerosene, cutting oils, hydraulic fluids, motor oils and greases. The compost used came from the base's own composting program, as did the heavy machinery (a front-end loader and a compost windrow turner). A local farmer supplied turkey manure used as an amendment. The abandoned asphalt taxiway was surrounded by concrete curbs to form an enclosed area 50 feet wide by 200 feet long. Tie-down eyelets were inserted every 5 feet along the curb, and the entire area coated with a sealer to prevent leaching into the soil. A gray reusable vinyl-coated nylon cover was placed on top of the soil to protect the pile from the elements, and to help maintain the proper moisture and temperature. Approximately 550 tons of contaminated soil could be treated at one time. A layer of compost, then soil, compost, and turkey manure was mixed by the compost turner in two passes. Soil was about 75 percent, compost 20 percent (varies from 5 to 30 percent depending on soil type), and turkey manure 5 percent of the final mix. The pile was left 1 month and is presumed clean when it is odor-free. If an odor is detected, the pile is turned again. Moisture content should be about 50-60 percent.

The treatment costs about $5 per ton for the machinery, construction of the treatment area, sampling and analysis. Further advantages include less idle time for the

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[1] Another possible control would have been to create a biopiles without amendments that was not tilled or watered, to determine if remediation occurred differently or not.

compost machine, which is used in the base's composting process and therefore was not a capital outlay cost to the bioremediation treatment. Soil can be treated as soon as discovered or as soon a spill occurs, and the soil itself, now clean, can be used to backfill the remediation site or used in base landscaping projects.

Site 3. Marine Corps Base, Twentynine Palms, California. A demonstration of a Heap Pile Bioremediation (HPB) (or biopile) system for the remediation of 1,500 yd^3 of fuel-contaminated soil was conducted at Twentynine Palms in 1992. Fuel contaminants were primarily JP-5 and diesel. The objectives of this demonstration test were to:

- Decontaminate the soil to levels specified by regulatory agencies
- Integrate previous bench-scale studies with field system requirements
- Identify and evaluate lessons learned for improvements in future operations.

For this project, a biotreatability study was first conducted to determine optimum conditions for enhanced microbial growth. A computer airflow modeling program was also used to determine maximum limitations on pile height, minimum blower size, and minimum vacuum required to develop an adequate rate of soil aeration to stimulate microbial activity.

A liner was laid down over a graded pad and three separate soil piles (two active and one control pile) were formed over the liner. The water supply and leachate collection systems were engineered as independent systems to avoid cross contamination. Slotted PVC pipes were placed beneath the soil mounds and connected to a blower/manifold system to draw air through the soil. Nutrients were added to the soil based on optimum levels defined in the treatability study. Soil moisture and pH were also maintained as prescribed in the treatability study.

Initial soil contamination levels averaged 683 ppm. Treatment reduced these levels to an average of 56 ppm. Because of the success of this project, HPB is being implemented at MCB Camp Pendleton, California; NCBC Port Hueneme, California; and MCAS Kaneohe Bay, Hawaii. Cleanup costs are estimated at \$40/yd^3.

Site 4. Scott Lumber Company Superfund Site, Alton, Missouri. From 1973 to 1985, the Scott Lumber Company, located near Alton, Missouri, operated a wood treating facility used to preserve railroad ties with a creosote/diesel fuel mixture. As a result of these operations, soil at the site was found to have been contaminated with polynuclear aromatic hydrocarbons (PAHs) at concentrations as high as 0.326 mg/kg in lagoon water, 12,400 mg/kg in sludge, and 63,000 mg/kg in soils. Benzo(a)pyrene (BAP) ranged from

16 to 23 mg/kg at initiation of treatment. An Action Memorandum was signed in July 1987, which specified the construction and operation of a land treatment unit (LTU) as a removal action for biopile treatment of PAH-contaminated soils at the site. Cleanup activities were performed in three phases. The first two phases involved decontamination and removal of surface debris and sludge at the site and excavation and stockpiling of contaminated soil at the site. Phase III involved on-site land treatment of the contaminated stockpiled soil. This was one of the early applications of land treatment at a Superfund site contaminated with creosote compounds.

Land treatment was performed from December 1989 through September 1991, and 15,961 tons of soil were treated during this application. The LTU included a clay liner and berms, run-on swales, and subsurface drainage system with a retention pond and irrigation system. Indigenous microorganisms were used to support biodegradation. Stockpiled soil was placed in the LTU in 2 lifts. Approximately 200 pounds/acre of ammonium phosphate fertilizer were added to the first lift to adjust the nutrients in the soil. No nutrient adjustments were made to the second lift. Each lift was cultivated once or twice a week and irrigated, as necessary, to maintain a moisture content between 1 percent and 4 percent.

Action levels for the soil at the site, established by EPA, were 14 mg/kg for BAP and 500 mg/kg for total PAHs. Land treatment at the Scott Lumber site reduced levels of BAP and total PAHs to below action levels. In Lift 1, BAP concentrations were reduced from 16 mg/kg to 8 mg/kg and total PAH concentrations were reduced from 560 mg/kg to 130 mg/kg within 6 months. In Lift 2, concentrations were reduced from 23 mg/kg to 10 mg/kg for BAP and from 700 mg/kg to 155 mg/kg for total PAHs within 3 months. The total costs for this removal action were $4,047,000, including $1,292,000 for the land treatment contractor (over a period of 3 years) and $254,000 for laboratory analyses, EPA contractors, and EPA oversight. Site demobilization was completed in September 1991.

Site 5. Brown Wood Preserving Superfund Site, Live Oak, Florida. From 1948 to 1978, the Brown Wood Preserving site was used to pressure treat lumber products with creosote. While pentachlorophenol was occasionally used, creosote was the primary wood preservative. Lumber was pressure treated in two cylinders and wastewaters from these cylinders were discharged to a lagoon. The lagoon and soils at the site were determined to be contaminated with high levels of organics (primarily PAHs found in creosote) and the site was placed on the National Priority List (NPL) in December 1982. In April 1988, following the completion of several interim removal activities, a Record of

Decision (ROD) was signed specifying land treatment for contaminated soils stockpiled during the interim removal activities.

Land treatment of the PAH-contaminated soils was performed from January 1989 to July 1990. Approximately 8,100 yd^3 of stockpiled soil were treated in 3 lifts. The cleanup goal specified in the ROD was 100 mg/kg for Total Carcinogenic Indicator Chemicals [TCICs — the sum of the concentrations of 6 PAHs selected by EPA based on the results of a risk assessment: benzo(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; chrysene; dibenzo(a,h)anthracene; and indeno(1,2,3-cd)pyrene] to be achieved within 2 years of operation. The cleanup goal was achieved within 18 months using land treatment, 6 months ahead of the time specified in the ROD. The concentrations of TCICs measured during verification sampling (July 1990) ranged from 23 to 92 mg/kg. The land treatment area was revegetated in October 1991 and approximately 90 percent of the former land treatment area (LTA) was covered with native grasses by March 1992.

The total treatment cost for this application at the Brown Wood site was approximately $565,400 (including solids preparation and handling; mobilization/setup; and short-term (up to 3 years) and long-term (more than 3 years) operation costs). The treatment costs included solids preparation and handling, mobilization and setup, and operation costs. In addition, there were before-treatment costs (mobilization and preparatory work, site work, and solids collection and containment) of approximately $58,000 (including mobilization and preparatory work, site work, and solids collection and containment) and after-treatment costs (demobilization) of approximately $9,800. This application is notable for being an application of land treatment of creosote-contaminated soil at a Superfund site.

Site 6. Public Works Center, Naval Air Station North Island, San Diego, California. The bioremediation treatment facility (BTF) was constructed with double liners and a leachate collection system to enable future treatment of hazardous wastes. The BTF was and will be used only to bioremediate petroleum hydrocarbon-contaminated soils generated at underground storage tank and installation restoration sites. A typical petroleum underground storage tank site that generated 1,000 tons of contaminated soil, when treated at the BTF, will save around $30,000 compared to thermal desorption or soil washing and local facilities and more than $100,000 compared to disposal at a permitted landfill.

Site 7. Solid Waste Management Unit #14, U.S. Naval Station, Mayport, Florida. The purpose of this effort was to clean approximately 1,000 yd^2 of concrete in the detention pond covered with a solidified mass of oily petroleum hydrocarbons, and treat approximately 100 yd^3 of soil containing petroleum. The concrete pad had been used for firefighting training; oil and other materials were placed on the pad, ignited, and water was used to extinguish the fire. Since 1987, the oily-water runoff was collected in an oil-water separator or the concrete detention basin before being pumped to an oily waste treatment plant.

A proprietary mixture of microorganisms and nutrients named Earthwise Formula One — the Bioremediation Catalyst, and WinterBio RBCTPH/RBC 109 were used on the concrete basin. Push brooms and a mechanical scrubber were used to emulsify and separate the oils from the concrete. After each application, a high-pressure washer created runoff and mobilized the petroleum. The runoff was collected before reaching a drain at the end of the detention pond and placed in a temporary tank. The soil treatment consisted of a spray of microbial solution on the land surface that was then covered with black polyethylene sheeting. The sheeting was removed for rototilling to 2 feet below the soil surface. The numbers of applications or rototillings were not given. Both the soil and the concrete pond treatments were started in January 1996, halted in February because of cool temperatures, and resumed in May with treatment ending in July 1996.

The detention pond looked cleaner after the application but may have been due to the high pressure hosing rather than bioremediation. Surface water samples indicated bioremediation did not work. Soil samples from the landfarming effort showed that bioremediation reduced TRPH levels to human-health targets but did not meet criteria for TRPH thermal treatment of petroleum-contaminated soil. No assessment was made as to a difference between application of the proprietary mixture versus microorganisms naturally present in the soil. The rototilling assisted in aerating the soil. The concentration values were not given, nor were costs.

2. Documentation

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Biopile Operation and Maintenance Manual. June 1996. Technical Memorandum TM-2190-ENV. Naval Facilities Engineering Service Center, 1100 23rd Street, Port Hueneme, California 93043.

Intrinsic Bioremediation of Petroleum Hydrocarbons. June 1996. Technical Report TM-2185-ENV. Naval Facilities Engineering Service Center, 1100 23rd Street, Port Hueneme, California 93043.

Section 4.4, "Treatment of Excavated Soil" from the handbook, “U.S. Air Force Remediation Handbook for POL-Contaminated Sites,” December 1995.

Technology Evaluation Report, Naval Environmental Leadership Program Technology Demonstration for Thermal Desorption of Petroleum-Impacted Soil at Solid Waste Management Units 6 and 7, U.S. Naval Station Mayport, Florida. Unit ID Code N60201. July 1997, Southern Division, Naval Facilities Engineering Command, North Charleston, South Carolina 29419.

3. World Wide Web Site(s)

- http://www.frtr.gov
- http://cayuga.nfesc.navy.mil/cc/projects/heap.htm (Specific to Site 2, Marine Corps Base, Twentynine Palms.)
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center.

V. GENERAL COMMENTS ON CHLORINATED SOLVENTS

A. GENERAL COMMENTS

Chlorinated solvents present two main difficulties: they resist remediation, and they sink below water due to their density. Because of their characteristic of being denser than water, they are also called dense non-aqueous phase liquids (DNAPLs). Sources of DNAPL contamination in the subsurface can rarely be located with precision, mainly due to the great cost of locating the pockets and layers that DNAPLs form in the saturated zone below the ground water, or in the vadose zone. One site at Hill AFB luckily happened to be near the pool of the DNAPL source. The pool was removed by pumping, but this is a rare occurrence.

However, chlorinated solvents are soluble in water to a limited, but detectable, extent. Therefore, plumes from chlorinated solvent contamination can more easily be located and treated. Since the cost of locating a plume of chlorinated solvents is less than locating a source, treatment of chlorinated solvents in the subsurface has often been limited to plume remediation. A plume may exist because of chlorinated solvent components dissolved in the ground water, or it may be a "plume" of chlorinated solvent vapors in the vadose zone. Vapors can come from contaminated ground water or from a pool of DNAPLs in the vadose zone.

At present, natural attenuation in soils and ground water and passive barrier walls for solvents in ground water are the two field-ready approaches that are potentially of greatest use because they are less expensive than other solvent cleanup methods. Dual-phase recovery followed by chlorinated solvent destruction at the surface is mentioned here because it is in field use, but it is expensive.

Surfactant use for product recovery, hydraulic barrier with poplar trees, and enhanced remediation are included in Chapter XII. Although they are not considered field-ready, they deserve mention because preliminary results indicate they could be effective. Planting poplar trees to prevent a chlorinated ground water plume from moving farther is inexpensive. The other two technologies, surfactant use and enhanced remediation, may be more costly since both involve adding materials to the subsurface. Surfactant use requires the injection of a surfactant to help remove solvents clinging to soil particles. The resulting surfactant-chlorinated solvent mixture is pumped to the surface for treatment. Adding a carbon source to the subsurface is known as enhanced remediation, and knowledgeable estimates are that a field-ready technology will be available in 1999 or 2000. Co-metabolic processes are enhanced by the presence of an energy source for microorganisms, since chlorinated solvents are not used as an energy source. Currently, the Air Force's Armstrong Laboratories, along with educational institutions, have selected ten sites to test the applicability of enhanced remediation. Results from five of these sites will be used to develop a protocol to determine whether a site is a candidate for enhanced remediation of chlorinated solvents.

In the introductory talk of the Symposium on Natural Attenuation of Chlorinated Organics in Ground Water (refer to Documentation below), the move to a risk-based approach to setting cleanup standards is discussed. Initial ground water cleanup standards often defaulted to concentration-based standards for drinking water (maximum concentration levels or MCLs), but technologies used to date have failed to meet those standards because of many factors not considered when the standards were set. Now, containment, instead of cleanup, and monitoring of the site while relying on natural attenuation, is part of the proposed risk-based approach.

1. Documentation

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Stanners, D. and P. Bourdeau, Editors. *Europe's Environment: The Dobris Assessment.* Office for Official Publications of the European Communities, Luxembourg. European Environmental Agency. 1995.

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Vogel, T.M., C.S. Criddle, and P.L. McCarty. "Transformations of halogenated aliphatic compounds." *Environmental Science and Technology* 21, p. 722, 1987.

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2. World Wide Web Site(s)

- http://www.mrd.usace.army.mil/mrded-h/mrded-h.html (U.S. Army Corps of Engineers Hazardous, Toxic, Radioactive Waste Center of Expertise)

- http://www.usgs.gov (U.S. Geological Survey)

VI. CHLORINATED SOLVENTS IN WATER

A. NATURAL ATTENUATION OF CHLORINATED SOLVENTS IN GROUND WATER OR BELOW GROUND WATER TABLE

Natural attenuation is defined by the USEPA as "the biodegradation, diffusion, dilution, sorption, volatilization or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility or volume to levels that are protective of human health and the environment."

Chlorinated solvents (DNAPLS) are resistant to biodegradation. Some natural attenuation occurs, either by oxidation-reduction reactions via microorganisms, by abiotic (chemical) reactions mediated by metals (e.g., iron or iron complexes), or by water (hydrolysis reactions). Advection, dispersion, and dilution also contribute to natural attenuation. Advection moves molecules along the ground water flow path, and dispersion moves molecules out and away from the expected ground water flow path. Diffusion disperses molecules as they move from an area of high concentration to an area of low concentration. Sorption is the adsorbing or the absorbing into geologic materials. Volatilization, or release from aqueous to vapor phase, occurs with some chlorinated solvents or their degradation products. Chemical molecules can also become chemically bound by a stabilizing agent, such as clay or humic materials, reducing mobility in the ground water.

Depending on the site conditions, contaminant concentrations, and the factors mentioned above, approximately 20 to 30 percent of sites can be naturally attenuated. Several factors govern the decision to use natural attenuation:

- Natural attenuation processes are observed at the site,
- No receptors are or will be adversely impacted,
- A continuing source exists that cannot be easily and cost-effectively located or removed,
- Alternative technologies are not cost-effective or are technically impractical,

- Alternative remedial technologies pose added risk by transferring contaminants to other media,
- Minimal disruption of facilities operation and infrastructure is desired.

1. Example Site(s)

Site 1. The Groundwater Remediation Field Laboratory (GRFL), located at Dover AFB, Delaware. This laboratory represents the first facility in the United States where researchers can conduct carefully planned contained releases of chlorinated solvents and fuels into a natural aquifer. They will be able to effectively test methods for characterizing, monitoring, and cleaning up areas contaminated with these materials. Established and operated by Armstrong Laboratory, Environics Directorate, Tyndall AFB, Florida, and funded by the Strategic Environmental Research and Development Program (SERDP), the GRFL is part of the National Environmental Technology Test Sites (NETTS) program designed to support research efforts and demonstrations of innovative environmental cleanup technologies.

The GRFL is a unique site for demonstrating technologies to clean up solvent contamination of the subsurface. The specific goal is to develop techniques for locating, monitoring, and cleaning up DNAPLs commonly associated with solvent contamination. The unique feature of the GRFL is the provision for performing carefully planned, experimental, contained releases of DNAPLs in the natural soil matrix. This capability establishes the GRFL as one of only two such sites in the world.

The NETTS test site network was developed by SERDP to accommodate the specific cleanup needs and technical expertise of the DoD and EPA. The Army, Navy, Air Force, and EPA each have specific responsibilities and each sponsor at least one test site.

The GRFL was developed by the Air Force primarily to demonstrate technologies to clean up solvent contamination of the subsurface. Contamination with industrial solvents is one of our most intractable cleanup challenges. Common solvents such as perchloroethylene and trichloroethylene (DNAPLs) have been used for decades to clean weapon systems. When spilled on the ground, these liquids filter through the earth. Denser than water, they continue to trickle even below the water table until they either simply play out or encounter a soil layer that they cannot penetrate, forming a pool. These pools or residuals are nearly impossible to locate or remove; they provide a chronic source of contamination to ground water that passes by the source zone.

DNAPL behavior in the subsurface is poorly understood. Current removal methods suffer from inaccurate estimates of initial DNAPL presence, making removal efficiencies unclear. Since nearly one-third of the Air Force's contaminated sites have a DNAPL component and since subsurface DNAPL cleanup is usually impossible at any price, we must develop better understanding of DNAPL behavior to develop cost-effective monitoring and cleanup technologies.

Site 2. Edwards Air Force Base, California. Strictly speaking, the work at this site is enhanced natural attenuation of chlorinated solvents. The Western Region Hazardous Substance Research Center (HSRC) recently completed a full-scale *in situ* demonstration of successful trichloroethylene (TCE) biodegradation in contaminated ground water at Edwards Air Force Base, California. Through the addition of toluene and oxygen in treatment wells, co-metabolism by toluene-using microorganisms caused TCE concentrations ranging between 1,000-1,400 mg/l in the influent aquifer water to fall by 85 percent with each pass through the wells.

Following several passes at flow rates of 25-38 L/min, TCE concentrations in ground water ranged from 25 - 50 mg/l, indicating 95 - 98 percent TCE removal. This 12-month demonstration project encompassed a 22-meter-square treatment zone and a 60-meter-wide influent ground water plume. Stanford University researchers designed a 2-well treatment system spanning 2 aquifers. Toluene, gaseous oxygen, and hydrogen peroxide were injected into each well and mixed with pumped-in contaminated ground water from 1 aquifer. The mixture then entered the other aquifer, where toluene and TCE biodegradation occurred. Ground water circulated between both wells and between both aquifers. Static mixers at each well dissolved 7 - 14 mg/L of toluene and a mixture of pure oxygen and hydrogen peroxide to provide the dissolved oxygen concentration of 30 - 40 mg/L required for toluene degradation. Hydrogen peroxide, added to prevent excessive bacterial growth near the well screens, dissociated in the aquifer to provide part of the required dissolved oxygen.

The system added oxygen and peroxide continuously, with additions of toluene in a pulse once per day averaging 1.6 mg/L, with a maximum measurement of 18 mg/L, which was far below health effects standards (100 mg/L for California and 1,000 mg/L for EPA) and below taste and odor thresholds (25-40 mg/L). The HSRC conducted this demonstration in cooperation with the Armstrong Laboratory, U.S. Air Force; Edwards Air Force Base; Earth Tech; Woodward-Clyde; and EPA's Robert S. Kerr Research Laboratory.

This site is listed in Chapter XII, Section A, as well.

Site 3. National Priorities List Site at St. Joseph, Michigan. In 1982, TCE was found in ground water at this site, with the chlorinated aliphatic compounds at concentrations ranging from 10 mg/L to 100 mg/L. The chemicals are thought to have entered the shallow sandy aquifer either through waste lagoons used from 1968 to 1976 or through disposal of trichloroethene (TCE) into dry wells at the site. The contamination was determined to be divided into eastern and western plumes, as the suspected sources were situated over a ground water divide. Both plumes were found to contain TCE, cis- and trans-1,2-dichloroethene (c-DCE and t-DCE), 1,1-dichlorethene (1,1-DCE) and vinyl chloride (VC). Natural anaerobic degradation of the TCE was occurring because transformation products and significant levels of ethene and methane were present.

The composite data set indicates that the oxygenated and methanogenic zones of the aquifer are clearly separated. Data from individual boreholes indicate that high cis-DCE concentrations were commonly associated with declines in oxygen and sulfate concentration and appeared on the upper edge of the methanogenic zone. Generally, ethene was found in the most methanogenic portions of the aquifer and was also associated with relatively high VC concentrations, suggesting that the ethene production was limited to those sample locations.

No cost data were given.

Site 4. Fort Wainwright, Alaska. The U.S. Geological Survey and University of Alaska Fairbanks (UAF), Water and Environmental Center (WERC), in cooperation with the U.S. Army Environmental Center, is investigating the natural-attenuation and biogeochemical processes that are occurring in a chlorinated hydrocarbon-contaminated active ground water and surface water system on Fort Wainwright, Alaska. The results of these investigations will help define the potential natural attenuation processes in this type of environment.

The Chena River stage increases during two major periods of the year in Fairbanks: spring snowmelt and late-summer precipitation events. The cyclic effect of these stage changes over the effective period for ground water contamination events is an important aspect to consider when evaluating fate and transport questions. The deviation from long-term trends in the stage changes is also important when considering the fate and transport aspects of ground water contamination, as well as how to apply short-term data to site investigations.

Some of the data collected during 1997 are from continuous data-collection sites located to the west of Building 1060. W1 is about 5 feet from the edge of the Chena River Bank. Pit 1 is located on the south side of Apple Road and is about 100 feet from bank. Pit 2 is located to the south of Pit 1 and is about 300 feet from bank.

The process of natural attenuation is slow, particularly so in the Alaskan environment. No reports of data or costs were available, but the site is included here because it is one of the few being investigated and certainly one of very few in an extreme environment.

2. Documentation

An Analysis of Ground-Water Information Contained in the Bioremediation Field Search System (BFSS), from Ground-Water Remediation Case Studies from EPA's Bioremediation Field Search System (BFSS). http://www.gwrtac.org/html/tech_misc. html#BFSS

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Chlorinated Organic Compounds in Ground Water. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, R. S. Kerr Research Center, Ada, Oklahoma.

3. Models

BIOSCREEN III is a screening tool for simulating the natural attenuation of dissolved hydrocarbons and chlorinated organics, and is (as of May 1997) being finalized. BIOSCREEN II is a screening tool for hydrocarbons only.

RT3D is a new (fall 1997) general-purpose, three-dimensional multispecies reactive transport model for use of accelerated bioremediation, bioventing, and natural attenuation.

4. World Wide Web Site(s)

- http://www.gwrtac.org
- http://www.icubed.com/rtdf
- http://www.frtr.gov
- http://ci.mond.org/9703/970314.html (Excellent article on Intrinsic Bioremediation and the considerations required)
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center
- http://www.brooks.af.mil/HSC/AL/EQ/prod14.html (Specific to Site 1, the GRFL)
- http://www-water-ak.usgs.gov/www_public/ess/aec/aec.html (Specific to the Fort Wainwright study)
- http://www-water-ak.usgs.gov/ess/ess.html
- http://www.uwin.siv.edu (Database of international water research compiled by the Water Resources Scientific Information Center of the US Geological Survey. The research covers from 1967 to October 1993, with more than 265,000 abstracts and citations that are key-word searchable.)

B. PASSIVE BARRIER WALLS TO TREAT CHLORINATED SOLVENTS IN GROUND WATER OR BELOW GROUND WATER TABLE

Passive barrier walls, also called passive reactive walls, permeable reactive barrier, or passive trenches, are a very promising technology. Researchers at the University of Waterloo observed that there was a statistically significant difference of remediation of chlorinated solvents in wells that were lined with stainless steel that was corroding (despite its name, versus wells lined with PVC. They traced the cause to the iron present in the stainless steel well casings.

In this process, water-permeable treatment walls are installed as permanent, semi-permanent, or replaceable units across the flow path of a contaminant plume, allowing the plume to move passively through while precipitating, sorbing, or degrading the contaminants

These mechanically simple barriers may contain metal-based catalysts for degrading volatile organics, chelators for immobilizing metals, nutrients and oxygen for microorganisms to enhance bioremediation, or other agents. Degradation reactions break down the contaminants in the plume into harmless byproducts. Precipitation barriers react with contaminants to form insoluble products that are left in the barrier as water continues to flow through. Sorption barriers adsorb or chelate contaminants to the barrier surface. The reactions that take place in barriers are dependent on parameters such as pH, oxidation/reduction potential, concentrations, and kinetics. Thus, successful application of the technology requires characterization of the contaminant, ground water flux, and subsurface geology. Although most barriers are designed to operate *in situ* for years with minimal maintenance and without an external energy source, the stability of aging barriers has not been established.

In some cases, bits of iron about the size of a rice grain are placed in an in-ground trench or wall a few inches to a few feet thick. Walls are strategically placed to intercept the contaminated ground water plume. In the wall, chlorine is removed and the hydrocarbon is left behind; the resulting ethene or ethane is then readily biodegraded. The thickness of the wall depends on the speed of ground water flow and the concentration of the chlorinated compound. The half life of TCE in a barrier wall is 1 hour, therefore, it is critical to know the ground water's velocity when planning a passive barrier wall installation.

At present, these barrier walls are limited to a 40-foot depth. We do not know if the iron retains reactivity over long periods of time or if it is best put in place with carrier fluids in a slurry emplacement process. There are approximately eight configurations for these walls.

The main perceived advantage of this technology over *ex situ* and other *in situ* ground water remediation approaches is reduced operation and maintenance costs. The first commercial application of zero-valent iron using a funnel-and-gate system for the removal of chlorinated hydrocarbons was in February 1995. Several field- and pilot-scale studies are evaluating the feasibility of this technology for treatment of both organic and inorganic contaminants. Considerable design details have already been developed through field- and pilot-scale applications. Some critical issues (e.g., establishing tested and proven design procedures, improving construction technologies, documenting long-term performance, and evaluating synergy with other ground water remediation technologies) still remain to be resolved.

Note that the DitchWitch® is a piece of trenching equipment and is often used to create passive barrier walls. Any contractor can use it for a shallow depth trench, but deeper trenches would need an experienced contractor.

1. Example Sites(s)

Site 1. Moffett Field Airfield and Naval Air Station, Mountain View, California. The iron permeable reactive wall is an innovative technology for the remediation of chlorinated hydrocarbons in ground water. This technology uses a basic chemical reaction in which zero-valent iron reacts with the chlorinated hydrocarbons in the ground water to produce non-toxic, readily biodegradable, hydrocarbon compounds (C2 - C5), iron and chloride ions, and hydroxides.

The Naval Facilities Engineering Service Center (ESC), NAVFAC Engineering Field Activity West, Battelle Memorial Institute, and PRC Environmental Management initiated a pilot study field demonstration project at Moffett Federal Airfield and Naval Air Station (Moffett Field), Mountain View, California (San Francisco Bay Area) in January 1996. A 50-foot long by 10-foot wide by 22-foot thick funnel-and-gate system was installed across a TCE and PCE contamination plume at the Moffett Field site in April 1996. The objective of this project is to demonstrate and validate the permeable reactive wall technology in remediating ground water contaminated with chlorinated hydrocarbons and to develop performance monitoring criteria and cost effectiveness data.

A baseline sampling effort of the permeable reactive wall was conducted in June 1996. Preliminary findings from this study indicated positive results. Additional permeable wall sampling in September 1996 has further substantiated the preliminary results. TCE concentrations above 1,000 micrograms per liter (µg/L) upgradient of the permeable wall were reduced to non-detectable levels within the first 2 feet of the permeable cell (gate). Tracer testing and slug testing are proposed in the near future to determine flow velocities, pathways, and capture efficiencies of the funnel-and-gate system. Other chemical and biological investigations are also proposed for the pilot study to assess the potential long-term precipitate effects on the permeable iron wall.

The unique benefit of permeable reactive wall technology is that it passively remediates the contaminated ground water using the natural flow properties of a site. When compared to pump and treat technology, permeable reactive walls can remediate the ground water more effectively and with lower operation and maintenance costs.

The Moffett Field demonstration project will be conducted for approximately 2 years (until about March 1998). At the end of this project, a technology transfer report will be prepared for Department of Defense use. Additionally, the report will be distributed to others through appropriate working groups, such as the EPA Remediation Technologies Development Forum (RTDF).

Site 2. Canadian Forces Base Borden, Ontario, Canada. Researchers installed a permeable reaction wall containing an iron-based catalyst about 16.5 feet downgradient from the source of a VOC contaminant plume to pilot test the capability of the wall to degrade halogenated organic compounds. The plume was about 6.5 feet wide and 3.3 feet thick with maximum concentrations along the axis of about 250,000 µg/L trichloroethene (TCE) and 43,000 µg/L tetrachloroethene (PCE). The source of the plume was located about 13 feet below ground surface and 3.3 feet below the water table. (Investigators believe the wall can be installed to depths of 50 feet, but no test results substantiate this.)

Using sealable-joint sheet piling, a rectangular cell was constructed on the surface and driven to a depth of 32 feet, the cell was sealed and dewatered and the native sand was replaced by the reactive material consisting of 22 percent by weight granular iron and 78 percent by weight course sand. The sand, which was coarser than the native materials, ensured that the wall would be more permeable than the surrounding sand. After installing the reactive material, the sheet piling was completely removed and natural flow conditions were achieved. The wall dimensions were 18 feet long, 5.2 feet thick, and 7.2 feet deep; it was positioned 3.3 feet below the water table.

This pilot test was completed in 1993. The Waterloo Centre for Groundwater Research is part of Ontario's Centres of Excellence program, a government sponsored partnership with academia and industry.

Multilevel monitoring wells were located 1.6 feet upgradient of the wall, in the wall at distances of 1.6 and 3.3 feet, and 1.6 feet downgradient of the wall for a total of 348 sampling points. Concentration distributions through the wall were determined on

13 occasions over 474 days, during which there was no decline in the effectiveness of the barrier. Most of the mass loss occurred within the first 50 cm of the wall; at greater distances into the wall, performance was below that expected. However, the reaction wall reduced the TCE concentration by 95 percent and the PCE concentration by 91 percent. No vinyl chloride was detected in the samples. Increased chloride concentrations downstream of the wall were consistent with the quantity of TCE and PCE that had been degraded. Only trace amounts of dichloroethene (DCE) were detected downstream of the wall.

No cost data are available.

Demonstration Sites. Several demonstration or pilot scale sites for this technology exist. (1) Canadian Forces Base Borden. Researchers are field testing an *in situ* semipassive permeable wall into which nutrient solutions that enhance biodegradation of organics are introduced. The wall is installed across the path of a contaminant plume containing TCE and carbon tetrachloride in an unconsolidated aquifer. Results indicate that by adding substances in the wall, the mixing with ground water is maximized to produce a stable microbial population that can be supported at some distance downgradient from the wall. An anaerobic population supporting this led to complete carbon tetrachloride removal from ground water but did not transform TCE. Work is continuing to overcome this limitation.

(2) General Electric, Sunnyvale, California. An above-ground field test reactor containing 50 percent iron was installed at this semiconductor manufacturing facility to test the feasibility of installing an *in situ* permeable reactive zone. Ground water was pumped through the reactor at a rate of 4 feet/day for 9 months. Initial concentrations of contaminants were 50 to 200 ppb TCE, 450 to 1,000 ppb cis-1, 2-dichloroethene (cis-DCE), 100-500 ppb vinyl chloride (VC), and 20 to 60 ppb Freon-113. The time required to degrade one-half of the contaminant mass in the above-ground field test was less than 1.7 hours for TCE, 1 to 4 hours for cis-DCE, 2 to 4 hours for VC, and less than 1.6 hours for Freon-113. Mineral precipitation, hydrogen gas production, and microbial effects also were evaluated. Based on the feasibility tests described above, a full-scale *in situ* permeable treatment wall was approved by the state regulatory agency and was installed in December 1994. The permeable reactive zone, which will be 4 feet thick, 40 feet long, 10 feet high, and about 25 to 30 feet deep, will contain 100 percent reactive iron. It will be installed using a trench box design.

The estimated cost is projected to be $175,000 - $200,000. Patents governing the *in situ* application of the metal enhanced dehalogenation are held by the University of Waterloo. EnviroMetal Technologies, Incorporated holds an exclusive license with the University of Waterloo for this treatment technology.

(3) Industrial Facility, New York State (most complete title). VOCs will be degraded using the EnviroMetal process (metal-enhanced reductive dehalogenation) in a pilot scale Funnel-and-Gate® *in situ* treatment system at a former plating facility contaminated with chlorinated solvents: VOCs and SVOCs, including TCE, PCE, DCE, and VC. The reactive zone, containing 100 percent granular iron, will be 10 feet wide, 3 feet thick, and installed at a depth of 15 feet, which is below the water table and near the source of the contaminant plume. Ground water will be directed towards the zone by 15 linear feet of Waterloo Barrier sheetpiling on either side. There is a confining layer of clay at 15 feet. A pilot scale unit was installed in May 1995. After the system is operating, the demonstration is expected to run for 6 months with the New York State Department of Environmental Conservation and U.S. EPA's SITE program overseeing the demonstration. EnviroMetal Technologies, Incorporated, holds an exclusive license with the University of Waterloo, the patent holder, for the commercial application of this treatment technology. Waterloo Groundwater Control Technologies, Incorporated, is commercializing the Funnel-and-Gate® system (patents pending) developed at the Waterloo Centre for Groundwater Research.

(4) Semiconductor Manufacturing Facility, New Jersey. Batch and column tests using 50 percent and 100 percent iron in the reactive media and ground water flowing at 1.5 feet/day were conducted to establish reaction conditions for a pilot-scale above-ground field trial (now underway). These tests are for the future installation of an *in situ* treatment wall. The contaminants are TCE, PCE, DCE, and VC. An above-ground field trial began in November 1994 under the EPA SITE demonstration program and is still operating.

(5) Massachusetts Military Reserve, Falmouth, Massachusetts. A pilot-scale test using granular iron in a Funnel-and-Gate® system is planned to treat a large and deep contaminant plume containing VOCs. The system will be installed near the leading edge of the plume, which is 40-100 feet thick and 180 feet deep. A preliminary test was conducted in the spring of 1995, which failed to reach the 180-foot depth. Consequently, the reaction zone and Funnel-and-Gate® system will not be pilot tested on that deep plume. Other options for the deep plume are under consideration by the National Guard,

sponsor of the demonstration. The reaction zone and Funnel-and-Gate® system may be tested on 2 other, more shallow, plumes at the site.

(6) Coast Guard Air Station, Elizabeth City, North Carolina. A series of large-diameter augered holes in a staggered 3-row array were located within an aquifer to intercept a contaminant plume of chromate (Cr^{+6}) and chlorinated organics (TCE, DCE, VC). A mixture (by volume) of 50 percent iron filings (two types), 25 percent clean coarse sand, and 25 percent aquifer material was poured down hollow-stem augers from 22 feet to 10 feet bgs. Each iron column was approximately 8 inches in diameter and a total of 21 columns were installed in a 60 ft^2 area. The mixed waste contaminant plume is between 14 and 20 feet bgs and the water table ranges from 5 to 6 feet bgs. One iron type was shown to be an effective reductant for Cr^{+6} in a 2-year laboratory study, but the other iron has been shown to be more effective in the reductive dechlorination of the organics. This field experiment is evaluating the effectiveness of this method of treatment wall emplacement and is providing additional *in situ* field data for full field-scale implementation. The demonstration has been in operation since September 1994. Preliminary results show complete reduction of Cr^{+6} to below detection (less than 0.01 mg/L) limits, greater than 75 percent reduction in initial TCE concentrations, and reduction of VC concentrations to less than 1 µg/L. These results are very promising, especially for the chlorinated organics, because the experiment was primarily designed to optimized Cr^{+6} remediation, not the chlorinated organics.

2. Documentation

Appleton, Elaine L. "A Nickel-Iron Wall Against Contaminated Groundwater." *Environmental Science and Technology* Vol 30, No. 12. 1996. p 536a.

"Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents." Prepared by Battelle for the Armstrong Laboratory, Environics Directorate, U.S. Air Force, February 1997. Site summaries for 14 sites in an appendix.

Vidic, Dr. Radisav D. and Dr. Frederick G. Pohland. "Treatment Walls." University of Pittsburgh, Department of Civil and Environmental Engineering. Ground-Water Remediation Technologies Analysis Center, October 1996, Publication Document Number: TE-96-01. Also available at the World Wide Web site.

"*In Situ* Remediation Technology Status Report: Treatment Walls." EPA542-K-94-004, April 1995. The sites listed above are all from this report except for Site 1.

O'Hannesin, S.F. *A Field Demonstration of a Permeable Reaction Wall for the In Situ Abiotic Degradation of Halogenated Aliphatic Organic Compounds*. Master's Thesis, University of Waterloo, Waterloo, Ontario, Canada. 1993.

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Devlin, J.F. and Barker, J.F. "A Semipassive Nutrient Injection Scheme for Enhanced *In Situ* Bioremediation." *Ground Water*, 32 (3), 1994, p 374.

O'Hannesin, S.F. and Gillham, R.W. "*In Situ* Degradation of Halogenated Organics by Permeable Reaction Wall." *Ground Water Currents*, March 1993, EPA/542/N-93/003.

Gillham, R.W. and O'Hannesin, S.F. "Metal Catalyzed Abiotic Degradation of Halogenated Organic Compounds." *Ground Water*, 29 (5), 1991, p. 752.

Puls, R.W.; Powell, R.M.; and Paul, C.J. "*In Situ* Remediation of Ground Water Contaminated with Chromate and Chlorinated Solvents Using Zero-Valent Iron: A Field Study." *Proceedings of the 209th American Chemical Society National Meeting,* Anaheim, California, 2 to 7 April 1995. 35 (1), p 788-791.

3. World Wide Web Site(s)

- http://www.gwrtac.org/html/tech_eval.html#TWALLS
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center.
- http://cayuga.nfesc.navy.mil/cc/projects/permwall.htm (Special to Site 1, Moffett Field, California.)
- http://www.uwin.siv.edu (Database of international water research compiled by the Water Resources Scientific Information Center of the US Geological Survey. The research covers from 1967 to October 1993, with more than 265,000 abstracts and citations that are key-word searchable.)

C. DUAL-PHASE RECOVERY TO TREAT CHLORINATED SOLVENTS IN GROUND WATER OR BELOW GROUND WATER TABLE

Whenever a technology treats two media, such as air and water or soil and water, the system is considered to be dual phase. It is also sometimes called multi-phase. If the project requires treatment of contaminated water, the first step is to pump water from the subsurface and then extract the vapors, possibly with activated carbon absorption.

Sometimes, the water is treated by UV oxidation or activated carbon absorption. Dual-phase recovery technology had its first patents issued in the 1800s.

Removing the source of a chlorinated solvent spill is virtually impossible, mainly because of the density of chlorinated solvents, which causes them to sink well into or below the ground water. Current state of the art technology cannot detect the extent of a DNAPL spill except at prohibitive expense, if at all. Therefore, remediation of DNAPL spills is usually plume cleanup. One site at Hill Air Force Base luckily happened to be located near the pool of DNAPL source. It was removed by pumping, but this is a rare occurrence.

1. Example Site(s)

Site 1. Rocky Mountain Arsenal Superfund Site (Motor Pool Area — Operable Unit 18), Commerce City, Colorado. Soil vapor extraction was performed at the Rocky Mountain Arsenal (RMA) Superfund site, motor pool area, in Commerce City, Colorado, to remove halogenated VOCs, primarily TCE, from the vadose zone. The motor pool area at RMA, referred to as Operable Unit 18, had been used for cleaning and servicing equipment, vehicles, and railroad cars and for storing diesel, gasoline, and oil products in aboveground and underground storage tanks. VOCs, detected in the motor pool area's soil and ground water have been attributed to releases of chlorinated solvents used during cleaning operations; these solvents were discharged through floor drains and pipes into unlined ditches at the site.

This system was initially considered to be a pilot study because it was expected to provide performance data on SVE at this site that could be used to expand the system to a full-scale operation. This application, operated from July to December 1991, demonstrated that a pilot scale SVE system removed sufficient vapor contaminants from the vadose zone, and that expansion of the system beyond pilot scale was not necessary. The SVE system used within the motor pool area consisted of one shallow vapor extraction well, screened between 43 and 58 feet bgs, and 1 deep vapor extraction well, screened between 43 and 58 feet bgs. Unconsolidated deposits beneath the Motor Pool Area consist of discontinuous sand and gravel lenses, 1-3 feet of low-permeability clay sand to clay layer 32-38 feet bgs. The moisture content was 4.7-30.9 percent; and permeability was 167 darcys at 38 feet bgs and 2,860 darcys at 55 feet bgs. Four clusters of vapor-monitoring wells were installed to aid in the assessment of the performance of the SVE system. There was also a liquid/vapor separator tank, a sediment filter, and a regenerative blower. The exhaust air from the blower was treated using 2 granular activated-carbon systems in series. TCE levels in soil vapors collected from the vapor monitoring wells were reduced to non-detect or to levels of less than 1 ppm from initial vapor-monitoring well samples as high as 65 ppm after 5 months of operation. The rate of TCE extraction decreased from 35 pounds per month to less than 10 pounds per month. Approximately 70 pounds of TCE were recovered during this cleanup action.

The operating parameters collected during the system's 1991 use indicated that a clay lense located beneath the site affected the SVE system's performance by limiting both the shallow and deep vapor extraction wells' vertical zones of influence. The contract award cost for procuring, installing, and operating the SVE pilot system, as well as preparing a pilot study report, was $182,800, broken down as follows: costs attributed to treatment activities – $75,600 (installation and operation); costs attributed to before-treatment activities – $88,490 (including mobilization and preparatory work, monitoring, and laboratory analytical), and costs attributed to after-treatment activities – $19,650 (including pilot study). This cost was approximately 15 percent less than the preliminary cost estimate provided by the remediation contractor for the project. Factors contributing to the lower cost included lower construction and system operating costs. The treated soil was approximately 34,000 yd^3 (70 foot radius by 60 feet deep). Cost per cubic yard was $6.

Site 2. Fairchild Semiconductor Corporation Superfund Site, San Jose, California. The Fairchild Semiconductor Corporation Superfund site (Fairchild) is a former semiconductor manufacturing facility which operated from 1977 to 1983. In late 1981, an underground storage tank used to store organic solvent was determined to be leaking. An estimated 60,000 gallons of solvents were released to the soil and ground water. The primary contaminants of concern in the soil were 1,1,1-trichloroethane (TCA), 1,1- dichloroethene (DCE), tetrachloroethene (PCE), xylene, acetone, Freon-113, and isopropyl alcohol (IPA).

Reported maximum concentrations of total solvents in the soil were as high as 4,500 mg/kg, with maximum concentrations of TCA and xylenes in soil of 3,530 mg/kg and 941 mg/kg, respectively. As part of a multi-site cooperative agreement between EPA, the State of California, and Fairchild, Fairchild conducted site remediation activities at the San Jose site, including installing a SVE system. The California Regional Water Quality Control Board established a soil cleanup goal for this remediation of a total chemical rate of less than 10 pounds/day, along with specific performance goals for individual wells.

The SVE system, which consisted of 39 extraction wells and 2 vacuum pumps (capacity of 4,500 cubic feet/min at 20 inches of Hg), operated from January 1989 to April 1990. The vapor treatment system consisted of a dehumidification unit and vapor phase granular activated carbon. The soil itself consisted of sands, silts, and clays; air permeability 0.12-0.83 cm/sec; transmissivity - 69,000 to 810,000 gpd/ft. The most rapid reductions in contaminant concentrations occurred during the first 2 months of operation. The SVE system was operated until total chemical removal rate was less than 10 pounds/day and the chemical removal rate from individual wells decreased to 10 percent or less of the initial removal rate or until the chemical removal rate declined at a rate of less than 1 percent per day for 10 consecutive days. This occurred after 8 months of operation. After 16 months of operation, the system achieved a chemical removal rate of less than 4 pounds/day, at which time the system was shut off.

The total costs for the SVE treatment system at Fairchild were approximately \$3,900,000. Actual capital costs were \$2,100,000 (including installation of wells and vapor extraction system, and engineering services), while total operation and maintenance costs for 16 months were \$1,800,000 (including water quality sampling and analysis, water level monitoring, equipment maintenance, engineering services, and carbon regeneration). The actual costs were about 7 percent less than the projected costs because the time required for the cleanup was less than originally estimated. This treatment application was part of a multi-faceted cleanup program, which included the installation of a slurry wall and removal of water from the aquifer, which accelerated contaminant removal from the soil.

The estimated volume of treated soil was 42,000 yd^3, which indicates an approximate treatment cost per cubic yard of \$93.

Site 3. <u>Verona Well Field Superfund Site, Thomas Solvent, Raymond Road (OU-1), Battle Creek, Michigan</u>. The Verona Well Field Superfund site is the location of the former primary well field that supplied potable water for the city of Battle Creek, Michigan. In early 1984, 27 of the 30 wells were determined to be contaminated.

The Thomas Solvent Raymond Road area was determined to be a source of contamination. Soil in this area contained chlorinated solvents, primarily PCE and 1,1,1-trichloroethane, as well as acetone and toluene. There were LNAPL in the ground water. The volume of organic compounds was estimated to be 3,900 pounds in ground water and 1,700 pounds in soil. Based on a capture zone of 36,000 ft^2 and depth of 20 feet, the amount of soil treated was 26,700 yd^3. This soil had a clay content of less than 5 percent, a moisture content of 5 percent, and the permeability was 10[Sup -3] cm/sec.

Soil and ground water cleanup standards for 19 constituents were established. These standards in soil ranged from 0.014 mg/kg for carbon tetrachloride, 1,1-dichloroethane, 1,1-dichloroethene, and tetrachloroethene to 16 mg/kg for toluene. The standards in ground water ranged from 0.001 mg/L for vinyl chloride, 1,1,2-trichloroethane, tetrachloroethene, and benzene to 0.8 mg/kg for toluene. SVE achieved the cleanup standards for all VOCs, and a total of 45,000 pounds of VOCs were removed.

Full-scale operation of an SVE to treat the soil began in March 1988 and ran intermittently until May 1992. This system was EPA's first application of SVE at a Superfund site. Over the course of the SVE operation, both carbon adsorption and catalytic oxidation were used to treat the extracted vapors prior to atmospheric discharge. Dual vacuum extraction and nitrogen sparging were implemented to enhance recovery rates during the latter stages of the ground water remediation effort. A total of 45,000 pounds of VOCs were removed from the subsurface soil and 10,000 pounds from the ground water during the remediation. Cleanup verification sampling of the soil occurred in June 1992 and the analytical results indicated that SVE reduced the constituent concentrations in the soil at this operable unit.

The cost attributed to treatment activities for this SVE application was approximately $1,600,000 (including solids preparation and handling, mobilization/setup, startup/testing/permits, operation, cost of ownership, and demobilization).

The cost attributed to before-treatment activities were approximately $480,000 (including monitoring, sampling, testing and analysis, along with drums, tanks, structures, and miscellaneous demolition and removal). Cost attributed to after-treatment activities was approximately $5,000 (including well abandonment and disposal of drums).

Site 4. Savannah River Site, Aiken, South Carolina. The U.S. DOE Office of Science and Technology (Subsurface Contaminant Focus Area) recently completed a full-scale demonstration of the use of hydrogen peroxide and iron to convert chlorinated solvents and hydrocarbons to nontoxic end products such as carbon dioxide, chloride ion, and water (Fenton's reaction). Through a cooperative venture that included Westinghouse Savannah River Company and Geo-Cleanse International, Incorporated, DOE achieved a destruction efficiency of 94 percent on a 64,000- yd^3 site containing nearly 600 pounds of DNAPL at the Savannah River Site in Aiken, South Carolina.

A cost evaluation concluded that "hot spot" treatment yields the most cost-effective use of this technology for treating DNAPL. Researchers determined that a DNAPL pool at a depth of 155 feet should contain 11,000 pounds or more of DNAPL for this technology to be considered more cost efficient than a conventional pump-and-treat system, a baseline technology for DNAPL-contaminated ground water. If time is a key factor in the decision-making process, however, this technology can remove contamination faster than pump-and-treat methods (weeks versus years).

The demonstration deployed this technology to destroy DNAPL below the water table. The DNAPL, consisting of solvents such as TCE and PCE, was located approximately 140 feet below ground surface in unconsolidated sediments. Treatment involved incremental injection of a total 4,200 gallons of hydrogen peroxide, along with ferrous sulfate. Increased chloride concentrations in ground water and decreased concentrations of TCE and PCE in both ground water and soil served as indicators of DNAPL destruction. Chloride ion concentrations increased from an initial concentration of 4 ppm to a final concentration of 25 ppm. Post-treatment analysis indicated that PCE and TCE concentrations in ground water fell to nearly zero from 120 mg/l and 20 mg/l, respectively. Pre- and post-tests showed that the total estimated DNAPL quantity dropped from 593 pounds to 36 pounds. Under its DNAPL remediation program, DOE's Subsurface Contaminant Focus Area soon will complete demonstrations of three additional forms of treatment. At the Portsmouth Gaseous Diffusion Plant, field tests are evaluating the use of potassium permanganate to degrade pure-phase TCE in saturated aquifer sediments using recirculation as a reagent delivery technique. Additionally, researchers are studying the use of stacked horizontal fractures propped with a new permanganate particle grout to form a permeable reactive barrier at the Portsmouth Plant. At a commercial wood treatment facility in California, DOE also is testing the use of hydrous pyrolysis/oxidation for use on DNAPLs and dissolved organic components.

2. Documentation

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Hinchee, Robert E., Anderea Leeson, and Lewis Semprini. *Bioremediation of Chlorinated Solvents*. Battelle Press, Columbus, Ohio, 1995. Fourth book in a series of ten books from the Third International *In Situ* and On-Site Bioreclamation Symposia, San Diego, California. Copies from Battelle Press, 505 King Avenue, Columbus, Ohio 43201 USA. 1-800-451-3543.

"Remediation Technologies Screening Matrix and Reference Guide," DoD Environmental Technology Transfer Committee, Second Edition, October 1994

Hinchee, Robert E., Ronald E. Hoeppel, and Daniel B. Anderson. *Bioremediation of Recalcitrant Organics.* Battelle Press, Columbus, Ohio. Seventh book in a series of ten books from the Third International *In Situ* and On-Site Bioreclamation Symposium, San Diego, California. Copies from Battelle Press, 505 King Avenue, Columbus, Ohio 43201 USA. 1-800-451-3543.

3. World Wide Web Site(s)

- http://www.frtr.gov
- http://www.frtr.gov/costper.html

D. AIR STRIPPING OF CHLORINATED SOLVENTS DISSOLVED IN GROUND WATER

The air stripping treatment process relies on the transfer of volatile organic compounds from water into air. Contaminated water is sprayed into the air from sprinklers or is pumped to the top of an air stripping tower and flows down through the packing material in a thin film. An air stream is forced upward through the tower. Within the tower, the contaminants are transferred from the thin film of contaminated water into the flowing air stream. Treated water exits from the bottom of the tower, but air containing the volatilized contaminants is exhausted through the top of the tower. Emissions may or may not be treated, depending on regulatory requirements.

In the first site listed below, a sprinkler irrigation system with small aperture nozzles and impact pads to produce thin films of water was used to assess efficient volatilization of organic chemicals in pumped ground water. Essentially, the air stripping tower became the sprinkler head and the upflow of air became ambient air.

Researchers vary in their opinions as to how much the ultraviolet light in sunlight may destroy these contaminants. Unless extensive monitoring is done, the assumption is that the organics are transferred from the water to the air.

1. Example Site(s)

Site 1. Furrow-irrigated corn field, 20 ha (50 acres) in Hastings, Nebraska. A site in Nebraska was used to pump ground water contaminated with ethylene dibromide (EDB), 1,1,2-trichloroethylene (TCE), 1,1,1-trichloroethane, and carbon tetrachloride (CT). The ground water is 36.5 meters below the land surface and contains trace levels of TCE, TCA, PCE, CT, and EDB. Also present are ultratrace quantities of solvent degradates and CT. A grain elevator 820 meters upgradient is the source of the fungicide EDB, and the solvents are allegedly from an abandoned landfill and industrial sites located southwest of the grain elevator.

In field tests involving the analysis of more than 250 samples collected from beneath a spray irrigation system, removal rate of these contaminants in samplers placed 0.5 meters above the ground exceeded 95 percent in almost all cases and approached 100 percent for the more volatile chemicals. The removal efficiencies of conventionally designed sprinkler irrigation systems were enhanced by using small aperture nozzles with impact pads designed to produce thin films of water. Droplet sizes were one factor found to control volatility. Higher air temperatures appear to slightly increase volatility, as did longer droplet trajectories.

Irrigation, a farming practice, is a possible means to not only cheaply and effectively remove volatile organic compounds from contaminated ground water, but also to use water beneficially and eliminate the costly disposal of both the remediated water and the contaminants.

For sprinkler irrigation to gain acceptance as a primary method for remediating VOC contaminated ground water, three items are essential. The irrigation well(s) must be able to capture the contaminated plume, the risk to the public and environment during the water-to-air exchange must be minimized, and the VOCs must be efficiently removed from the water during irrigation.[1] A fourth criteria may be indirect: that the sun must be shining, or at least ultraviolet (UV) light is available from the sun (that is, a thin cloud cover may be acceptable).

The atmospheric releases of the VOCs can be estimated from the mass of each individual chemical pumped annually. For example, if the concentration of TCE is 750 µg/L and the pumping rate is 272 m^3/hr (1,200 gal/min), and it is assumed that 100 percent of the TCE is lost to the atmosphere, 5 kg of TCE per day (11 pounds/day) would be volatilized. At this removal rate, the Nebraska Department of Environmental Quality Title 129 Rules and Regulations for air emissions would not be exceeded; these rules

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[1] Some researchers hesitate or object to the idea of using chlorinated solvent contaminated water on crops or crop land. This example is given because it worked surprisingly well to bring the contaminant level in the water (measured at the sprinkler head) to non-detectable level (measured 2 meters below the sprinkler head) for the more volatile compounds, and 95 percent for the less volatile compounds. The question of how much risk is associated with this method remains open.

allow that if more than 34 kg/day of any toxic air pollutant is emitted, then the procedure requires a permit.

Once volatilized from the sprinkler system, the chemicals are rapidly dispersed in the atmosphere, and at these emission levels, health risk models show the lifetime risk of cancer would not exceed the one-millionth threshold.

The data indicated that most of the volatility occurred in the 2-meter space between the nozzle and the highest sampler. High capacity wells and sprinkler systems can efficiently remediate VOC-contaminated water and comply with the criteria necessary for the containment and mass removal of the contaminants. Irrigation systems save money in treatment as well as using the water for irrigating farmlands.

No cost data were available.

Site 2. Orange County Water District site, Irvine, California. The extent of TCE removal was investigated through both drip and sprinkler irrigation systems. Volatility losses averaged 42 percent in the drip irrigation system with source TCE concentrations ranging from 17.3 to 18.3 µg/L. Volatility efficiency was much greater with sprinkler irrigation, which removed an average of 97 percent of the 24 µg/L TCE in the source water. The removal efficiency increased with smaller droplet size, higher trajectories, and greater fall distances.

No cost data were available.

Site 3. Fort Lewis Logistics Center, Fort Lewis, Washington. The Logistics Center site has been in use at Fort Lewis since 1942. It was an ordnance facility until 1963, when it was transformed to the post's primary nonaircraft maintenance facility. TCE, a common industrial and commercial solvent and degreaser, was used at the site until the mid-1970s and is the main ground water contaminant at the site. The other significant contaminant is 1,2-dichloroethylene (DCE), also a solvent.

Soil in the East Gate Disposal Yard contains some elevated levels of TCE and DCE. The TCE ground water contamination plume appears to flow southeast to northwest under the Logistics Center and off-post toward American Lake. All surface water that could be affected by contamination was sampled. Lynn Lake and Murray Creek, both on Fort Lewis, showed low levels of TCE and DCE contamination. The human health risk assessment indicated that the shallow ground water presented an unacceptable risk to human health and required a cleanup action. The environmental risk assessment indicated no adverse toxic effect from TCE or DCE to aquatic organisms in surface water and sediments of water bodies on- and off-post, which includes American Lake, Lynn Lake, Lake Mondress, and Murray Creek.

Of the three methods for cleanup considered, extraction and air stripping of ground water along the interstate highway and near source areas was chosen for the following reasons: it will reduce the spread of contamination, treat extracted ground water to one-tenth of the drinking water standards before returning it to the aquifer, reduce the contaminant levels found in the found water to drinking water standards at the boundary of the sources of releases at or near the Logistics Center, reduce the time required for cleanup. In addition, federal and state laws require cleanup of ground water that is a potential source of drinking water.

The system consists of a line of wells parallel to the interstate highway on Fort Lewis property. The ground water is pumped to the top of a tower. As the water flows down in the tower, air is forced upward to evaporate the contaminants. After sampling, the treated ground water is pumped to a recharge system and is returned to the ground water.

This preferred alternative, the extraction and air stripping treatment of contaminated ground water, has been constructed and in operation since August 31, 1995. Cleanup of the aquifer to drinking water standards is expected to require approximately 30 - 40 years.

Site 4. Treatment Facility D, Lawrence Livermore National Laboratory, California. Air stripping was the treatment method chosen for volatile organic compounds at this site, and ion exchange was chosen to treat chromium in the ground water for the Lawrence Livermore National Laboratory's (LLNL's) Treatment Facility D (TFD). TFD was activated in September 1994. An advanced interlock-control system eliminates spills caused by equipment failure and minimizes releases of contaminants to the environment, exposure of workers to contaminants, and DOE occurrence reporting.

Air stripping of the hard ground water removes VOCs and carbon dioxide (CO_2). Removal of CO_2 causes a rise in pH to near the discharge limit and results in enhanced calcium carbonate scaling. Scaling was severe enough to freeze the discharge pump and threatened to damage the ion-exchange system. This problem was mitigated by the addition of CO_2 and polyphosphate.

The ion-exchange system effectively removed the hexavalent chromium. The resin in the system was chosen for maximum efficiency, and the use of sodium chloride was selected as the least hazardous regeneration agent. The dual-resin column allows the ground water to be routed to either column first. Careful management of the ion-exchange system minimizes the amount of secondary hazardous and nonhazardous waste generated.

No cost data were available.

Site 5. A/M Area, U.S. Department of Energy Savannah River Site, Aiken, South Carolina. At this site, efforts were made to remediate soil and ground water contaminated with VOCs using *in situ* air stripping with a horizontal well. The remediation activities were part of a field demonstration program involving other innovative technologies to provide information for long-term remediation efforts.

The A and M areas at Savannah River have been the site of administrative buildings and manufacturing operations, respectively. The Savannah River Laboratory is also located within the A area. Specific manufacturing operations within the M area include aluminum forming and metal finishing. The M area operations resulted in the release of process wastewater containing an estimated 3.5 million pounds of solvents. From 1958 to 1985, 2.1 million pounds were sent to an unlined settling basin which is the main feature of the M-Area Hazardous Waste Management Facility (HWMF). The remaining 1.3 million pounds were discharged to Tim's Branch, a nearby stream, primarily during the years 1954 - 1982.

Discovery of contamination beneath the settling basin in 1981 initiated a site assessment effort eventually involving approximately 250 monitoring wells over a broad area. A pilot ground water remediation system began operation in February 1983. Full-scale ground water treatment began in September 1985. These systems have removed over 300,000 pounds of solvents from the ground water to date.

High levels of residual solvent are found in the soil and ground water near the original discharge locations. Technologies to add to the pump and treat effort (for example vacuum extraction) *in situ* air stripping, and bioremediation have been tested and are being added to the permitted corrective action.

The analysis focuses on the use of horizontal wells and *in situ* air stripping to remove solvents beneath the former process sewer line connecting the manufacturing area to the HWMF. Performance data are through September 1993.

Contaminants of greatest concern are 1,1,2-trichloroethylene (TCE), tetrachloroethylene (PCE), and 1,1,1-trichloroethane (TCA). Approximately 71 percent of the total mass of VOCs released to both the settling basin and Tim's Branch was PCE, 28 percent was TCE, and 1 percent was TCA.

The estimated amount of dissolved organic solvents in ground water in concentrations greater than 10 ppb is between 260,000 and 450,000 pounds and is estimated to be 75 percent TCE. This estimate does not include contaminants sorbed to solids in the saturated zone or in the vadose zone. The area of VOC-contaminated ground water has an approximate thickness of 150 feet, covers about 1,200 acres, and contains contaminant concentrations as high as 223 μg/L.

DNAPLs, found in 1991, present challenges for long term remediation efforts. Vadose zone contamination is mainly limited to a linear zone associated with the leaking process sewer line, solvent storage-tank area, settling basin, and the A-014 outfall at Tim's Branch.

The A/M area is approximately 1 mile inward from the northeast boundary of the 300 mi^2 Savannah River Site. Adjacent to the site boundary are rural and farming communities. The horizontal well site is located in the southwestern corner of the M area, and it encompasses the M area settling basin, the abandoned process sewer leading to the basin, and the outfall A-104. The Savannah River Site includes a complex hydrogeology arising from variations in the multilayer aquifer system and discontinuous sand and clay layers.

Sediments are composed of sand, clay and gravel. Clay layers are relatively thin and discontinuous, with the exception of the clay layers at 160 foot depth and a thicker zone of interbedded clay and sand found at 90 foot depth. Water table is approximately 135 feet below grade.

A moderate downward gradient appears to exist beneath the M area. Vertical flow rates have been estimated to be 2 - 8 feet/year. Radial flow outward from a groundwater plateau surrounding most at the A/M area exists. Flow is approximately 15 to 100 feet/year.

A cost study was conducted that compared *in situ* air stripping with horizontal wells against the conventional cleanup technologies of combined pump and treat and soil extraction. A comparison of costs indicated that *in situ* air stripping can remove VOCs for approximately 60 percent of the cost of conventional methods. Total site costs were: well installation, \$170,085; annual labor costs \$62,620; total equipment costs, \$253,525; total annual consumable goods, \$157,761.

A study of cost effectiveness of *in situ* air stripping illustrated that equipment costs drop to a smaller percentage of total system costs when capital costs are annualized over 10 years. Based on annual extraction rate of 33,612 pounds of VOCs and a total VOC quantity of 16,000 pounds, total costs/pound of VOC removed was $15.59, divided at Savannah River as follows: for equipment, $1.51; for the site preparation, $0.31; labor, $3.91; and consumables, $9.86.

For the same cost study, carbon adsorption was included for off-gas treatment. However, a more highly engineered off-gas treatment system can be expected to reduce the annual costs substantially.

Costs for installation of horizontal wells is much higher than costs for installation of vertical wells (approximately 10 times greater using the petroleum industry, 35-foot-radius top-drive technique; approximately $360 per foot). Some horizontal drilling techniques can be expected to be far less expensive, particularly at shallower depths. The 40 - 50 foot depth indicated a critical distinction between drilling technologies for horizontal wells. Shallower than 40 - 50 feet, the utility industry compaction or river-crossing techniques may be used with a cost as low as $50 per foot. For depths greater than 40 - 50 feet, the petroleum industry technology and its hybrid petroleum/utility river-crossing technology can be used. Costs for the deeper horizontal wells range from $360 per foot up to $700 per foot. As drilling companies gain experience with horizontal wells, the costs are expected to decrease.

Despite the high drilling costs, carbon adsorption contributes the largest part to the total remedial system cost if it is used as the off-gas treatment.

2. Documentation

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Orange County Water District. *Results of an investigation of TCE removal during sprinkler and drip irrigation in the Irvine area.* Irvine, California: Orange County Water District: 1989.

June 1996 Fort Lewis Newsletter, “Investigation at Fort Lewis Logistics Center,” published by the Fort Lewis Public Affairs Office.

3. World Wide Web Site(s)

- http://www.epa.gov/rgytgrnj/programs/spfd/ms_hastings.html (Specific to the Hastings site)
- http://www.nws.usace.army.mil/geotech/logctr/logctr.htm (Specific to the Fort Lewis Logistics Center site)
- http://www.em.doe.gov/tie/spr9505.html (Specific to the Treatment Facility D, Lawrence Livermore National Laboratory, Berkeley, CA)
- http://www.srs.gov (General site for the Savannah River Study)
- http://em-50.em.doe.gov/BEST/techs/sites/site0031.html (also on Savannah River)

VII. CHLORINATED SOLVENTS IN SOIL

A. SVE AND VAPOR DESTRUCTION TO TREAT CHLORINATED SOLVENTS IN SUBSURFACE SOIL

The most promising method for removing chlorinated solvents during the late 1980s and early 1990s was soil vapor extraction (SVE). However, there have been few examples of restoration to normal cleanup standards with SVE alone. The goal at most sites is to remove contaminant mass to the point where water infiltrating through the vadose zone will not contain contaminant concentrations above U.S. drinking water standards. This is best achieved in homogeneous sand or gravel where rapid air flow can circulate throughout the contaminated zone. However, even in such an ideal vadose zone, SVE is not effective in the capillary fringe, nor will it be in fine-grained layers or lenses in mixed deposits, which, along with high water deposits, will limit air flow. In non-ideal vadose zones, heat and steam are being investigated as means to achieve enhancements of SVE *in situ*.

Once brought above ground, vapors have to be destroyed or contained, and two systems that work well for vapor destruction are from Thermatrix, Incorporated, and the Purus-PADRE® system. The Thermatrix Flameless Thermal Oxider,® used by the Air Force at Plattsburg AFB, is actually a ceramic matrix with mini-flames, which attains total destruction of chlorines without release of nitrous oxides. The other method, Purus-PADRE, has two designer resin beds: one absorbing, one desorbing. The resins can be regenerated on-site producing free product in the process. Thermatrix recently acquired the Purus-PADRE technology.

1. Example Site(s)

Site 1. Sacramento Army Depot Superfund Site, Tank 2 (Operable Unit #3). The Sacramento Army Depot (SAAD) located in Sacramento, California, is an Army support facility. Past and present operations conducted at the site include equipment maintenance and repair, metal plating, parts manufacturing, and painting. During investigations of the facility in 1981, soil contamination was identified in the area of an underground storage tank and designated as Tank 2 Operable Unit. Tank 2 had been used to store solvents, and the primary contaminants of concern included ethylbenzene (0.006 to 2,100 mg/kg), 2-butanone (0.011 to 150 mg/kg), tetrachloroethene (0.006 to 390 mg/kg), and xylenes (0.005 to 11,000 mg/kg). A Record of Decision (ROD), signed in December 1991, specified soil cleanup levels for the 4 primary constituents of concern and allowed 6 months for achieving these levels. SVE was selected for remediating the contaminated soil because it was determined to be the most cost-effective alternative.

The SVE system consisted of 8 vacuum extraction wells installed to depths of 15-28 feet bgs, a positive displacement blower, a vapor-liquid separator, and primary and secondary carbon adsorption units. In operation from 6 August 1992 to 25 January 1993, the system achieved the specified soil cleanup levels 1 month ahead of the specified date. In addition, the SVE system removed approximately 2,300 pounds of VOCs.

The contaminated soil was approximately 650 yd^3 (25 feet by 35 feet by 20 feet deep) of silt with clay content of less than 30 percent, a moisture content of 25.6-26.5 percent, air permeability of 1.7 x 10[Sup -7] to 6.2 x 10[Sup -5] cm/sec; porosity of 44.3-45.8 percent, and total organic carbon of 0.011-0.44 percent.

During system operation, Freon 113 was unexpectedly encountered. Extraction of Freon 113 significantly increased the quantity of carbon required to treat the extracted vapors. The total treatment cost for this application was $556,000. This cost was greater than originally estimated primarily as a result of the additional carbon required to deal with the presence of Freon 113. The total cost attributed to treatment of non-Freon contaminants (adjusted assuming operation costs equivalent for Freon and non-Freon contaminants) was $290,000.

In planning the project, the Army used a computer model treatability study. The study predicted SVE using 4 extraction wells could reduce concentrations of volatile organics to non-detectable levels within 6 months. This was achieved, and cleanup goals [2-butanone (1.2 ppm); ethylbenzene (6 ppm); tetrachloroethene (0.2 ppm); and total xylenes (23 ppm)] were met or exceeded, that is, the contaminants were at non-detectable levels.

Site 2. Verona Well Field Superfund Site, Thomas Solvent, Raymond Road (OU-1), Battle Creek, Michigan. The Verona Well Field Superfund site is the location of the former primary well field that supplied potable water for the city of Battle Creek, Michigan. In early 1984, 27 of the 30 wells were determined to be contaminated.

Soil in the Thomas Solvent Raymond Road area was contaminated with chlorinated solvents, primarily tetrachloroethene (PCE) and 1,1,1-trichloroethane, as well as acetone and toluene. There were LNAPLs in the ground water. The volume of organic compounds was estimated to be 3,900 pounds in ground water and 1,700 pounds in soil. Based on a capture zone of 36,000 square feet and depth of 20 ft, the amount of soil treated was 26,700 cubic yards. This soil had a clay content < 5 percent and a moisture content of 5 percent.

Soil and ground water cleanup standards for 19 constituents at the site were established. These standards in soil ranged from 0.014 mg/kg for carbon tetrachloride, 1,1- dichloroethane, 1,1-dichloroethene, and tetrachloroethene to 16 mg/kg for toluene. The standards in ground water ranged from 0.001 mg/L for vinyl chloride, 1,1,2-trichloroethane, tetrachloroethene, and benzene to 0.8 mg/kg for toluene. SVE achieved the cleanup standards for all VOCs, removing a total of 45,000 pounds of VOCs.

Full-scale operation of SVE to treat the soil began in March 1988 and ran intermittently until May 1992. This was EPA's first application of SVE at a Superfund site. Over the course of the operation, both carbon adsorption and catalytic oxidation treated the extracted vapors prior to atmospheric discharge. Dual vacuum extraction and nitrogen sparging were implemented to enhance recovery rates during the latter stages of the ground water remediation effort. In addition to the 45,000 pounds of VOCs removed from the subsurface soil, an additional 10,000 pounds came from the ground water during the remediation.

The cost attributed to treatment activities for this SVE application was approximately $1,600,000 (including solids preparation and handling, mobilization/setup, startup/testing/permits, operation, cost of ownership, and demobilization).

The cost attributed to before-treatment activities were approximately $480,000 (including monitoring, sampling, testing and analysis, along with drums, tanks, structures, and miscellaneous demolition and removal). Cost attributed to after-treatment activities was approximately $5,000 (including well abandonment and disposal of drums).

Site 3. <u>Luke Air Force Base, Arizona. North Fire Training Area.</u> Routine fire training exercises at Luke Air Force Base in Arizona between 1963 and 1990 used petroleum, oil, lubricant wastes, and JP-4 fuel. Fire training pits number 3 and 4 were used since 1973. During site investigations conducted between 1981 and 1989, soils at these pits were determined to be contaminated with total petroleum hydrocarbons (151 - 1,380 mg/kg TPH), methyl ethyl ketone (MEK, concentration not given), benzene (0.2 - 16 mg/kg), toluene (10 - 183 mg/kg), ethylbenzene (21 - 84 mg/kg), and xylenes (69 - 336 mg/kg). One soil vapor-extraction well was installed in each fire pit with 35-foot screens to depths of up to 57 feet. Cleanup goals were established for TPH and BTEX in soil based on Arizona Action Levels (AALs): TPH at 100 mg/kg and BTEX at 412 mg/kg.

The soil consisted of very permeable silty sands, clean well-graded to poorly graded sands, and permeable to low permeability inorganic silts. The moisture content was 10 percent, with permeability of top soils ranging from 1 x 10[Sup -4] to 3 x 10[Sup-3] cm/sec, and porosity ranging from 36 to 46 percent.

A full-scale cleanup using SVE in the 2 pits was conducted from October 1991 until December 1992. A thermal oxidizer destroyed organic vapors extracted from the soil. The full-scale system, which used the thermal oxidizer, removed 12,000 pounds of contaminants in 30 weeks of operation. Removal rate remained at 40 pounds/day after 30 weeks of operation. TPH and BTEX levels were below the AALs after 5 months of operation, with TPH and benzene reported as not detected in March 1992. Soil gas concentration reductions achieved in 6 months for 8 constituents ranged from 72 percent to 96 percent (benzene). Results of sampling in November 1992 showed ethylbenzene, toluene, and xylenes as not detected. The system was not working about 1 percent of the time during this period. After a temporary shutdown period, an attempt to restart the system caused a malfunction in the thermal oxidizer with destruction of the burner. As of December 1992, future activities at the site were pending.

The total cost of this treatment application was $507,185. Capital costs were $297,017 (including site preparation, site work, startup, engineering, pipes, buildings, permitting, and regulatory). Annual operating costs were $210,168 (including labor, laboratory charges, monitoring, fuel, electricity, maintenance, and disposal of residuals).

It was noted that the site investigation underestimated the amount of contamination at the site. A pilot scale study was conducted at Luke prior to implementing the full scale system. The pilot scale system used vapor-phase granular activated carbon to treat extracted soil gas. Because of unexpectedly high concentrations of volatile organic constituents, the carbon supply was exhausted after 2 days of operation, and the study ended.

In discussing remediation of sites contaminated with JP-4 jet fuel, the report includes a discussion of the relative benefits of using SVE and bioventing techniques.

Site 4. Naval Air Station, Site 11, Industrial Waste Treatment Plant, North Island, San Diego, California. A pilot scale study on an SVE at the contaminated site removed VOCs from the ground water and soil. The system combined air sparging, SVE, and catalytic oxidation to destroy the contaminants. Two air injection and 6 extraction wells were installed. The wells were connected by manifold piping to an air compressor and blower to provide pressure to sparging and vacuum for extraction. The air injection wells, which were screened in the upper portion of the saturated zone, were used to remediate water by injecting air under pressure to sparge the ground water. VOCs in rising bubbles reached the vadose zone, where the contaminants were removed by vapor-extraction wells installed in the unsaturated zone. Extraction wells were connected to a liquid gas separator to remove fluids. The air effluent was treated using a catalytic oxidation unit, which consisted of a catalyst especially designed to oxidize VOCs into carbon dioxide and water vapor. This catalytic oxidation unit from Terra Vac, Incorporated, demonstrated a destruction efficiency of 99 percent. Up to 250 pounds (33 gallons) per day of VOCs were effectively removed from the vadose zone and destroyed in the catalytic oxidation unit.

Results indicated that the soils and contaminant mass distribution at this site were amenable to remediation using this technology.

No cost data were available.

2. Documentation

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Soil Vapor Extraction and Bioventing. U.S. Army Corps of Engineers, Engineering Manual. EM 1110-1-4001, 30 November 1995.

3. World Wide Web Site(s)

- http://www.frtr.gov
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center.
- http://www.frtr.gov/abstracts/00000027.html (Specific to the Sacramento Army Depot Site.)
- http://www.crcpress.com/jour/sss/arts/340030.htm (Article340030: "Estimation of Effective Cleanup Radius for Soil-Vapor Extraction Systems" by David H. Bass)
- http://www.seas.ucla.edu/~yhsun/sves_0.html (Soil Vapor Extraction System Design by William W-G. Yeh)
- http://earth.agu.org/revgeophys/rathfe01/rathfe01.html ("Soil Vapor Extraction and Bioventing: Applications, Limitations, and Future Research Directions" K. Rathfelder, J.R. Lang, and L.M. Abriola, Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor)

4. Models

VENT2D & VENT3D: Models of SVE at sites with finite-difference of multi-compound vapor transport and phase distribution. URL: http://www.hydro.unr.edu/homepages/benson/brochure/v2dbroch.html

B. EXCAVATION, SLURRY-PHASE TREATMENT, AND LANDFILLING TO TREAT CHLORINATED SOLVENTS ON SURFACE SOIL

If chlorinated solvent contaminated soil has been on the surface for some time, it is possible that much of the solvent will be gone, as most chlorinated solvents are volatile or semi-volatile. The UV light from the sun apparently degrades chlorinated solvents once vaporized in sunlight. If enough contamination is left to pose a threat to life and health, the choice is to excavate and landfill. Excavation itself may further volatilize the contaminant, and the remaining material may be placed in a landfill rather than a biopile or landfarm, since bioremediation or natural attenuation of chlorinated solvents generally does not occur in aerobic conditions.

If the choice is made to place the material in a landfill, considerations regarding landfills are listed in Appendix F.

1. Example Site(s)

Site 1. French Limited Superfund Site, Crosby, Texas. The French Limited Superfund site in Crosby, Texas, is a former industrial waste disposal facility where an estimated 70 million gallons of petrochemical wastes were disposed in an unlined lagoon at the site between 1966 and 1971. The primary contaminants at the site included benzo(a)pyrene, vinyl chloride, and benzene, as well as arsenic and PCBs. The site contaminants included volatile organics (up to 400 mg/kg); pentachlorophenol (up to 750 mg/kg); semivolatiles (up to 5,000 mg/kg); metals (up to 5,000 mg/kg); PCBs (up to 616 mg/kg); and arsenic.

In 1983, the parties potentially responsible for the site formed the French Limited Task Group (FLTG) to lead the remediation. The ROD, signed in March 1988, specified bioremediation of the lagoon maximum allowable concentrations in lagoon subsoils and sludges for 5 contaminants: benzo(a)pyrene (9 mg/kg), total PCBs (23 mg/kg), vinyl chloride (43 mg/kg), arsenic (7 mg/kg), and benzene (14 mg/kg); further, the ROD specified an action level for total VOCs of 11 ppm for 5 minutes at the site boundary at any time during treatment. Air emission limits specified in the ROD were not exceeded during treatment.

Slurry-phase bioremediation of the lagoon was performed from January 1992 through November 1993, in 2 treatment cells designed to hold 17 million gallons each. An innovative system (the MixFlo system) was used for aeration to minimize air emissions while supplying oxygen to the biomass, thereby maintaining dissolved oxygen concentration at 2.0 mg/L. This system used pure oxygen and a series of eductors to oxygenate the mixed liquid while minimizing air emissions. During this time, approximately 300,000 tons of contaminated sludge and soil in the lagoon were treated to levels below those specified in the ROD. Soils varied from fine grained silts to coarse sand. The sludges were tar-like and consisted of a mixture of petrochemical sludges, kiln dust, and tars (styrene and oils). Note that tarry sludge was dredged and treated separately from the subsoil in the lagoon.

The specified cleanup criteria were met within 10 months of treatment for Cell E and 11 months of treatment for Cell F, without exceeding the established cost factors. Total costs were approximately $49,000,000 (including project management, pilot studies, technology development, EPA oversight, and backfill of the lagoon) $26,900,000 of total costs were for activities directly attributed to treatment (including solids, liquid, and vapor/gas preparation and handling, pads/foundations/spill control, mobilization/setup, startup/testing/permits, training, and operation). This amounted to $87 per ton. Before-treatment activities cost $16,500,000 including mobilization and preparatory work, monitoring sampling, testing, and analysis, site work, surface water, ground water, and air pollution/gas collection and control, solids and liquids/sediments/sludges collection and containment, and drums/tanks/structures/miscellaneous demolition and removal. After-treatment activities costs were $5,600,000, including decontamination and decommissioning, commercial and non-commercial disposal, site restoration, non-treatment unit demobilization, topsoil, and revegetation.

This application was notable as being the first application of slurry-phase bioremediation at a Superfund site and included approximately $12,000,000 in technology development and pilot-scale testing work. According to FLTG, the costs for future applications of slurry-phase bioremediation depend on site-specific chemical and physical conditions with oxygen and nutrient supply being key factors affecting the cost of bioremediation systems.

Further Site Examples. Sites for excavation and landfilling are not included here. These treatment methods are well known and covered elsewhere. The main considerations include preventing further contamination to other media or receptors during excavation and ensuring that the landfill is well sited, well lined, and well covered. Please see additional comments in Appendix F.

2. Documentation

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3. World Wide Web Site(s)

- http://www.envirolink.org/issues/landfills (Information on environmental impact of landfills)
- http://www.frtr.gov
- http://epdwww.engr.wisc.edu/iscourses/landfill/A180-bib.html (A bibliographic list for a landfill design course at the University of Wisconsin)
- http://www.epa.gov/attic/ - Alternative Treatment Technology Information Center.
- http://www.epa.gov/oerrpage/superfnd/web/oerr/impm/products/cursites/ctxclade.htm (Specific to the French Limited site.)

4. Models

HELP model for Windows - Landfill design tool for an open, partially closed or closed landfill.

C. THERMAL DESORPTION TO TREAT CHLORINATED SOLVENTS ON SURFACE SOIL

Thermal desorption is an innovative treatment technology that treats soils contaminated with hazardous wastes by heating the soils to temperatures of 200-1,000 °F. Contaminants with low boiling points will vaporize and separate from soil particles. The vaporized contaminants are collected and treated, typically by an air emissions treatment system. If other soil contaminants are present, they are treated by other means.

Most thermal desorption units consist of the pre-treatment and material-handling system. If the soil treatment is done *in situ*: the desorption unit and the post-treatment system for both the gas and the remaining soil are used.

In a permeable matrix, soil vapor extraction in the unsaturated zone and air sparging in the saturated zone appear to be successful in removing some of the volatile contaminants. However, limiting factors to the success of these two techniques include the rate of phase transformation between solid and vapor and the limited permeability of clays and organic soils, which restrict removal of the volatile contaminants. With these limitations, substantial removal of contaminants by soil vacuum extraction may be long and costly. By selectively heating the soils, the rate of volatilization is increased and the release of contaminants from the soil can be improved significantly.

Both radio frequency (RF) and electrical resistance (alternating current or AC) heating are effective in expelling organic contaminants from soil even in low permeability, clay-rich zones. The electrical properties of the clay zones have been shown to preferentially capture the RF or AC energy, thus focusing the power. By selectively heating the clays to temperatures at or above 100 °C, the release and transport of organics can be enhanced by: (1) an increase in the contaminant vapor pressure and diffusivity; (2) an increase in the effective permeability of the clay with the release of water vapor and contaminant; (3) an increase in the volatility of the contaminant from *in situ* steam stripping by the water vapor; and, (4) a decrease in the viscosity, which improves mobility. This method is self limiting as the clays heat and dry, current will stop flowing.

RF is particularly attractive to engineers needing a rapid, *in situ* treatment technology to avoid expensive excavation and treatment methods to meet near-term regulatory requirements. Much like a microwave-oven heating approach, an electrical field is created at an ISM (industrial, scientific, medicine) frequency of 6.68, 13.56, 27.12, or 40.68 megahertz (MHz). Specially designed electrode rods can be placed in vertical or directionally drilled holes for optimal "excitation" of the contaminated treatment zone, vaporizing hydrocarbons beyond their boiling points for capture in a vacuum extraction system. POLs and other contaminants, which have been vaporized, are then transported to condensate and vapor treatment systems on- or off-site.

In sandy, more permeable formations, steam can be injected. The advancing pressure front displaces soil, water, and contaminants by vaporization. The organics are transported in the vapor-phase to the condensation front where they condense and can be removed by pumping. The injection of moderately hot water (50 °C) in a contaminated zone can increase the solubility of many free-phase organics; this improves their removal by pumping. A more important mechanism may be the reduction of viscosity of these free-phase liquids allowing the hot water to displace them. Hot water does not create as harsh an environment as other heating methods, and the biomass may be enhanced to remove residuals.

With regard to composting chlorinated solvents by means of landfarming and biopiles, these treatments are not amenable to destruction of chlorinated solvents because dechlorination, the first and most important step, does not occur under aerobic conditions.

Sample costs of thermal desorption from three operations were: $200/ton, $280/ton, and a range of $150 to $250/ton, respectively.

1. Example Site(s)

Site 1. Pristine, Inc. Superfund Site, Reading, Ohio. Pristine, Incorporated, performed liquid waste disposal operations at the site from 1974 to 1981. Spills and on-site disposal of treated wastes led to soil contamination. Soils at the Pristine site were contaminated with volatile organics up to 0.14 ppm and semivolatile organics up to 130 ppm, PAHs, pesticides, and metals, with lead ranging from 26 ppm to 1,100 ppm.

The soils also contained more than 2 percent of elemental sulfur. This application was notable for treating soil with a wide range of pH and moisture conditions, with soil moisture ranging from 12 to 25 percent, and a pH of 1-2 for some feed soils.

SoilTech's 10 ton/hour mobile Anaerobic Thermal Processor (ATP) system was used for treating the contaminated soil at the Pristine site. The SoilTech ATP system included a feed system, the ATP unit (rotary kiln thermal desorber with proprietary sand seals), a vapor recovery system, a flue gas treatment system, and a tailings handling system. Air emissions were controlled using cyclones, a baghouse, scrubbers, a fractionator, a condenser, and gas-oil-water separator. Water was treated on site using an oil/water separator, hydrogen peroxide oxidation, sand filtration, and carbon adsorption, all in an on-site wastewater treatment system. The ATP system was operated at the Pristine site from 1 November 1993 until 4 March 1994, treating approximately 12,800 tons of contaminated soil.

The ATP system treated contaminants in soil to levels below the cleanup goals. Levels of 6 of the 11 target constituents were reduced to concentrations at or below the reported detection limits for dioxin/furan emissions and particulates. All stack gas air emission performance standards were met in this application, with occasional spikes over the 20 ppm performance standard. Average throughput was approximately 6.5 tons/hour, and average on-line availability was approximately 62 percent.

No cost data were available for this site.

Site 2. Savannah River, Georgia (Department of Energy). In November 1993, researchers placed a Six Phase Array at a TCE and PCE contaminated site. Six electrodes were placed around a central vent in the soil. Each electrode was equipped with a separate transformer wired to provide each electrode with a separate phase. This ensured a more uniform distribution of electrical current in the soil. Because the key to resistive heating is to maintain a small amount of moisture in the zone to conduct the electricity, splitting the current into six phases prevents overheating and excessive drying around the electrodes. Resistive heating dissipated the electrical energy in the contaminated zone, and vapor was withdrawn from the central vent. The Six Phase heating process did not require large energy resources compared to incineration and other thermal treatment methods, as the need to heat soils past 100 °C is unnecessary.

The target contaminated zone was a 10-foot thick clay layer approximately 40 feet below the surface. The electrode array was circular with a 30-foot diameter. The contaminants were dissolved TCE and PCE.

The demonstration lasted 25 days. Of this, it took 10 days to reach the treatment temperature of 100 °C which was maintained for the following 15 days. The demonstration was 99.99 percent successful, reducing contaminants from 100–200 ppm to less than 1 ppm.

No cost data were available for this site.

Site 3. Savannah River, Georgia. TCE and PCE contaminants were treated in a field demonstration of *in situ* radio frequency heating. The objective of the demonstration was to investigate the effectiveness of *in situ* RF heating as an enhancement to vacuum extraction techniques of residual solvents held in vadose zone clay deposits. Conventional soil vacuum extraction techniques are mass transfer limited because of the low permeabilities of the clays. By selectively heating the clays to temperatures at or above 100 °C, the release or transport of the solvent vapors will be enhanced as a result of several factors, including an increase in the contaminant vapor pressure and diffusivity and an increase in the effective permeability of the formation with the release of water vapor.

The *in situ* heating demonstration at the Savannah River site integrated RF applicator technology and vacuum extraction from a single, horizontal well. The horizontal well was drilled through a shallow, contaminated, subsurface clay layer to a depth of approximately 40 feet and was continuously screened over a 300-foot horizontal section. The applicator, approximately 17 feet long, operated at a maximum power output of 25 kilowatts (kW) and a frequency of 13.56 MHz. The applicator was inserted to a location approximately 100 feet from the start of the screened zone to heat 1 section of the well. The vacuum extraction system consisted of a rotary lobe blower capable of providing a flow of approximately 150 cfm at 6 inch Hg vacuum. Gases drawn from the well were destroyed with a skid-mounted, thermal-catalytic oxidation system. Operators placed several vertical boreholes both in and adjacent to the expected heated zone and in a "cold" control zone to monitor temperatures, pressures, and soil gas concentrations.

The demonstration was conducted in March and April 1993. The heating stage of the test was conducted over a 34-day period with approximately 27 days of operation. Gas concentrations from the well rose steadily during the initial stage (first 15 days) to levels ranging from 150 to 200 ppm of perchloroethylene and from 20 to 30 ppmv of trichloroethylene. These levels were sustained over the latter half of the heating stage and appeared to correlate directly with periods of applicator power output. The maximum soil temperature at approximately 6 feet from the center of the applicator reached 63 °C from an initial ambient temperature slightly below 20 °C. The RF power output was controlled using commercial fiber optic temperature sensors located on the applicator and at the screen wall. The control temperatures ranged from 100-130 °C. Power output was cycled to maintain temperatures within these control values established by the limitations of the well-casing material (fiberglass-reinforced epoxy). The maximum RF output per cycle ranged from 10 to 25 kW.

The radio frequency energy was coupled efficiently to the targeted clay layer from a horizontal borehole. The single RF applicator delivered over 95 percent of its available power to the surrounding contaminated clayey sediments. The entire RF system was estimated to operate with an 80-percent delivered energy efficiency to the clay. During the demonstration period, more than 11,000 kilowatt-hours of RF energy were successfully coupled to the subsurface sediments and heated a soil volume of approximately 2,000 ft^3 to temperatures greater than 60 °C.

More than 170 kg of chlorinated solvents were successfully extracted from the sediments over the course of the demonstration. The thermal catalytic oxidation system destroyed the contaminants with an efficiency ranging from 80 to 95 percent. All discharges to the environment were well within the permissible guidelines required by the state of South Carolina.

Because of the problems encountered with the integration of RF heating using a borehole applicator combined with vacuum extraction from a single horizontal well, the results of the demonstration did not provide enough data to adequately assess the feasibility of applying the technology for thermally enhanced remediation of contaminated clays in the unsaturated zone. The demonstration provided a greater understanding of the important component and system designs, the critical operating parameters, and the essential site characterization requirements for *in situ* RF heating applications. The results and insights from this demonstration also have led to selecting specific solutions to address the problems encountered. The primary limitations resulted from the use of a relatively long, single horizontal well design screened within a low-permeable clay formation. A horizontal borehole application is advantageous for vadose zone remediation as the applicator can be moved through the well, heating a progressively larger volume of the contaminated tabular clays. However, such an application must consider the proper choice of well completion materials that are compatible with the installation technique and the expected temperatures.

Site 4. Undescribed AT&T site in the Midwest. The chlorinated solvents TCE and TCA were treated at this site in the Midwest. The site had moderately tight soil configuration with undissolved or dense non-aqueous phase liquids. Steam was injected into areas of highest contamination to volatilize and mobilize the volatile components. A shallow SVE system was designed and installed to capture the volatiles. Extraction wells collected and controlled the mobilized contaminants. At the outer fringes of the contaminant zone, where concentrations were lowest, enhanced biotransformation was performed using an injected nutrient slurry. Heating the nutrient slurry promoted the biotransformation and maintained between 20 °C and 40 °C for optimal growth of bacteria.

The facility began using the technology in early 1991 and, as of early 1994, was still in full operation with the median concentration in the ground water reduced to below cleanup criteria.

To determine the effectiveness of biotransformation, ratios of the "daughter" and "parent" compounds were compared. Preliminary results indicated that biotransformation rates were highly temperature and concentration dependent. Maintaining optimal temperatures has been observed to promote the ground water cleanup.

More than 18,000 pounds of solvent have been removed in 3.5 years through vapor and ground water extraction. Quarterly sampling of the ground water shows that the plume has been reduced in size. Monitoring for cleanup at one location for 6 months shows that where cleanup has been attained for all chlorinated aliphatic compounds, concentration rebound was not observed.

No cost data were available.

Site 5. U.S. Naval Station, Mayport, Oily Waste Treatment Plant Units 6 and 7. An estimated 250,000 gallons or more of bilge water and several thousand gallons of waste oil that possibly contained solvents and transformer oils were beneath the sludge drying bed of the oily waste treatment plant. Bilge water had been pumped directly from ships into the pit, and wastes seeped into the underlying soil. Soil and ground water samples taken in 1988 indicated LNAPLs on the water table hydraulically downgradient of unit #6, indicating that petroleum-related products from #6 and #7 contributed to the presence of LNAPLs. The estimated total volume of contaminated soil was 29,600 yd^3, or 35,200 tons.

The treatability study used 2,400 tons of soil from the two areas from 15 April to 4 May 1996. Two separate storage cells, each lined with 10-mil plastic, were made. One was for petroleum impacted soil, the other for clean soil or soil that might need re-treatment. The thermal desorber was a rotary dryer 4 feet in diameter, 20 feet long, using temperatures from 600 to 700 °F. The exhaust gas was treated by collecting the particulates in a pulse jet baghouse; the gas portion was treated in a thermal oxidizer at a temperature of 1,300 to 2,000 °F, residence time of 1 second. During the treatability test, optimum feed rates and temperatures were determined. Higher temperatures were required because of a high moisture content and many oyster shells. Materials larger than 2 inches were screened out.

Samples were analyzed for volatile organic aromatics (VOAs), volatile organic halocarbons (VOHs), polynuclear aromatic hydrocarbons (PAHs), total organic halides, metals, and total recoverable petroleum hydrocarbons (TRPH).

VOHs, PAHs, and total organic halides, if present, were not detected at concentrations exceeding the detection limit. Two VOAs and seven inorganic analytes (arsenic, barium, cadmium, chromium, lead, mercury, and selenium) were detected as well as TRPH. The treatability test demonstrated that the thermal desorption unit was capable of treating the soil. One soil supply had to be retreated.

In the full-scale treatment, 54 piles of soil were treated. Of these, 10 did not meet the thermal desorption treatment criteria for total volatile organics and 7 did not meet the criteria for TRPH. Six piles were retreated.

The treatment of soil so far appears to have been effective, although some uncertainty exists because the contractor did not document whether the piles were retreated and the results of the retreatment. If the entire area is treated, a larger rotary dryer is suggested because of the requirement for high temperatures (740-1,000 °F) and lower feed rates because of the soil moisture.

No cost data were available.

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VIII. GENERAL COMMENTS ON HEAVY METALS

The techniques used to remediate heavy metals vary and are often puzzling. Generally speaking, if soil is contaminated, it is left where it is if it is not a threat to life or health. If it *is* a threat because it is contaminated with potentially toxic metal cations such as lead (Pb_2^+), zinc (Zn_2^+), chromium (Cr_3^+), cadmium (Cd_2^+), or mercury (Hg_2^+), it is then dug, hauled, solidified, landfilled, permanently flooded, covered by a cap, or contained in a slurry wall. If the choice is made to remove heavy metal contaminated soil or sediment to a landfill, then other issues about landfill placement, design, and maintenance arise, including liners and caps. If water is contaminated with heavy metals, it must be treated or its use must stop. Some progress has been made in the remediation of heavy metal contaminated water in the mining industry, but treatment results are not consistent.

Determining the species of a metal determines its toxicity. For instance, chrome(VI) is quite toxic, but Cr(III) is almost non-toxic; generally no more than 20 percent of chrome is Cr(VI). However, very few direct experimental methods are available for speciation. Therefore, identifying these species (speciation) and obtaining reasonable estimates of their thermodynamic and kinetic stabilities are the problems that continue to plague environmentalists and toxicologists. Emerging technologies for site assessment of heavy metal contaminated sediments may lend insight into this troublesome area. Please refer to Appendix G for additional information.

The difficulty arises because of the different valence states metals can assume, depending on conditions such as pH, organic ligand availability, soil composition, contact with microorganisms that change valence states, and presence of other metals.

For these reasons, standards for determining risk to human health and the environment has not been formally assessed for heavy metals as has the risk for petroleum contamination. If, however, the ground water or soil are acidic or vulnerable to acidic conditions (such as acid rain), the metals can become or are bioavailable. If human beings must contact the heavy metal directly or indirectly, such as by eating plants grown in soil or drinking water that is contaminated with heavy metals, then the contamination needs to be removed.

In cases where the dig and haul method is chosen, generally only the first 18 inches of soil need be removed. Soil washing (treating heavy metal contaminated soil as if it were complex laundry and using physical and aqueous chemical methods to remove contamination) is very costly, requiring extensive engineering and labor investment. For this reason, soil washing is not included in this document. For heavy metal contaminated ground water that is pumped and used for drinking or irrigation water, the water must be either be treated or use must stop.

Although living organisms require trace amounts of some heavy metals, including chromium, cobalt, copper, iron, manganese, molydenum, vanadium, selenium, strontium, and zinc, excess levels of such metals can be detrimental to health. Heavy metals of particular concern to surface water systems are cadmium, mercury, lead, arsenic, and antimony, and excessive amounts of chromium and selenium.

All heavy metals exist in surface waters in colloidal, particulate, and dissolved phases, although dissolved concentrations are generally low. The colloidal and particulate metal may be found in hydroxides, oxides, silicates, or sulfides, or adsorbed to clay, silica, or organic matter. The soluble forms are generally ions or unionized organometallic chelates or complexes. The solubility of trace metals in surface waters is predominately controlled by the water pH, the type and concentration of ligands on which the metal could adsorb, and the oxidation state of the mineral components, as well as the redox environment of the system.

Generally, the heavy metals of concern in Central Europe are chromium and arsenic. Chromium is a priority pollutant in the United States because it is known to cause cancerous mutations. Because it is one of the most widely used metals in industry, large quantities are discharged into the environment. In contrast to most metals, chromium is usually soluble under oxidizing conditions, and only limited removal can be achieved by conventional precipitation methods. Reducing hexavalent chromium [Cr (VI)] to trivalent chromium [Cr (III)] detoxifies it, but the best range of reduction-oxidation (redox) potential for Cr(VI) reduction has not yet been well established. Inorganic arsenicals such as As(V) and As(III) are very toxic. Arsine is the most toxic form of arsenic, with one major effect being the hemolysis of red blood cells followed by kidney failure and death. Typical conditions that result in accidental arsine formation include water solutions of arsenic, an acid or base, and a metal in its elemental form. An acid sludge with arsenic in a galvanized bucket or an aluminum tank with arsenic and containing sodium hydroxide could generate arsine.

On military installations in the United States, heavy metal contamination varies, with contamination of many metal species from various operations. The most by bulk and weight is at firing ranges, both ordnance and small arms. On small arms firing ranges, the main concern is lead — the majority of the bulk of the bullet — with secondary contamination from the outer casing of the bullets that are made of copper and zinc. Ironically, the threat of environmental contamination from these sources is low, hence cleanup of these heavy metal contamination sources is low priority. Demonstrations of mining and leaching technologies for small arms ranges have been jointly done by the U.S. Army and the U.S. Navy.

Lead contamination also arises from leaded gasoline spills, where often the gasoline has disappeared. Lead in gasoline is in the form of tetra-ethyl lead and can threaten drinking water.

A general document of interest may be the EPA's *Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites*. This document contains information presented in a series of three seminars initiated by the EPA in 1994. Representatives from EPA, the DOE, contractors, and several state representatives discussed the state of knowledge at that time, including basic fundamentals of acid mine drainage, known and probable effects on the public health and environment, and control technologies known and under investigation. Some of the techniques included bioremediation, composting, and innovative approaches being investigated by EPA and others.

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- http://www.usgs.gov (US Geological Survey)

IX. HEAVY METALS IN GROUND WATER

A. SURFACE TREATMENT OF HEAVY METALS IN GROUND WATER: COAGULATION AND PRECIPITATION OR DISPOSAL TO A SANITARY SEWER

Precipitation of metals has long been the primary method of treating metal-laden industrial wastewaters. As a result of the success of metals precipitation in such applications, the technology is being considered and selected for use in remediation ground water containing heavy metals, including their radioactive isotope(s). In ground water treatment applications, the metal precipitation process is often used as a pretreatment for other treatment technologies, such as chemical oxidation or air stripping, where the presence of metals would interfere with the other treatment processes.

Metals precipitation from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such a clarification, settling, and filtration.

The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation. Metals typically precipitate from the solution as hydroxides, sulfides, or carbonates. The disadvantages include the presence of multiple metal species. This leads to removal difficulties because the removal of one may prevent removal of another species. Other disadvantages are that the metal may be sorbed to the soil, and treatment of the ground water will not remove it; further treatments may be required if standards become more stringent, reagent addition must be carefully controlled to preclude unacceptable concentrations in treatment effluent, the process may generate toxic sludge which requires disposal, and the entire process can be quite costly.

The primary capital cost factor is design flow rate. Capital costs for 75 and 250 L/min (10 gpm and 65 gpm) packaged metals precipitation systems are approximately $85,000 and $115,000, respectively. Labor and operating costs are the primary factors. Operating costs are typically from 8 to 18 cents per 1,000 liters (30 to 70 cents per 1,000 gallons) of ground water containing up to 100 mg/L of metals.

Sludge disposal adds to the cost. It may be estimated to increase operating cost by approximately 13 cents per 1,000 liters (50 cents per 1,000 gallons) of ground water treated. Actual sludge disposal costs have been estimated at approximately $330 per metric ton ($300 per ton) of sludge.

Laboratory treatability study costs for metals precipitation may range from $5,000 to $20,000. Depending on the degree of uncertainty or other requirements, a pilot study or field demonstration may be needed. Associated cost may range from $50,000 to $250,000.

1. Example Site(s)

Site 1. Electro-Coatings, Incorporated, Linn County, Cedar Rapids, Iowa. The 1-acre Electro-Coatings, Incorporated, site is a plating shop located in Cedar Rapids that has been in operation since 1947. The plant currently performs chromium, cadmium, nickel, and zinc plating.

The site lies on the northern shore of Cedar Lake, a 150-acre impoundment owned by a utility company. The Cedar River is located just west of Cedar Lake. In 1976, high levels of chromium were discovered in water from a neighboring industrial well. The contamination was traced to a leaking tank containing chromic acid at the Electro-Coatings plant. Shortly after the discovery, Electro-Coatings began a series of actions to monitor the contamination and prevent further releases. The City of Cedar Rapids, which has a population of over 108,700 people, obtains water from 46 shallow wells along the Cedar River. The closest city well is located approximately 2,000 feet west of the site.

The primary ground water contaminant is hexavalent chromium. Other heavy metals, including cadmium and nickel, have been found at elevated levels in ground water on site. VOCs have also been detected in site ground water. However, most of the VOCs have been attributed to a neighboring industry. The contaminated ground water has been found to be largely contained by the neighboring industrial well. Water from this industrial well is not used for drinking and the contaminants do not adversely affect its use. No ground water contamination has been detected in the municipal drinking water wells. The potential for contamination of Cedar Lake has also been a concern; however, no significant impact to Cedar Lake has been observed.

In 1976, Electro-Coatings, Inc., removed the leaking deep-pit tank and initiated a leak prevention program throughout the plant. Electro-Coatings installed five monitoring wells that they sampled periodically in addition to the neighboring industrial well. In

1992, contaminated soils were discovered as a chromium dipping tank was being taken out of service. Chromium-contaminated soil and concrete were removed and disposed of as hazardous waste.

The potentially responsible parties, under State oversight, performed an intensive study to determine the nature and extent of contamination. The investigation was completed in 1994. The chosen remedy resulting from this study includes continued pumping of the contaminated ground water with discharge to the sanitary sewer and ongoing ground water monitoring. Continued pumping of the neighboring industrial area should provide adequate containment of ground water contaminants; if not, a new recovery well (or wells) will be installed and operated to contain the contaminants.

As a result of initial actions, the Electro-Coatings, Inc., site does not pose an immediate threat to public health or the environment. Significant declines in contaminant levels have and will continue to occur as pumping and treating of contaminated ground water proceeds.

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3. World Wide Web Site(s)

- http://clu-in.com/pubindex/htm#2
- http://www.epa.gov/region07/programs/spfd/nplfacts/electro.html (Specific to the Electro Coatings, Incorporated site.)
- http://www.sowatreco.com/Mr-40.tds.html (Specific to a liquid formulation designed for removal of heavy metals from waste water)

- http://www.modenvtech.holowww.com/me03025.htm (treatment and possible recovery of heavy metals in industrial wastewater streams)
- http://strategis.ic.gc.ca/sc_indps/canenvir/engdoc/emwasw.html (Industry Canada - Canadian Environmental Solutions, including removal of heavy metals)
- http://www.uwin.siv.edu (Database of international water research compiled by the Water Resources Scientific Information Center of the U.S. Geological Survey. The research covers from 1967 to October 1993, with more than 265,000 abstracts and citations that are key-word searchable.)

B. SURFACE TREATMENT OF HEAVY METALS IN GROUND WATER: PHYTOREMEDIATION

This technology is in the early stage of commercialization for treatment of soils contaminated with metals and, in the future, may provide a low cost option under specific circumstances. At the current stage of development, this process is best suited for sites with widely dispersed contamination at low concentrations where only treatment of soils at the surface (in other words, within depth of the root zone) is required.

Two basic approaches for metals remediation include phytoextraction and phytostabilization. Phytoextraction relies on the uptake of contaminants from the soil and their translocation into above-ground plant tissue, which is harvested and treated. Although trees, shrubs, herbs, grasses, and crops have potential, crops seem to be most promising because of their greater biomass production. Nickel and zinc appear to be the most easily absorbed, although preliminary tests with copper and cadmium are encouraging. Significant uptake of lead, a commonly occurring contaminant, has not been demonstrated in any of the plants tested thus far. However, one researcher is experimenting with soil amendments that would facilitate uptake of lead by the plants.

Phytostabilization achieves risk reduction by stabilizing contaminants located near the surface. This result is achieved by the secretion of compounds by plants to affect soil pH and to form metal complexes with reduced solubility. In addition, the plants help control surface erosion and reduce leaching through increased evapotranspiration. Laboratory studies indicate the potential effectiveness of this approach for lead.

Metals considered essential for at least some forms of life include vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), and molybdenum (Mo). Because many metals are toxic in concentrations above minute levels, an organism must regulate the cellular concentrations of such metals. Consequently, organisms have evolved transport systems to regulate the uptake and distribution of metals. Plants have remarkable metabolic and absorption capabilities, as well as transport systems that can take up ions selectively from the soil. Plants have a great diversity of genetic adaptations to handle potentially toxic levels of metals and other pollutants that occur in the environment. In plants, uptake of metals occurs primarily through the root system, in which the majority of mechanisms to prevent metal toxicity are found. The root system provides an enormous surface area that absorbs and accumulates the water and nutrients essential for growth. In many ways, living plants can be compared to solar-powered pumps that can extract and concentrate certain elements from the environment.

Plant roots cause changes at the soil-root interface as they release inorganic and organic compounds (root exudates) in the area of the soil immediately surrounding the roots (the rhizosphere). Root exudates affect the number and activity of microorganisms, the aggregation and stability of soil particles around the root, and the availability of elements. Root exudates can increase (mobilize) or decrease (immobilize) directly or indirectly the availability of elements in the rhizosphere. Mobilization and immobilization of elements in the rhizosphere can be caused by changes in soil pH; release of complexing substances, such as metal-chelating molecules; changes in oxidation-reduction potential; and increases in microbial activity.

1. Remediation Types

Phytoremediation technologies can be developed for different applications in environmental cleanup and are classified into three types: phytoextraction, phytostabilization, and rhizofiltration. Each is discussed below.

a. Phytoextraction

Phytoextraction technologies use hyperaccumulating plants to transport metals from the soil and concentrate them into the roots and above-ground shoots that can be harvested. A plant containing more than 0.1 percent of Ni, Co, Cu, Cr, or one percent of Zn and Mn in its leaves on a dry-weight basis is called a hyperaccumulator, regardless of the concentration of metals in the soil.

Almost all metal-hyperaccumulating species known today were discovered on metal-rich soils, either natural or artificial, often growing in communities with metal excluders. Actually, almost all metal-hyperaccumulating plants appear in such soils, suggesting that hyperaccumulation is an important ecophysiological adaptation to metal stress and one way the plant shows of resistance to metals. The majority of hyperaccumulating species discovered so far are restricted to a few specific geographical locations. For example, Ni hyperaccumulators are found in New Caledonia, the Philippines, Brazil, and Cuba. Ni and Zn hyperaccumulators are found in southern and central Europe and Asia Minor.

Dried or composted plant residues or plant ashes that are highly enriched with metals can be isolated as hazardous waste or recycled as metal ore. The goal of phytoextraction is to recycle as "bio-ores," metals reclaimed from plant ash in the feed stream of smelting processes. Even if the plant ashes do not have enough concentration of metal to be useful in smelting processes, phytoextraction remains beneficial because it reduces the amount of hazardous waste to be sent to landfills by as much as 95 percent. Several efforts researching the use of trees, grasses, and crop plants are being pursued to develop phytoremediation as a cleanup technology. The following paragraphs briefly discuss these three phytoextraction techniques.

Trees can take in significant amounts of metal because of their high biomass production. However, the use of trees in phytoremediation requires long-term treatment and may create additional environmental concerns about falling leaves. When leaves containing metals fall or blow away, recirculation of metals to the contaminated site and migration off-site by wind transport or through leaching can occur.

Some grasses accumulate surprisingly high levels of metals in their shoots without exhibiting toxic effects. However, their low biomass production results in relatively low yield of metals. Genetic breeding of hyperaccumulating plants that produce relatively large amounts of biomass could make the extraction process highly effective; however, such work has not yet begun.

Many crop plants can accumulate metals in their roots and above-ground shoots, potentially threatening the food chain. For example, in May 1980 regulations proposed under the Resource Conservation and Recovery Act (RCRA) for hazardous waste (now codified at 40 CFR Part 264) include limits on the amounts of cadmium and other metals that can be applied to crops. Recently, however, the potential use of crop plants for environmental remediation has been under investigation. Using crop plants to extract metals from the soil seems practical because of their high biomass production and relatively fast rate of growth. Other benefits of using crop plants are that they are easy to cultivate and they exhibit genetic stability.

b. Phystostabilization

Phytostabilization uses plants to limit the mobility and bioavailability of metals in soils. Ideally, phytostabilizing plants should be able to tolerate high levels of metals and to immobilize them in the soil by sorption, precipitation, complexation, or the reduction of metal valences. Phytostabilizing plants also should exhibit low levels of accumulation of metals in shoots to eliminate the possibility that residues in harvested shoots might become hazardous wastes. In addition to stabilizing the metals present in the soil, phytostabilizing plants also can stabilize the soil matrix to minimize erosion and migration of sediment. Researchers at Kansas State University are studying phytostabilization in poplar trees, which were selected for the study because they can be deep-planted and may be able to form roots below the zone of maximum contamination.

Since most sites contaminated with metals lack established vegetation, metal-tolerant plants are used to revegetate such sites to prevent erosion and leaching. Such an approach offers containment rather than a remediation strategy. Some researchers consider phytostabilization an interim measure to be applied until phytoextraction becomes fully developed. However, other researchers are developing phytostabilization as a standard protocol of metal remediation technology, especially for sites at which metals removal does not seem to be economically feasible. Field applications conducted by a group in Liverpool, England, resulted in varieties of three grasses becoming commercially available for phytostabilization: *Agrostis tenuis, cv Parys* for copper wastes, *Agrosas tenuis, cv Coginan* for acid lead and zinc wastes, and *Festuca rubra, cv Merlin* for calcareous lead and zinc wastes.

c. Rhizofiltration

One type of rhizofiltration uses plant roots to absorb, concentrate, and precipitate metals from wastewater, which may include leachate from soil. Rhizofiltration uses terrestrial plants instead of aquatic plants because terrestrial plants develop much longer, fibrous root systems covered with root hairs that have extremely large surface areas. This variation of phytoremediation uses plants to remove metals through sorption, which does not involve biological processes. Use of plants to translocate metals to the shoots is a slower process than phytoextraction.

Another type of rhizofiltration, more fully developed, involves construction of wetlands or reed beds for the treatment of contaminated wastewater or leachate. The technology is cost-effective for the treatment of large volumes of wastewater that have low concentrations of metals.

Contaminated ground water can be pumped to the surface and treated using phytoremediation with cyanide-degrading microorganisms. Commercial use of cyanide-degrading microorganisms has been used since the early 1980s. Homestake Mining has an operation that treats tens of thousands of gallons of cyanide-contaminated wastewater per day.

2. Example Site(s)

Plants have been used to treat wastewater for more than 300 years, and plant-based remediation methods for slurries of dredged material and soils contaminated with metals have been proposed since the mid-1970s. Reports of successful remediation of soils contaminated with metals are rare, but the suggestion of such application is more than a decade old, and progress is being made at a number of pilot test sites. Successful phytoremediation must meet cleanup standards in order to be approved by regulatory agencies.

No full-scale applications of phytoremediation have been reported. One vendor, Phytotech, Incorporated, is developing phytostabilization for soil remediation applications. Phytotech also has patented strategies for phytoextraction and is conducting several field tests in Trenton, New Jersey, and in Chernobyl, Ukraine. Also, as was previously mentioned, a group in Liverpool, England, has made three grasses commercially available for the stabilization of lead, copper, and zinc wastes.

Currently, because it has not been used in any full-scale applications, the potential of phytoremediation for cleanup of contaminated sites cannot be completely ascertained.

Please also refer to the section on Phytoremediation in Chapter XII, Section C.

3. Documentation

Recent Developments for In Situ Treatment of Metal Contaminated Soils. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, D.C. 20460, 1997.

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4. World Wide Web Site(s)

- http://www.clu-in.com/pubindex.htm
- http://www.mrd.usace.army.mil/mrded-h/IT/itphyto.html
- http://www.mrd.usace.army.mil/mrded-h/mrded-h.html
  U.S. Army Corps of Engineers home page
- http://www.rtdf.org
  Research Technology and Development Forum
- http://www.ecc.ksu.edu/HSRC/Annual.Research.html

- http://www.ecc.ksu.edu/HSRC/phytorem/home.html

X. HEAVY METALS IN SOIL AND SEDIMENTS

A. HEAVY METALS IN THE SUBSURFACE OR SURFACE SOILS, DIG AND HAUL TO A LANDFILL, WITH OR WITHOUT SOLIDIFICATION

Although seemingly simple, the option of digging and hauling contaminated soil has drawbacks. The heavy metal contaminated soil is still a danger, so some system of solidifying it (physically bounded or enclosed within a stabilized mass) or stabilizing it (reducing mobility through chemical reaction) is required. Placing contaminated soil in landfills in another place requires additional consideration. The site chosen should be lined with an impermeable liner (plastic or other type), the leachate collected and processed, and the landfill capped with an impermeable cap or possibly with a transpiration cap of grasses. Please refer to Appendix F for further information on landfill considerations.

Sites that have had excavation and landfilling as sole treatment options are not included in this document. These treatments are well known and information is available elsewhere.

1. Example Site(s)

Site 1. <u>E.I. Dupont De Nemours & Company, Incorporated, West Point, New York.</u> This site illustrates that more than one approach may be chosen to remediate a location. The E.I. DuPont de Nemours & Company, Inc. (County Road X23) site, an industrial waste dump in a rural area of Lee County, consists of two areas off County Road X23, about 3 1/2 miles southeast of West Point. In the early 1950s, DuPont sent wastes from its nearby Fort Madison paint plant to the 2 disposal sites, which are about 1 mile apart and cover 4 acres. One is known as the Baier farm subsite and the other as the DuPont/McCarl subsite. DuPont estimates that between 1949 and 1953 a contractor disposed of 48,000-72,000 drums of paint waste at the subsites. These wastes were placed in shallow trenches and burned, then the soil was graded flat. The properties drop off to ravines on the northwestern sides. The company estimates that 4,500-7,000 tons of ash and unburned sludges still may exist on the areas. Approximately 1,200 people depend on private wells within 3 miles of the site as their sole source of drinking water. Two creeks about 1 mile from the site are used for limited recreational activities. Approximately 160 people live within 1 mile of the site; 1,250 live within 3 miles, with the closest population being 500 feet from the site. There are 40 private wells within 1 mile and 330 private wells within 3 miles; the nearest is 500 feet from the site. Water is consumed by the local population and livestock.

Ground water and soils were contaminated with heavy metals, including cadmium and lead, and VOCs from former disposal activities. The concentrations were not given. Potential health threats consisted of ingesting contaminated ground water and coming into direct contact with both ground water and soil. Contaminants also could have accumulated in plants that were consumed by cattle.

In 1985, the EPA installed three ground water monitoring wells at the Baier subsite. Sampling in 1986 showed elevated concentrations of metals. Downstream water samples showed similar findings. When the McCarl subsite was studied in 1986, ground water and soil samples again revealed metals. In 1989, the EPA ordered DuPont to perform a study of contamination at the site. DuPont completed the study in early 1991. Based on the results of this study, the EPA selected stabilization and solidification of contaminated soil and monitoring of the ground water as the cleanup remedies. DuPont completed the design of these remedies in late 1992 and cleanup activities began shortly after. In late 1991, DuPont removed contaminated surface material that could not be stabilized to an off-site, Federally approved disposal facility. Site cleanup activities were completed in 1993.

The removal of contaminated surface material, treatment of the contaminated soil, and monitoring of the ground water has eliminated risks to public health or the environment. All cleanup activities are complete. The EPA deleted the site from the National Priorities List in September 1995.

No cost data were available for this site.

Site 2. Bunker Hill Superfund Site, Kellogg, Idaho. The site, 21 mi^2 in size, is a former mining and smelting complex. It is one of the largest and most complex abandoned hazardous waste sites in the United States.

Mining began here is the late 1800s and smelting in the early 1900s. The mines and smelters produced lead, zinc, cadmium, silver, gold, and alloys of these heavy metals. Lead, arsenic, cadmium, and zinc are the primary contaminants, originating from mine tailings, past air emissions, smelter complex materials and residuals, acid mine drainage, and inflow of contaminants from other upstream mining and milling operations. The smelter and other Bunker Hill activities ceased operation in late 1981. Some limited mining operations have been performed at Bunker Hill by various entities since that time.

Much of the soil on the hillsides in the area has eroded since the clearing of trees nearly 100 years ago. Subsequently, the trees have been unable to re-establish themselves in many areas due to the metals and the lack of soil. Since the site was large, it was divided into two operable units: Populated Areas and Non-Populated Areas. Work in Populated Areas involves removal of contaminated soils in residential areas and public use areas throughout the 21-mi^2 area to a nominal depth followed by replacement with clean fill and either sod or gravel. This work is ongoing.

The Non-Populated Area work is being performed by contractors under the direction of the U.S. Army Corps of Engineers and involves the following:

- Demolition of almost 200 structures in the Bunker Hill Complex
- Removal of contaminated soils and other materials in the complex
- Construction and closure of a disposal cell in the complex that was developed and used for the disposal of debris and contaminated materials
- remediation of numerous gulches and stream channels
- Control of erosion and re-vegetation of the hillsides in and around the complex
- Removal of approximately 1.5 million yd^3 of contaminated soil, tailings, and other materials from the Smelterville Flats area
- Closure of a 240-acre tailing impoundment area known as the Central Impoundment Area.

The demolition of the almost 200 structures is complete, with the majority of the demolition work being done by Morrison-Knudsen. The demolition work was completed at a cost savings of approximately $4 million. The total cost data were not given.

Work is underway to remove contaminated soils and materials from the Industrial Complex area along with remediation of numerous gulches and stream channels. This work is also being done by Morrison-Knudsen and was scheduled to be completed by the summer of 1997.

Continued work includes the closure of the Industrial Complex disposal cell, removal of the 1.5 million yd^3 of contaminated soil, tailings, and other materials from

Smelterville Flats, and closure of the Central Impoundment Area. These aspects of the project are scheduled to begin in the summer of 1997 and to be completed by 2001.

No estimates of cost were given. No details of the excavation and landfilling of the soils were given.

2. Documentation

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Lane, W. N. and R.R. McDonald. ‘Land Suitability Analysis: Landfill Siting.” *Journal of Urban Planning and Development*, May, 1983, page 50 ff.

Sittig, M. *Landfill Disposal of Hazardous Wastes and Sludges.* Noyes Data Corporation, 1979.

Skitt, J. *Waste Disposal Management and Practice.* John Wiley and Sons, New York, New York, 1979.

Weiss, Samual. *Sanitary Landfill Technology.* Noyes Data Corporation, 1974.

3. World Wide Web Site(s)

- http://www.envirolink.org/issues/landfills (Information on environmental impact of landfills)
- http://www.frtr.gov
- http://www.srs.gov
- http://cayuga.nfesc.navy.mil/cc/projects/landfill.htm
- http://epdwww.engr.wisc.edu/iscourses/landfill/A180-bib.html (A bibliographic list for a landfill design course at the University of Wisconsin)
- http://www.epa.gov/region07/programs/spfd/nplfacts/eidupont.html (Specific to the Dupont County Road site.)

4. Models

HELP model for Windows - Landfill design tool for an open, partially closed or closed landfill.

B. HEAVY METALS IN THE SUBSURFACE OR SURFACE SOILS: SOLIDIFICATION AND STABILIZATION

In situ stabilization or solidification, also known as *in situ* fixation, or immobilization, is the process of altering organic or inorganic contaminants to an non-toxic and/or immobile state by injection or infiltration of stabilizing agents into a zone of contaminated soil or ground water. Contaminants are physically bound or enclosed within a stabilized mass (solidification), or their mobility is reduced through chemical reaction (stabilization). Excellent understanding of the hydrogeologic regime for potential projects is essential for this to work properly. It is best applied in moderate to high permeability soils.

Solidification and stabilization (S/S) technologies are used to change the physical characteristics and leaching potential of waste. The term S/S refers to treatment processes that use reagents or thermal energy to accomplish one or more of the following objectives:

- Reduce the mobility or solubility of the contaminants to levels required by regulatory or other risk-based standards.
- Limit the contact between site fluids (such as ground water) and the contaminants by reducing the permeability of the waste, generally to less than 1×10^{-6} cm/sec.
- Increase the strength or bearing capacity of the waste, as indicated by unconfined compressive strength (UCS) or measured by the California bearing ratio.

1. Types of Solidification and Stabilization

There are two basic types of S/S treatment processes: reagent-based systems and thermal-based systems. Reagent-based systems use chemicals to solidify and stabilize the contaminants in the soil matrix. Thermal-based systems use heat to melt the soil to solidify and stabilize the contaminants after cooling.

a. Reagent-Based Systems

In situ reagent-based S/S technologies consist of a reagent formulation and a delivery system. With the exception of near-surface applications (that is, to depths of 15 feet deep), a reagent-based S/S delivery system usually consists of a slurry batch plant, delivery hoses, and one or more augers. Most reagent formulations for *in situ* S/S applications consist of ordinary pozzolanic reagents, although proprietary reagents are often used in conjunction with or instead of pozzolanic reagents. Pozzolanic mixtures are based on siliceous volcanic ashes similar to substances used to produce hydraulic cement. Depending on the characteristics of the waste to be treated and the desired properties of the treated wastes, additives such as bentonite or silicates may be added to the cement and/or fly ash mixture. For example, addition of bentonite increases the ease of pumping of the wet reagent slurry and decreases the permeability of the treated waste. Silicates form chemical complexes with metals, often providing greater insolubility than do hydroxide, carbonate, or sulfate precipitates. (Other additives or proprietary reagents, such as activated carbon or organophilic clays, can be used to stabilize SVOCs in wastes).

Wastes containing lead can be stabilized with the addition of trisodium phosphate; the resulting lead phosphate precipitate is insoluble in water. Although solidification of the waste treated with trisodium phosphate is not necessary to provide a barrier to leaching, it may be done for other purposes such as providing sufficient bearing strength to support a cap. Additionally, lead phosphate is toxic by inhalation. Solidification or other means of encapsulation may be used to prevent air-borne particulates from escaping the treated waste. Alternatively, solidification may be used to provide a barrier to acids or alkaline solutions that could dissolve the lead phosphate.

In general, contractors performing S/S work use a patented auger consisting of blades or paddles studded with injection ports through which the reagent mixture flows. Some vendors emphasize the kneading and shearing action of their augers, but others emphasized grout (reagent mixture) control and the capability to deliver two or more mixtures simultaneously. The vendors also differ with respect to the size of injection ports and their operating pressure. Choice of auger diameter varies, but generally depends on depth of drilling, consistency and hardness of the soil, and soil porosity. For example, augers from 4 to 12 feet in diameter generally can be used to a depth of 40 feet. The diameter selected will depend on the porosity of the soil. Augers of larger diameter may be used in sludges and sands, but silts and clays require augers of a smaller diameter. One vendor uses small-diameter augers for all depths because large-diameter augers affect mixing efficiencies. Beyond a depth of 35-40 feet, a smaller-diameter auger (from 2.5 to 4 feet in diameter) is suggested. Using a smaller auger permits treatment to depths as great as 100 feet or more. Only 2 of the 5 vendors contacted in a USEPA study treated soil at depths of more than 40 feet; however, most soil contamination is encountered at depths of 10-20 feet and only rarely deeper than 40 feet (although treatment to depths of more than 40 feet is becoming more common).

b. Thermal-Based S/S Processes

The only thermal-based S/S treatment process commercially available is *in situ* vitrification. *In situ* vitrification uses electrical power to heat and melt soils contaminated with organic, inorganic, and metal-bearing wastes. The molten material cools to form a hard, monolithic, chemically inert, stable product of glass and crystalline material that incorporates and immobilizes the inorganic compounds and metals. The resultant vitrified product is a glassy material, with very low leaching characteristics. Organic wastes initially are vaporized or incinerated by the process. Those contaminants migrate to the surface, where they are treated in an off-gas treatment system.

A single company, Geocon, accounted for most of the *in situ* applications reported; however, little data on applications are available. Each vendor's system is well established, tracing its roots to established construction technologies. (Deep soil mixing and the installation of cement footers and grout curtains or slurry walls are construction techniques that have been employed for many years.) An emerging development for American vendors is the injection of dry reagents when high levels of moisture in the soil preclude the use of liquid reagents. Although this variation of the technology has been employed in Europe for more than 20 years, only 1 U.S. vendor (Hayward Baker) has used it. Although conveying dry reagents pneumatically requires some expertise, both Millgard and Geocon currently are experimenting with the technique. It is notable that *in situ* application of dry reagents tends to decrease the effective depth of treatment for a given auger diameter and soil porosity. (Conversely, wet slurries help extend the depth of treatment.)

Only 1 company offers *in situ* thermal-based S/S treatment processes. Geosafe Corporation of Richland, Washington, offers the *in situ* vitrification (ISV) technology commercially. ISV uses electrical current to heat and vitrify the contaminated material in place. A pattern of electrically conductive graphite containing glass frit is placed in the soil between the electrodes. When power is supplied to the electrodes, the mixture of graphite and glass frit conducts the current through the soil, heating the surrounding area and melting the soil between and directly adjacent to the electrodes.

Molten soils are electrically conductive and can continue to transmit the electrical current, melting soil downward and outward. The electrodes are lowered further into the soil as the soil becomes molten, continuing the melting process to the desired depth of treatment. One setting of four electrodes is referred to as a melt. For the Geosafe system, the melting process occurs at an average rate of approximately 3 to 4 tons/hour. The

Giosafe ISV process was used at Parsons Chemical/ETM Enterprises site, see Site 1 in this section.

The cost of *in situ* S/S can range from as low as $20 to $40 per cubic yard to as much as $100 to $200 per cubic yard, depending on the volume to be treated, the structure of the soil (porosity), the treatment depth, the type of contaminant, and the post-treatment objectives (leachability, permeability, or bearing ratio) desired. The low end of the cost range would apply to solidifying dredge spoils, and the high end would apply to treatment of high concentrations of contaminants at great depths. For application at a hazardous waste site consisting of sands to silts at a depth of 25 feet, $75 to $90 per cubic yard would be typical (20 percent of that figure would be the cost of reagent).

The major factors affecting cost of ISV are the amount of water present, the treatment zone, depth, combustible waste load, scale of operation, and price of electricity. The vendor estimates costs between $375 and $425 per ton, which makes this process especially suited for hard to treat wastes, such as mixtures of metals and organics

2. Example Site(s)

Site 1. Parsons Chemical/ETM Enterprises Superfund Site, Grand Ledge, Michigan. A full-scale soil remediation system using ISV was conducted at the Parsons Chemical/ETM Enterprises Superfund site (Parsons). This was the first application of full-scale *in situ* vitrification at a Superfund site to treat soils and sediments contaminated with pesticides, heavy metals, and dioxins. It is included here as a sample site for heavy metals contamination to emphasize the fact that contamination is often mixed.

Soils and sediments at the site were contaminated with pesticides, heavy metals, phthalates, PAHs, and dioxins as a result of former agricultural chemical manufacturing processes. Dioxin levels in soil at the site were reported as high as 1.13 ~g/kg. Maximum levels of other contaminants in the soil range from 0.99 mg/kg for phenanthrene, up to 34 mg/kg for mercury, and up to 340 mg/kg for DDT. Soil cleanup requirements were established for 4 constituents (chlordane, DDT, dieldrin, and mercury). In addition, the gases from the ISV unit were required to meet state air requirements for these constituents during operation.

The ISV system used at Parsons included 9 melt cells and an air emissions control system, consisting of gas collector, hood, water scrubber, and thermal oxidizer. Standards for gases were established for 4 constituents: chlordane (1 mg/kg / 25 pounds/hour); DDT (4 mg/kg / 0.01 pounds/hour); dieldrin (0.08 mg/kg / 0.00028 pounds/hour); and mercury (12 mg/kg / 0.00059 pounds/hour).

Contaminated soil was excavated and staged at the site because of the shallow nature of the contamination. The melt cells were installed in a 16-foot deep treatment trench, and each cell was 26 feet by 26 feet. Eight melts were completed from June 1993 to May 1994. The melts ranged in duration from 10 to 19.5 days and consumed between 559,000 and 1,100,000 kilowatt-hours of electricity per melt. Several operational problems were encountered during this period including fires and equipment problems. These problems were addressed through modifications of equipment and operating practices.

Because the melt requires approximately 1 year to cool before samples of the subsurface can be collected, data on the performance of the ISV were not available. According to the vendor, initial results of samples taken from the surface indicate that near-surface vitrified materials contained acceptable levels of pesticides and mercury. Data on typical air emissions indicate that stack gas emissions were in compliance with state standards during operation. A total of 3,000 yd^3 of silty clay soil with high moisture content was treated. The soil was reported to be difficult to work under both very wet and very dry conditions. The cost ceiling identified in the action memorandum for this application was $1,763,000, including the cost objectives of $800,000 for vitrification activities; approximately $800,000 for before-treatment activities (mobilization, site administration and preparation, sampling and analysis, and site configuration); and $90,000 for after-treatment activities (backfill and restoration, drainage structures, and demobilization)

Site 2. Pristine, Inc. Superfund Site, Reading, Ohio. Pristine, Incorporated, performed liquid waste disposal operations at the site from 1974 to 1981. Spills and on-site disposal of treated wastes led to soil contamination. Soils at the Pristine site were contaminated with volatile organics up to 0.14 ppm and semivolatile organics up to 130 ppm, PAHs, pesticides, and metals, with lead ranging from 26 ppm to 1,100 ppm.

The soils also contained more than 2 percent of elemental sulfur. This application was notable for treating soil with a wide range of pH and moisture conditions, with soil moisture ranging from 12 to 25 percent, and a pH of 1-2 for some feed soils.

SoilTech's 10 ton/hour mobile Anaerobic Thermal Processor (ATP) system was used for treating the contaminated soil at the Pristine site. The SoilTech ATP system included a feed system, the ATP unit (rotary kiln thermal desorber with proprietary sand seals), a vapor recovery system, a flue gas treatment system, and a tailings handling system. Air emissions were controlled using cyclones, a baghouse, scrubbers, a fractionator, a condenser, and gas-oil-water separator. Water was treated on site using an oil/water separator, hydrogen peroxide oxidation, sand filtration, and carbon adsorption, all in an on-site wastewater treatment system. The ATP system was operated at the Pristine site from 1 November 1993 until 4 March 1994 and was used to treat approximately 12,800 tons of contaminated soil.

The ATP System treated contaminants in soil to levels below the cleanup goals. Levels of 6 of the 11 target constituents were reduced to concentrations at or below the reported detection limits for dioxin/furan emissions and particulates. All stack gas air emission performance standards were met in this application, with occasional spikes of THC over the 20 ppm performance standard. Average throughput was approximately 6.5 tons/hour, and average on-line availability was approximately 62 percent.

No cost data were available for this site.

Site 3. Landfill Cut, Installation Restoration Site 2, Naval Air Station, North Island, San Diego. An exposed face of a landfill cut containing contaminated ash-like materials presented a risk of exposure to a variety of human and other receptors. The contaminants of concern were arsenic and lead. The near-vertical slope of the landfill cut was also a physical hazard due to its unstable condition, and poor stormwater drainage created the possibility for contaminated materials to migrate from the site. The site itself occupies 5 acres and measures 1,500 by 200 feet. The Landfill Cut is located on the southern portion of Site 2, and measures 110 feet long by 12 feet high. Ash-like materials, presumably from trash incineration at a nearby building from 1938 to 1947, were exposed.

The objectives in this Non-Time Critical Removal Action were to prevent erosion, contact, runoff, and airborne emission and to restrict leaking of contaminants from the soils. The selected remedial technology to reduce the risk of exposure to arsenic and lead included regrading the near-vertical Landfill Cut to a 1.5 horizontal to 1 vertical (1.5H:1V) slope:

- Re-use of an existing 90 yd^3 stockpile of soil, to the extent feasible, as backfill during the regrading process
- Placement of a containment cap over the regraded slope as a clean barrier to minimize exposure to arsenic and lead and to minimize surface water infiltration into the regraded slope

- Revegetation of the regraded slope with a non-irrigated native seed mix
- Installation of drainage improvement structures to intercept surface water runoff from a nearby parking lot
- Repair of damaged asphalt in the immediate vicinity of the Landfill Cut
- Reconfiguration of two retaining walls to create one wall, allowing a gradual and smooth transition of the regraded slope and increasing the landfill volume so that all excavated materials, including the existing 90 yd^3 stockpile of soil, were placed back into the landfill prior to capping.

The total costs were $262,000 as follows: pre-construction submittals, $37,000; mobilization/demobilization, $5,000; excavation of slope, $48,000; slope reconstruction and cover system, $53,000; post-construction submittals, $20,000; and project management, health, and safety, $96,000.

Since the removal action's objective was to control contact with the contaminants of concern from soils at the exposed back of incinerator ash, confirmation sampling was not warranted.

Site 4. Big River Mine Tailings/St. Joe Minerals Corporation, Desloge Missouri. The Big River Mine Tailings/St. Joe Minerals Corporation site is located in a former mining region known as the "Old Lead Belt," which is 70 miles south of St. Louis. Numerous tailings ponds and piles are found in this rural region, approximately 110 mi^2 in size. From 1929 to 1958, mine tailings rich with lead, cadmium, and zinc were disposed of at the 600-acre Big River Mine Tailings area by the St. Joe Minerals Corporation. Three sides of this site are bounded by the Big River.

In 1972, St. Joe Minerals Corporation donated 502 acres of land in the area to St. Francois County. In 1973, St. Francois County Environmental Corporation (SFCEC) leased approximately 60 acres of the southern portion of the tailings pile from the county to operate a sanitary landfill; the landfill is no longer in operation. A transfer station and recycling center is now located on site. In 1977, heavy rains caused an estimated 50,000 yd^3 of tailings to slump into the Big River. In 1981, St. Joe Minerals Corp. made an attempt to stabilize the tailings. Elevated levels of lead were first detected in bottom-feeding fish by the Missouri Department of Conservation and, in 1982, in surface water by the Columbia National Fisheries Research Laboratory. Local residents were advised not to eat the fish. The Big River is used for recreational purposes such as fishing, as well as for commercial activities such as watering livestock. Approximately 23,000 people reside within 4 miles of the site.

Elevated levels of lead, cadmium, and zinc have been detected in the tailings pile. Surface water and various forms of life in the Big River contain elevated concentrations of lead. Wind erosion and airborne dust have contaminated the surrounding air and are a potential hazard to on-site workers, residents, and children at a nearby day care center. Fish in the Big River have shown elevated levels of lead. People at the site risk being exposed to contaminants in the soil.

The parties potentially responsible for site contamination have begun in-place stabilization of the pile, designed to prevent further contamination of the river. Other activities that will be performed include revegetating the area to control contaminant run-off, covering the site with a soil and clay cap, and vegetating the cap.

Investigations to determine the nature and extent of contamination are being conducted and are scheduled for completion in 1996. Following the investigations, a remedy for final site cleanup will be selected.

Stabilizing the pile has reduced the potential for exposure to site contaminants at the Big River Mine Tailings/St. Joe Minerals Corporation site while further initial actions and investigations are underway.

No cost data were available.

Site 5. Former Scrap Metal Processing Yard, Port of Los Angeles, California. Approximately 100,000 tons of heavy metal contaminated soil from a former scrap metal processing yard at the Port of Los Angeles were treated using a polysilicate technology in a processing system. Soil was treated at a rate of 100-125 tons/hour. A metal or, more commonly, the metal oxide, is transformed into a metal-silicate structure such as lead oxide to form a lead metasilicate. Relatively small quantities of polysilicate and cementitious material are required resulting in a small volume increase after treatment. The result is a crumbly soil that can be moved with conventional loading equipment and is suitable for backfilling or other reuse. A Lopat K20 potassium silicate blend was used for this particular project, with the principal heavy metals being lead, cadmium, copper, zinc, nickel, and chromium. Typically, the soluble levels of these metals, in the range of several hundred milligrams per liter, were reduced by 1 to 2 orders of magnitude by the treatment. The soil, now nonhazardous, was backfilled on the site in compliance with local water board requirements. This process allows soil to be treated cost effectively at throughput rate not previously achievable. No cost data were available.

3. Documentation

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EPA. *Recent Developments for In situ Treatment of Metal Contaminated Soils.* Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, D.C. 20460, 1997.

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Yang, David S., Sigeru Takeshima, Thomas A. Delfino, and Michael T. Rafferty. "Use of Soil Mixing at a Metals Site." *Proceedings of Air & Waste Management Association, 8th Annual Meeting.* June 1995.

4. World Wide Web Site(s)

- http://www.frtr.gov/costper.html
- http://www.clu-in.com/pubindex.htm
- http://www.epa.gov/region07/programs/spfd/nplfacts/big_river.html (Specific to Big River Mine Tailings.)
- http://www2.uwin.siu.edu:4001/usr/local/data/wrsic/1993.text_2508954_1993 (Specific to the Port Los Angeles former scrap metal processing yard)

- http://www.srs.gov (includes *in situ* vitrification)
- http://www.env-sol.com/ETUS/hp-detox.html (An *in situ* and *ex situ* detoxification and stabilization technology)
- http://www.crcpress.com/PRODS/L1080.HTM (Site to obtain books, including The Application of Solidification/Stabilization to Waste Materials)

C. HEAVY METALS IN SEDIMENTS: DREDGE, HAUL, AND TREAT

Sediments contaminated with heavy metals present special difficulties, as do any contaminated sediments. In any cleanup, the first consideration is to determine the extent of contamination, then the risk. Terrestrial site remediation decisions are primarily driven by human health risks, which have known standards. The source of the contamination is generally well defined, and there are many active remedial options. For marine or fresh water sites, the remediation decision is primarily driven by ecological risks, which have no known standards. The source of contamination is often undefined, and few active remedial options exist.

Environmental managers use only a few different methods to keep toxic chemicals in these sediments from being released into water and entering the food chain. The options for working with them are to cover them up, dig them up, or leave them alone.

One approach is to remove pollutants by chemical means; however, no sites where this was attempted could be located.

The second approach is to dredge the sediment, placing it on an upland area in a landfill, with or without further treatment. Further treatment of dredged material is some form of S/S. Solidification is the process of eliminating the free water in a semisolid by hydration with setting agent(s) or binder(s). Stabilization can be both physical and chemical. Solidification usually provides physical stabilization but not necessarily chemical stabilization. Physical stabilization refers to improved engineering properties such as bearing capacity, trafficability, and permeability. Alteration of the physical character of the material to form a solid material reduces the accessibility of water to the contaminants within a cemented matrix and entraps or microencapsulates the contaminated solids within a stable matrix. Since most of the contaminants in dredged material are tightly bound to the particulate fraction, physical stabilization is an important contaminant immobilization mechanism.

Chemical stabilization is the alteration of the chemical form of the contaminants to make them resistant to aqueous leaching. S/S processes are formulated to minimize the solubility of metals by controlling pH and alkalinity. Anions, which are more difficult to bind in insoluble compounds, may be immobilized by entrapment or microencapsulation. Chemical stabilization of organic compounds may be possible, but the mechanisms involved are poorly understood.

Binders include cements, pozzolans, or thermoplastics. In certain instances, proprietary additives may also be added to the process. Results of reactions of binders to the contaminated sediment are not always predictable because of varying contaminant types and concentrations within the test material. Therefore, laboratory leach tests must be conducted on a sediment-specific basis.

A third, less complex and less costly, but not as well proven, treatment alternative is to isolate pollutants from the surrounding environment without dredging. This can be done with *in situ* solidification and stabilization, or *in situ* capping. S/S is a promising treatment for containing and immobilizing dredged material contaminants within a disposal site. S/S technology has been applied in Japan to bottom sediments containing toxic substances and in the United States to industrial wastes. Laboratory investigations of S/S of dredged material have been performed for Indiana Harbor, Indiana; Everett Bay, Washington; and New Bedford Harbor, Massachusetts. While S/S is not a solution to every disposal problem, it offers improved physical characteristics that reduce the accessibility of water to contaminated solids and reduce leachability for many contaminants.

Another nonremoval treatment showing special promise is *in situ* capping, which seals off contaminated sediments under a layer (or layers) of soil, rock, or synthetic material. *In situ* capping is a low-cost, low-technology alternative for keeping contaminated sediments from polluting lakes, rivers, bays, and coastal estuaries. Please refer to the Section D, which follows.

Characterization of the sediment itself helps predict what management protocols would be reasonable for a given site. Part of that characterization examines site-specific contaminant-sediment interactions. Contaminant bioleachability indicates the fraction of the contaminant that is of ecological concern and defines realistic endpoints. The contaminant distribution, with grain size and mass, indicates how it may be possible to reduce the volume of sediment to be treated. Assessing the microbial health and degradation potential indicates the potential of *in situ* or *ex situ* biotreatment. Testing for contaminant chemoleachability indicates the risk that could occur during dredging and potential for chemical treatability.

The data can be used to separate contaminated from uncontaminated sediments. If little or no fraction of the contamination is bioleachable, then biodegradation is probably not an option, and perhaps the contaminants are not a threat to the ecology or to human health. If the contaminants are easily bioleachable, then control measures may be placed during dredging. Perhaps gentle leaches may decontaminate the sediment, or simple aeration (in the case of petroleum contamination) may be sufficient to decontaminate.

To control the cost of sediment management, the volume of treated sediment must be minimized. Minimizing sediment volume requires good site assessment and field screening tools to define the contaminated areas. Risk assessment along with understanding contaminant behavior in sediments will be used to develop the appropriate criteria for cleanup. Only those sediments determined to be the risk will need to be treated by dredging or capping. Please refer to Appendix G.

Contaminated sediments can be removed by dredging, depending on depth, threat to life and health, equipment availability, and treatment facilities. Dredging operations are costly, ranging from \$30 to \$1,350 per cubic yard. Treatment of contaminated sediments could range from simply landfilling the material, which would also involve an impermeable liner, leachate collection and landfill cap, to the cleanup of contaminated water and sediment material with technologies such as UV oxidation and incineration. The report from the National Research Council, *Contaminated Sediments in Ports and Waterways*, notes that current treatment technologies available for large volumes of sediments generally are too costly, averaging more than \$100 per cubic yard, as compared to \$20 for removing and transporting sediments and \$5 for conventional navigational dredging, which does not require special disposal procedures.

1. Example Site(s)

Site 1. Buffalo River Sediments, New York. Past industrial and municipal discharges to the Buffalo River have polluted the river and its sediments with a variety of contaminants, including polynuclear aromatic hydrocarbons (PAHs), poly-chlorinated biphenyls (PCBs), and heavy metals.

A pilot-scale demonstration in Buffalo, New York, in the fall of 1991 evaluated the ability of a thermal desorption process to remediate Buffalo River sediments of the

PAHs and PCBs. A portion of the residual solids from the thermal treatment process was mixed with various proportions of Portland cement to evaluate the ability of one solidification/stabilization process to bind heavy metal contaminants. The solidified blocks were sampled and analyzed to determine the effectiveness of the solidification.

Based on analyses of the untreated sediment, five metals were selected for evaluation: chromium, copper, lead, nickel, and zinc. Initial screening tests were conducted on the sediment to narrow the range of binder-to-soil ratios to be prepared in the detailed evaluation. Three binder materials were evaluated: cement, kiln dust, and lime/fly ash. Based on the results of the initial screening test, binder-to-soil ratios were selected for the detailed evaluation. Specimens were prepared by mixing sediment and binder materials in a Hobart K455S mixer and molding the mixture. The specimens were cured for 28 days at 23 °C and 98 percent relative humidity.

Contaminant release tests determined the effectiveness of the binder materials on immobilization of the contaminants. The S/S specimens were subjected to the U.S. Army Engineer Waterways Experiment Station serial leach test (SLT) and the toxicity characteristic leaching procedure (TCLP). The SLT results were compared to the drinking water standards, and the TCLP results were compared to the levels required for the maximum concentration of the contaminant in the TCLP extracts.

Sediments remained in the thermal desorption unit from 30 to 90 minutes and sediment temperatures reached 300-480 °F. Removal of PAHs was from 43.2-97.9 percent, while 9.1 to 100 percent of total PCBs (Aroclors 1248 and 1254) were removed. Although this thermal process had little effect on most metals, 16.7-100 percent of mercury was removed from sediments during processing. Removal rates for constituents of concern did not correlate well with treatment times or temperatures.

Concentration levels for chromium ranged from less than 13-312 μg/g while concentration levels for mercury ranged from 0.0109-1.93 μg/g. Lead concentrations ranged from 28-314 μg/g, and zinc concentrations ranged from 32-900 μg/g. In general, the highest concentration levels of metals were in the terminal end of the Buffalo Ship Canal and in the middle third reach of the Buffalo River.

In 1990 and 1991, sediment vibracore samples were collected by USEPA. Generally, approximately 1-3 meter core samples were taken and analyzed. Results indicated that sediment contamination is either relatively low and consistent with respect to depth or increases with respect to depth to a maximum level — at which point a relatively clean, natural clay layer is reached.

Sediment transport modeling is being conducted by the USEPA under the Assessment and Remediation of Contaminated Sediments (ARCS) Program.

No cost data were available.

Site 2. Old Navy Dump/Manchester Superfund Site, Washington. Located south of the Manchester State Park and north of the Naval Supply Depot near Manchester, Washington, this site has been divided into three main areas: the former Net Depot, the former Landfill, and the former Fire Training Areas. The former Landfill extends into the park and the tidelands of Clam Bay and is the only area of these three included in this document.

Choice of cleanup method has not been finalized. Public comment was to have been received by May 2, 1997. However, the choices and the associated costs are illuminating.

Between 1946 and 1962, the Navy filled a former tidal lagoon between the Net Depot and the Fire Training Area with building demolition debris, garbage from the Puget Sound Naval Station, scrap metal, and other debris. The resulting landfill, which has an average thickness of 6 feet and covers about 6 acres, was covered with a 1-foot thickness of sand and gravel. The southeastern edge of the landfill is exposed along Clam Bay. Erosion of exposed debris has resulted in PCB contamination of mudflat sediments and shellfish. Shallow ground water flow from infiltration and tidal flow of saltwater into and out of the landfill debris transport dissolved metals and PCBs into Clam Bay.

Water samples collected in the vicinity of the landfill showed elevated levels of metals, which could pose a risk to the marine environment in Clam Bay. However, the drinking water for surrounding residents and site employees is not affected. Ground water in the vicinity of the landfill is not a current or potential source of water supply. Analysis of sediment samples from the shoreline of Calm Bay indicated levels of metals, PCBs, and dioxin/furans above standards. These levels are a risk to the marine environment and the shellfish populations, specifically the clams from the nearshore areas. Consumption of shellfish from the shoreline could pose a health risk. However, there is no indication that subsistence shellfishers or a significant number of current recreational shellfishers exist. Finfish or shellfish found outside of the site vicinity do not appear to be affected.

Four cleanup alternatives were as follows:

- No Action — the Landfill and the Clam Bay sediments would be left as they are.

- Capping the Upland Landfill, Armoring Over the Intertidal Debris, and Placing a Thin Cap Over the Remaining Impacted Sediments — The cap would prevent infiltration of rainwater into the landfill, be designed to meet state requirements, and be consistent with the long-term plans for the property. Armoring the landfill areas lying within the intertidal zone of Clam Bay with a layer of rocks would prevent further erosion of the landfill and provide a physical barrier to keep people and wildlife away from the debris. The armor layer may be 2-3 feet thick and would be filled with finer grained soils to provide a suitable environment for marine organisms.

  The armor would raise the level of the beach, causing an outward shift in the high water line and losing about 0.9 acres of existing aquatic area. Measures to mitigate the loss of aquatic habitat would need to be addressed.

  Rows of clean sediment windrows would be placed over sediments exceeding the state cleanup standards if these are not covered by the armor layer. Tide and wind forces would spread the clean sediment naturally and evenly over time. Remaining sediments with low concentrations of contamination are expected to recover rapidly once erosion of landfill waste is eliminated.

  Long-term land use restrictions and a cap maintenance program would be implemented. Short-term restriction on harvesting shellfish would apply until sediment and tissue cleanup levels are met. Sediment and shellfish would be monitored for 3-5 years, the time period estimated for recovery by natural processes.

  The cost is estimated to be $3.2 million to $3.7 million.

- Capping of Upland Landfill, Excavation of Intertidal Debris and Placement of Design Fill, and Placement of the Thin Cap Over Remaining Impacted Sediments — Similar to the second alternative, this would cap the upland landfill, but debris in the intertidal zone would be excavated and placed on the upland landfill before capping. The objective of this alternative is to minimize the effect on the aquatic habitat and maximize long-term beach stability. The excavation would be backfilled with a clean fill material covered by a protective rock/cobble layer similar to the one for the second alternative, but covering a smaller beach area. The fill material would be designed to further reduce the potential for water quality impact associated with seep discharge.

  Excavation of landfill debris is expected to be difficult because of the presence of submarine nets and the nature of the debris. Special equipment may be required, including hydraulic shears and torches. A temporary dike would be constructed offshore to minimize the potential for drainage of landfill runoff and suspended sediment into Clam Bay during excavation and construction activities. As in the second alternative, placement of windrows of clean sediment, the same land use restrictions, cap maintenance, restrictions on subsistence shellfish harvesting, and sediment/tissue monitoring would apply.

The estimated cost of this alternative is $4.9 million.

- Excavation/Dredging, Limited Treatment and Off-Site Containment of All Landfill Debris, Soils, and Impacted Sediments — In this choice, all landfill debris, both intertidal and upland, would be excavated and placed in an approved off-site landfill. Some of the waste may require special handling and treatment before disposal.

  A large volume of soil and debris would need to be excavated in this alternative. The upland excavation areas would be restored by backfilling with clean imported fill and revegetating. Intertidal excavation would be backfilled with cobble and habitat material. All Calm Bay sediments exceeding the state cleanup standards would also be removed and disposed of in an off-site landfill. No long-term monitoring would be necessary.

  The estimated cost of this alternative is $47 million.

2. Documentation

EPA. *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Status and Needs.* Office of Science and Technology and Office of Solid Waste, Washington, DC. Document is in draft form: the final form will be available late 1997.

Briefing Report to the EPA Science Advisory Board on the Equilibrium Partitioning Approach to Predicting Metal Bioavailability in Sediments and the Derivation of Sediment Quality Criteria for Metals - Vol. I. EPA#: 822/D-94-002. ERIC#: D-036, 1994.

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Environmental Toxicology and Chemistry. Vol. 15 No. 12, December, 1996. This issue contains 15 articles about the prediction of bioavailability of cationic metals in sediments, including how to derive sediment quality criteria for cadmium, copper, nickel, lead, and zinc. The papers describe the use of metal acid volatile sulfide relationships and interstitial water chemistry to predict metal toxicity, key metal-binding phases in sediments, models, and associated data for predicting the stability of metal sulfide complexes such as in conjunction with bioturbation. The lead article presents the technical basis of deriving sediment quality criteria for metals.

Fleming, E. C., D. E. Averett, M. G. Channell, B. D. Perry. Abstract and Table of Contents to "An Evaluation of Solidification/Stabilization Technology for Buffalo River Sediment," Miscellaneous Paper EL-91-11 [online]. University Center, Mich.: Consortium for International Earth Science Information Network (CIESIN). URL: http://epaserver.ciesin.org/glreis/glnpo/data/arcs/EL-91-11/EL-91-11.html (Specific to the Buffalo River site), 1991.

Handling and Treatment of Contaminated Dredged Material from Ports and Inland Waterways. Permanent International Association of Navigation Congresses (PIANC) Working Group 17. This report, soon to be available in CD-ROM format completes the final stages of a 4-year, comprehensive assessment of the handling and treatment of contaminated dredged material (CDM). It is a two-volume report: Volume I provides general guidance for the preparation of dredging projects that handle and treat CDM and is primarily for navigation authorities, permitting agencies and review agencies. Volume II is a completely searchable database of 86 Technology Fact Sheets and 18 Case Studies containing much of the technical information and sources of technologies and international experiences in dealing with CDM. These details are needed by the practicing engineer or other professional requiring specific data and pertinent sources of information. In the United States, this report will be available by late 1997 in CD-ROM format from U.S. Section Permanent International Association of Navigation Congresses, CODE PTC 11 - CD-ROM, 7401 Telegraph Road, Alexandria, VA 22315-3868, or for distribution in Europe or Asia from PIANC General Secretariat, WTC - Tour 3 - 26th Floor, Boulevard Simon Bolivar 30, B1210 Brussels, BELGIUM.

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QA/QC Guidance for Sampling and Analysis of Sediments, Water, and Tissues for Dredged Material Evaluations, Chemical Evaluations. 1995. EPA#: 823/B-95-001. ERIC#: D-A29

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Tiered Testing Issues for Freshwater and Marine Sediments: Proceedings of a Workshop. 1993. EPA#: 823/R-93-001.NTIS#: PB93-152619. ERIC#: D-138

U.S. Army Engineer District. 1993. Abstract and Table of Contents to "Pilot-Scale Demonstration of Thermal Desorption for the Treatment of

Buffalo River Sediments," EPA-905-R93-005. University Center, Michigan: Consortium for International Earth Science Information Network (CIESIN).

3. World Wide Web Site(s)

- http://www.epa.gov/OST/
- http://www.epa.gov/OST/pc/sqc.html (Sediment Quality Criteria)
- http://epawww.ciesin.org/glreis/glnpo/data/arcs/EPA-600-SR93-242/EPA-600-SR93-242.html (Specific to the ARCS Quality Assurance Program)
- http://epaserver.ciesin.org/glreis/glnpo/data/arcs/EPA-905-R93-005/EPA-905-R93-005.html (Specific to the Buffalo River Pilot Study)
- http://epawww.ciesin.org/glreis/glnpo/data/arcs/EL-91-11/EL-91-11.html#ABS (Also specific to the Buffalo River Pilot Study)
- http://www.nws.usace.army.mil/geotech/manchest/manch.htm (Specific to the Old Navy Dump/Manchester site)

D. HEAVY METALS IN SEDIMENTS: *IN SITU* CAPPING

In situ caps are designed to seal contaminated sediments in place for long periods of time. Because the most widely used remediation methods call for treatment or removal of these pollutants, *in situ* capping is somewhat controversial.

The material presented here on *in situ* caps has been developed by the Hazardous Substance Research Centers, a research, technology transfer, and training organization sponsored by the USEPA.

In general, capping is most effective where long-term stability of the cap is likely. Good candidates are underwater disposal sites that do not need maintenance dredging to keep shipping lanes open and are not prone to storms that cause erosion and movement of bottom sediments. Capping can also be used in areas prone to erosion and sediment movement, if the cap is stabilized with a layer of rocks.

Capping works well in sealing a variety of sediment bed types and a broad range of chemical pollutants. Some of the chemicals it effectively isolates include aliphatic hydrocarbons, chlorinated solvents, inorganics (metals and radionuclides), oxygen-demanding materials, nitrates, pesticides, phosphates, polychlorinated biphenyls, and polynuclear aromatic hydrocarbons.

Advantages of *in situ* capping are reasonable cost, simplicity, and lack of contaminant disturbance.

Capping is significantly less expensive than the removal and treatment of contaminated sediments. To dredge and cap costs $5 to $25 per cubic yard, while removal and treatment costs $30 to $1,350 per cubic yard. Remove and treat costs are higher because of the high water content in dredged sediment materials that must be remediated, the large volume of sediment that must be removed, and the generally low level of contamination in extracted sediments. The technology is simple, and not leaving polluted sediments in place decreases the possibility of toxicity.

In capping projects, expenses consist of capping materials, construction equipment, and labor. These costs will vary according to a number of factors, including capping design, site accessibility, and water depth. Expenses can be reduced in cases where clean dredged material can be used in a project. The costs of operating and maintaining an *in situ* site involve monitoring programs and regular replenishment of the cap. Based on experience in dredged material capping, the U.S. Army Corps of Engineers' New England Division estimates the cost of a routine 3-year monitoring cycle of $30,000.

The disadvantages include application uncertainty, placement, and leaving the contaminants untreated. Research is continuing to determine better capping alternatives. Placement can be problematic due to mixing and consolidation of the underlying sediment, which may squeeze out contaminated water and stir up contaminants in the sediment. Poorly executed placement may not result in uniform, adequate coverage. Although capping has been shown to seal contaminated sediments, it does leave toxic chemicals intact. Their continued presence may or may not be a problem, depending on the effectiveness of the capping job and the rate of natural recovery processes.

1. Example Site(s)

Site 1. Eagle Harbor Superfund Site, near Bainbridge Island, Washington. The Army Corps of Engineers worked in support of USEPA by designing and constructing the project, the first in the Pacific Northwest, to use clean dredged material at a Superfund site to confine contaminated sediments. Approximately 275,000 yd^3 of clean sediments have been placed on the bottom of the East Harbor, forming a layer ranging from 1-3 feet thick. Water depth remains more than adequate for boat and ferry traffic.

The south shore of Eagle Harbor was the location of a wood treating operation for more than 80 years. A shipyard operated on the harbor's north shore. The wood treating facility, harbor, and other upland sources were included as one site. Bottom sediments in much of the harbor are contaminated with chemicals from wood treating and shipyard operations. These chemicals (specifically, creosote and mercury) are toxic to marine organisms. Beginning in October 1993 and ending in March 1994, the EPA and the Corps of Engineers covered contaminated sediments in the East Harbor with a cap of clean sediment. The sediment was dredged from the Snohomish River as part of an annual project to keep the river channel open for ship navigation. The sediment was placed using 2 methods: split-hull barge and hydraulic wash-off. The material was placed in incremental layers over 54 acres of contaminated harbor sediments to provide clean habitat for marine life. Video monitoring in March 1994 indicated that marine life had already begun to re-occupy the cap. Sea anemones, sea pens, gobies, starry flounder, and a skate were observed.

Periodic monitoring of the cap is planned to assure the long-term effectiveness of the sediment cleanup. The current monitoring plan covers an initial 10-year period and includes measurements of cap thickness, suspended sediment chemistry, and cap sediment chemistry, as well as qualitative observations of biological recolonization. Cap baseline monitoring was completed in the fall of 1995 and show that the cap is functioning as planned.

No cost data were available.

2. Documentation

Leclair, Vincent. "Contaminated sediment management needs better assessment tools, NRC says," *Environmental Science and Technology* Vol. 31, No. 5, 1997.

The following United States Environmental Protection Agency (USEPA) documents are available on the World Wide Web, or a hard copy can be ordered from the United State Environmental Protection Agency:

USEPA - Assessment and Remediation of Contaminated Sediments (ARCS) Program: Assessment Guidance Document. EPA-905-B94-002. The full text of this document is available at the Internet site of: http://epawww.ciesin.org/glreis/glnpo/data/arcs/EPA-905-B94-002/EPA-905-B94-002-toc.html

USEPA - Assessment and Remediation of Contaminated Sediments (ARCS) Program: Remediation Guidance Document, EPA-905-B94-003. The full text of this document is available at the Internet site of: http://epawww.ciesin.org/glreis/glnpo/data/arcs/EPA-905-B94-003/EPA-905-B94-003-toc.html

USEPA - Office of Wetlands, Oceans, Watersheds (OWOW) and the U.S. Army Corps of Engineers: Evaluating Environmental Effects of Dredged

Material Management Alternatives: A Technical Framework. EPA842-B-92-008. The full text of this document is available at the Internet site of: http:// www.epa.gov/OWOW/oceans/framework/index.html

USEPA - Office of Wetlands, Oceans, Watersheds (OWOW) and the U.S Army Corps of Engineers: Evaluation of Dredged Material Proposed for Ocean Disposal. EPA 503/8-91/001. The full text of this document is available at the Internet site of:
http:// www.epa.gov/OWOW/oceans/gbook/index.html

3. World Wide Web Site(s)

- http://wwwel.wes.army.mil/el/dots/dots.html (United States Army Waterways Experiment Station Dredging Operations Technical Support). This site may require special permission to view.
- http://eoeml-www.gtri.gatech.edu/home/markh/capping/index.html (In-Situ Capping Homepage.)
- http://www.epa.gov/OW/OST/

XI. RISK ASSESSMENT

The underlying principle of risk-based corrective action is the creation of an appropriate cleanup standard that includes (but is not limited to) such factors as target populations at risk as well as the fate, transport, and toxicity of constituents.

The Air Force Center for Environmental Excellence prefers a risk-based approach. For example, for petroleum release sites the Center promotes a four-step strategy: first, to negotiate a realistic cleanup standard to BTEX, instead of total petroleum hydrocarbons, followed by assessment of the natural attenuation capacity of the ground water. Next, recover any free product using bioslurper equipment, which can then be used for other technologies if needed, and lastly, for the soils, to remove the source from the soils by soil vapor extraction or bioventing.

In the heavily regulated atmosphere of U.S. environmental issues, changes to standards take time. To move to a risk-based corrective action stance would be possible but can require changes to many laws and many people's minds. In Central Europe, where standards differ, a risk-based corrective-action strategy could exist at the inception of the program.

The U.S. Environmental Protection Agency, Region III, annually distributes a risk-based concentration (RBC) table by mail to interested parties, or it can be viewed on the World Wide Web. This risk-based concentration table contains reference doses and carcinogenic potency slopes for nearly 600 chemicals, and soil screening levels (SSLs) for ground water and air. The RBC is used by USEPA Region III toxicologists to screen sites not yet on the National Priority List, respond rapidly to citizen inquiries, and spot-check formal baseline risk assessments. The RBC has important limitations. Transfers from soil to air or ground water, and cumulative risk from multiple contaminants or media are excluded. Moreover, the information in the table may contain errors. These concentrations alone are not the basis for valid no-action levels or cleanup levels, as other factors weight on this decision.

Using risk-based corrective action and risk-based assessment may be a wise move because, thus far, such standards tend to save money on cleanup efforts. We do not know what impacts these contaminants truly have. Some commentators have indicated that ecoreceptors may need to have standards in the parts per trillion (ppt). Chronic exposure to many contaminants especially affects the unborn, and deleterious effects are observed in animals and plants. Some of the suspected effects of chronic exposure to endocrine mimics are decreased growth rate, feminization of males, over feminization of females, accelerated or increased rates of breast, thyroid, and testicular cancer, and difficulties with metabolic rates.

A. ENVIRONMENTAL MODELS AND MODELING FOR RISK ASSESSMENT

Entering data from a site into a model and having the model design or choose a system can be cost effective. The expertise of many people, and the experience from actual sites has been part of the creation of many models. Appendix D lists environmental models, including the models that are listed under a technology section. Others are listed as reference sources.

B. REGULATORY IMPACT ON TECHNOLOGY SELECTION

In the United States, technology use is often driven by regulation. If the regulation requires a very low concentration of contaminant, such as in the parts per billion or parts per million, the means to attain that standard may be incineration or other expensive destructive methods. If, however, the standard is set based on risk and is set in the parts per thousand, for example, a simpler and less expensive technology could reach this standard, such as landfarming or bioventing.

Regulatory standards outside the United States may differ and can affect the choice of cleanup technology.

C. ON-SITE CHARACTERIZATION RISK ASSESSMENT

Air Force, Army, and Navy personnel extol the virtues of the Site Characterization and Cone Penetrometer System (SCAPS) for its speed and mobility. This system is a truck-mounted, hydraulic pressurized, hollow slender rod in sections through which microfibers are threaded to the tip or first rod section that has a sapphire window. A pulse of laser light is sent from the truck unit down the filament, leaves the window, and excites any hydrocarbons in the soil to fluoresce. Any fluorescence is captured by a second microfilament and returned to a detector in the truck. Hydrocarbons have a characteristic pattern in laser fluorescence that can reveal types and concentrations.

The disadvantages to SCAPS are that it is expensive (cost per day $4,000-$6,000), can only be used in soils through which the penetrometer can be pushed, and at present only uses a nitrogen laser to detect hydrocarbons. The advantages are the real-time data, the ease of delineating the plume in one to few days with several pushes of the penetrometer, and mobility of the unit.

Several commercial vendors have these systems, as does the Army Corps of Engineers and the U.S. Navy. Please refer to Appendix G.

Field instruments are available for fuel and solvent contaminant-screening purposes such as a field gas chromatograph, or Hach chemical analysis kits. Low-cost, field-portable electrochemical sensors exist for detection of heavy metals in surface or ground water. Biosensors have begun entering the commercial market. Some biosensors are reusable and thus have continuous monitoring capability.

Field data from any source could be transmitted to another location for analysis and design of a cleanup effort.

An internet site of EPA's Office of Wetlands, Oceans, and Watersheds is an online Watershed Tools Directory, listing several hundred assessment methods, models, documents, and other resources for watersheds or water supplies. http://www.epa.gov/OW/watershed/tools

D. INCORPORATING ISO 14000 STANDARDS WITH RISK ASSESSMENT

International Standardization Organization (ISO) 14000 Standards are global environmental management standards and will have considerable commercial impact on technology. Certification in these standards means progressing through a planning stage and creating a comprehensive management system. Companies that are certified in ISO 14000 standards will have an advantage in the trade and business sector. ISO 14000 Integrated Solutions, a service of the American National Standards Institute, provides critical information for companies desiring to do multi-national business and needing up-to-date information on country standards, auditors certified to do conformity assessments, and certified companies.

These voluntary environmental management standards are a framework for industry to redesign the way it is regulated. ISO 14000 is designed to make it easier for businesses to track their own environmental operations and performance. Many companies in Europe and the United States had already developed their own environmental management systems (EMS), and many are assessing their own EMSs against ISO 14000.

Risk assessment and ISO 14000 standards are a natural fit for a company. Importing and exporting companies and multi-nationals will find it easier to do business in other countries. In addition, such standards may make it easier to measure environmental performance and make meaningful comparisons across borders. This will certainly affect how environmental companies handle their own environmental issues.

E. ENVIRONMENTAL SYSTEMS MANAGEMENT, ANALYSIS, AND REPORTING NETWORK (E-SMART)

Current methods for gathering, analyzing, and reporting environmental data for contaminated sites is time-consuming and often involves specialized personnel. Extensive sensor development programs are already underway among Federal agencies to enhance the technology for *in situ* monitoring; however, the wide variety of such systems in use often results in an incompatible network and does not provide the operator with detailed information. The E-SMART network simplifies integration of these systems, significantly reduces the costs of environmental monitoring, assists site remediation managers, and helps ensure environmental compliance.

The continuing development of E-SMART, a technology that integrates a diverse set of environmental sensors, sampling systems, and software modules into large monitoring and control networks, will simplify the environmental monitoring of ground water, soil, and surface water. This system can detect spilled fuels, chlorinated solvents, and heavy metals and will be compatible with DoD E-SMART standards. It is expected to be extended to cover air contamination, compliance monitoring, and process control applications.

Sensor modules and digital networking form the backbone of this system and will work with virtually any type of environmental sensor or transducer. Complete data management and analysis software are integrated with the system. Use of *in situ* sensors greatly reduces sampling and analytical laboratory costs while maintaining required quality. E-SMART can be designed to fit a current application or be expanded to meet future needs. It uses intuitive display screens and menus, which reduce operator training time and provide clear presentation of data.

Future goals are to develop a new class of smart, highly sensitive, and chemically specific *in situ* sensors and a large, commercially viable set of compatible sensors, samplers, and management systems. Also needed is a low-cost, high-performance, user-friendly set of software for modeling with three-dimensional (3-D) visualization tools for fate and transport studies and remedial design.

F. SPECIAL CONSIDERATIONS FOR CENTRAL EUROPE

Some urgent problems require a remedy quickly, especially where contamination poses an imminent threat to human health or life. According to already established guidelines in central Europe, these contaminated sites are to be treated immediately. Second priority for treatment are sites that are a real threat to drinkable water supplies.

If a technology choice involves microorganisms in soil or ground water, the living cells in the contaminated zones may have been destroyed. In choosing a technology involving bioremediation, a check of the viability of organisms is required, as well as a test to determine if they are degrading the contaminant. There may be a possibility that organisms need to be introduced. These are not specialty organisms for sale. Rather, they are naturally occurring organisms from the local area, obtained from soil or ground water that is not contaminated. Essentially, this is a method of reintroducing natural micro flora to an area if it lacks its own.

Technologies are available to remediate fuels and chlorinated solvents. However, heavy metal contamination is problematic. If remediation is not possible for a heavy metal contaminated site for a variety of reasons, the site may have to be made inaccessible, either by fencing or perhaps by establishing a flooded area. This may create a wetland that may, over time, immobilize the heavy metals contamination.

In September 1996, the opening ceremony for the Risk Abatement Center for Central and Eastern Europe (RACE) was held. RACE is a forum where the ideas, problems, and inspirations of the people dealing with abatement of human and environmental risk in Central and Eastern European countries will be presented and thus provide opportunities to address the approaches already adopted in East and West European countries. This group is developing the Risk Abatement Network (RANET), a cooperative network designed for professionals and organizations to come together, exchange experience, and collaborate in the fields of environmental risk management and environmental restoration. Two networks exist in Western Europe: NICOLE (Network for Industrially Contaminated Land in Europe) and CARACAS (Concerted Action on Risk Assessment of Contaminated Land in Europe). RANET is a Central and Eastern European counterpart to these two networks. The RACE NEWS is the newsletter of this group, published quarterly by the Risk Abatement Center for Central and Eastern Europe, ul. Kossutha 6, 40-833 Katowice, Poland. Tel: +48-32-2546031 ext 275. E-mail: race@ietu.katowice.pl. This group's activities are orientated toward research and technology and their practical application. Another group first established in Budapest, Hungary, called the Regional Environmental Center (REC), focuses more on education and public awareness. Both of these groups can contribute to environmental awareness in the Central and Eastern European region and will be cooperating with each other. Another group, the Institute for Ecology of Industrial Areas in Katowice, performs broadly understood cooperation both with Western countries, especially the United States and Central and Eastern European countries. This institute acts according to legal regulations for scientific and research institutions, whereas RACE was formed to meet the challenge of finding solutions for arising problems. The Institute for Central and Eastern European Cooperative Environmental Research (ICEECER) participates with RACE and is based at Florida State University, Tallahassee, Florida.

G. DOCUMENTATION

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Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. ASTM Designation: E1739-95 (1. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428.

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The Integrated Risk Information System (IRIS), prepared and maintained by the U.S. EPA, is an electronic database that contains information on (1) health risk: maximum concentration levels (MCLs), carcinogenicity, and ambient water quality, and (2) U.S. EPA regulatory information on almost 700 specific substances. Contains over 5,000 pages of printed information. World Wide Web site maintained by the USEPA: http://www.epa.gov A CD-ROM format is also available.

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Risk Assessment and Risk Management in Regulatory Decision-Making. March 1997. President's Commission on Risk Assessment and Risk Management. Copies of the 150-page report may be requested by facsimile at (202) 233-9540 or accessed via http://www.riskworld.com

H. WORLD WIDE WEB SITE(S)

- http://www.epa.gov/reg3hwmd/risk/rbc_new.htm (The U.S. Environmental Protection Agency, Region III annually distributes a risk-based concentration table by mail to interested parties, or it can be viewed at this World Wide Web site.)
- http://www.epa.gov (The Integrated Risk Information System (IRIS) electronic database contains health risk and USEPA regulations in a fully indexed, searchable database.)
- http://www.env-sol.com/solutions/IRIS.HTML (The Web site to obtain a CD-ROM format of IRIS)
- http://www.brooks.af.mil/HSC/AL/EQ/prod09.html (E-SMART information)
- http://www.iso14000.org (ISS On-Line™ , an interactive network to educate, train and inform industry, government and non-government organizations about ISO 14000 standards)
- http://www.ovam.be/internetrefs/english.htm (Environmental information with an emphasis on Europe, provides links to other sites)

- http://www.ulb.ac.be/ceese/cds.html (Provides an alphabetical listing by subject of European environmental sites.)
- http://www.eea.dk:80 (European Environmental Agency - provides some agency reports, stronger on policy than on data)

XII. TECHNOLOGIES THAT ARE ALMOST FIELD READY

The following technologies are included in this document because they are inexpensive or effective, and they are close (by 1999 or 2000) to being field proven and ready: enhanced co-metabolism, surfactants, two phytoremediation technologies, and passive barrier walls to treat heavy metal contaminated ground water.

A. ENHANCED CO-METABOLISM (ENHANCED REMEDIATION)

Researchers are cautiously enthusiastic about this technology. Chlorinated compounds, also known as DNAPLs, are notorious for being recalcitrant to degradation. Both passive barrier walls (see Section F) and enhanced co-metabolism appear to be breakthroughs in treating these compounds that are so persistent.

Co-metabolism is the degradation of chlorinated compounds by enzymes from other nearby microorganisms that do not use chlorinated solvents for energy or as electron acceptors. Feeding the nearby microorganisms could enhance co-metabolic processes: the food source could be naturally occurring organics, accidentally spilled non-chlorinated organics, or deliberately placed organics such as benzene, high fructose corn syrup, raw molasses, butane gas, sodium benzoate, or acetate.

Enhanced anaerobic biodegradation of jet fuels in ground water is being demonstrated at a site with a coordinated effort now under way by Armstrong Laboratory's Environics Directorate and the Environmental Protection Agency's National Risk Management Research Laboratory (NRMRL). Nitrates, at a concentration below the drinking water standard, are introduced into the subsurface of a JP-4-contaminated aquifer to stimulate growth and activity of anaerobic bacteria; these bacteria break down the toxic compounds in the fuel as their energy source, while reducing nitrate to nitrogen. Success of this effort would provide a site cleanup method more cost-effective than pump-and-treat methods now in use.

This technology is being tested at Eglin AFB, Florida. A pilot-scale demonstration is being conducted in a JP-4-contaminated aquifer to assess the rate and extent of bioremediation of fuel components when nitrate is added. The site has been characterized at several locations, using an automated cone penetrometer and a geoprobe to delineate fuel mass and distribution, stratigraphy, and hydraulic conductivity of the soil. Water quality information and microbial characterization under both aerobic and anaerobic conditions have been obtained, as well as other baseline information about the site.

Jet fuel is composed of hundreds of hydrocarbons; the most important, because of their classification as EPA-priority pollutants are the aromatic hydrocarbons, otherwise knows as benzene, toluene, ethylbenzene, and xylene (BTEX). Microorganisms require oxygen or some other electron acceptor to carry out their biodegradation activities for these compounds.

Until now, *in situ* biodegradation of such fuels has been limited to aerobic processes which require large amounts of oxygen for stimulation of biological activity. Inability to provide sufficient oxygen to contaminated saturated soils has been a limiting factor. Delivery methods using hydrogen peroxide to introduce oxygen have been inefficient because of expense, rapid hydrogen peroxide decomposition, poor oxygen distribution, clogging of aquifer, and toxicity to microbes. Studies have shown, however, that alternative electron acceptors such as nitrate can be used in place of oxygen to enhance biodegradation of hydrocarbons. Nitrate is less expensive and more soluble than the previously used hydrogen peroxide.

1. Example Site(s)

Site 1. A full-scale demonstration of *in situ* co-metabolism has been completed at Edwards Air Force Base in California. For co-metabolic processes to occur, a population of microorganisms must be stimulated to grow on a preferred food source or substrate. These microorganisms then produce monooxygenases to degrade their preferred substrate but which happen also to degrade chlorinated hydrocarbons. These processes occur under aerobic conditions, so the microorganisms are provided with an oxygen source such as molecular oxygen or hydrogen peroxide as well as their preferred substrate such as methane, ethane, ethene, propane, butane, toluene, phenol, or ammonia.

The Edwards AFB site was chosen after an extensive search to unambiguously demonstrate the effectiveness of the proposed system. Here, a contaminated plume with TCE in the hundreds of µg/L range, and a location sufficiently distant from a source of non-aqueous phase contamination presented ideal conditions. The area of the plume lies about 200 meters from the contamination source, and the ground water surface lies about 9 meters below ground surface. Two aquifers are present, one above the other. The TCE concentrations in both aquifers were about the same, between 600 and 1,400 µg/L. The aquifer material consists of fine to medium size sand with some silt, and sorbs TCE only slightly, with an estimated retardation factor of two, which means the mass of sorbed TCE is not more than that in solution.

A novel 2-well treatment system was used. No water was brought to the surface except for monitoring samples. Toluene and either gaseous oxygen or hydrogen peroxide were pumped into each well to mix with contaminated ground water that was pumped so that it circulated through the well. The mixture entered the ground water where toluene and TCE biodegradation occurred. Each well was screened in 2 locations, one in the upper aquifer and the other in the lower aquifer. The system was set up to circulate water between the 2 wells and the 2 aquifers as well. The wells were 10 meters apart, a distance based on a detailed hydrogeological characterization of the site. The data reported here are over an initial 5-month period.

Oxygen injection began at the end of 1995 (day 357 of the year) well before toluene, which was added at 2.5 mg/L on day 39 of 1996, along with oxygen for a continuous 2-day period. Pumping and chemical addition stopped for 9 days while a population of toluene-oxidizing bacteria developed and the toluene concentration decreased. A second 2-day pulse of toluene at 3.8 mg/L with oxygen on day 50, then a third 2-day pulse of toluene at 7.6 mg/L and oxygen was introduced on day 54. Continuous pulsed injection of toluene began on day 57.

During the first 60 days of toluene injection, TCE removal increased to about 45 percent, and through the steady-state period of operation from days 145 to 270, removals averaged 87 percent in the upper aquifer and 69 percent in the lower aquifer. The effectiveness of TCE degradation is also indicated by the change in TCE concentrations in ground water moving out of the monitored zone. In the upper aquifer, the concentration at the east compass monitoring point was reduced to 50 µg/L and the south compass monitoring point to 25 µg/L. When toluene injection began, the TCE concentrations were about 600 µg/L at each of these points. Studies to improve TCE removal in the lower aquifer have begun.

2. Documentation

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Sims, J.L., J.M. Sufflita, and H.H. Russell. "*In situ* bioremediation of contaminated ground water." Ground Water Issue. Office of Research and Development, Office of Solid Waster and Emergency Response, U.S. Environmental Protection Agency, 1992. EPA/540/S-92/003.

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Vogel, T.M., C.S. Criddle, and P.L. McCarty. "Transformations of halogenated aliphatic compounds." *Environmental Science and Technology* 21, 1987, p. 722.

3. World Wide Web Site(s)

- http://www.brooks.af.mil/HSC/AL/EQ/prod07.html

B. SURFACTANTS

Cosolvents, mixtures of surfactants, or surfactant/co-surfactant/cosolvent mixtures are added to the ground water system to aid in mobilizing or solubilizing non-aqueous phase liquids (NAPL) or contaminants sorbed to the soil matrix. This technology is considered an enhancement to conventional pump and treat systems by increasing the contaminant mass removal per pore volume of ground water flushing through the contaminated zone. Excellent understanding of the hydrogeologic conditions is essential for this technology, and it works best in moderate to high permeability geologic materials.

When chlorinated solvents are an immediate threat to health, a site-specific surfactant is designed to remove the contaminant from the subsurface. Surfactant washes the PCE, TCE, and other chlorinated compounds off the soil particles, and the resulting liquid is then pumped and treated with a steam stripper. This technology, though effective, is expensive. It is included in this document because, if a site contaminated with DNAPLs already has a pump-and-treat system in place, this strategy may be adapted as a lower cost replacement alternative. It could be installed instead of a pump-and-treat system, but is quite costly.

Enhancing the remediation of subsurface environments with surfactant/cosolvent flushing has generally been tested and demonstrated in the field at several sites in the United States and Canada. These small scale tests are usually performed under highly controlled conditions. One full-scale test has been completed in Quebec, Canada, where surfactants facilitated the removal of 160,000 pounds of NAPL.

Although many tests have been performed in the 6 years since the first demonstration, the most critical limitation to the widespread acceptance of the technology appears to be the general lack of information regarding it, as well as a lack of personnel with expertise in applying it in the field.

The report from the Ground Water Remediation Technologies Analysis Center, listed below, discusses the current status of the technology, including the science involved. Several field demonstration summaries are presented, with such information as: participants, compounds treated, surfactants/cosolvents used, site characteristics, results, and contacts. Also discussed are costs, regulatory requirements, and constraints and limitations of this emerging technology.

1. Documentation

Jafvert, Chad T., "Surfactants/Cosolvents," Purdue University, School of Civil Engineering, published by the Ground-Water Remediation Technologies Analysis Center, December 1996, Document Number: TE-96-02. This document is available from the World Wide Web.

2. World Wide Web Site(s)

- http://www.gwrtac.org/html/tech_eval.html#SURF

C. PHYTOREMEDIATION

Phytoremediation uses plants to clean up contaminated soil and ground water, taking advantage of plants' natural abilities to take up, accumulate, and/or degrade constituents of their soil and water environments. The five basic types are: (1) **rhizofiltration**, a water remediation technique involving the uptake (absorption, concentration, and precipitation) of contaminants, especially heavy metals, by plant roots; (2) **phytoextraction**, a soil technique involving extraction and accumulation of contaminants in harvestable plant tissues such as roots and shoots; (3) **phytotransformation**, applicable to both soil and water, involving the degradation of complex organic molecules to simple molecules which are incorporated into plant tissues; (4) **phyto-stimulation** or plant-assisted bioremediation, also used for both soil and water, which involves the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone, and (5) **phytostabilization**, using plants to reduce the mobility and migration potential of contaminants in soil through absorption and precipitation of these contaminants, principally metals, by plants. These methods may or may not involve periodic harvesting of plants, depending upon the method.

Results of research and development into phytoremediation processes and techniques report it to be applicable to a broad range of contaminants including numerous metals and radionuclides, various organic compounds (such as chlorinated solvents, BTEX, PCBs, PAHs, pesticides/insecticides, explosives, nutrients, and surfactants). General site conditions best suited for potential use of phytoremediation include large areas of low to moderate surface soil (0-3 feet) contamination or large volumes of ground water with low concentrations of contaminants subject to strict treatment standards.

Phytoremediation is most effective where ground water is within 10 feet of the surface, and soil contamination is within 3 feet of the ground surface.

Major advantages reported include the possibility of generating fewer secondary wastes, minimal associated environmental disturbance, and the ability to leave soils in place and in a usable condition following treatment. Cited disadvantages include the long lengths of time required (usually several growing seasons), depth limitations (3 feet for soil and 10 feet for ground water), and the possibility of contaminant entrance into the food chain through animal consumption of plant material.

1. Documentation

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Research and Technology Development Forum site will carry session papers on phytoremediation projects.

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2. World Wide Web Site(s)

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- http://www.mrd.usace.army.mil/mrded-h/IT/itphyto.html
- http://www.mrd.usace.army.mil/mrded-h/mrded-h.html
  U.S. Army Corps of Engineers home page
- http://www.rtdf.org
  Research Technology and Development Forum
- http://www.ecc.ksu.edu/HSRC/Annual.Research.html
- http://www.ecc.ksu.edu/HSRC/phytorem/home.html

D. HYDRAULIC BARRIER WITH POPLAR TREES

Poplar trees can be a means of creating a hydraulic barrier strip to remediate contaminated ground water. The trees use the ground water for growth and, in the process, prevent a contaminated plume from continuing to spread, rather than actually remediating the contamination itself. It could be described as a natural pump system that redirects the water through the tree, but leaves the contaminant in place. The limitation is the depth to ground water: poplar tree roots can extend up to 6 feet, but only if planting methods ensure that the poplars, normally shallow rooted, depend upon water from the saturated zone. One to several rows of trees can be planted according to site requirements.

1. Example Site(s)

Site 1. Research on a poplar tree barrier for heavy metal contaminated sites. Abandoned sites associated with old heavy metal mining and smelting activities often have a large proportion of their area without vegetative cover. This allows erosional forces to proceed at a maximum rate, and materials with high heavy metal concentrations are dispersed by wind and water. Unfortunately, little research has addressed use of poplar trees in such a situation.

This project has utilized an abandoned zinc/lead smelter site near Dearing, Kansas, for its investigation. Poplar trees were first planted in June 1994 but survival as of September of that same year was only 7 percent. This was attributed to the late planting date (which was necessary because of extremely wet conditions), a reduction in tree viability due to storage, and drought conditions following planting. The trees were replanted in March 1995, a more appropriate planting time, in a split-plot design with the main plots being the in-trench treatments with or without manure and the subplots being poplar cultivar. Height and trunk diameter of each tree was measured to serve as a baseline to which all future measurements could be compared. Survival measurements and leaf samples have been taken. As of September 1995, 400 out of the original 576 trees were alive for an overall survival rate of 69.4 percent. Addition of manure to the trenches significantly increased growth via increases in height and trunk diameter. The data clearly show that tree cultivar and soil amendments can influence survival and growth parameters. Soil samples have been collected from 8 different areas and analyzed for lead concentration. Soil lead concentrations will be compared to leaf tissue lead concentrations after those analyses are complete. This project is in its third year.

Site 2. Cottonwood trees taking up TCE at Naval Air Station Joint Reserve Base Fort Worth, Texas (formerly Carswell AFB). This demonstration project is part of EPA's Superfund Innovative Technology Evaluation Program. Only one year after being planted, these cottonwood trees appear to be taking up the TCE contaminating the ground water beneath them.

Eastern cottonwoods were chosen because they are indigenous to the site, are members of the same genus as poplar trees, and grow at similarly rapid rates. Saplings were planted in 5-gallon buckets and cuttings were planted on a 1-acre site. Using deep planting techniques such as auguring, researchers want to determine whether the cuttings can absorb TCE as readily as anchored trees. If so, significant cost savings may be realized.

The trees are planted to intercept the flow gradient of water and to determine if cottonwoods can metabolize TCE and its daughter compounds under field conditions and to ensure that TCE is co-metabolized in the rhizosphere.

Extensive monitoring of the site includes ground water and vegetation chemistry samples, hourly depth-to-ground water measurement, and plant enzyme determination in plantation and nearby riparian trees. The transpiration data thus far are encouraging.

2. Documentation

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Betts, Kellyn S. "Phytoremediation project taking up TCE." *Environmental Science and Technology.* Vol. 31, No. 8, 1997, p. 347A.

3. World Wide Web Site(s)

- http://www.ecc.ksu.edu/HSRC/Annual.Research.html
  (Specific to the use of poplar trees to remediate heavy metal contaminated sites.)

E. WETLANDS

Use of natural, or more often, constructed wetlands for remediation of wastes is being considered for non-point source contamination that runs into or near water, and where there is enough land to create a wetland area. Remediation of hazardous waste by wetlands is a use of wetlands not widely applied. However, natural or constructed wetlands have been used for municipal waste for many years, and lately have been constructed specifically to process storm water runoff.

Storm water runoff, especially in urban, industrial and agricultural areas, often contains pollutants transported from surfaces which accumulate during dry periods and are washed away during precipitation events. This type of pollution is termed "non-point source," or NPS. Such contamination has adversely impacted receiving water bodies such as streams, lakes, and oceans to the extent that a recent EPA study indicates that 37 percent of U.S. bodies of water are unsafe for basic uses such as fishing and swimming, largely due to polluted storm water runoff. To add to the problem, many of the wetlands surrounding these receiving waters have been destroyed in recent years. These wetlands had served to filter out many of the NPS contaminants by virtue of their very active and dense macro- and microbiota.

Besides conservation and restoration of our existing wetlands, construction of carefully designed wetlands can serve as a partial remedy to the NPS pollution problem in storm water runoff. Constructed wetlands, while typically not having the full suite of benefits of a hundred- or thousand-year-old natural wetland, can remove many of the NPS contaminants by biological, chemical, and physical means much the same as a natural wetland. In addition, constructed wetlands can be engineered to treat specific contaminants, provide flood control, and provide many of the ancillary benefits of natural wetlands such as wildlife habitat, aesthetically pleasing open space and, in some cases, recreational opportunities.

1. Example Site(s)

Site 1. The Environmental Department (Installation Restoration Division of The Naval Facilities Engineering Service Center (NFESC) constructed a tidally influenced wetland to investigate treatment of contaminants in stormwater runoff at the Naval Amphibious Base in Little Creek, Virginia. The construction of the two experimental wetland cells began during June 1996 and was completed in August. The Navy placed approximately 20,000 plants in the cell bottoms and interior side slopes during mid-August; monitoring equipment is being used to remotely monitor the site from a Navy facility in Southern California. The cells each measure 60 x 650 feet and receive water from a nearby drainage channel which empties into the Little Creek Cove.

At the Little Creek Cove site, water flows from the channel to the cells via 24-inch diameter pipes with equipped with one-way check valves. This forces one-way flow of water through the cells from the stormwater channel and into the Cove, the cell discharge points. The discharge piping is also equipped with check valves on the outlet end. The driving force to move water through the cells is the rise and fall of the tide and influx of storm water in the channel. The bottom of the wetland cells are graded to mean sea level. The pipe inverts are also installed to mean sea level elevation. As such, the wetland cells fill with water when the tide is rising, or when storm water runoff fills the channel above mean sea level.

Construction started in June 1996 with clearing and grubbing of the site. Around the site was erected silt retaining fence, which served its purpose by holding silt carried from the site by the heavy rains in the Norfolk area during the summer months. The cells were excavated from the perimeters using excavators; no equipment entered the cells themselves. Removing water from the site proved difficult because of clay soils, which prevented facile movement of water to the dewatering pits.

Construction was completed during August with placement of rubber pinch valves (TideFlexvalves by Red Valve) on the effluent pipes. Wetland construction was performed by Coastal Design and Construction, Incorporated, of Gloucester, Virginia.

The wetland cells, slopes, and buffer areas were planted with salt-tolerant wetland plants native to the area, including *Spartina alterniflora* (up to spring high tide line), *Spartina patens* (interior side slopes down to mean high tide line), *Panicum amarum* (upper side slopes and on the berm tops) and *Iva* (upper side slopes and on the berm tops). The site was formerly covered with a near monoculture of Phragmites, which were sprayed with the herbicide Finale after they sprouted on the sideslopes after construction of the cells. The herbicide appeared to do its job, killing off the Phragmites in areas where it was generously applied to well-leafed, 3- to 4-foot tall plants (areas which were excavated earliest and where the plants had the longest time to grow before application of the herbicide). The killing was not as complete in areas where it was applied at a lighter rate on less mature plants.

Extensive monitoring of the water, soil, and biota in and around the wetland is underway. Probes with multiple sensors (Hydrolab H20s) were deployed in the channel and cells to monitor water level, temperature, pH, conductivity, salinity, total dissolved solids, turbidity, redox potential, and dissolved oxygen. The probes are connected to a data-collection platform that will allow remote accessing of the data collected by the probes and a rain gauge. The measurements from the probes and rain gauge will cause a trigger signal to be sent by the data logger to autosamplers to collect water samples for laboratory analyses. In addition, grab water samples will be taken to analyze for labile contaminants such as volatile organics. Other media sampled regularly include soil and sediment, plant tissue, invertebrates, and other organisms, which will also be submitted for laboratory analyses.

NFESC's Constructed Wetlands Technology Application Team is compiling a Technology Application Guide for Constructed Wetlands, slated to be available in early 1998.

2. Documentation

Kadlec, Robert H., and Robert L. Knight. *Treatment Wetlands.* Lewis Publishers, division of CRC Press, Boca Raton, Florida, 1996. This book is comprehensive, and almost no other reference is needed for the engineer or environmental manager interested in this possibility. Includes case studies.

Young, Patrick. "The new science of wetland restoration." *Environmental Science and Technology* . Vol. 30, No. 7, 1996.

3. World Wide Web Site(s)

- http://cayuga.nfesc.navy.mil/cc/projects/cnwthom.htm (Specific to the Little Creek, Virginia, site)
- http://www.inform.umd.edu/EdRes/Topic/AgrEnv/Water/Constructed_Wetlands_all (Bibliography compiled by the US Department of Agriculture Staff, National Agricultural Library.)
- http://www.mrd.usace.army.mil/mrded-h/mrded-h.html (The U.S. Army Corps of Engineers home page)
- http://www.wes.army.mil/el/wetlands/wlpubs.html (Waterways Experiment Station)
- http://kh465a.ag.ohio-state.edu/wetlinks.html (Wetland Hot Links)
- http://www.epa.gov/OWOW/info/PubList/publist1.html#wet (The EPA Office of Water, Office of Wetlands, Oceans and Watersheds publications)
- http://enterprise.nwi.fws.gov/ (National Wetlands Inventory plans, directs, coordinates, and monitors the gathering, analysis, dissemination, and evaluation of information relating to the location, quantity, and ecological importance of the Nation's wetlands.)
- http://www.nwi.fws.gov/more.html (Mission Statement of National Wetlands Inventory)

F. PASSIVE BARRIER WALLS TO TREAT HEAVY METALS DISSOLVED IN GROUND WATER

Passive barrier walls are gaining prominence in the arena of chlorinated solvent cleanup, but the same technology is being applied to heavy metal contamination. Numerous hazardous waste sites have significant concentrations of metals and radionuclides that contaminate ground water. Traditional technologies, such as pump and treat, require an external energy source and their cost is high. Subsurface residuals frequently remain at undesirable levels. Thus, subsurface permeable treatment walls are being considered as a cost-effective *in situ* water treatment alternative.

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

1. Example Site(s)

Site 1. Valley Wood Treating, Turlock, California. The process removes chromium from contaminated ground water using a variation of traditional pump-and-treat methods. Contaminated ground water is brought to the surface and treated using conventional treatment systems such as ferrous iron. A reducing agent is added to the treated water, which is reinjected around the plume margin where it reacts and reduces residual levels of chromium, forming a precipitate. Such reinjection creates a "barrier" of elevated water levels around the plume, enhancing the gradient and associated hydraulic control. The reinjection also allows for *in situ* reduction and subsequent fixation of residual chromium.

The technology was accepted into the SITE Program in the summer of 1992. Arrangements are being made to demonstrate the technology in 1995.

Site 2. Hanford 100D Area, Washington. Chromium is the heavy metal studied here. Field experiments are planned for the Arid Soils VOC Integrated Demonstration to test the feasibility of *in situ* redox manipulations with chemical reagents using a forced gradient, single well, reactive tracer test. Field experiments will involve injecting the reagent sodium dithionite into the aquifer creating a 60- to 100-foot diameter geochemical barrier in advance of a contaminant plume. After allowing 5 to 30 days for the reaction to occur, water containing the reaction byproducts and any remaining reagent will be pumped out. The longevity of the system to maintain a reducing environment also will be evaluated.

The demonstration was scheduled for summer 1995. The researchers have conducted an initial site characterization using existing monitoring wells and have submitted a draft test plan to DOE, EPA, and the State of Washington's Department of Ecology. The Department of Energy is sponsoring the research.

Site 3. DOE Savannah River, South Carolina. Researchers are constructing a gravel trench 300 feet long by 30 feet deep that will intersect the highest contaminant concentration of a plume contaminated with nickel, lead, and chromium. Pumping wells will be constructed within this wall to remove contaminated ground water, but the major focus is to study the hydraulics. The studies are designed to investigate ground water retention time in the wall and problems associated with injecting a treatment medium in the gravel matrix. The contaminant plume is shallow and the surrounding soils are interbedded clays and sands.

Under construction. Pump tests were scheduled for July and August 1995.

Site 4. Coast Guard Air Station, Elizabeth City, North Carolina. Chromium, along with TCE, DCE, and vinyl chloride, are being treated at this site. A series of large-diameter augered holes in a staggered 3-row array were located within an aquifer to intercept a contaminant plume of chromate and chlorinated organics. A mixture (by volume) of 50 percent iron filings (2 types), 25 percent clean coarse sand, and 25 percent aquifer material was poured down hollow-stem augers from 22 feet to 10 feet below ground surface. Each iron column was approximately 8 inches in diameter and a total of

21 columns were installed in a 60 ft^2 area. The mixed waste contaminant plume is between 14 and 20 feet bgs and the water table ranges from 5 to 6 feet bgs. One iron type was shown to be an effective reductant for chromate in a 2-year laboratory study by RSKERL scientists, while the other iron has been shown to be more effective in the reductive dechlorination of the organics. This field experiment is evaluating the effectiveness of this method of treatment wall emplacement and is providing additional *in situ* field data for full field-scale implementation.

The demonstration has been in operation since September 1994.

Preliminary results show complete reduction of Cr^{+6} to below detection (<0.01 mg/L) limits and greater than 75 percent reduction in initial TCE concentrations and reduction of vinyl chloride concentrations to less than 1 µg/L. These results are very promising, especially for the chlorinated organics, because the experiment was primarily designed to optimize chromate remediation, not the chlorinated organics. Longer residence times are planned for the latter in the full field scale test to be installed in August 1995.

Site 5. Several Sites in Canada and the United States – *In Situ* Permeable Reaction Wall for Treatment of Inorganics. Inorganic contaminants in ground water, especially dissolved chromium, iron, sulfate, phosphate, and radionuclides, are treated using *in situ* porous reactive walls. Wall materials are placed in the path of the plume and react with the contaminant via reduction and precipitation. This technology is being developed for treating mine and industrial wastes and septic systems and agricultural effluent.

Field trials are ongoing. Preliminary results indicate contaminant concentrations are decreased by orders of magnitude and to below drinking water levels.

2. Documentation

Blowes, D.W. and Ptacek, C.J. "Geochemical Remediation of Groundwater by Permeable Reactive Walls: Removal of Chromate by Reaction with Iron-Bearing Solids." *Proceedings of the Subsurface Restoration Conference, Third International Conference on Groundwater Quality Research,* 21 to 24 June 1992, Dallas, Texas, pp. 214-216.

Blowes, D.W. and Ptacek, C.J. System for Treating Contaminated Groundwater (Redox Curtain). United States Patent 5,362,394. 1994.

Blowes, D.W.; Ptacek, C.J.; Bain, J.G.; Waybrant, K.R.; and Robertson, W.D. "Treatment of Mine Drainage Water Using *In Situ* Permeable

Reactive Walls." *Proceedings of the Sudbury 1995 Mining and the Environment Conference,* May 28-June 1, 1995, Sudbury, Ontario.

Fruchter, J.S. *In Situ Redox Manipulation: Enhancement of Contaminant Destruction and Immobilization.* Semi-Annual Office of Technology Development (OTD) Information Meeting (2nd), Houston, Texas, 26 to 28 January 1993, NTIS Order Number DE93007877.

Puls, R.W., Powell, R.M., and Paul, C.J. "*In Situ* Remediation of Ground Water Contaminated with Chromate and Chlorinated Solvents Using Zero-Valent Iron: A Field Study." *Proceedings of the 209th American Chemical Society National Meeting,* Anaheim, California, April 2-7, 1995. 35 (1), pp. 788-791.

3. World Wide Web Site(s)

- http://www.clu-in.com

G. NANOPOROUS POLYMERIC MATERIALS AS POTENTIAL ACTIVATED CARBON OR ZEOLITE SUBSTITUTE

Los Alamos National Laboratory researchers developed a polymer-based material that forms nanometer-sized pores that can absorb and trap organic contaminants in water. This "nanosponge" polymer could be used to clean up tricholoroethylene, toluene, phenol derivatives, and a number of dye compounds. The nanosponge material is made of polymeric building blocks called cyclodextrins that form cylindrical cages to trap organics. The hydrophilic sites make then soluble in water, yet the hydrophobic sites attract the organics. The molecular binding between organic contaminants and the polymer is 100,000 times greater than with activated charcoal and the process is 100 percent reversible.

Conventional processes with activated carbon or zeolites are inefficient in reducing contaminants in water and are totally ineffective in removing organic compounds from water down to the parts-per-trillion level, as this polymer can. They are also easily deactivated by moisture in the air and cannot function effectively once they are completely saturated with water.

The porous polymer material remains effective in air, does not absorb moisture from the air, does not have to be "activated," can be placed immediately into the contaminated medium for *in situ* treatment, is transparent, and changes color when bound with organic contaminants. This property can be used to determine when the material is almost completely saturated. The polymeric material is cheap to manufacture and rinsing it with ethanol releases the trapped contaminants. The nanosponge can be reused again and again.

These polymers can be fabricated into granular particles, powders, and optical quality films, making them compatible with most water treatment technologies. Some potential uses include purification of municipal water supply, recycling and reuse of industrial waste water in a continuous on-line process, clean up of oil or organic chemical spills, *in situ* remediation of hazardous organics in underground water, and clean up of organic explosives.

1. Documentation

The Brownfields Report, Vol. 2, Number 16, August 14, 1997. p. 4.

2. World Wide Web Site(s)

- http://www-emtd.lanl.gov/TD/Remediation/NanoPorousPolymer.html

Appendix A

ACRONYMS

Appendix A
ACRONYMS

3-D	three-dimensional
AAL	Arizona Action Level
AC	alternating current
acfm	actual cubic feet per minute
AFB	Air Force Base
ARA	Advanced Research Associates
ARCS	Assessment and Remediation of Contaminated Sediments Program
As	arsenic
ASTM	American Society for Testing and Materials
ATP	Anaerobic Thermal Processor
AVGAS	aviation gasoline
BAP	benzo(a)pyrene
BCD	Base Catalyzed Decomposition
BFSD	Benthic Flux Sampling Device
BFSS	Bioremediation Field Search System
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene and xylenes (meta-, ortho-, and para-)
BTF	bioremediation treatment facility
c-DCE	cis-1,2,dichloroethene
CARACAS	Concerted Action of Risk Assessment of Contaminated Land in Europe
Cd	cadmium
CDM	contaminated dredged material
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CGR	Columbus Groundwater Research
cm	centimeter
cm/sec	centimeter per second

Co	cobalt
CO_2	carbon dioxide
Cr	chromium
Cr(III)	trivalent chromium
Cr(VI)	hexavalent chromium
Cr^{+6}	chromate
CT	carbon tetrachloride
Cu	copper
DCE	dichloroethene
DDT	1,1,1-trichlor, 2-2 bis-(p-chlorphenyl) ethane
DNAPL	dense non-aqueous phase liquid
DOE	Department of Energy
E-SMART	Environmental Systems Management, Analysis, and Reporting Network
EDB	ethylene dibromide
EMS	Environmental Management Systems
EPA	Environmental Protection Agency
ESC	Engineering Service Center (U.S. Navy)
ET	evapotranspiration
FACTS	Field Analytical and Characterization Technologies
Fe	iron
FFD	Fuel Fluorescent Detector
FLTG	French Limited Task Group
FPXRF	Field-Portable X-ray Fluorescence Spectrometry
ft^2	square feet
ft^3	cubic feet
GAC	granular activated carbon
GIS	geographic information system
gpd	gallons per day
gpm	gallons per minute
GRFL	Groundwater Remediation Field Laboratory
GWRTAC	Ground Water Remediation Technologies Analysis Center
HAVE	hot air vapor extraction
Hg	mercury
HPB	Heap Pile Bioremediation
HSRC	Hazardous Substance Research Center

HVW	horizontal vent well
HWMF	Hazardous Waste Management Facility
ICEECER	Institute for Central and Eastern European Cooperative Environmental Research
in^3	cubic inch
IPA	isopropyl alcohol
ISM	industrial, scientific, medicine
ISO	International Organization for Standardization
ISV	*in situ* vitrification
ITT	Innovative Treatment Technologies
kg	kilogram
KMS	Kuryluk Mineral Separator
KPEG	potassium polyethylene glycolate
kW	kilowatt
L	liter
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LNAPL	light non-aqueous phase liquid
LTA	land treatment area
LTU	land treatment unit
LUFT	leaking underground fuel tanks
MCAS	Marine Corps Air Station
MCL	maximum concentration level
MED	Marine Environment Detector
MEK	methyl ethyl ketone
mg	magnesium
mg/kg	milligrams per kilogram
Mhz	megahertz
Mn	manganese
Mo	molybdenum
MTBE	methyl tertiary butyl ether
NAPL	non-aqueous phase liquid
NAS	Naval Air Station
NAVFAC	Naval Facility
NETTS	National Environmental Technology Test Sites
NFESC	Naval Facilities Engineering Service Center

Ni	nickel
NICOLE	Network of Industrially Contaminated Land in Europe
NPL	National Priority List
NPS	non-point source
NRaD	Naval Research and Development
NRMRU	National Risk Management Research Laboratory (USEPA)
NWS	Naval Weapons Station
O_2	oxygen
OH	hydroxyl radical
PAH	polynuclear aromatic hydrocarbons or polycyclic aromatic hydrocarbons
Pb	lead
PCB	poly-chlorinated biphenyls
PCE	tetrachloroethene from it's synonym, "per chloro ethene," to distinguish this compound from TCE
PIANC	Permanent International Association of Navigation Congresses
POL	petroleum, oil, lubricants
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
ppt	parts per trillion
PVC	polyvinyl chloride
RACE	Risk Abatement Center for Central and Eastern Europe
RANET	Risk Abatement Network
RBC	Risk-Based Concentration
RBCA	Risk-Based Corrective Action
RCRA	Resource Conservation and Recovery Act
RDX	Royal Demolition Explosive
REC	Regional Environmental Center
redox	reduction-oxidation
RF or rf	Radio Frequency
RMA	Rocky Mountain Arsenal
RNA	remediation through natural attenuation
ROD	Record of Decision
ROST	Rapid Optical Screening Tool
rpm	revolutions per minute
RTDF	Remediation Technologies Development Forum (USEPA)

S/S	Solidification and Stabilization
SAAD	Sacramento Army Depot
SCAPS	Site Characterization and Cone Penetrometer System
SCAPS-LIF	Site Characterization and Analysis Penetrometer System with Laser-Induced Fluorescence
scfm	standard cubic feet per minute
sec	second
SERDP	Strategic Environmental Research and Development Program
SFCES	St. Fancois County Environmental Corporation
SIVE	steam injection vacuum extraction
SLT	serial leach test
SPDES	State Pollution Discharge Elimination System
SSLs	soil screening levels
SVE	soil vapor extraction
SVOC	semi volatile organic carbon
t-DCE	trans-1,2,dichlorethene
TCA	1,1,1-trichloroethane
TCE	trichloroethylene
TCIC	Total Carcinogenic Indicator Chemical
TCLP	toxicity characteristic leaching procedure
TEL	threshold effect level
TEPH	total extractable petroleum hydrocarbons
TFD	Treatment Facility D
TMA	Trace Metal Analyzer
TNT	trinitrotoluene
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TVH	total volatile hydrocarbons
UAF	University of Alaska Fairbanks
UCS	unconfined compressive strength
USACEWES	United States Army Corps of Engineers Waterways Experiment Station
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UV	ultraviolet

UVB	“Unterdruck Verdampfer Brunne, the German words for Vacuum Vaporizer Well
UVF	ultra violet fluorescence
V	vanadium
VC	vinyl chloride
VISITT	Vendor Information System for Innovative Treatment Technologies
VOA	volatile organic aromatic
VOC	volatile organic compound
VOH	volatile organic halocarbon
VR	vapor recovery
WERC	Water and Environmental Center
XRF	X-ray Fluorescence Spectrometry
yd^3	cubic yards
Zn	zinc
μg	micrograms
μg/ml	micrograms per milliliter

Appendix B

REMEDIATION TECHNOLOGIES NOT CONSIDERED ELSEWHERE IN THIS DOCUMENT

Appendix B
REMEDIATION TECHNOLOGIES NOT CONSIDERED ELSEWHERE IN THIS DOCUMENT

http://www.clu-in.com/remed1.htm#tools
This World Wide Web site lists sources of information about technologies. Some of the material listed below was gleaned from this World Wide Web site. Further material was obtained from the Ground Water Remediation Technologies Center. http://www.gwrtac.org/

A. GRANULAR ACTIVATED CARBON, AIR, AND LIQUID PHASE OF INCOMING CONTAMINANTS

Absorbing of contaminants onto granular activated carbon (GAC) is an effective method of removal. The disadvantages are the difficulty of obtaining sufficient amounts of the activated carbon, and, once the GAC in a canister is saturated with the contaminant, being able to regenerate the carbon and treat the desorbed contaminant. As a complete treatment method for organics in the air or in water, it would be expensive. As a secondary or tertiary treatment mainly to ensure a waste stream is clean, it could be a viable option.

Therefore, this technology is not completely excluded. As a stand-alone treatment, it is excluded from consideration because of expense and potential lack of supply in Central Europe. As a secondary treatment, it may be useful.

B. LASAGNA PROCESS

Contamination in low permeability soils poses a significant technical challenge to *in situ* remediation efforts. The lasagna process is one in which eletro-osmosis is used to move contaminants into treatment zones that are installed directly in the contaminated soils. Called lasagna due to the layered appearance of electrodes and treatment zones, the technology could conceptually treat organic and inorganic contamination as well as mixed wastes.

This technology was excluded from consideration in this document because of expense.

C. BIOSORPTION OF HEAVY METALS

The potential of metal biosorption by biomass materials has been well established in the past 10 years. Metals bind to organic ligands and, because of economic reasons, abundant biomass types are of particular interest (such as waste byproducts of large-scale industrial fermentations or certain metal-binding algae found in large quantities in the sea). Lead and cadmium, for instance, have been effectively removed from very dilute solutions by the dried biomass of some species of brown marine algae.

Some mining operations use biomass to clean waste streams. However, the technology, though known, is not well established or accepted in industry. The potential for effective use exists, but efficient technologies for the mechanism of metal binding and the subsequent release of the metal, reuse of the biomass, and disposal of the contaminant have yet to be clarified and standardized.

This technology was excluded from consideration because of expense, and lack of efficient technologies, and standardization.

D. INCINERATION

Total destruction of many compounds occur when properly incinerated. This technology requires a well-run incinerator and transport of the contaminant, contaminated soil, or contaminated water to the incinerator, as well as solidification and disposal of the residue. This technology was excluded from consideration in this document because of expense.

E. GROUND WATER PUMP AND TREAT

Pumping contaminated ground water to the surface for treatment has been shown to be ineffective as a remediation strategy for the subsurface. In addition, it is expensive to treat the water.

F. IN-WELL VAPOR STRIPPING OR UNTERDRUCK-VERDAMPFER-BRUNNEN (UVB)

This technology is also known as *in situ* vacuum, vapor, or air stripping (it is also referred to as UVB for its German term, *Unterdruck Verdampfer Brunnen*). It is an in-well vapor stripping technology meant to create a ground water circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating ground water. Air-lift pumping lifts ground water and strips it of contaminants.

Contaminated vapors may be drawn off for above-ground treatment or released to the vadose zone for biodegradation. Partially treated ground water is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated ground water enters the well at its base, replacing the water lifted through pumping. The partially treated water is presumed to cycle back through the well through this process until contaminant concentration goals are met.

Modifications include combinations with soil vapor extraction and above-ground treatment of extracted vapors and/or injection of nutrients and other amendments to enhance natural biodegradation of contaminants. There are several commercial types of in-well vapor stripping that strive to make the general process most efficient or to use the process to enhance metals fixation by taking advantage of the circulation cell development. Applications of in-well stripping have generally involved chlorinated organic solvents (e.g., TCE) and petroleum product contamination (e.g., BTEX). Proposed system modifications to this technology may address non-halogenated VOC, SVOC, pesticide, and inorganic contamination. In-well stripping has been used in a variety of soil types from silty clay to sandy gravel.

Reported advantages of in-well stripping include lower capital and operating costs due to use of a single well for extraction of vapors and remediation of ground water and lack of need to pump, handle, and treat ground water at the surface. It can be integrated with other remediation techniques such as bioremediation and soil vapor extraction. Its design is simple and requires limited maintenance. Problems associated with this technology include limited effectiveness in shallow aquifers, possible clogging of the well due to precipitation, more maintenance when installed due to site conditions, lack of clear evidence that any remediation occurring is due to the in-well stripping, and the potential to spread the contaminant plume if the system is not properly designed or constructed.

This technology was excluded from consideration in this document because it has not been shown to be effective. See http://clu-in.com/site/complete/democomp/westonn.htm.

G. ELECTROKINETICS

Electrokinetics is an *in situ* physical process involving application of low intensity direct electrical current across electrode pairs implanted in the ground on each side of a contaminated area of soil, causing electro-osmosis and ion migration. Contaminants migrate toward respective electrodes depending upon their charge. The process may be enhanced through use of surfactants or reagents to increase contaminant removal rates at the electrodes. The process separates and extracts heavy metals, radionuclides, and organic contaminants from saturated or unsaturated soils, sludges, and sediments. This technology is especially unique since it works in low permeability soils as well as high permeability soils and is applicable to a broad range of organic and inorganic contaminants.

This technology was excluded from consideration in this document because of its high installation cost and the high level of maintenance and operation required, both in expertise and expense.

H. SOIL WASHING (SOIL FLUSHING)

This technology involves extraction of contaminants from soil using water or other suitable aqueous solutions, or, to state it another way, it is an attempt to clean soil as if it were laundry. The washing fluid may be composed of water, water and chelating agents, water and surfactants, acids, or bases, depending on the contaminant to be removed. Although additives such as acids and chelating agents have had some commercial use for full-scale *ex situ* soil washing projects, they have not been demonstrated as feasible for *in situ* applications.

Soil flushing has been selected at seven sites with metals present; however, at six of those sites, organic contaminants are the primary targets. For metals, soil flushing would be most effective in removing water-soluble species, such as hexavalent chrome. Two soil flushing remedies are currently ongoing at Superfund sites, with some preliminary data available from a hexavalent chrome application.

Leached contaminants are typically recovered from the underlying ground water by pump-and-treat methods. Site-specific conditions must be carefully considered to address the possible spread of contamination.

The process requires movement of volumes of soil, in itself potentially difficult. Due to sorption on soil particles, separating soil from contaminant may involve several different steps where chemicals are added then washed off, as well as physical separation steps (e.g., separating large pieces of bullets from firing range berm soil). The liquid waste stream from such a procedure can be voluminous and must be treated.

The psychological factor of "cleaning" the soil in this way, and the complicated engineering expertise and equipment required, may contribute to a recommendation for this technology in spite of it's high cost.

This technology was excluded from consideration in this document because of the high cost of installation and the high level of maintenance and operation required in expertise, labor, and generated waste stream cleanup.

I. ULTRAVIOLET/OXIDATION TREATMENT PROCESSES FOR THE TREATMENT OF CONTAMINATED GROUND WATER

UV/oxidation is a an *ex situ* destruction process that oxidizes organic and explosive constituents in contaminated ground water by the addition of strong oxidizers and irradiation with UV light. The oxidation reactions are achieved through the synergistic action of high intensity UV light alone or in combination with patented treatment reactor design (in some cases), ozone, or hydrogen peroxide. The UV/oxidation process generates highly reactive hydroxyl radicals ($OH^{\cdot}$) that react with and destroy most organic chemical compounds. If complete mineralization is achieved in the reaction, the final products of the process are carbon dioxide, water, and inorganic salts.

A wide variety of organic and explosive contaminants is susceptible to destruction by UV/oxidation, including petroleum hydrocarbons; halogenated solvents; phenol; pentachlorophenol; pesticides; dioxins; glycols; polychlorinated biphenyls; explosives such as TNT, RDX, and HMX; creosote; Freon 113; vinyl chloride; benzene, toluene, ethylbenzene, and xylenes; methyl tertiary butyl ether; cyanide; mixed organic/radioactive waste; and other organic compounds. According to the information reviewed, UV/oxidation has most often been used for contaminant concentrations in ground water below 500 mg/L. Organics such as benzene can be treated to nondetectable levels; others, such as, 1,1-dichloroethane, are typically reduced by 96 percent. Also, organisms such as Salmonella and E. Coli have reportedly been significantly reduced using UV/oxidation.

UV/oxidation processes can be configured in batch or continuous flow operations, depending on the flow rate under consideration. A key advantage cited for UV/oxidation treatment technology is that it is a destruction process (i.e., no toxic by-products are generated in the reaction), as opposed to air stripping or carbon adsorption, for which contaminants are extracted and concentrated in a separate phase.

This technology was excluded from consideration in this document based on expense.

J. AIR SPARGING

Air sparging involves injecting a gas (usually air or oxygen) under pressure into the saturated zone to volatilize ground water contaminants and to promote biodegradation in saturated and unsaturated soils by increasing subsurface oxygen concentrations. Volatilized vapors migrate into the vadose zone where they are extracted via vacuum, generally by a soil vapor extraction system. The term biosparging is sometimes used interchangeably with air sparging to highlight the bioremediation aspect of the treatment process or can refer to situations where biodegradation is the dominant remedial process, with volatilization playing a secondary role.

Air sparging has been used to address a broad range of volatile and semivolatile ground water and soil contaminants including gasoline and other fuels and associated BTEX components and chlorinated solvents. Sites with relatively permeable, homogeneous soil conditions favor the use of air sparging because of greater effective contact between sparged air and the media being treated and effective migration or extraction of volatilized vapors. Other appropriate site conditions include relatively large saturated thicknesses and depths to ground water. These factors both control the area of influence of a sparging well, and, if saturated thickness or depth to ground water are small, the number of wells required for adequate coverage may become cost-prohibitive.

Several applications of air sparging technology indicate that, when applied properly, this technique can be a cost effective method for meeting remedial objectives within reasonable timeframes. Air sparging reportedly can be more effective than pump-and-treat methods since contaminants desorb more readily into the gas phase than into ground water and since increased volatilization can overcome the diffusion-limited extraction of VOCs from ground water. Another reported advantage of air sparging is that, in contrast to vapor extraction, it can be used to treat contamination in the capillary fringe and below the water table.

This technology was excluded from consideration in this document because of the expense involved in determining if air sparging would be an appropriate technology to apply since it has a narrow range of applicability, because of operation and maintenance costs, and because it is not always an effective treatment.

K. *IN SITU* FLUSHING

Also known as injection/recirculation or *in situ* soil washing, this technology injects or infiltrates a solution into a zone of contaminated soil or ground water, followed by downgradient extraction of ground water and elutriate (flushing solution mixed with the contaminants) and above-ground treatment or re-injection. Solutions may consist of surfactants, cosolvents, acids, bases, solvents, or plain water. Any variety of configurations of injection wells, horizontal wells, trenches, infiltration galleries, and extraction wells or collection trenches may be used to contact the flushing solution with the contaminated zone. Excellent understanding of the hydrogeologic regime for potential projects is essential; the technique is best applied to moderate to high permeability soils. *In situ* flushing may be used for variety of organic contaminants, including NAPLs, and may have application to some inorganic contaminants.

This technology was excluded from consideration in this document based on the expense of the operation as well as the expense of thoroughly characterizing the hydrogeology of the site.

L. HORIZONTAL WELLS

Horizontal wells, also known as directional wells, are trenched or directly drilled wells installed at any non-vertical inclination for purposes of ground water monitoring or remediation.

Horizontal well technology has been incorporated into many current environmental remediation applications (and associated contaminants), such as *in situ* bioremediation, air sparging, vacuum extraction, soil flushing, hydraulic and pneumatic fracturing, free product recovery, and so forth. This technology is most applicable to sites with relatively shallow soil or ground water contamination and can potentially enhance remediation efforts at sites with low hydraulic conductivities.

Types of horizontal wells include both trenched and directionally drilled, with trenched wells involving simultaneous borehole advancement and casing/screen and backfill installation (in a larger diameter boring). Directionally drilled wells involves a smaller borehole with well installation subsequent to the completion of drilling activities.

Some reported advantages of horizontal wells include the fact that their long horizontal screens contact a larger area of contaminated media and so may more effectively transmit additives associated with remedial activities (amendments, air, surfactants, etc.), and the configuration of these wells is more consistent with natural conditions, since ground water transmissivity is generally greater in the horizontal, rather than the vertical direction. This may allow more efficient recovery of ground water or vapors via horizontal wells and is especially useful when contaminant plume covers a large area and has linear geometry. Directionally drilled horizontal wells can be installed in areas with subsurface obstructions (e.g., vertical wells, utility lines) and can be used beneath surface obstructions such as buildings, lagoons, wet lands, etc. Disadvantages cited include the limited depths to which these wells can be installed, the lack of drilling contractors experienced in horizontal techniques, and expense.

This technology was excluded from consideration in this document based on the disadvantages listed.

M. ARTIFICIALLY INDUCED OR BLAST-ENHANCED FRACTURING TO IMPROVE GROUND WATER RECOVERY FOR TREATMENT AND MIGRATION CONTROL

Fracturing techniques create enhanced fracture networks to increase soil permeability to liquids and vapors and accelerate contaminant removal. These fracturing techniques are especially useful for vapor extraction, biodegradation, and thermal treatments. Hydraulic fracturing involves injection of high pressure water into the bottom of a borehole to cut a notch; a slurry of water, sand, and thick gel is pumped at high pressure into the borehole to propagate the fracture from the initial notch. The gel biodegrades, leaving a highly permeable sand-filled lens that may be up to 60 feet in diameter. Pneumatic fracturing involves injection of highly pressurized air into consolidated sediments to extend existing fractures and create a secondary fracture network. This technique is most applicable for unconsolidated sediments or bedrock.

This technology was excluded from consideration in this document based on expense.

N. SLURRY PHASE BIOREMEDIATION

Contaminated soil and sludge can be treated by an enclosed system (bioreactor) that maintains intimate contact of microorganisms with the hazardous compounds in a slurry, creating the appropriate environmental conditions for optimal microbial degradation of the target contaminants. The solids-to-water ratio is based on soil type and type of mixing and aerating equipment. The slurry is mechanically agitated in a reactor vessel, with nutrients added. When remediation is complete, water is removed from the slurry. The process is amenable to simultaneous treatment of solids and liquids, so residual water may or may not require treatment.

This technology was excluded from consideration in this document based on expense and the intensive technology required.

O. BIOFILTRATION

Vapor phase organic contaminants are pumped though a soil bed and sorb to the soil surface where they are degraded by microorganisms in the soil. Specific strains of bacteria may be introduced into the filter and optimal conditions provided to preferentially degrade specific compounds. This technology requires enclosed containers that range in size from that of railroad cars stacked in series to smaller metal cylinders perhaps 4 feet in diameter.

This technology was excluded from consideration in this document because biofilters are sometimes ineffective, most known field uses are for odor control, or these systems are expensive to install and maintain due to the recurring need to renew the soil beds.

P. BIOAUGMENTATION

Bioaugmentation is the adding of cultured microorganisms to a site.

This technology was excluded from consideration in this document because it has not been shown to work better than the soil microbes already present Cleanup of contaminated sites that apparently were enhanced with bioaugmentation were shown, on closer examination, to be due to nutrient mixtures added to the site with the microorganisms.

Q. DECHLORINATION BY POTASSIUM POLYETHYLENE GLYCOLATE (KPEG)

Chlorinated organics in contaminated organic soils can be dechlorinated by potassium polyethylene glycolate (KPEG), where the KPEG solution reacts with the chlorinated organic to displace the chlorine and produce a salt. The process involves slurrying equal portions of contaminated soil and KPEG in a heated reactor that is then brought to a high temperature, mixed, and retained for 0.5 to 5 hours, depending on the type and concentration of the contaminants. Excess reagent is then removed and the soil is washed two or three times with water to remove residual reagent and the reaction products. The decontaminated soil is then removed from the reactor. The liquids can be recycled to treat additional soil.

This technology was excluded from consideration in this document because of expense and the intensive technology required.

R. BASE CATALYZED DECOMPOSITION PROCESS (BCD)

The principle of BCD is the use of hydrogen radicals generated from a hydrogen donor to completely replace the chlorine ions in the chlorinated hydrocarbons. The key operating variables for the reaction are temperature, base catalyst, and hydrogen donor concentrations. Contaminated soil is screened, processed with a crusher and pug mill, and mixed with a base such as sodium bicarbonate or sodium hydroxide, and a catalyst. The mixture is heated to approximately 630 °F in a rotary reactor to decompose and partially volatilize the contaminants. The soil is cooled and removed.

This technology was excluded from consideration in this document because of expense and the intensive technology required.

S. AIR STRIPPING

Volatile organics are partitioned from ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

This technology might be useful in a limited situation. It was excluded from consideration in this document (except for Chapter VI, Section D) because of expense.

T. PUMP DRAW-DOWN

Pump draw-down is a way to create a "slope" of ground water by removing water from below the ground water table, creating a depression. For fuel products that float on the ground water table, free product "slides" into the depression, and in theory is more easily removed. Two drawbacks are that this creates a smear zone where the contaminant may be forced deeper into the subsurface than before, and more water must be pumped to the surface for treatment than with bioslurping. Further, the radius of influence for pump draw-down is not large. Depending on soil porosity, this radius may be only 1 foot.

Bioslurping has been shown to have a radius of influence of 20 feet under similar conditions.

This technology was excluded from this document because bioslurping is a more effective means of free product removal.

U. BIOCELL TREATMENT OF PETROLEUM-CONTAMINATED SOILS

Military installations may need to clean up small quantities of petroleum-contaminated soils, such as those near fuel storage tanks, maintenance and vehicle wash areas, and training areas. The biocell system converts commercial roll-off dumpsters into fully contained bioremediation units by adding plumbing and materials for nutrient and air supply. Individual units can treat up to 40 yd^3 of contaminated soil at a time. The unit is effectively a contained heap pile, and the system works effectively for small quantities of soil to contain released gases, and for ease of monitor sampling during the process.

This technology was excluded from consideration from this document largely because of the engineering involved. It may be a cost-effective method for small quantities of soil as compared to landfilling or incineration.

V. EXTRACTION METHODS

Each of the following technologies was excluded from consideration in this document because of expense and intensive technology required:

- *Organic Solvent Extraction* is based on using the natural solubility of hazardous compounds in various solvents to perform a physical separation. The solvent comes into contact with the waste stream, dissolves the contaminant, and removes it from the media. After solvent and solute are separated, the solvent can be used again in the same process.
- *Critical Fluid Extraction* is the use of liquefied gases (propane or carbon dioxide) as solvents to remove organic constituents form sludges. The system uses vapor recompression and conventional distillation to recycle the solvents and concentrate the organic constituents.
- *In Situ Hot Air Injection/Vacuum Extraction* involves the injection of hot air into the saturated or unsaturated zone to increase the mobility of volatiles and facilitate extraction.
- *In Situ Radio Frequency Heating/Vacuum Extraction* involves heating subsurface soils by installing probes that generate radio waves. Radio

frequency heating is used to increase the mobility of volatiles and facilitate extraction.

- *In Situ Electric-Resistance Heating/Vacuum Extraction* involves heating subsurface soils by installing probes that generate an electric current. Electric-resistance heating is used to increase the mobility of volatiles and facilitate extraction.
- *High Vacuum Liquid/Soil-Gas Extraction* occurs by applying high vacuum system to simultaneously remove liquid and gas from low-permeability or heterogeneous formations.
- *In Situ Steam Injection/Vacuum Extraction* forces steam into an aquifer through injection wells to vaporize volatile and semi-volatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.
- *Heavy Metals Recovery by Extraction From Soils or Ore* is popular when an ore contains a precious metal such as gold or silver. Mining technology can extract other metals as well. One example is the Kuryluk Mineral Separator (KMS) Concentrator's heavy metal recovery system. Originally developed for the purpose of separating gold from precious metal ores, it has since been adapted to recover heavy metals such as mercury, lead, copper, zinc, etc.; heavy alloys such as brass; and precious metals such as gold and silver from various material matrices (soils and mineral ores primarily). Materials handling requires earth-moving equipment to deliver feedstock to a feed hopper which supplies a screening unit via a conveyor system. The site requires a water supply. However, following initial system commissioning, the process water is recycled and reused; make-up water requirements are minimal.
- *Hot air vapor extraction (HAVE)* uses a combination of thermal, heap pile, and vapor extraction techniques to remove and destroy hydrocarbon contamination in soil. The technology effectively cleans soils contaminated with gasoline, diesel, heavy oils, and PAHs. Its advantages are the rapidity of the process (500 yd^3 of diesel-contaminated soil pile cleaned in 7 days), that the system can be trailer mounted and ready for deployment, and its low cost compared to other thermal technologies. The disadvantages are the higher cost compared to the technologies in the body of this document and the engineering required.

W. SKIMMING OF FUELS FLOATING ON THE GROUND WATER

Conventionally, skimming refers to the pumping removal of the top layer of LNAPL and some ground water by means of an open well not under vacuum, inside of which is a smaller tube or pipe through which the floating free product and water is drawn. Since the well is not under vacuum, the inner pipe must be lowered into the liquid phase. When a free product layer exists, the method is called skimming. Pump and treat refers to ground water with no free-product phase but with dissolved fuel components in the ground water. Tremendous volumes of water are pumped out along with the free product. These phases must be separated and the contaminated water treated, both costly procedures.

Another meaning to skimming refers to a case where contamination is near the surface. Trenches are dug into which the free product floats and is skimmed off. Drawbacks to this method are the disruption to the soil, vapor release to the atmosphere of any volatiles, and expense. Although it can be an effective means of free-product recovery, it can also be costly.

Conventional skimming may work in some situations better than bioslurping, but bioslurping is the method of choice for free product removal and reducing the volume of contaminated water.

This method was excluded from consideration in this document because bioslurping is proving to be a more efficient and cost-effective method.

Appendix C

POTENTIAL SOURCES OF ASSISTANCE FOR ENVIRONMENTAL TECHNOLOGY USE

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POTENTIAL SOURCES OF ASSISTANCE FOR ENVIRONMENTAL TECHNOLOGY USE

A. ORGANIZATIONS AND COMPANIES

Difficulties arise in creating a list such as this. Personnel in Central European nations responsible for site cleanup need to be able to trust the potential contractor both to do the work and to demonstrate the appropriate expertise. Funds are limited. Time is of the essence. Contractors effective in one technology and set of contaminants may not have appropriate expertise even if just one additional contaminant is in place at the site. Additionally, communication between any potential U.S.-based contractor and Europe may be difficult. For these reasons, a governmental liaison between European nations and U.S. contractors or European contractors is suggested. The Intergovernmental and Superfund Support Branch of the United States Army Corps of Engineers provide experienced personnel in contract bid review and contract management, and their experience in both these areas would serve Central European nations and the contractors.

Point of Contact: Mr. James Waddell, Headquarters, United States Army Corps of Engineers, 20 Massachusetts Avenue, Washington, D.C. 20314, Tel: (202) 761-8879, Fax: (202) 761-0525, jim.waddell@hg01.usace.army.mil

Web site: http://www.hq.usace.army.mil/cemp/e/es/working/2frames-mp.htm Corps of Engineers, Military Programs, Environmental Division, Intergovernmental and Superfund Support Branch.

Battelle Memorial Institute, 505 King Ave., Columbus, Ohio 43201-2693, Tel: (614) 424-6424, Fax: (614) 424-3404. World Wide Web site: http://www.battelle.org Environmental Restoration: innovative bioremediation approaches, natural attenuation, bioventing application evaluation, bioslurping, physical/chemical treatment technologies, waste solidification/stabilization, soil vapor extraction, passive barrier walls, groundwater modeling, integrated bioremediation technology demonstrations.

Canonie Environmental Services Corporation (Point of contact: Dennis Curran), 441 N. Whisman Road, Building 23, Mountain View, California 94043, Tel: (415) 960-1640. Soil vapor extraction.

DitchWitch is a piece of equipment that digs trenches and is often used in the technology of creating passive barrier walls. Any contractor can use it for a shallow depth trench, but deeper trenches would need an experienced contractor.

DuPont Glasgow, Central Research and Development, Suite 301, Newark, Delaware 19714, Tel: (302) 451-9940. Phytoremediation.

Electrokinetics, Inc., Louisiana State, University South Stadium Drive, Baton Rouge, Louisiana, 70803-6100, Tel: (504) 388-3992. Electrokinetics for heavy metals.

Engineering Science, Incorporated, 1700 Broadway, Suite 900, Denver, Colorado 80290. Composting, biopiles, bioventing, land treatment.

ENSR (Point of Contact: Jonathan Greene), 3000 Richmond Avenue, Houston, Texas 77098, Tel: (713) 520-9900. Slurry-Phase Bioremediation.

Envirocon, Inc., P.O. Box 5367, Los Alamitos, California 90720, Toll-free Tel: 1-800-499-9919, E-mail: enviroconinc@earthlink.net
Soil vapor extraction.

EnviroMetal Technologies, Inc., 42 Arrow Road, Guelph, Ontario, N1K 1S6 Canada, Tel: 519-824-0432. EnviroMetal Technologies, Inc., holds an exclusive license with the University of Waterloo for passive barrier walls treatment technology. See "*In Situ* Remediation Technology Status Report: Treatment Walls." EPA542-K-94-004, April 1995.

Environmental Restoration Systems (ERS), 9 Dogwood Lane, Middletown, Pennsylvania 17057, Toll Free Tel: 800-944-5515, Tel: 717-944-5508, Fax: 717-944-4551 Internet: http://www.ersinfo.com/index.htm ERS is an industry leader in environmental remediation systems design and manufacture.

ETUS Incorporated, 1511 Kastner Place, Sanford, Florida 32771, Tel: (407) 321-3098, E-mail: etus@env-sol.com, Internet: http://www.env-sol.com/etus/

Geocon, 4075 Monroeville Blvd., Corp 1 Bldg. 2 Suite 400, Monroeville, Pennsylvania 15146, Tel: (412) 856-7700. Solidification and stabilization.

Geosafe Corporation, 2952 George Washington Parkway, Richland, Washington 99352, Tel: (509) 375-0710. Solidification and stabilization.

Geraghty & Miller, Inc., Water Information Center, 1099 18th St., Suite 2100, Denver, Colorado 80202-1921, Contact Name: Ms. Dee Farrell, Tel: (303) 294-1200, Fax: (303) 294-1239, E-Mail: gmgwwest!denver!dfarrell@gmdenver.attmail.com

Grace Dearborn Inc., Environmental Engineering Group, 61 Carleton Street, Suite 3, Fredericton, New Brunswick, E3B 3T2, Canada. Tel: (506)459-8587, Fax: (506)453-9860, E-mail:gracedb@mail.mi.net. Offices also in Mississauga, Ontario, and 300 Genesee Street, Lake Zurich, Illinois 60047, Toll-free Tel: 1-800-265-9304. Bioremediation, real time monitoring of contaminated soils and sediments, Daramend® bioremediation of soils with chlorophenols and PAHs, composting, biopiles, specialty engineering services, and solutions to industrial water processing problems in the energy, mining, mineral processing, textile, and other sectors.

Groundwater Services, Inc., 2211 Norfolk, Suite 1000, Houston, Texas 77098-4044. Tel: (713) 522-6300, Fax: (713) 522-8010, Internet: http://www.gsi-net.com/. An engineering firm that specializes in the assessment and management of environmental risk, and innovative solutions to soil, ground water, surface water, and air pollution problems.

Hayward Baker, 1875 Mayfield Rd., Odenton, Maryland 21113, Tel: (410) 551-1995. Solidification and stabilization.

HNU Systems, Inc., 160 Charlemont Street, Newton Hightlands, Massachusetts 02161-9987, Tel: (617) 964-6690. Field Portable X-Ray Fluorescence Spectometers.

Horizontal Technologies, Incorporated, Cape Coral, Florida, Tel: (941) 995-8777, Fax: (941) 995-8465, Internet: http://www.horizontal.com/htisoq.html

Institute of Gas Technology, 1700 S. Mount Prospect Rd., Des Plaines, Illinois 60018, Tel: 708-768-0500, Fax: 708-768-0501. Composting, biopiles, bioremediation.

James Perkins Terra Vac, Inc. 14798 Wicks Boulevard, San Leandro, California 94577, Tel: (510) 351-8900. Soil Vapor Extraction.

James E. Hanson Geosafe Corporation 2950 George, Washington Way Richland, Washington 99352, Tel: (509) 375-0710. *In Situ* Vitrification.

Joseph Hutton SoilTech ATP System, Inc., 800 Canonie Drive Porter, Indiana 46304, Tel: (219) 926-8651. Thermal Desorption - Rotary kiln desorber with proprietary sand seals.

Kiber Environmental Services, Inc., 3786 Dekalb Technical Parkway, Atlanta, Georgia 30340, Tel: (770) 455-3944. Solidification and stabilization.

Metcalf & Eddy International Headquarters, 30 Harvard Mill Square, Wakefield, Massachusetts 01880-5371, Tel: (617) 246-5200, Fax: (617) 245-0823, E-mail: meint@tiac, Internet: http://www.m-e.com/txfiles/txindx.htm, Metcalf & Eddy provides environmental treatment and services to industry, municipalities, and governmental clients, specializing in the fields of water, wastewater, solid and hazardous waste, and air quality services. Established in 1907, M&E serves its clients through branch offices, located across the United States and around the world.

Metorex, 1900 N.E. Division St., Suite 204, Bend, Oregon 97701, Toll-free Tel: 1-800-229-9209. Field Portable X-Ray Fluorescence Spectometers.

Millgard Environmental, 19200 Stark Rd., Fivonia, Michigan 48150, Tel: (313) 261-9760. Solidification and stabilization.

Monsanto, 800 North Lindberg, St. Louis, Missouri 63167, Tel: (314) 694-1466, Internet: http://www.monsanto.com/monsanto/index1.html. Lasagna^{TM} Process. Nationwide environmental consulting and engineering firm in ground water remediation, bioslurping, bioventing, soil-washing technology, natural attenuation, and engineering. Its publishing subsidiary Water Information Center, publishes *The Groundwater Newsletter, Water Newsletter*, *International Water Report*, and other books and maps for groundwater professionals. Ground Water Technology Capabilities: bioremediation, vadose zone monitoring

Moretrench Environmental Services, Incorporated, Corporate Office, 100 Stickle Avenue, Rockaway, New Jersey 07866, Tel: 201-627-2100, Fax: 201-627-6078, Internet: http://www.moretrench.com/ Since 1925, Moretrench Environmental Services, Inc., has been providing services to public and private facilities, including landfill gas recovery systems, ground water pump and treatment systems, slurry cut-off walls construction, dewatering, ground freezing, drilling services, wastewater treatment, beach stabilization.

Niton Corporation, 74 Loomis St., P.O. Box 368, Bedford, Massachusetts 01730-0368, Tel: (617) 275-9275. Field Portable X-Ray Fluorescence Spectometers.

Parsons Engineering Science, Inc., 100 W. Walnut St., Pasadena, California 91124, Tel: (818) 440-2000, Fax (818) 440-2630, Internet: http://www. parsons.com. Natural attenuation of fuels and chlorinated organics, bioventing

PHYTOkinetics, 1770 N. Research Park Way, Suite 110, N. Logan, Utah 84341, Tel: (801) 750-0985. Fax: (801) 750-6296. Phytoremediation of organic chemical wastes in surface soils and ground water, use of poplar trees for ground-water plume barrier, grasses and alfalfa on surface soil with creosote, PCP and petroleum hydrocarbon contamination, wetlands.

Phytotech, Inc., 1 Deer Park Drive, Suite I, Monmouth Junction, New Jersey 08852 (908) 438-0900. A development-stage environmental biotechnology company founded to discover, develop, and market products and services for the treatment of soil and water contaminated with toxic metals such as lead and cadmium as well as radionuclides. Although these technologies are on their way to being field proven, this vendor is included here as the initial findings are encouraging. Hydraulic barriers with poplar trees and wetlands are probably the two technologies closest to being field ready.

Praxair Inc., 39 Old Ridgebury Road, Danbury, Connecticut 06810, Tel: (203) 837-2174, Point of contact: Gary Storms. Slurry-Phase Bioremediation.

Remediation Technologies, Inc. (ReTeC), 1001 S. 24th Street, W., Suite 105, Billings, Montana 59102, Tel: (406) 652-7481; and 1011 Southwest Klickitat Way, Suite 207, Seattle, Washington 98134, Tel: (206) 624-9349. Land treatment.

Roy F. Weston, Inc., 1 Weston Way, West Chester, Pennsylvania 19380, Tel: (610) 701-3000, Fax: 610-701-3186, Internet: http://www.rweston.com Large company, has offices in many U.S. states and in Ireland, Poland, and Taiwan. Provides technical expertise and comprehensive approach to environmental management; can develop a complete environmental program, including many of the remediation technologies included in this study.

RSI (Remediation Service, International), 2060 Knoll Drive, Ventura, California 93003, Tel: (805) 644-5892, Fax: (805) 654-0720. Internal combustion engine used to remediate heavily contaminated gasoline sites.

Rust Environmental and Infrastructure, P.O. Box 24000, Greenville, South Carolina 29616, Tel: 864-234-3000. Bioslurping, soil vapor extraction, thermal oxidation.

SCAT Engineering, a Division of ATI Inc., Box 266, Kelhi, Iowa 52223, Tel: 319-922-2981, Fax: 319-922-2130, Toll-free Tel: 1-800-843-7228. Composting, biopiles.

Scientific Software Group, E-mail: info@scisoftware.com, Internet: http://www.scisoftware.com A software and publications company, established in 1984, sells and supports environmental software and publications. Among those served are engineers, public utilities, and industrial clients, as well as Federal, state, and local governments. Software includes USGS, EPA, and privately developed models and modeling programs for ground water, surface-water, storm water, parameter estimation, coastal areas, geochemical, watershed, risk assessment, pesticide transport, geostatistical, contaminant transport, hydrocarbon, soil water, and such software programs as water quality analysis, seepage analysis, slope analysis, remediation, boring log and well construction, 3-D environmental visualization, geology, solid waste management, landfill design, SURFER, GRAPHER, bioremediation, compilers, geotechnical, kriging, environmental assessment, pump test analysis, DTM, COGO, GIS, and highway design, among others.

Scitec Corporation, 415 N. Quay, Kennewick, Washington 99336-7735, Tel: (319) 323-5419. Field Portable X-Ray Fluorescence Spectometers.

S.M.W. Seiko, 2215 Dunn Rd., Hayward, California 94545. Tel: (510) 783-4105. Solidification and stabilization.

SoilTech ATP System, Inc., 800 Canonie Drive, Porter, Indiana 46304 (219) 926-8651. Thermal Desorption.

SOLUTIONS Software Corporation, 1795 Turtle Hill Road, Enterprise, Florida 32725, Tel: (407) 321-7912, Fax: (407) 321-3098, E-mail: solution@env-sol.com, Internet: http://www.env-sol.com/ SOLUTIONS Software Corporation publishes public-domain reference material on CD-ROMs at a low cost while using state-of-the-art search and retrieval software. Their philosophy encompasses two important positions: (1) U.S. Government data are public-domain materials and they are not (and never have been) subject to any copyright. SOLUTIONS Software republishes this material in a useful, compact format with appropriate indexing and cross-referencing to assist the user. The software engine(s) is copyrighted as is the native format of the datafiles. (2) SOLUTIONS Software Corporation provides this essential reference data on CD-ROM at the lowest possible cost. They have many U.S. Government documents and data bases. In their Testing & Environmental References, they have Solid Waste Test Methods: EPA SW-846 Procedures plus TSCA Chemical Database, Test Methods for Regulated Substances (EMMI), IRIS (Integrated Risk Information System) Database, and the Innovative Technology Database: thousands of waste management solutions. Each of these is in CD-ROM format.

Southern Water Treatment Company, Toll-free Tel: 1-800-873-1755, Fax: 1-800-995-5414, Internet: wysiwyg://47/http://www.sowatreco.com/

Terra-Vac, Inc., 9030 Secor Road, Temperance, Michigan 48182, Tel: (313) 847-4444. Soil Vapor Extraction.

Thermatrix, Inc., 308 N. Peter Road, Suite 225, Knoxville, Tennessee 37922. Tel (615) 539-9603 Fax (615) 539-9643. Two systems for destruction of chlorinated solvent vapors at the surface: Thermatrix Flameless Thermal Oxidizer, and Purus-PADRE system of resin beds.

TN Spectrace, 2555 N. IH 35 P.O. Box 800, Round Rock, Texas 78680-0800, Toll-free Tel: 1-800-736-0801. Field Portable X-Ray Fluorescence Spectometers.

United States Army Corps of Engineers. Jerome Stolinksi CERMO U.S. Army Corps of Engineers, Omaha District.

Waterloo Centre for Groundwater Research, University of Waterloo, Waterloo, Ontario N2L 3G1 Canada, Tel: 519-885-1211. Treatment walls.

Woodward-Clyde Federal Services, 4582 S. Ulster St., Suite 1200, Denver, Colorado 80237, Tel: (303) 740-2600. Soil Vapor Extraction.

B. USEFUL WEB SITES:

- Agencies linked to the Federal Remediation Technologies Round Table, http://www.frtr.gov/agencies.html
- Brownfields information, http://www.epa.gov/brownfields
- DOE "Rainbow Report," http://www.doe.gov Contain the same information as cost to performance: see the Web site
- EPA Hazardous Waste Clean-up Information http://clu-in.com voice help 301-589-8368, 9 AM-5 PM Eastern Time. And CLU-IN Electronic Bulletin Board System (301) 589-8366, download the same files and databases offered on the WWW site. Four databases available for downloading: (1) Bioremediation in the Field Search System (BFSS), (2) Vendor Information System for Innovative Treatment Technologies (VISITT), (3) Innovative Treatment Technologies (ITT) Annual Status Report Database, and (4) Vendor Field Analytical and Characterization Technologies System (Vendor FACTS). Also, there are: Encyclopedia of Innovative Technologies with links to other sites: Technology Innovation New Survey — Biweekly update: *Tech Trends*, a newsletter for those in the field; *Ground Water Currents* — newsletter on ground water remediation; Bioremediation in the Field — at CERCLA, RCRA, UST and TSCA sites. Underground Tank Technology Update: Innovative Treatment Technologies (ITT) Annual Status Report - offers application of innovative technologies and a companion ITT Database provides site-specific information. There are full text documents on many technologies.
- *EarthLink* is a bi-monthly current awareness newsletter produced by INFOTERRA/USA. *EarthLink* provides information on international environmental activities, publications and news of interest to EPA staff and other environment professionals. Contact INFOTERRA in the EPA Headquarters Information Resources Center, Tel: (202) 260-5917, Fax: (202) 260-3923, E-mail: library-infoterra@epamail.epa.gov., http://www.epa.gov/earlink1/INFOTERRA/index.htm
- Federal Remediation Technologies Round Table, http://www.frtr.gov
- Ground Water Research Technologies, http://www.gwrtac.org/htbl/vendors.html
- National Center for Environmental Research and Quality Assurance, Office of Research and Development, USEPA. Lists topics being researched. http://es.inel.gov/ncerqa/hsrc/detection/index.html

- TechKnow database, http://www.gnet.org/forsite/?SubSystemID=1&ComponentID=4936
- United States Geologic Survey - http://www.water.usgs.gov
  All water reports from 1939 to 1994 are there. From 1994 to present, only the cleanup of contaminated water reports. A second site for toxics: http://toxics.usgs.gov
- http://www.echs.ida.org
- http://maps.esri.com has maps of many areas in U.S. and world. It is possible to download the file for the map of your area of interest and using GIS and GPS data, superimpose well data or contaminant data from samples on the site: maps can be generated directly with contaminant information on the map instead of placing data by hand.

Sources for some of these sites:

- *Environmental Science and Technology*, "On-line Resources," Vol. 30, No. 5, 1996, p. 217A.
- *Environmental Science and Technology*, "Environment On-Line," Vol. 30, No. 2, 1996, p. 76A.
- *Environmental Science and Technology*, "Environmental GIS: The World in a Computer," Vol. 30, No. 8, 1996, p. 340-343A.
- *Environmental Science and Technology*, "World Wide Web Resource," Vol. 30, No. 8, 1996, p. 357A.

EPA Watershed Tools Directory

- An Internet site of EPA's Office of Wetlands, Oceans, and Watersheds is an on-line Watershed Tools Directory, listing several hundred assessment methods, models, documents, and other resources for watersheds or water supplies.
  http://www.epa.gov/OW/watershed/tools

Geographical Information Systems

- Geographic information system (GIS) computer programs that manipulate and analyze spatial data represent one of the hottest growth areas in the world of computing. For a list of GIS software packages, see http://triton.cms.udel.edu/~oliver/gis_gip/gis_gip_list.html

Below are listed other GIS sites

- Federal Geographic Data Committee Internet Site
  http://fgdc.er.usgs.gov
- EPA Internet Data Sites
  http://nsdi.epa.gov/nsdi
  http://www.epa.gov/docs/grd
  SITEINFO: http//www.epa.gov/region10/www/siteinfo.html
  North Carolina Center For Geographic Information And Analysis
  http://cgia.cgia.state.nc.us
  GIS data publishers
  http://www.esri.com/products/arcdata/publishers.html
  Alexandria Digital Library
  http://alexandria.sdc.ucsb.edu
  Friends of the Earth
  http://www.foe.co.uk/index.html

Regional Environmental Center For Central And Eastern Europe

- A nonprofit organization established to promote environmental solutions in the region.
  http://www.rec.hu

Web Sites Related To Europe

- http://www.ovam.be/internetrefs/english.htm
- Alphabetical listing by subject of European environmental sites
  http://www.ulb.ac.be/ceese/cds.html
- European Environmental Agency, some agency reports, strong on policy matters
  http://www.eea.dk:80

California Environmental Protection Agency Brochures

- A series of brochures from the California Environmental Protection Agency on a wide variety of topics related to environmental cleanup issues.
  http://www.calepa.cahwnet.gov/dtscdocs/BBSPUBL&.TXT

U.S. Environmental Protection Agency Home Page

- http://www.epa.gov

U.S. Department of Energy Home Page

- http:www.doe.gov

National Environmental Information Resources Center

- http://gwis.circ.gwu.edu:80/~greenu

U.S. Geological Survey Wrsic Research Abstracts Database

- http://www.uwin.siu.edu/databases/wrsic/index.html

List of University Environmental Web Sites

- http://bigmac.civil.mtu.edu/aeep/univ.html

University of California Los Angeles Center For Clean Technology

- http://cct.seas.ucla.edu

University of California Berkeley Digital Library Project

- http://elib.cs.berkeley.edu

Cornell University List of Environmental And Natural Resources Databases

- http://mannlib.cornell.edu/catalog/subject/env.html

List of Environmental Listservs

- http://www.tribnet.com/environ/env_list.htm#environmental

Water Environment Web

- A nonprofit technical and education organization, the Water Environment Federation, sponsors this page, with a guide to programs, publications and workshops, links to other water web pages, and much more.
  http://www.wef.org

Waterweb

- Features an on-line bookstore, classified ads for water professionals and a discussion group. Sponsored by Digital Resources Corporation of Scottsdale, Arizona.
  http://www.waterweb.com

Water Online

- Offers a database of more than 2000 water-related product suppliers, lists trade meetings and event and provides links to agencies and associations.
  http://wateronline.com

Environmental Routenet

- A fee-based service (see the Web site) for access to 11 environmental databases, many of them proprietary. Data available include 2 million records of site-specific information on environmental hazards and accidents, patent abstracts, grant and funding sources, and daily and weekly news updates.
  http://www.csa.com/routenet

Some Environmental Journals On The Web

- Elsevier Science Tables of Contents only
  http://www.elsevier.nl/locate/estoc
- American Chemical Society's Journals and Magazines
  http://pubs.acs.org/journals/jrnhome.html
- Springer Journals Preview Service
  http://www.springer.de/server/svjps.html

EPA Pollution Prevention Information

- A clearinghouse of pollution prevention information funded by the EPA and by the Strategic Environmental Research and Development Program with links to the National Pollution Prevention Roundtable, Dial-up bulletin board (703) 908-2092
  http://es.inel.gov

Center For Subsurface Modeling Support

- Free downloadable ground water related software packages, such as BIOPLUME II, CHEMFLO, and MODFLOW. Site is part of the EPA's Robert S. Kerr Environmental Research Center in Ada, Oklahoma.
  http://www.epa.gov/ada/csmos.html

Appendix D

ENVIRONMENTAL MODELS AND MODELING

Appendix D
ENVIRONMENTAL MODELS AND MODELING

This list is not exhaustive. A list of models for pressure distribution, airflow, and vapor transport usable with personal computers can be found as Table C-1 of the document, "Soil Vapor Extraction and Bioventing," U.S. Army Corps of Engineers, EM 1110-1-4001, 30 November 1995.

A suite of 51 software packages and related materials, used by the United States Geological Survey for hydrologic analysis and modeling, is available at http://water.usgs.gov/software/

The Register of Ecological Models is a site with more than 360 models, it is maintained by Germany's University of Kassel, and can be seen at http://dino.wiz.uni-kassel.de/model_db/server.html

Enviromod Software Repository http://hydrosystems.com/ehisrvr.html contains public domain ground water model software, as does the Groundwater Model Library at http://kilburn.keene.edu

At the Center For Subsurface Modeling Support, there is free downloadable ground-water-related software packages, such as BIOPLUME II, CHEMFLO, and MODFLOW. The site is part of the EPA's Robert S. Kerr Environmental Research Center in Ada, Oklahoma.
http://www.epa.gov/ada/csmos.html

A. MODELS

3DFATMIC — 3-D subsurface flow, fate, and transport of microbes and chemicals.

3-D — Finite-difference ground-water flow model.

BALANCE — Calculates mass transfer for geochemical reactions in ground water.

BIO1D — Biodegradation and sorption in contaminant transport

BIOCHLOR will be the counterpart to BIOSCREEN, but for chlorinated solvents, it will be a screening tool.

BioF&T 2D/3D — Biodegradation, flow, and transport in the saturated and unsaturated zones.

BioMOD 3-D — Bioremediation, fate, and transport for MODFLOW.

BIOPLUME II — Transport of dissolved hydrocarbons under the influence of oxygen-limited biodegradation. It is a model to give an exact figure of the assimilatory capacity of the aquifer, which is determined by the electron acceptors at the site. Samples of clean ground water upgradient from the site as well as plume ground water are tested for electron acceptors. However, BIOPLUME II is limited to aerobic conditions and for fuel hydrocarbons. The next iteration of this model, BIOPLUME III is (as of May 1997) being finalized. It will include anaerobic conditions and natural attenuation of chlorinated organics.

BIOSCREEN is an easy-to-use screening tool for simulating the natural attenuation of dissolved hydrocarbons at petroleum release sites under aerobic conditions. See "The BIOSCREEN Computer Tool," by Charles J. Newell, R. Kevin McLeod, and James R. Gonzales in: Symposium on Natural Attenuation of Chlorinated Organics in Ground Water, EPA 540/R-96/509. It is designed to answer the question, "Should I invest in a natural attenuation study?" If the answer is yes, then the next model to use is BIOPLUME II. BIOSCREEN is intended to be used in two ways: as a screening model to determine whether intrinsic remediation is feasible at a given site, and as the primary intrinsic remediation ground-water model at smaller sites.

BIOSLURP — Multiphase hydrocarbon vacuum enhanced recovery and transport.

BioSVE — Vacuum enhanced recovery with bioventing.

ChemPath — An innovative solute transport package.

ChemPoint — RCRA and CERCLA ground-water analysis database for Windows with GRITS/STAT.

HEC-1 — Watershed modeling system with this model.

HELP model for Windows — Landfill design tool for an open, partially closed or closed landfill.

INTRAVAL — An international cooperative project focusing on evaluation of conceptual and mathematical models for ground-water flow and transport in the context of performance assessment of geologic repositories. INTRAVAL consists of many test cases and involves 26 participating parties from 12 countries and 11 field experiments. The primary objective of INTRAVAL is to increase scientific confidence in approaches to modeling flow and transport in a variety of geologic settings. The first phase began in October 1987, consisting of both numerical modeling and experimental work. The results of the first phase, completed in September 1990, showed a need for closer collaboration between experiments and models. The second phase began in October 1990 with modelers attempting to predict the results of experiments. Comparisons of predictions with laboratory or field measurements are used to evaluate the current scientific understanding of flow and transport and the conceptual models employed. http://www.arc.unm.edu/research/gwtt/intraval.html

KYSPILL — Scale-dependent ground-water pollution model capable of predicting three dimensional dispersion in soils and the subsequent two-dimensional propagation in unconfined heterogeneous aquifers. Useful for underground storage tank leaks, sanitary landfill leaching, accidental chemical spills, and saturated or unsaturated zone spills.

MARS 2D/3D — Multi-phase aerial remediation simulator.

Micro-Fem — Finite-element program for multiple-aquifer steady-state and transient ground-water flow modeling.

MODFLOW — Three-dimensional ground-water flow model developed by the USGS to simulate ground-water flow. World's most popular ground-water flow model.

MODFLOWP —USGS computer program for parameter estimation of a transient or steady-state, three-dimensional, ground-water flow model using nonlinear regression. Data used to estimate parameters in MODFLOWP can include existing independent estimates of parameter values, observed hydraulic heads or temporal changes in hydraulic heads, and observed gains and losses along head-dependent boundaries (such as streams). Model output includes statistics for analyzing the parameter estimates and the model.

MODFLOWT — 3D Contaminant Transport Model with MODFLOW.

MODINV — MODFLOW parameter optimization.

MONTE CARLO — Model is adapted for use with phytoremediation.

MONITOR 5 for Windows — Environmental data management, assessment, and reporting software.

MOVER — Multiphase aerial flow with vacuum-enhanced recovery.

PEST — Parameter estimation for any model.

PHREEQE — Models geochemical reactions.

PHRQPITZ — Geochemical calculations in brines and other electrolyte solutions to high concentrations.

PLOTCHEM for Windows — Water quality data plotting program.

RAND3D — Three-dimensional random walk program.

RECESS — Recession of ground water discharge and estimating mean ground-water recharge and discharge from streamflow records.

RETC — Analyzes soil water retention and hydraulic conductivity functions of unsaturated soils.

RT3D — A new (fall 1997) general-purpose, three-dimensional multispecies reactive transport model for use of accelerated bioremediation, bioventing, and natural attenuation.

SESOIL — Model for long-term pollutant fate and migration.

SiteGIS — Windows-based software to analyze and present environmental data used in subsurface remedial investigations.

SPASE — Spatial database manager

SUTRA-ANE — 2-D saturated/unsaturated transport.

SWIFT/486 — 3-D model to simulate ground-water flow, heat, brine, and radio nuclide transport/

VENT2D & VENT3D — Models of soil vapor extraction (SVE) at sites with finite-difference of multi-compound vapor transport and phase distribution. http://www.hydro.unr.edu/homepages/benson/brochure/v2dbroch.html

TECHBASE — Geologic information system.

WATERSHED MODELING — Hydrologic analysis of drainage basin.

WMS — Watershed modeling system.

B. VENDORS

Scientific Software Group, an internationally known software and publications company established in 1984, provides environmental software and publications. Among those served are engineers, public utilities, and industrial clients, as well as Federal, state, and local governments. Software includes USGS, EPA, and privately developed models and modeling programs for ground water, surface-water, storm water, parameter estimation, coastal areas, geochemical, watershed, risk assessment, pesticide transport, geostatistical, contaminant transport, hydrocarbon, soil water, and such software programs as water quality analysis, seepage analysis, slope analysis, remediation, boring log and well construction, 3-D environmental visualization, geology, solid waste management, landfill design, SURFER, GRAPHER, bioremediation, compilers, geotechnical, kriging, environmental assessment, pump test analysis, DTM, COGO, GIS, and highway design, among others.

Scientific Software Group, e-mail: info@scisoftware.com.
World Wide Web site: http://www.scisoftware.com

Appendix E

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE REMEDIATION MATRIX – HIERARCHY OF PREFERRED ALTERNATIVES

Appendix E

U.S. AIR FORCE ENVIRONMENTAL RESTORATION STRATEGY SELECTION MATRIX

The matrix was designed for managers of environmental restoration projects. Across the top are the contaminants and the media that are contaminated. Down the left side are various remediation strategies. The numbers in each column have two purposes: first, the presence of a number indicates that remediation strategy applies to that contaminated media; second, the numbers rank these strategies with regard to least cost, starting with number 1. Managers of remediation strategies at Air Force bases are required to use the strategy with the least cost unless a justifiable reason exists to use a more costly strategy.

Appendix E. AFCEE Remediation Matrix – Hierarchy of Preferred Alternatives

	POL-Vadose Zone (i.e., jet fuel, diesel)	POL-Excavated Soil	Floating Product Deep (>20ft)	Floating Product Shallow (<20ft) Low Permeability	Floating Product Shallow (<20ft) High Permeability	Dissolved Fuel in Ground Water (BTEX)	Chlorinated Solvents in Vadose Zone (i.e., TCE)	Dissolved Chlorinated Solvents in Ground Water	Heavy Metals In Vadose Zone	Heavy Metals in Excavated Soil	POL Vapor Treatment	Chlorinated Solvent Vapor Treatment
Natural Attenuation/Assimilation	1	1	1	1	1	1	1	1	1	1		
Bioventing	2	4					3 co-metabolism					
Soil Vapor Extraction	3	5					2					
Heat Enhanced Vapor Extraction	4						4					
Low Permeability Cover/Cap	5						6		3			
Excavate and/or Haul	6	8					7		4	4		
Composting (no tilling)		2										
Land Farming		3								2		
Low Temp Thermal Desorp		6										
Incineration (High Temp)		7										
Apparent vs. Actual Studies			2	2	2							
Passive Extraction Wells			4	5	4							
Hand Bail if Appropriate			3	3	3							
Vacuum Assist Pumping			5	4	5							
Dual Pump System			6									
Air Sparging*						3		3				
Passive Treatment Wall						4		4				
Conventional Pump and Treat						5		5				
Slurry Wall						6		6				
Stabilization							5		2	3		
Permitted Direct Emission											1	1
Flare											2	
Biological Filter											6	4 Co-metabolism
Catalytic Incineration											4	2
On-Site Regenerated Polymer											5	3
Carbon Adsorption											7	
Internal Combustion Engine											3	
GW Recirculation/Stripping						2		2				5

This matrix is an attempt to rank technologies/processes that should be considered for use at common Air Force sites. Managers should use this hierarchy for screening technologies/processes and should be able to justify why a particular technology/process was selected over others with lower numbers. For instance, if soil vapor extraction (3) is the selected technology/process for POL in the vadose zone, then managers should be able to justify why neither natural attenuation (1) nor bioventing (2) was selected. The natural attenuation/assimilation should always be considered first and, if selected, should be based on a scientifically defensible risk assessment. Selection of this technology/process should be accompanied by field sampling and modeling to quantify and predict natural attenuation rates. A long-term monitoring program should be implemented to verify natural attenuation model predictions.

*Very susceptible to subsurface heterogeneities, applicable where the installation of a high density of sparging (extraction) points is economically favorable.

Appendix F

COMMENTS ON LANDFILLS

Appendix F
COMMENTS ON LANDFILLS

If the option for landfilling a contaminated soil or dredge spoil is chosen as a remediation strategy, several items are to be considered. The contamination is still in the material, it is simply being moved to another location to contain it, control it, or prevent ecological or human health contact. The landfill is subject to rainfall and other precipitation that may leach the contaminant out of the soil like tea from a teabag.

First, and perhaps foremost, is the site of the landfill itself. With every precaution followed in designing and placing for the liner and the cap, there will still be leaching from the landfill. Therefore, it is important that the site of the landfill of contaminated material be considered carefully.

Prevention of leaching may occur if no water seeps through the landfill. The ideal situation, likely unattainable, is to have all water run from the top of the landfill and none percolate through. Therefore, the landfill cap is of critical importance. The following study on landfill caps is included for information.

A. COMMENTS ON LANDFILL DESIGN

The prevention of ground water contamination from waste management facilities must be achieved through some combination of siting and engineering design. In years past very little of either was done. Landfills were often sited in abandoned gravel pits; tailings ponds were sited purely on the basis of convenience; few precautions were taken to cope with spills at wood preservative dipping tanks. As a result, contaminated leachates were a common occurrence, and they often led to the formation of contaminant plumes in high permeability aquifers.

An emerging set of design features offers hope for improvement. Modern landfill design uses basal liners, surface caps, and leachate collection systems. The basal liner can be a natural clay material or a synthetic polyethylene membrane. It is not uncommon in the United States for regulatory agencies to require more than one liner at the base of a hazardous waste landfill.

There is concern, however, that modern design technology does not really prevent ground water contamination, but merely postpones it. There is little solid information yet on the expected life of synthetic liners, for example, but estimates run in the range of 10-50 years. It is known that liners can be breached by pinhole flaws, improperly constructed seams, animal burrows, and breakdown by acidic or corrosive leachates. The next few decades will provide needed information on whether improved engineering provides a long-term solution to waste containment at land-based facilities.

Given these doubts about the effectiveness of improved design, the issue of siting takes on greater importance. The rate of migration of contaminants in ground water is controlled by the hydraulic conductivity of the geological materials at the site. If land-based waste management facilities could be sited on thick, unfractured clay or silty clay deposits, then contaminant migration rates would not exceed a few centimeters per year. Good siting is the single most important step that could be taken to reduce groundwater contamination from a waste management facility. Unfortunately, siting issues tend to lie in the political arena rather than the technical arena, and there seems little likelihood that this situation will change.

If good siting cannot be guaranteed and good design is still unsure, the need for effective monitoring networks and good leachate collection systems becomes of the utmost importance. Land-based waste disposal facilities seldom contain waste fluids completely; their design must be based on a philosophy of leachate management.[1]

World Wide Web site:

http://www.env.gov.bc.ca/main/stock/top_page.gif

http://wtrwww.env.gov.bc.ca/wat/

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[1] Exerpted from: British Columbia Ministry of Environment, Lands & Parks. *Groundwater, Groundwater Contamination: Occurrence, Sources and Transport of Contaminants in Groundwater.* November 19, 1996. Rod Zimmerman. Section 5.4.2, "Siting and Design of Waste Disposal Activities."

B. ALTERNATIVE LANDFILL CAP DESIGNS, MARINE CORPS AIR STATION, KANEOHE BAY , HAWAII

Most of the past work on landfill covers have been conducted in arid or semi-arid environments with annual precipitation of less than 20 inches per year. In more humid climates, and especially those which average more than 30 inches of precipitation per year, the amount of soil moisture that can potentially be removed by vegetation is usually less than the annual precipitation. This leads to an excess of soil moisture that is available for subsurface percolation into the waste materials. Consequently, a cover design is needed for sites where the amount of water that infiltrates into the soil exceeds the potential for evapotranspiration (ET) to remove it, especially at sites with more than 75 cm of precipitation per year where snow is an important source of annual precipitation.

More than 225 landfills or surface impoundments have been identified throughout the Navy for site remediation. The options for remediation include *in situ* treatment, containment (either capping and/or subsurface barriers), or removal and off-site containment or treatment. During 1994 to 1996, the Naval Facilities Engineering Service Center (NFESC), along with Colorado State University, Marine Corps Air Station (MCAS) - Kaneohe Bay, Hawaii, and Los Alamos National Laboratory (LANL), conducted a demonstration at MCAS Kaneohe Bay to evaluate alternative landfill cap designs.

In the demonstration, three cap profiles were constructed adjacent to an active landfill: a standard soil cap and two water-harvesting cap designs. The water-harvesting designs combined the evaporative forces of vegetation with engineered structures to divert precipitation so that the remaining amount of water that infiltrated the soil could be removed easily by evapotranspiration.

The two new designs will be evaluated for cost and performance in relation to the RCRA guidance. The new system is designed to improve the efficiency and lifespan of the cap and to simplify installation. The information obtained from the short-term monitoring and evaluation of the two caps will be used to write new RCRA landfill cap guidance. This technology will be advocated by EPA for use if it is successfully field demonstrated. Costs of implementation is expected to be $50,000/acre.

During the summer of 1994, a demonstration cap was installed by NFESC and LANL at Kaneohe. The goal of these studies is to develop a variety of field tested capping designs so that the risk manager has cost-effective design alternatives to match the need for hydrologic control at the site.

Los Alamos capping technologies incorporate design features that control one or more of the processes governing the fate of precipitation falling on a site. The fate of meteoric water falling on the surface of a landfill is often referred to as the water balance of the site. It can be represented as an equation:

$$DS/Dt = (P - Q - ET - L) / Dt$$

where: DS/Dt = the time rate of change in soil moisture

P = precipitation per unit area

Q = runoff per unit area

ET = evapotranspiration per unit area

L = percolation below the root zone per unit area

t = unit of time used in solving the equation

Application of the concept of water balance in designing landfill caps takes advantage of the fact that there are strong interactions between the various components of the water balance. For example, a reduction or elimination of the runoff term, Q, increases infiltration of water into the soil, resulting in increased soil moisture storage followed by an increase in evapotranspiration, ET, and/or percolation, L. The coupled nature of the processes that compose the water balance can be used to design landfill caps that minimize or eliminate processes in the water balance that contribute to contaminant migration (i.e., percolation) while enhancing other terms (i.e., evapotranspiration) that do not.

C. KANEOHE STUDY — ADDITIONAL INFORMATION

The study at Kaneohe uses an innovative, but simple and inexpensive, concept to manipulate the fate of water falling on waste sites with high precipitation. The infiltration of water through the cap was controlled by combining the very powerful evaporative forces of native vegetation to remove soil water with engineered structures that limit infiltration of precipitation into the soil. This approach relies on diverting enough of the annual precipitation to controlled runoff so that any water that infiltrates the soil can be removed easily by evapotranspiration.

The study field demonstrated two infiltration-control designs, one involving a 20 percent enhancement of runoff, the other a 40 percent enhancement; and a conventional soil cap (control) served as a basis of comparison. The equivalency of the three designs to the EPA RCRA design was evaluated by comparing the field monitoring data with the predicted performance of the RCRA design using the HELP model.

All plots were equipped with instruments to monitor daily precipitation, percolation, runoff and sediment yield, and soil moisture in order to compute a water balance for each design. Evapotranspiration was estimated. Automated data acquisition systems were used for most of the measurement variables. Periodic measurements of species composition, biomass, canopy cover, ground cover, and leaf area index were also taken of the vegetation cover on each plot.

Some of the data that have been collected on precipitation, runoff, and percolation from the Marine Corps Base at Kaneohe cover designs for the 14-month period between November 1995 and December 1996 and are summarized here. Short-term results support the concept of using runoff enhancement to manage landfill-site water balance. The infiltration control designs increased runoff over the soil cover design and reduced percolation to about one-quarter to one-third of that measured from the soil cover. Results also demonstrated that the hydrologic response of the cover designs is highly dependent on season and a related variable; the amount of precipitation falling during a particular month. Should the performance characteristics of the designs that have been observed thus far be validated with further monitoring data, these designs would offer a simple and inexpensive alternative for interim stabilization or closure of landfills, particularly in more humid sites.

The study used relatively large-scale lysimeters to estimate the hydrologic performance of three cover design alternatives to a clay barrier design. Field data are presented for two infiltration control designs and one soil cover design, including measurements on vegetation cover, precipitation, runoff, and percolation, for the period between November 1995 and December 1996. Soil moisture data were not presented because data analysis was not complete as of December 1997. The equivalency of the three cover designs in controlling runoff and percolation was compared to results for a RCRA clay cap design, obtained with version 3 of the Hydrologic Evaluation of Landfill Performance, or "HELP3" model (EPA/600/R-94/168a).

Most capping technologies incorporate design features that control one or more of the processes governing the fate of precipitation falling on the landfill, which is referred to as the water balance of the site. A simplified representation of water balance describes surface runoff and one-dimensional movement of water in the soil profile to the plant rooting depth.

The Kaneohe study focused on methods to limit infiltration of precipitation into the cover soil by enhancing surface runoff to reduce soil water that must be partitioned between the ET and percolation. Essentially small ditches alternated between rows of plants. Excess water ran off, some percolated in, and the rest became ET. These preliminary results suggest that the two infiltration cover designs and the modified RCRA cover were within a factor of two to three in their ability to limit percolation into the area.

The use of infiltration control techniques for managing waste site water balance is potentially attractive because it can be applied to an existing landfill cover, where it is easily repairable and involves a minimum of material, equipment, and labor. The technique has its roots in ancient history: Hebrew farmers in the Negev desert used the same techniques to support a flourishing agriculture more than 8,000 years ago.

If the performance characteristics of the infiltration designs are confirmed at Kaneohe, these designs could offer a simple inexpensive alternative for interim stabilization or final closure of landfills in humid sites. The design is simple, easy to install over an existing landfill cover, and easy to remove if the land is used for other purposes. In 1998 a report should be ready that will summarize and analyze final data from the study.

Additional information is available in, *A Water Balance Study of Infiltration Control Landfill Cover Designs at Marine Corp Base Hawaii*, T.E. Hakonson, Dep. Radiological Health Science, Colorado State University, Fort Collins, CO 80523, Leslie Karr and Bryan Harre, NFESC, Code 411, 1100 23rd Ave, Port Hueneme, CA 93043.

http://cayuga.nfesc.navy.mil/cc/projects/landfill.htm

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E. WORLD WIDE WEB SITE(S)

- http://www.envirolink.org/issues/landfills (Information on environmental impact of landfills)
- http://www.CSRA.net/SETC (Site demonstration of an aerobic biodegradation system installed at a landfill in Columbia County, Georgia.)
- http://epdwww.engr.wisc.edu/courses/landfill/A18 (An Internet course on Landfill Design from the University of Wisconsin)
- http://epdwww.engr.wisc.edu/iscourses/landfill/A180-bib.html (A bibliographic list for the landfill design course at the University of Wisconsin)
- http://www.cae.wisc.edu/~foose/research.html (Web site that evaluates the effectiveness of Landfill Liners)

Appendix G

CAPABILITIES POTENTIALLY APPLICABLE TO EASTERN EUROPE SITES

Appendix G
CAPABILITIES POTENTIALLY APPLICABLE TO EASTERN EUROPE SITES

Both aquatic and terrestrial pollution of former Soviet military sites in the Baltic Republics of Latvia, Lithuania, and Estonia is being documented, and in some cases cleanup programs have begun. Experiences in Germany have provided substantial background information and applicable methods, especially in terrestrial sites. Since valuable coastal ports were also former Soviet military sites, the issue of marine pollution will need to be investigated and corrected where economic and technical assistance can be applied. Regarding environmental pollution of coastal areas, the Navy's Space and Naval Warfare Systems Center – San Diego (SSC-SD) has extensive experience in measurement and detection technologies, as well as risk assessment concepts. This experience would be well suited for application to such sites as the Liepaja Kara osta site in particular.

Many Navy facilities border coastal regions and estuaries. Hazardous-waste sites, nonpoint source runoff from urban and agricultural lands, industrial and sewage discharges, ship discharges and activities, and the resuspension of contaminated sediments can have significant impacts on these sensitive marine environments. SSC-SD has taken a leading role in developing methods to assess and mitigate impacts from Navy operations in these complex, highly dynamic environments which are vitally important environmental, economic, and aesthetic resources.

The SSD-SC Environmental Sciences Division has been active in the field of Ecological Risk Assessment since 1980. Division personnel have applied the knowledge and methodologies developed during this period to the cleanup of several Navy Comprehensive Environmental Response, Compensation and Liability Act/Resource Conservation and Recovery Act (CERCLA/RCRA) sites, to evaluations of solid waste and effluent discharges from Navy ships, and to the assessment and development of an integrated approach to shipyard water compliance issues. They have also used this approach to develop effective environmental management strategies for the determination of cleanup and corrective actions at contaminated sites. The "EcoRisk" model has also been used by the Division to propose environmental standards that are both scientifically defensible and acceptable to Fleet operations.

In conjunction with the EPA's research laboratories, SSC-SD has developed improved risk assessment methodologies for marine environments and hazardous-waste sites. These demonstrations are part of collaborative studies to provide test-bed validations of improved methods and protocols. SSC-SD has conducted a series of ecological risk assessment case studies in diverse coastal and estuarine environments such as: San Diego Bay, California; Whidbey Island, Washington; Pearl Harbor, Hawii; Kittery, Maine; and Davisville, Rhode Island.

EcoRisk employs diverse assessment tools that include the U.S. Navy's Marine Environmental Survey Capability (MESO) assets, dynamic three-dimensional models, measurement platforms and advanced bioassay capabilities including sublethal biochemical indicators (biomarkers) such as the comet assay. SSC-SD has assisted Navy Fleet and Shore Facilities with ecological risk assessment requirements. Interactions with EPA, National Oceanic and Atmospheric Administration (NOAA), state and local regulatory agencies, and the private sector have enhanced technical and regulatory acceptance of SSC-SD's technology development.

The information in this appendix will be especially relevant to the former Naval base at Liepaja, Latvia. The contamination in the sediments, particularly heavy metals, are a serious problem. The Naval Research and Development Center (SSC-SD) in San Diego, California, has been developing on-site detection technologies for sediments. Contaminated sediments are of concern in two basic situations: when dredged material is too contaminated to dump in the water, and when sediment areas already below water are determined to be a risk to ecological or human health. Sediments shift with changing water flows and currents, whether these be in a river, stream, lake, sea, or ocean. Marine sediments have some unique characteristics from those of fresh water, and the research at SSC-SD specifically addresses these issues. In addition, the ability to measure contaminants while the media is in flux is a great benefit, which requires real-time monitoring and measurement when possible.

A description of the technologies employed at SSC-SD for the determination and assessment of environmental pollution follows.

A. FIELD PORTABLE TRACE METAL ANALYZER

This instrument is capable of automated trace metal analysis of arsenic, cadmium, chromium, copper, lead, mercury and zinc in the field using potentiometric stripping analysis. The potentiometric stripping process has the sensitivity to detect concentrations in the low part-per-billion range, and has been used to detect metals in drinking water, sediment extracts, seawater and industrial plating baths. This instrument is unique in its capabilities. Other instruments that detect trace metals in industrial process control are the graphite furnace atomic absorption spectroscope and the inductively coupled plasma mass spectrometer. These instruments are large, expensive, require considerable infrastructure support, and are not mobile.

Current methods for field testing are difficult to use, usually lack simultaneous multi-channel capability, and require intervention by personnel in order to operate properly. The Field Portable Trace Metal Analyzer (TMA) has none of these drawbacks. It is operated through a Windows-based interface, which enables non-technical personnel to operate the instrument and collect data with minimal training. The instrument continually monitors performance and will automatically notify the operator and log problems that it cannot correct. It is sealed from the external environment to prevent sample contamination. The instrument provides a capability to perform on-site, discrete analyses at less that half the cost of conventional analysis. No sample preparation is required. TMA has multi-element analysis capability, and analysis is done within 2 to 5 minutes.

The TMA shows good correlation for laboratory results for a number of minor and major elements, particularly copper, zinc and lead. These are often contaminants of interest or they can serve as proxies for other contaminants. A special advantage would be in support of remediation efforts, particularly where trace metals measurements must be frequently monitored over extended time periods at a low cost. The TMA is in final demonstration and production, with a partnership developed in the commercial sector to produce this instrument as the Metalizer 5000TM in late 1997.

B. FIELD-PORTABLE X-RAY FLUORESCENCE SPECTROMETRY

X-ray fluorescence spectrometry (XRF) is a technique in which the fluorescence spectrum of x-rays that occur when atoms are excited by a radiation source are measured. The energy of the emitted x-rays reveals the identity of the metals in the sample, and the intensity of emitted x-rays is related to their concentrations. Rapid, multi-element analysis can be performed by XRF. An XRF spectrometer can analyze a wide range of elements (*e.g.*, sulfur through uranium), with a wide dynamic range, from parts per million to percent levels, encompassing typical element levels found in soils and sediments. Field-portable units (FPXRF), which are commercially available, provide near real time measurements with minimal sample handling, allowing for extensive, semi-quantitative analysis on site. The FPXRF provides rapid, multi-element analysis in different matrices including water, powders, soils and sediments. It is a non-destructive technique, which is an added benefit because confirmatory analyses can be performed on the same samples.

The capabilities of a portable instrument for metals determination in marine sediments have been tested. FPXRF results of sediment samples from various locations were compared with results from standard analyses. The results from the comparison of data sets demonstrate several things about FPXRF technologies. The FPXRF is capable of providing near real time data on site for Cu, Zn and Pb, which compares well to standard methods for rapid screening and assessment of a site. Although the FPXRF under-predicts the results as compared to the other methods, a linear relationship is observed. This is important in delineating hot spots. One of the main purposes for using field-screening tools such as the FPXRF is to guide on-site decision making for mapping strategies and detailed sampling. By pin-pointing hot spots and ranking relative contamination levels, these data can guide further sampling, and an intelligent selection of meaningful, rather than random, samples for subsequent, more quantitative laboratory analysis.

Documentation

Kirtay, V. J., J.H. Kellum and S.E. Apitz. "The Validation of Field-Portable X-Ray Fluorescence Spectrometry for the Analysis of Metals in Marine Sediments." *The Fifth International Symposium on Field Analytical Methods for Hazardous Wastes and Toxic Chemicals*, 29-31 January 1997. Las Vegas, Nevada.

C. BENTHIC FLUX SAMPLING DEVICE

The Benthic Flux Sampling Device (BFSD) is an autonomous system which collects time-sequenced benthic flux water samples from the sediment interface at contaminated sites. It is an open-bottomed chamber mounted in a tripod-shaped framework with associated sampling gear, sensors, control system, power supply, and deployment/retrieval equipment. The device is approximately 1.2m by 1.2m from leg to leg. The maximum deployment time is approximately 4 days, based on available battery capacity. Sample analysis leads to quantitative measurement of contaminant mobility and associated risk determinations for environmental and human health decisions. It is designed for deployment from a boat by lowering it to the bottom at marine harbor and bay sites with depths approximating 150 feet (50 meters).

The BFSD is designed for *in situ* measurement of toxicant flux rates from sediments. A flux out of, or into the sediment is measured by isolating a volume of water above the sediment, drawing off samples from this volume over time, and analyzing these samples for increased or decreased toxicant concentration. Increasing concentrations indicate that the toxicant is fluxing out of the sediment, and visa versa. Initial tests, carried out in conjunction with the Scripps Institution of Oceanography and the EPA's Environmental Research Laboratory at Newport, Oregon, show that the system is capable of measuring a variety of contaminant and nutrient fluxes. A contract is in the process of being awarded to bring this device into commercial production.

D. BIOCHEMICAL ASSESSMENT OF ENVIRONMENTAL CONTAMINATION

The biochemical assessment of environmental contamination uses test organisms as environmental condition sensors, and measures biochemical changes that occur in the organism as a result of environmental conditions. Maintaining DNA integrity is of paramount importance to all living things. For this reason, living organisms possess very efficient and intricate mechanisms for the protection of their genetic material. Significant stresses eventually result in the dysfunction of these mechanisms and an increase in observed DNA damage (Shugart 1992). To date the SSC-SD's Biomarkers Lab has studied DNA damage in response to stress in cells from over 3 dozen plant and animal species using the Comet DNA strand break assay (Steinert 1998A and 1998B).

The Comet assay allows the rapid, sensitive and inexpensive determination of DNA strand breaks in individual cells. Commonly known as the single-cell gel electrophoresis method, the Comet assay measures the amount of damage an organism's DNA has attained as a result of contaminant exposure. The assay only requires samples of ~10,000 cells which are quite easily collected with minimal impact on many organisms. Using the technique, one can determine within each cell in a sample increases in DNA damage, DNA repair activity, identify specific types of DNA alterations, as well as increases in cell turnover rates. Currently, the assay must be performed on fresh invertebrate tissues. Vertebrate studies using human and fish cells have successfully used frozen cells.

Initially, the assay was used with human beings for tracking the effects of cancer treatment, but has recently been used on tissue or fluid samples from various animal species for the monitoring of environmental contamination. Increased levels of DNA strand breaks in field deployed and resident mollusks have been found to occur in areas with elevated levels of trace metals and PAHs in water and sediment (Steinert 1998A and 1998B). Increased levels of DNA damage have also been linked with higher levels of biological effects, such as decreased growth and embryonic development. Biochemical methods such as the Comet assay can be useful tools for understanding the complex interactions occurring in the field, yielding useful information on contaminant transport and the processes influencing the expression of biological effects. The Comet assay guidelines are being submitted for approval by the American Society of Testing and Materials (ASTM).

Documentation

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E. QWIKLITE, A BIOLOGICAL ASSESSMENT OF EFFLUENTS AND MARINE SEDIMENTS WITH A RAPID TOXICITY TEST

Rapid assessment of effluents and contaminated marine sediments is an immediate need. Current standard bioassays involve taking samples to an appropriate laboratory that has personnel skilled in toxicity assays that can be performed quickly. The Navy has developed a rapid bioassay test system, called QwikLite, which tests media such as metals, storm drain discharge, ship hull coating leachates, and contaminated marine sediments. The basis of detection is measurement of light reduction being emitted from bioluminescent dinoflagellates after exposure to a toxicant. The response is usually measured within 24 hours from the start of the test.

The essence of QwikLite is to determine if any detected or undetected contaminants are bioavailable. It is sensitive to a range of metal and organic contaminants. QwikLite requires less time to set up and conduct the bioassay. Standard bioassays require 4 to 8 days of labor for a standard 4-day acute test with fathead minnows, water fleas, or shrimp. The Microtox system, which utilizes marine bioluminescent bacteria, requires 15 to 20 minutes per assay. QwikLite is more sensitive than Microtox for some metals, however, and also has the advantage of conducting the bioassay for 4 days (acute) or 7 days (chronic) to assess sublethal effects. That is, from an ecological risk assessment, lower concentrations of a contaminant in question may be determined using the bioluminescent phytoplankton with a longer exposure time in the 4 day or 7 day bioassay test with QwikLite. Microtox is only a 15 minute exposure test, and will not react to moderate or low level contamination. Microtox only responds to high levels of contamination (high metal load). The QwikLite test correlates well with the sea urchin development test (48 hour development test). The endpoint, called the IC_{50} (inhibition concentration of a contaminant which reduces light output from the dinoflagellates by 50 percent) has been defined for these metals: TBT – 1.6ppb, silver - 13 ppb, copper sulfate – 23 ppb, DBT - 34 ppb, lead – 321 ppb, zinc – 430 ppb, chromium - 538 ppb, cadmium – 782 ppb. QwikLite can also be used in fresh water or brackish environments by adjusting the salinity of the sample up to 33 parts-per-thousand. The QwikLite system is patented and undergoing final review for American Society of Testing and Materials (ASTM) standardization. It has been commercialized with Ocean Test Equipment, Incorporated, of Ft. Lauderdale, Florida.

F. PORTABLE MICROCOSMS FOR ENVIRONMENTAL TESTING (POMFRET)

POMFRET is a system that can be deployed at specific aquatic sites to evaluate the chronic effects of pollutants on resident marine organisms. The core of the system consists of 12 outdoor 100-gallon aquaria (microcosms) capable of maintaining low- to medium-diversity assemblages of organisms for periods of several months. The microcosms are provided with continuous unfiltered seawater and are exposed to normal sunlight. As such, they are linked energetically to the natural world, receive input of ambient sunlight and nutrients, and are colonized by larval organisms entering the supply water. POMFRET requires about 700 square feet of nearshore areas with access to freshwater and 110 VAC power. The system can be assembled by 2 technicians in about 5 working days. Operation during experiments requires 1 full-time technician. Typical experiments run from one to six months.

G. *IN SITU* MEASUREMENT AND SPECIATION MODELING OF COPPER IN MARINE ENVIRONMENTS

Use of the copper ion selective electrode (ISE) with voltammetry allows researchers to distinguish among various forms of copper. This is known as speciation. SSC-SD is developing speciation criteria using the ISE and voltammetric techniques for on-site instrumentation. The objective is to be able to perform tests for speciation remotely and autonomously from "smart" buoys strategically placed in harbors. Data would be relayed to a land-based station to provide real-time environmental assessment capability. The ISE may also be used to map copper species distributions from a moving vessel in real time sampling.

H. ASSESSMENT TOOLS FOR CONTAMINANTS OTHER THAN METALS

1. Advanced Sediment Characterization Using Biogeochemical Fingerprinting

Contaminated marine sediments are highly complex systems. Sediments can be composed of naturally occurring organic matter (from fresh detrital material to highly humified residues), and one or many minerals, exhibiting varying properties such as surface chemistry, grain size and porosity. Optimum procedures for adequately assessing and cleaning up contaminated sediments prior to on-land or at-sea disposal have not yet been determined. A critical issue in contaminated marine sediments is that in almost all cases, they are impacted by more than one class of toxic chemical. It is necessary, therefore, to determine how multiple contaminants (*e.g.*, toxic metals, PAHs, PCBs), interact with one another and with the sediment itself. Each component differs in its reactivity, solubility, volatility, mineral surface affinity, and biodegradability. Furthermore, interactions between components and the mode of introduction of the contaminant into the soil or sediment, postdepositional weathering and diverse mobility characteristics can drastically alter the composition of the bulk contaminant, as well as its bioavailability, risk, and the best approach to its management.

For all these reasons, simply knowing the geographic extent of sediment contamination within a bay or estuary does not provide sufficient insight to help a site manager or another interested party to begin to assess how to manage sediments deemed either an ecological risk or regulatory violation. A better approach would be to assess contaminant distribution and behavior at a micro-scale in parallel with macro-scale site assessments. In such an approach, a site investigation includes an assessment of contaminant or sediment biogeochemisty, as it will impact bioavailability, risk, and management choices. With such information in hand, a site manager can make a streamlined and informed decision about what remedial options are available, based upon the site specific sediment characteristics, allowing for rapid progress toward a decision and cleanup.

Such a sediment fingerprinting profile has several parts, examining different aspects of contaminant or sediment interactions.

- Contaminant distribution, specific surface area and organic content as a function of grain size and mass. This assessment determines how contaminants, and the factors which control their behavior, are distributed within the sediment itself. Such an assessment provides insight into whether sediment is amenable to particle separation for volume minimization, whether the contaminant load is subject to easy resuspension during disturbances, and often, how highly sequestered the contaminants are.
- Contaminant leachibility. Such an assessment helps determine how easily contaminants are remobilized during disturbance, and how amenable sediments are to remediation by chemical leaching.
- Bioavailability. Such assessments help determine how sequestered or available contaminants are to target biota.
- Microbial health and capacity. This assessment determines the health and biodegradative potential of the native microbial community.

Documentation

Apitz, S.E. "Streamlining Contaminated Sediment Management: The Use of Sediment Treatability Profiles During Site Assessment." *Proceedings, International Conference on Contaminated Sediments*, Rotterdam, the Netherlands, 7-11 September 1997.

2. Pier Side Oil Spill Detection Project

An automated oil spill monitoring and alarm system for use at Navy marine facilities is in progress. The core technology consists of an underwater multi-channel fluorometer used to detect petroleum hydrocarbons dissolved in and floating on sea water. In the event of a spill or leak, the system will provide immediate notification to emergency responders so that rapid corrective action may be taken to stop and contain the spill. The system will be particularly valuable at night and during periods of reduced watch manning when an unnoticed leak could continue for hours or days. A contract has been developed with Spectrogram Corporation of North Haven, Connecticut. Persons there have expressed a strong desire to license the oil spill detection technology developed at SSC-SD in order to manufacture and market a commercial system. The terms of any such licensing agreement have not yet been negotiated.

3. SCAPS-LIF (Site Characterization and Analysis Penetrometer System with Laser-Induced Fluorescence)

Initial sensors for this system detect petroleum contamination. Sensors to detect other contaminants, such as metals and halogenated hydrocarbons, are in development. The SCAPS system has a suite of equipment mounted in a specially engineered enclosed truck body on a 60,000 pound weight class truck chassis, customized for operation at hazardous waste sites. The laser itself is in the computer/instrumentation room in the van. Attached to the laser is a long fiber optic cable threaded through separate sections of hollow metal tubing, at the end of which is a hollow metal tube called the probe, approximately 3 feet long and 1.5 inches diameter, with a very small sapphire window on the side of the probe near the tip. The probe is pushed into the ground by a hydraulic system in the truck. Depths up to 150 feet are attained by attaching the hollow metal tube sections to the probe and then to one another as the probe is pushed into the ground (the hydraulic controls and penetrometer equipment are in a second room in the van). The fiber optic cable transmits a flash of UV laser light at a specified wavelength down the cable to the window, where the light exits into the soil. The light causes petroleum contaminants to fluoresce, which is collected and transmitted back up the fiber optic cable to the detectors in the truck. Depending on the wavelength and amplitude of the wave, the category of petroleum and an approximate quantity is determined. The detectors record this information in a computerized system.

The SCAPS platform also has survey and site-mapping equipment, as well as equipment for decontaminating the penetrometer rods and backfilling each penetrometer push cavity. Strain gages in the probe provide data about tip compression and sleeve friction. This data is used in a classification scheme to identify the types of soil encountered by the probe. Other sensors include a video imaging probe and soil moisture probes.

Video imaging provides insight into soil dynamics and allows grain size analysis. Soil moisture properties can be measured in the vadose zone using a time domain reflectromety probe, or in the saturated zone using a piezocone. Other sensor systems in development will extend measurement capacity to metals, chlorinated solvents, and other volatile and semi-volatile organic compounds. The commercialization for the initial petroleum hydrocarbon sensor is complete. The Army Waterways Experiment Station holds the technology patent for the Department of Defense and has issued two licenses. A technology reinvestment project led by the U.S. Air Force resulted in a commercial system named Rapid Optical Screening Tool (ROST), deployed world-wide by Fugro Geoscience of Houston, Texas. A competitor, Advanced Research Associates (ARA) operates several systems at the Department of Energy sites, and a subsidiary of ARA, Vertek, Incorporated, produces and sells the Fuel Flourescent Detector (FFD) sensor as well as associated equipment. The U.S. Army and the Navy both operate SCAPS systems for site assessment and characterization as well as sensor development.

4. UV Fluorescence for Polycyclic Aromatic Hydrocarbons

Defining the nature and extent of contamination in marine sediments can be a difficult problem. Detailed site investigations require extensive sampling and subsequent laboratory analyses, for both metal and organic contaminant chemistries. Additional laboratory analyses including several different types of bioassays, are conducted to determine any possible adverse biological effects to organisms exposed to the sediment. Samples often are collected without any *a priori* knowledge of the nature and extent of contamination. Due to the high cost of all these laboratory analyses, samples taken for analysis are often limited. Zones of contamination in marine sediments can be missed, or, if located, over- or under-estimated. For more detailed spatial information on extent of contamination, sites of interest must often be sampled and analyzed in an iterative manner. This approach can be prohibitively costly, slow and labor-intensive. An alternative to this approach is to combine standard laboratory analyses with field screening using a number of techniques to characterize both the contaminant chemistry and any possible biological effects. By utilizing near real-time screening techniques during the sampling procedure, the full extent of contamination and any possible biological effects can be rapidly mapped.

In addition to metal contaminants, many sediments contain organic contaminants that are also of concern. Since polycyclic aromatic hydrocarbons (PAHs) are common organic contaminants at Navy sites, UV fluorescence (UVF) spectroscopy can be used to estimate total PAH levels in the sediments. PAHs in the sediments may originate from many sources due to incomplete combustion of wood or petroleum products. They are common constituents in automobile tires (and therefore stormwater) and creosote (and therefore pier pilings). The screening method is based on measurement of the amount of fluorescence observed following UV excitation of solvent extracts separated from bulk sediments. A field portable fluorometer can provide near real-time results in 10-30 min.

Because many different PAHs can fluoresce, this method is not able to quantify individual PAHs, but can serve to screen for bulk PAH levels in the sediment. Many studies have used UVF to assess total PAH levels in various types of sediment (see Owen et al., 1995).

Documentation

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5. SCAPS- Video Microscope

This is a specialized sensor, a color video camera and optical system capable of providing real-time static and dynamic microscopic digital images of subsurface soils which can be viewed and recorded. Application and development of image processing techniques of the soil images provide soil grain size, grain size distribution, hydraulic conductivity estimation, and potentially direct detection of contamination. An SSC-SD patent is in process and potential partners for commercialization are being considered.

I. MARINE ENVIRONMENTAL SURVEY CAPABILITY (MESC)

To meet its needs for marine environmental monitoring, the Navy has developed the Marine Environmental Survey Capability (MESC). The MESC integrates state-of-the-art sensors, computer systems, and navigation equipment to determine spatial and temporal variability of physical and chemical water quality characteristics from a moving vessel. The MESC system was developed by the Navy to address water quality issues related to the operation of ships and facilities in the coastal environment.

The MESC technology provides significant potential for cost reduction and cost avoidance by reducing per-sample cost, minimizing the number of samples for laboratory analysis, and providing more detailed results, thus minimizing the necessity for overly conservative compliance action. Rapid, synoptic, cost-effective survey techniques are essential for determining the distribution and fate of contaminants associated with Navy and industrial discharges in the marine environment. Traditional methods for environmental sampling in which discrete samples are collected and returned to the laboratory for later analysis are expensive and time intensive. These limitations prohibit the collection of sufficient information to adequately describe highly-dynamic pollution processes in aquatic ecosystems. Using multiparameter, real-time mapping techniques, the MESC allows contaminant sources and distributions to be resolved, as well as the hydrographic processes that control their dispersion and fate. MESC has the following capabilities:

- Monitoring Sensors
    - Temperature
    - Salinity
    - Sample depth
    - Dissolved oxygen
    - pH
    - Light transmission
    - Particle sizing
    - Chlorophyll
    - Oil
    - Dye
    - Trace metals
    - Bathymetry
    - Currents
    - Wind speed/direction
    - Multiband radiance
- Navigation
    - Differential GPS
- Acquisition & Processing System
    - Computers - Pentium® 166
    - Multi-channel RS232
    - Multi-channel analog
    - MS Windows® -based software
- Real-time Display
    - Real-time chart and position display
    - Spatial concentration maps
    - Time series plots
    - Correlation plots
    - Vertical profiling
    - Wind/current speed and direction
- Research Vessel - RV ECOS
    - Dimensions: 40' (length) x 12'(beam) x 2' (draft), 15 tons
    - Speed: 6 knots (survey), 12 knots (max)
    - Tow System:
    - Hydraulic winch/davit
    - 15, 50, and 100 meter Kevlar® tow cable
    - Transport: Truck and air transport certified

Documentation

Chadwick, D.B. and M.H. Salazar. "Integrated Measurement Technologies for Monitoring the Marine Environment." *Proceedings of Oceans '91*, 1:343-350, 1991.

Katz, C.N. and D.B. Chadwick, 1993. "Synoptic Mapping and Modeling of A Sewage Outfall Plume." *Proceedings of MTS '93.* Long Beach, California, 1:207-215, 1993.

Lieberman, S.H., C. Clavell and D.B. Chadwick. "Techniques For Feal-time Environmental Mapping and Monitoring." *Proceedings, 16th meeting, US-Japan Marine Facilities Panel: United States-Japan Cooperative Program in Natural Resources on Marine Facilities*, pp 495-499, 1989.

J. HYDRODYNAMICS, WATER QUALITY AND CONTAMINATED SEDIMENT MODELING

Personnel of SSC-SD have developed several fate and transport (water quality) models useful for studying coastal and estuarine systems with contaminated sediments. Personnel of SSC-SD also have accumulated valuable experience in applying these fate and transport models for various water-quality and contaminated-sediment related issues. In general, coastal water bodies function as the destination for a number of contaminants, including toxic organic matters and metals. Models can be knowledgeably applied in improved understanding of the relationships between external load and level of contamination in the Baltic Sea. Models can also be used in simulating and quantifying effects of various scenarios, including existing conditions, load reduction and any other man-made or natural alterations of the environmental conditions. Specifically, SSC-SD personnel have successfully applied a hydrodynamic and sediment transport model, TRIM, in quantifying the migration and deposition of contaminated sediments that are resuspended into the water column during docking of Navy ships in San Diego Bay. Model results of the fate and transport of solid deposits and associated contaminants from docking scenarios can be used to control or manage docking scenarios for the Navy ships in San Diego.

Documentation

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Wang, P.F., R. B. Ambrose, Jr., and K.J. Novo-Gradac. "South San Francisco Bay Water Quality Modeling and Waste Load Allocation Study," EPA Report for the Regional Water Quality Control Board, California, U.S. Environmental Protection Agency, Athens, Georgia.

Appendix H

RELATIVE COST

Appendix H
RELATIVE COST

The graph below is oversimplified, but is nevertheless helpful in showing the relative costs of various technologies versus time.

Exceptions to the relative costs for cleanup of a site illustrated in this graph will occur, of course, due to such items as variations in size of the contaminated site or the contaminant plume or pool; the matrix or matrices that are contaminated; the experience and resources of the contractor; the distance from supply of any resource; the amount of contamination; and whether the contamination is a mixture of various contamination classes or not.

This graph is the creation of Dr. Charles Michael Reynolds, Research Scientist, Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers, New Hampshire.

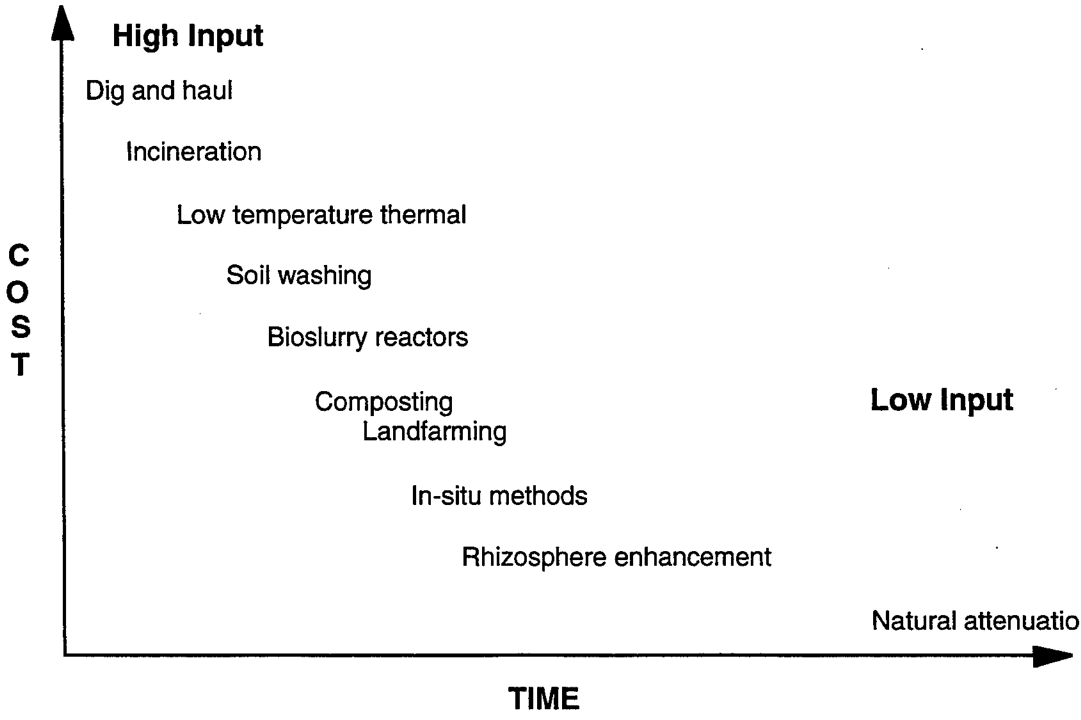

Figure H-1. Relative Inputs and Treatment Time for Remediation Technologies

Appendix I

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per repsonse, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE March 1998

3. REPORT TYPE AND DATES COVERED Final

4. TITLE AND SUBTITLE

Environmental Restoration—Expedient Methods and Technologies: A User Guide with Case Studies

5. FUNDING NUMBERS

DASW01-94-C-0054

Task No. T-AM1-1457

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8. PERFORMING ORGANIZATION REPORT NUMBER

IDA Paper P-3383

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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document collects information on potential methods and technologies that could be used to support environmental restoration projects undertaken by NATO Cooperation Partners (Partnership for Peace nations) in Central and Eastern Europe and the Former Soviet Union. The information is presented according to the type of pollution that is the object of remediation plans but is limited to pollution problems involving fuels, chlorinated solvents, and heavy metals. Case studies include descriptions of the problems to be solved, the methods used to resolve problems, relative successes, the anticipated cost and actual cost (if known), and technologies that are soon to become available. Also included are discussions of technical problems encountered and World Wide Web sites that may have added information. Risk assessment and risk-based corrective actions are covered. Appendices include discussions of models and modeling, a guide to a hierarchy of preferred alternatives for each type of problem, and emerging technologies useful for former naval installations. One appendix includes short discussions of alternatives deemed not to be useful and why

14. SUBJECT TERMS NATO, North Atlantic Treaty Organization, Committee for the Challenges of Modern Society, environmental restoration, former military lands, Central Europe, Eastern Europe, restoration methods and technologies, Partnership for Peace, fuels, chlorinated solvents, heavy metals

15. NUMBER OF PAGES 250

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102