Groundwater solutions

- At an MGP, page 6
- Using site specific field tests, page 16
- Tackling chlorinated solvents, page 38
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Write in 026
As I prepare this issue of Soil & Groundwater Cleanup for publication, there is a senator in town speaking on the town square a block from my office in support of eliminating the IRS tax code. He is speaking to a group of small business owners. This idea of eliminating the IRS tax codes is an appealing topic, of course. But more exciting is the idea of a group of individuals with their own agendas and goals coming together to work for something that will improve the lot of small business owners everywhere.

There are many opportunities for those involved in the contaminated soil and groundwater industry to step to the forefront of shaping the industry. Conferences, committees, and other educational opportunities allow professionals to share ideas and develop practices that will benefit the entire industry.

Once such opportunity comes from Subcommittee E50.01 on Storage Tanks, part of American Society of Testing and Materials (ASTM) Committee E-50 on Environmental Assessment. The subcommittee is investigating the possibility of forming two new task groups, one to address the evaluation of performance data for new remediation technologies for underground storage tanks; and one to address criteria for remedial technology selection for USTs.

The proposed task groups will seek to provide some much needed guidance in this area. The first group will focus on writing a standard or series of standards to help users determine the performance capabilities of new remediation technologies, which includes processes and equipment. The second will address selecting the proper technology for a specific site and provide guidelines for combining technologies.

The subcommittee is seeking input and participation from anyone involved in remedial services industry, such as contractors and consultants, federal and state regulators and manufacturers and suppliers of equipment.

For more information, contact Dennis Rounds, South Dakota State Petroleum Release Compensation Fund, 445 E. Capitol, Suite 200, Pierre, S.D. 57501; phone: 605-773-3769 or fax: 605-773-6048. Or call Susan Canning of ASTM at 610-832-9714; fax: 610-832-9666; or e mail: scanning@astm.org.

This is just one opportunity for you to shape the direction of your industry for the betterment of everyone involved.

Jody Becker
Managing Editor

The CROW technique was used at a manufactured gas plant site to remediate coal tar contaminated groundwater.

Photo courtesy of RETEC
October 1997

6  MGP site remediation using enhanced DNAPL recovery
By Alfred P. Leuschner, Mark W. Moeller, Jason A. Gerrish and Lyle A. Johnson

14 Use of a new ASTM TPH screening method
By Susan S. Sorini, John F. Schabron, Ph.D., James R. Bowes, and Seth H. Frisbie, Ph.D.

16 Field tests, monitoring verify system’s effectiveness
By Jerald W. Jacobi, P.E., and Marek Ostrowski, P.E.

20 Selective recovery of NAPLs from groundwater using oleophilic suction lysimetry
By Christopher Barker, Clifford J. Bruell, Ph.D., and Ralph S. Baker, Ph.D.

27 Academix: What is soil?
By Alfred Conklin, Ph.D.

38 PCE removal from groundwater with dual-gas microporous treatment system
By William B. Kerfoot, Ph.D.

Departments
19 Environmental Hot Spots on the Internet
30 Focus on software
32 What’s happening
34 What’s new
36 1997 Buyer’s Guide Update
42 Environmental Marketplace
45 Advertiser Index & Fast Response Hotline

Here’s How It Works
43 Enzyme Technologies DO IT system
44 HydroTechnics In Situ Flow Sensor
In 1982, the Brodhead Creek site was placed on the National Priorities List. The remediation process entails the injection of hot water into the subsurface to mobilize the coal tar. The hot water is injected at the perimeter of the tar formation and withdrawn from the center of the formation. In this way, the site is hydraulically isolated. Tar is mobilized by the hot water, and will flow to the production wells, where along with the hot water, it is removed from the subsurface.

Alfred P. Leuschner is an environmental engineer and principal; Mark W. Moeller is an environmental engineer and project manager; and Jason A. Gerrish is an environmental scientist with Remediation Technologies Inc., Concord, Mass. Lyle A. Johnson is technology director with Western Research Institute, Laramie, Wy.
MGP in hot water

Injections successfully tackle coal tar contaminants

By Alfred P. Leuschner, Mark W. Moeller, Jason A. Gerrish and Lyle A. Johnson

A former manufactured gas plant (MGP) facility in Stroudsburg, Penn has been successfully remediated using an enhanced dense non-aqueous phase liquid (DNAPL) recovery technique called Contained Recovery of Oily Wastes (CROW™).

The Brodhead Creek Site occupies a floodplain area of about 5 hectares at the confluence of Brodhead Creek and McMichael Creek. The plant was in operation from 1888 to 1944. In 1955, Brodhead Creek flooded the site. Due to this flood, the Army Corps of Engineers designed and built a flood control levee for the local creeks. In 1980, as the flood control levee was extended, a coal tar discharge was noted.

Emergency response measures performed by Pennsylvania Power & Light (PP&L) included installation of a filter fence, underflow dams, and coal tar recovery pit. In 1981, a cement and

Continues on page 8 →
bentonite slurry wall was installed along Brodhead Creek. The slurry wall is 197 meters long and 5 meters deep and protects Brodhead Creek from the discharge of free coal tar from the site.

In 1982, the site was placed on the National Priorities List (NPL). From 1982 to 1983, a free coal tar recovery pumping system was installed and 30,280 liters of coal tar were recovered from the subsurface. A remedial investigation was conducted from 1987 to 1989 and a feasibility study was conducted from 1989 to 1991.

According to the investigations, free subsurface coal tar existed in two areas at the site: the area near the recovery well RCC and the area near monitoring well MW-2. The coal tar appeared to have permeated the porous stream gravel layer near the surface, and accumulated on a silty sand layer 6 to 9 meters below the surface. Investigations revealed the silty sand layer effectively contained further vertical migration of the coal tar.

The two areas of free coal tar accumulation are stratigraphical depressions within the stream gravel layer. The RCC area is a natural depression area, but the MW-2 area is not. Coal tar appears to have accumulated in the MW-2 area due to the presence of the slurry wall. The total volume of free coal tar in the RCC area was estimated at 22,700 liters; and in the MW-2 area estimated to be less than 1130 liters.

EPA Region III agreed to allow coal tar removal in the RCC area first before committing to a removal technology for the MW-2 area. According to the Record of Decision (ROD), all recovered coal tar is to be incinerated.

**Mobilizing tar with CROW**

The remediation entails the injection of hot water into the subsurface to mobilize the coal tar. The hot water is injected at the perimeter of the tar formation and withdrawn from the center of the formation. In this way, the site is hydraulically isolated. Tar is mobilized by the hot water, and will flow to the production wells, where along with the hot water, it is removed from the subsurface.

On the surface, an initial water treatment step separated the coal tar from the water. Next, dissolved inorganics, predominantly iron and manganese, were removed through the oxygenation of the water and pH adjustment. The inorganics were subsequently separated by gravity. Next, the water was reheated and reinjected into the subsurface. A greater amount of water was produced than injected so the formation would be hydraulically isolated. This overdraw of water was treated in a fluidized bed reactor and...
discharged to Brodhead Creek.

The ROD was signed in March 1991. From then until September 1992, the Consent Decree was negotiated and signed. The design process required 19 months to complete, and included preparation of the Remedial Design Work Plan, 30 percent Design, Prefinal Design and Final Design. The design for the remedy was completed and approved by EPA Region III in March 1994. Construction was initiated in June 1994 and continued until November. Startup then required 10 months of operation and necessitated several design modifications. Actual operation began in July 1995 and continued through May 1996 when the system was shut down and decommissioned.

**CROW in the laboratory**

An initial laboratory study was performed on material from the Brodhead Creek Site. The study was sponsored by Gas Research Institute (GRI) and the EPA SITE Program, and performed by Western Research Institute (WRI) and Remediation Technologies Inc. (RETEC). The results showed that the tar content of the site soils could be substantially reduced as water flushing temperatures were increased to an optimum level of 68°C.

Ultimately, more than 60 percent of the coal tars in soil could be removed with 98 percent of the removable tar being recovered after 19 pore volumes flushed through the surface. These data formed the basis for design of the system ultimately installed at the site.

A predesign investigation was performed by Atlantic Environmental Services Inc. for delineating the pool of coal tar in the RCC area. Thirty-eight borings were installed in the area and 23 were finished as piezometers. Over a four-month period, tar level measurements were taken three times. Of the 23 piezometers, 11 consistently showed free tar levels. These levels varied from a few centimeters to almost 2 meters depending on the piezometer location. The results were used to define the areal extent of the remedy.

**Designing and installing CROW**

The CROW™ system for the RCC area was designed to recover about 22,700 liters of subsurface coal tar. The process relies on injection and recovery wells drilled in such a pattern that groundwater will be laterally contained within the area of concern. Hot water is injected into the aquifer at several points surrounding the tar accumulation to heat and mobilize the main accumulation. Heating the tar reduces both the density and viscosity of the tar to enable it to migrate with the groundwater flow.

Tars are contained vertically during the hot water flush by controlling temperatures during the hot water displacement. Downward migration of tar is reduced by thermal expansion of the tar to a lower density. Balancing the hot water injection and production rates controls the upper boundary of the contaminated area preventing fluid displacement into the overlying material.

Volatilization of the lighter constituents of the tar can be controlled by maintaining a cold water cap over the pattern area. However, at the Brodhead Creek Site, about 4.5 meters of groundwater exists over the area to be swept. This acts as a natural cold water cap. Any volatile organics would subsequently condense once they reach the cold water and migrate back to the sweep area.

Mobilized tar and soluble constituents are contained laterally by groundwater isolation. Based on specific hydraulic measurements from the Brodhead Creek Site, WRI modeled several injection and production scenarios to design the appropriate well pattern for the RCC area. The well pattern and pumping rates were specifically designed to contain all mobilized liquid phases by controlling the potentiometric surface around the affected area.

The CROW well pattern included six external injection wells and two internal production wells. The injection wells were instilled by boring with a 25 cm hollow stem auger, placing a 6 to 7.5 meter segment of 125 mm stainless steel well and well screen within the hole, backfilling the annulus with a 0-variety sand pack, grouting the sand pack to the surface, and sealing the well in place with concrete.

One of the wells was installed through the flood control levee. To install this well, all well installation plans had to be approved by the Bureau of Flood Protection and a soil ramp constructed adjacent to the dike to access the well installation point. A track-mounted rig was mobilized to install this injection well.

The production wells were installed by initially advancing a 60 cm borehole to the bottom of the stream gravel layer. However, some of the cobbles within this layer were 20 cm in diameter, thus slowing the advancement of the hole. The first attempt used a bucket auger rig. After this rig advanced the hole about 4 meters, the surrounding earth caved into the hole, backfilling it to only 2.5 meters.

At this point, a 60 cm casing was advanced and the material within the casing was removed with the rig. However, the casing met refusal at 6.4 meters, 1.2 meters short of its final position. Without the ability to drive the casing, a Barber rig was mobilized to the site. Several of the existing monitoring wells were cut back and flush mounted to provide the clearance necessary to bring in the large equipment trucks that were mobilized with a Barber rig.

The Barber rig was successful at installing the two 7.6 meter segments of 35.5 cm galvanized well and well screen. The annulus was backfilled with 0-variety sand, grouted to the surface, and sealed with a concrete cap.

*Continue on page 10 →*
MGP, from page 9

All soil cuttings were stored within a 15 cubic meter rolloff box and disposed of at an industrial waste landfill. The well installation activities produced about 23 cubic meters of soil waste materials.

The heated aquifer water altered the tar density and viscosity such that it can be recovered with the water phase. The in-well submersible pumps used can create a tar-water emulsion that is pumped into the separation tanks on the surface. The tar at the Brodhead Creek Site has a specific gravity of 1.06 at 21°C. However, when heated to 37°C, the tar has a specific gravity of 1.00 due to thermal expansion. Therefore, to separate the tar from the water, any emulsion must be broken and the temperature must be cooled.

During the treatability testing, WRI attempted to break simulated emulsions by adjusting the water chemistry. WRI concluded that reducing the pH to 5.0 would sufficiently break any tar/water emulsion. Therefore, an acid tank was plumbed into the production line so the pH of the produced waters could be lowered to 5.0 before beginning the separation process.

The remainder of the separation process relied in gravity separation. To accomplish this, the temperature of the liquid in the tanks would have to be reduced as much as possible. Because this system was designed to operate during the winter, all separation tanks were specified to be 6 mm, non-insulated, carbon steel. This would allow the ambient air to sufficiently cool the liquids and promote gravity settling.

Each of the tar separation tanks was designed to provide 2.9 hours of retention time. Because the three separation tanks were connected with gravity lines with no pumps or mixers, the total retention time available was 8.7 hours. Each of these tanks were 75,700 liters in volume. A fourth 75,700 liter tank was used as a reservoir before recycling the water. A fifth tank, 37,850 liters, was used to store tars generated by the recovery process before disposal.

To contain lateral movement of liquids, the injection/production system was operated to induce a gradient toward the production wells. The gradient was significant enough to overcome other natural gradients such that all injected water was captured by the production wells. This is accomplished by producing more water than is injected. This system was designed to continuously produce 115 gpm from the aquifer while injecting only 100 gpm.

After coal tar separation, 100 gpm of the remaining water was pumped to the water heater which raises the water temperature to 82°C. The heated water is then reinjected into the ground. The remaining 15 gpm was treated by an Envirosite Model 190 GAC/FBR followed
by four 90 kg carbon adsorption units — two parallel sets of two. The GAC/FBR provides a continuous reactor feed of 190 gpm.

The forward flow from the tar separation system is 15 gpm and the reactor recycle flow is 175 gpm. The reactor tower is 4.5 meters high and 1.4 meters in diameter. The reactor is filled with water and granular-activated carbon which remains in fluidized suspension by the upward 190 gpm flow through the reactor. The fluidized carbon provides a tremendous amount of surface area in which to grow bacterial colonies. The Model 190 unit is equipped with nutrient feed and oxygen injection systems which are calibrated to provide optimal bacterial growth conditions. The CA units were installed at the request of the EPA to provide a polishing step, and to reduce the sampling, analytical, and water storing requirements before discharge.

How the CROW flew

From November 1994 through July 1995, the CROW process was intermittently operated in a startup mode at the site. There was one significant problem which caused a series of operational problems requiring system modifications. The addition of hot water in the subsurface at the site caused an increase in reduced or dissolved iron in site groundwater from background levels of less than 2 ppm to more than 8 ppm. When the groundwater was brought to the surface and exposed to the air, oxygen was introduced into the water. This caused the iron to oxidize and precipitate. The iron precipitate caused coal tar separation problems, fouling of the GAC/FBR, heater fouling, fouling of the CA units and plugging of the injection wells.

The problem was solved through a variety of changes. A schematic of the process with modifications is shown in Figure 1, page 10. To aid in the separation of coal tar and water, acid injection to the production water was used to lower the pH to 5.0. This assisted in cracking any emulsions formed and allowed the tar to settle. Subsequently, the pH was raised to 7.0 and peroxide was added to oxidize the iron in the produced water. These solids were then gravity separated in tank two.

A series of bag filters were added throughout the process, before the heater, before the injection wells, and before the CA units, along with a sand filter, to remove any precipitated solids that carried over from the gravity separators. A well juttering system was installed on the injection wells to assist in keeping them clear of solids.

From July 1995 to June 1996, the system was continuously operated and recovered coal tar from the subsurface. Design flows of 100 gpm injection and 115 gpm production were never reached predominantly due to the initial iron solids problem. Injection flow rates of 33 gpm and production of 40 gpm were typical of this operation. Injection temperatures varied from 71°C to 93°C, and production temperatures varied from 38°C to 66°C.

The system was shown to be effective in hydraulically isolating the area being swept by the CROW process. Thermocouples were installed throughout the site to record the temperature profile of the groundwater throughout the RCC area. Groundwater temperatures of 66°C were achieved around the injection wells and 54°C temperatures were achieved at the production wells. However, within 6 meters outside the 66°C isotherm, the groundwater was at the background temperatures of 13°C. This shows that not only was the hot water being effectively directed at the area being swept, but also that mobilization of coal tar outside of the sweep area was not occurring.

Continues on page 12 →

---

**Figure 2: Material Disposed of After CROW Process Operation**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tar</td>
<td>5,390 liters</td>
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<tr>
<td>Water</td>
<td>22,954 liters</td>
</tr>
<tr>
<td>Inorganics</td>
<td>12,135 liters</td>
</tr>
</tbody>
</table>

---

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Write in 103

Soil & Groundwater Cleanup October 1997 11
Figure 3: Cost Summary of Brodhead Creek Site Remediation

<table>
<thead>
<tr>
<th>Cost component</th>
<th>R&amp;D cost</th>
<th>Superfund Site Cost</th>
<th>Remediation Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatability</td>
<td>$208,000</td>
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<td>$15,000</td>
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<tr>
<td>Predesign Investigation</td>
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<td>$110,000</td>
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<td>$925,000</td>
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<td>$45,000</td>
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</tr>
<tr>
<td>Decommissioning</td>
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<td>$15,000</td>
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<td>$92,000</td>
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<tr>
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<td>$311,000</td>
<td>$1,757,000</td>
<td>$2,914,000</td>
</tr>
</tbody>
</table>

MGP, from page 11

Over the 10-month operation, 29 pore volumes of hot water were swept through the RCC area. The hot water was effective in recovering the tar from the formation.

A total of 5400 liters of tar was recovered as pure tar with no water or organics. This was determined through chemical analyses of the material disposed of from the site. Along with the tar, water and inorganic solids — iron sludge — were removed by tankers. See Figure 2, page 11.

The GAC/FBR and CA units were found to be effective in treating the slipstream of water generated from production. During startup, there were several exceedances of the daily discharge limit of total PAHs. These were due entirely to solids carryover and not soluble organics in the discharge water. After operations began, only one exceedance of the daily discharge limit for total PAHs occurred. This was again associated with solids carryover.

Costs associated with project

The project was funded by the site owner, PP&L, the EPA SITE Program, GRI, Electric Power Research Institute (EPRI) and Department of Energy. There were various components to the costs. These included treatability testing, the predesign investigation, design, construction, operation, and decommissioning of the site. In addition, the costs for these components were evaluated based on whether the work performed was associated with remediation of the site, costs associated with a Superfund Site which would not have resulted if this site were not on the NPL, and cost associated with research and development since this was the first time this technology was applied in the field. See Figure 3, this page.

A significant amount of initial treatability testing was performed in the laboratory by WRI to demonstrate that this technology was feasible for a MGP site. Therefore, the majority of treatability costs have been allocated to R&D. The costs allocated to the remediation are reflective of subsequent treatability test costs since the R&D effort was performed.

The predesign investigation also had an R&D component. The work was predominantly performed by Atlantic Environmental Services Inc. with EPRI sponsorship. A portion of the work performed involved an evaluation and comparison of a variety of sampling techniques for MGP sites. The remainder of the costs are associated with delineating the location of free coal tar. This was used in the design of the remedy.

The design component costs have been allocated between the remedy and additional costs associated with a full Superfund design. The full Superfund design required a 30 percent design, a 60 percent design, 95 percent design and a final design. This process took more than a year. On a non-NPL site, this process would have been shortened and streamlined. The cost allocated to remediation are reflective of subsequent CROW designs.

The construction component was applied almost entirely to the cost of remediation. The only costs applied to R&D were those associated with the GAC/FBR water treatment system.

The operation costs are split between R&D, additional Superfund costs, and remediation. This was done because of the startup problems encountered, and the costs associated with retrofitting the system to remove iron from the production water were R&D associated costs. In subsequent designs, these issues have been accounted for, and therefore, should not be repeated. Superfund costs are associated with an additional month of operation to verify that the remedy was complete.

Lastly, decommissioning costs have been allocated to the remediation of the site and additional Superfund site related costs. The additional Superfund related costs are associated with sampling which was required by EPA above what was required for disposal of material. 

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EMAT West: November 4-6, 1997 in Long Beach, CA  EMAT '98: May 19-21, 1998 in Atlantic City, NJ

50
ASTM screening method works for heavier fuel products

By Susan S. Sorini, John F. Schabron, Ph.D., James R. Bowes and Seth H. Frisbie, Ph.D.

Measurement of fuels and other petroleum products in soils is an important environmental activity. Field screening methods for this purpose are especially useful for defining boundaries of contamination and providing information on where samples should be taken for more expensive and time-consuming laboratory analyses.

More volatile petroleum products in soil, including gasoline and solvents, such as trichloroethylene (TCE), can be measured in the field by simple, inexpensive headspace screening techniques using portable photoionization or flame ionization detection. However, mid-range distillate products, such as diesel fuel, and heavier products, including lubricating oil, are not readily measured by these techniques.

In addition, as diesel fuel in soil is weathered and subjected to bacterial degradation, the remaining fuel is more aromatic and less volatile than the original material. As a result, diesel fuel and other petroleum products containing aromatic compounds require a different type of field screening approach.

ASTM Method D-5831-95, Standard Test Method for Screening Fuels in Soils, provides a screening procedure for soils that is sensitive to a wide range of petroleum products having aromatic compounds. The method has been shown to be fast at about 10 minutes per sample, easy and inexpensive to perform at less than $10 per sample. The method allows a large number of samples to be screened in a short period of time.

The method also is effective for screening organic-rich soils, which often cause interferences for other screening methods having similar application. These other screening methods often require the use of solvents that are harmful to the environment and human health, require refrigeration of the test reagents, and involve lengthy and time-consuming procedures.

The simple procedure described in the ASTM method involves treating a soil sample with calcium oxide and extracting it with a relatively low-toxicity solvent — isopropyl alcohol. The resulting extract is filtered, and the ultraviolet absorbance of the extract is measured at 254 nanometers (nm).

Three tiers of information can be determined using ASTM Method D-5831-95. If the contaminant fuel is available for calibration, a highly accurate determination of the concentration of the fuel in the soil can be made. If the contaminant fuel type is known, but not available for calibration, an estimate of the concentration of the fuel in the soil can be determined using average response factors given in the

---

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<th>Location</th>
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<th>EPA Method 8100 TPH Concentrations mg/kg</th>
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<td>---a</td>
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<td>2</td>
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<tr>
<td>11</td>
<td>310</td>
<td>---</td>
</tr>
</tbody>
</table>

*a No laboratory sample collected

Susan S. Sorini is principal scientist and John F. Schabron, Ph.D., is manager of the Chemical Monitoring Division, of Western Research Institute, Laramie, Wy. James R. Bowes, C.P.G., is senior scientist, and Seth H. Frisbie, Ph.D., is senior chemist and engineering laboratory manager, with The Johnson Company Inc., Montpelier, Vt.

14 October 1997 Soil & Groundwater Cleanup
method. If the nature of the contaminant fuel is unknown, this screening method can be used to identify the possible presence of contamination.

This method was used to screen soil samples during site investigation of a former tank farm in the eastern United States. The objective was to determine through an economic yet accurate manner, the degree of surface soil contamination in the areas beneath the former aboveground storage tanks (ASTs). Samples from three of the sampling locations were also sent to an analytical laboratory for analysis.

Materials and methods

The ASTM method was used to screen soil samples collected at a former tank farm for their concentrations of total petroleum hydrocarbons (TPH). The field characterization involved collecting 11 soil samples about 15 to 25 cm in depth from areas which were formerly beneath ASTs. The samples were collected using a soil auger, which was decontaminated between sampling locations using isopropyl alcohol followed by a distilled water rinse. Each sample was stored in a plastic freezer bag, sealed, and labeled for subsequent on-site analysis.

As described in the ASTM method, 5 grams of soil sample were mixed with 5 grams of calcium oxide. This procedure minimizes the interferences from humic materials and moisture that may be present in soils. The sample was then extracted by adding 50 mL of isopropyl alcohol and stirring the slurry for three minutes. The extract was filtered through a 0.45-micron Teflon membrane and analyzed by ultraviolet absorption spectrometry at 254 nm. Measurements were made relative to standard solutions prepared by dissolving the contaminant fuel associated with the site in isopropyl alcohol.

Samples from three of the sampling locations were also collected for laboratory analysis; two for gas chromatography analysis by EPA Method 8100 for TPH, and the third for gas chromatography/mass spectrometry analysis by EPA Method 8260 using methanol preservation for volatile organic compounds (VOCs). The samples were packaged and delivered under chain-of-custody to the analytical laboratory.

ASTM method better for site

The concentrations of TPH determined by screening the soil samples using the ASTM method are listed in Figure 1, page 14, along with the results of the laboratory analysis for TPH. For both samples analyzed by EPA Method 8100, the TPH concentrations determined by the ASTM method are about 30 percent less than the values determined using the laboratory method. The values reported from the EPA 8100 analysis are subject to interpretation and are based on measurements made relative to standard solutions prepared using a generic fuel type.

In the ASTM method, the absorbance reading of the sample extract is read directly from the photometer. Site-specific standard solutions were used for the ASTM screening method. As a result, the values determined using the ASTM method are based on a milligram of site-specific contaminant per kilogram of soil, instead of being based on a milligram of generic fuel per kilogram of soil.

The TPH concentrations determined using the ASTM method may actually be more accurate than the values determined using EPA Method 8100. The best way to compare the two methods would have been to run both methods using standards prepared with the site-specific fuel. However, as is most often the case, a sample of the site-specific fuel was not submitted to the lab for preparation of laboratory standards.

The proposed remedial action limit for TPH at the site was based in part on a risk-based concentration of 6,500 mg/kg. As a result, based on the data generated by the ASTM method, remediation of locations 3-7 and 10 was indicated. See figure 1, page 14.

A sample from location 4 was analyzed by EPA Method 8260 for VOCs. The sample was preserved in methanol to prevent loss of VOCs during transport to the lab.

The concentrations of benzene, toluene, ethylbenzene, and the xylenes (BTEX) in the sample total 8.247 mg/kg, and the other volatiles total 7.362 mg/kg. Comparing these values to the TPH concentrations generated by the ASTM method shows that the contamination in the soil at the site is primarily in the form of heavier fuel products.

As a result, screening techniques designed for detecting more volatile components would not have been suitable for screening this site and providing accurate information on the levels of contamination.
Site specific field tests determine successful route for groundwater remediation

By Jerald W. Jacobi, P.E., and Marek Ostrowski, P.E.

When a large industrial firm in Michigan began removing or closing 20 former underground storage tank (UST) farms at its 80-hectare production facility, it discovered that problems at the site were more severe than anticipated.

The USTs were used primarily to store petroleum-based products that supported manufacturing operations, and the firm was hopeful that contamination was confined to the soil. However, during the cleanup process, evidence of tank leakage was reported at several locations. Subsequently, contaminants were detected in the groundwater aquifer beneath the farms.

As a result of those findings, the firm retained URS Greiner to devise a system of groundwater monitoring wells, perform additional hydrogeologic modeling of the aquifer to determine the magnitude and direction of the contaminated groundwater flow, and develop an extraction and treatment process to remove affected groundwater from the aquifer.

The remedial process would provide a safety net to protect the bedrock water-bearing unit used by the municipality for potable water. The safety net system was developed with respect to the nature and results of field investigations; predictive modeling; the design and construction of the collection and extraction system; post-construction field testing of the system; and measuring the system’s performance against the objectives and the modeling forecast.

At this point, some members of the regulatory community expressed doubts about the effectiveness of the proposed system. They believed that, based on the typical geology of the area, the extraction and treatment flow rates should be at least five to 10 times higher that those used for the design.

However, site-specific field tests and monitoring suggested otherwise. The use of data culled from the field tests rather than information based on typical regional data, resulted in significant savings in the implementation of the groundwater extraction and treatment system. Once the system was in place and operating, its performance was tested and optimized with the aid of data collection and modeling systems previously used in the design process.

Field investigations determine system design

In addition to the 32 monitoring wells already in place, three new monitoring wells were installed to further characterize site hydrogeology and supplement the groundwater monitoring program. Boreholes were advanced into the bedrock by air rotary drilling to a total depth of about 45 meters each. Well screens were installed based on the results of the vertical profiling and geophysical logging data.

Field technicians sampled and monitored the levels in 35 groundwater wells located beneath affected UST areas on a quarterly basis for more than two years. A series of pump tests were conducted to measure the aquifer permeability and productivity. The information gathered was used to
develop a database from which modeling was performed.

The results of the modeling efforts were used to determine the design basis for the groundwater extraction and treatment system and to select the best location for the installation of two extraction wells. The extraction wells would create a capture zone of sufficient size to prevent the offsite migration of affected groundwater exceeding established state criteria.

Treatment system has three basic elements

Based on the field investigation and modeling efforts, sufficient information was obtained to design the base extraction and treatment system, which consists of three basic elements:

- A groundwater collection system consisting of two wells, precisely located and based on computer modeling, to maximize the capture zone, the first of which is being pumped at a rate of 470 lpm, and the second at 190 lpm;
- Piping passing from the well collection points beneath road and manufacturing areas from the collection point to the treatment plant; and
- A carbon adsorption water treatment system to remove the petroleum-related hydrocarbons.

The carbon adsorption system incorporates a pre-filter; two 4500 kg capacity pressurized, activated carbon tanks; a backwash; and hydropneumatic activated carbon loading and unloading equipment. The treatment process is located in a pre-engineered, temperature-controlled structure equipped with a fire-suppression system.

The system began operating in 1995 at an average flow rate of 780 lpm. Several rounds of monitoring well-level information have been taken since start-up for input to the modeling system to predict and optimize ultimate performance.

Modeling for better implementation

The U.S. Geological Survey (USGS) MODFLOW program was selected for use as the modeling tool for the project. MODFLOW is a three-dimensional, finite difference, groundwater flow model. It allows simulation of both steady-state and transient flow of water in confined and unconfined aquifers.

Some of the elements of the hydrogeologic system that can be modeled using MODFLOW are: heterogeneous and anisotropic water-bearing layers, infiltration, streams, evapotranspiration, drains, specified head and specified flow boundaries, and horizontal flow barriers.

MODPATH, a MODFLOW-compatible particle tracking algorithm, was also used. MODPATH uses output from MODFLOW in the form of velocity field to simulate movement of particles within the flow domain. It can work in either forward tracking or backward tracking mode, in both steady-state and transient flow fields. Particles can be released either instantaneously or over a specified period of time. Results can be viewed through a MODPATH-PLOT graphical interface.

The model of the base hydrogeologic system of the study area was developed using available well monitoring information. The objective was to use the model as an aid in estimating the necessary extraction and treatment rates of a then-proposed extraction system. It also was used in evaluating possible design well flows and location alternatives for the system wells and evaluating the influence of the changes in the regional flow on the performance of the system.

Continues on page 18 →
Field test, from page 17

The model was updated by URS Greiner to incorporate additional wells and update the data in the model to reflect pump tests and new water level information. In constructing the model, the elements of the hydrogeologic system were included in a "conceptual model," which was then presented in mathematical form, suitable for use as input to the MODFLOW program suite.

The conceptual model of the site included three hydrogeologic units: the overburden till, the shaley sandstone, and the basal sandstone. To accommodate the penetration depths of the existing wells, the hydrogeologic units were divided into seven model layers. No natural hydrologic boundaries were present within the study area. The model boundaries were assumed based on the observed flow patterns as either specified head or specified flow. They were varied during the calibration process to produce the most reasonable approximation of the observed flow regime.

Other elements of the system varied during the calibration/sensitivity analysis process, including the recharge from infiltration, hydraulic conductivities of the model layers, induced recharge from the river, and pumping rates of the nearby production wells. The site groundwater flow was primarily controlled by the presence of four offsite production wells used to supply the city.

Once a satisfactory approximation of the hydrogeologic system of the site was obtained, the model was used, in a predictive mode, to analyze the anticipated effect of the inclusion of the groundwater.
extraction system. Numerous simulations of the system were performed, with the varying numbers, locations, and pumping rates of the wells.

The objective of the simulations was to design a system that would accomplish the hydraulic separation of the site from the surrounding aquifer while minimizing the required total extraction rate. The sensitivity of the results to the assumed values of hydrogeologic parameters also was investigated.

The two-well system implemented after the completion of the modeling study has been pumping water from the aquifer at a rate of 780 lpm. The water levels within the study area were monitored for six months, after which the modeling study was resumed. Water level data from all the monitoring wells were used to determine the effectiveness of the system, as well as to fine-tune the mathematical model of the hydrogeologic regime.

**Site specific tests spell success**

Studies indicated that the new extraction system resulted in achieving a high degree, but not complete, hydraulic separation between the site and the surrounding aquifer. A critical portion of the groundwater from the eastern portion of the site was still making its way toward the nearby group of four ofsite municipal production wells. Several simulations were performed to identify a remedy.

It appeared that the two-well system was unable to produce extraction rates sufficient to extend the capture zone over the eastern section of the site. Predictive-mode simulations indicated that as long as a total of 2270 lpm was required from the four ofsite wells, regardless of the distribution of pumping rates among them, that portion of the site would remain outside the capture zone of the extraction system.

As a result, it was concluded that an additional extraction well, pumping at 190 lpm, would be required to extend the capture zone sufficiently eastward to capture all plant groundwater contamination. With appropriate pump and piping changes, there now is adequate spare capacity within the treatment system to accommodate the extra volume, although there is a modest decline in carbon adsorption efficiency.

All told, however, the system is accomplishing its objective of removing contaminated groundwater from the site. Its success is testimony to the virtues of conducting site-specific field tests and monitoring rather than relying on the typical geology of an area when designing and implementing a groundwater extraction and treatment system.

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### Environmental Hot Spots on the Internet

This feature runs periodically as space permits. If you would like to see your website featured in *Soil & Groundwater Cleanup*, submit the information to the magazine at 204 W. Kansas, Suite 103, Independence, MO 64050 or send by email to jbecker@sgcleanup.com. Visit the SGC website at www.sgcleanup.com.

- Aeromix Systems Inc. offers its website as a research tool for those interested in water pollution, aeration and mixing equipment. The site is available at www.aeromix.com.


- Plant Health Care Inc. has a website devoted to biological plant health care products including information on root zone ecology, mycorrhizal fungi, beneficial bacteria and biostimulants. Visit the site at http://planthealthcare.com.

- Solinst Canada Ltd. has launched a website at http://www.solinst.com. The site contains data sheets that can be viewed and downloaded in Adobe® Acrobat® PDF format and read under Windows, Mac and Unix operating systems.
Selective recovery of NAPLs using oleophilic suction lysimetry

By Christopher C. Barker, Clifford J. Bruell, Ph.D., and Ralph S. Baker, Ph.D.

Oleophilic suction lysimetry (OSL) uses an oil recovery lysimeter covered by an oleophilic, hydrophobic membrane to recover non-aqueous phase liquids (NAPLs) from contaminated vadose zone soil. The lysimeter is placed into the ground to intercept a region of soil contaminated by NAPL. Vacuum pressures are applied to the lysimeter to draw NAPL through the membrane. The recovered NAPL is then conveyed from the lysimeter to the ground surface. OSL is unique as a remediation technology because it focuses on the selective removal of pure NAPL contaminant and excludes the removal of air and water.

Experiments using coarse soil, loam and diatomaceous earth determined OSL could be used in a soil environment to selectively remove NAPL such as dodecane from wet soils. However, evaluations of OSL in a 2-D test chamber (See Figure 1, Page 20) illustrated the limitations of the technology.

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20 October 1997 Soil & Groundwater Cleanup
pressure which can overcome capillary forces. To develop a pressure gradient within NAPL in a soil, contact between the oleophilic membrane and interconnected soil pores containing NAPL is required. These interconnected pores can be visualized as ganglia of NAPL extending out in the soil from the location of the membrane. See Figure 2, this page. When a vacuum pressure is applied at the membrane, pressure gradients develop in the NAPL ganglia and NAPL is thus pulled toward and through the membrane.

Since pore sizes vary in soil surrounding the membrane, forces holding the NAPL within the pores also vary. Applying a vacuum pressure and then increasing it in a step-wise manner would allow NAPL to be removed from larger pores first, and then from increasingly smaller pores as long as there is continuity within interconnected pores that remain NAPL-filled.

Exceeding the air entry pressure of the membrane during OSL would cause a flow of air through the soil and into the membrane, thus greatly reducing the effectiveness of OSL. Therefore, it was theorized that an oleophilic membrane with a high air-entry pressure would be most desirable for OSL. Such a membrane, being hydrophobic, would also exclude water.

Continues on page 22 →
Selectively, from page 21

Materials and methods

Twenty porous, oleophilic hydrophobic membranes were tested for their air-entry pressure. A Teflon® membrane, Tetratex model 6525 from Tetratex Corp., Feasterville, Penn., had an air-entry pressure of 17.2 psi and was observed to be physically suitable for use in soil. Therefore, it was used in all subsequent experiments.

A bench scale, two dimensional chamber, 81.3 cm by 5/2. cm by 2.5 cm thick, used to examine the recovery of NAPL from the vadose zone, had three rows of five oil tensiometer ports each. The bottom section of the U-shaped metal spacer had holes which allowed water to be added to the 2-D chamber through an opening in the side of the spacer. The OSL device (See Figure 3, this page) was positioned inside the 2-D chamber to contact the NAPL contaminated soil.

The soils used in the experiments were a coarse sand, loam, and diatomaceous earth. See figure 4, page 23. The 2-D chamber was placed on a vibrating table and the soil of interest was packed in about 50 mm layers with a tremie tube. After adding each layer, the 2-D chamber was vibrated for 30 seconds while moderate force was applied to the top of the soil layer with a 25 mm thick metal piston.

The contaminant used was reagent grade dodecane. In experiments with sand and loam, the water table was established after the 2-D chamber was packed with soil. The water table elevation was adjusted to keep dodecane between the top and bottom rows of ports.

While the height of capillary rise in the coarse sand and the loam were 15 cm and 41 cm, respectively, capillary rise in diatomaceous earth was determined to be in excess of 1 meter; therefore, introducing a water table in diatomaceous earth would cause high water saturation of the soil in the region between the top and bottom rows of ports. Dodecane injected into this region might become trapped or forced up by water to the top region of soil where tensiometers would not be present to monitor changes in dodecane tensions.

Therefore, rather than introducing a water table, diatomaceous earth was mixed with water to a moisture content of 50 percent by mass with 15.7 percent volumetric moisture content and then packed into the 2-D chamber. To prevent dodecane from distributing to the bottom of the 2-D chamber, the bottom of the chamber was elevated to 50 mm below the bottom row of tensiometer ports.

In the experiment with coarse sand, a screen recovery well (6 mm O.D., 9.5 mm I.D.) was positioned vertically in the 2-D chamber to allow gravity drainage of dodecane before vacuum extraction. This was done to simulate conditions in which OSL is used to recover residual NAPL only after free product has been removed by conventional recovery wells. In subsequent experiments on loam and diatomaceous earth, a screened recovery well was not used. Gravity drainage through the OSL device was used instead, as an initial NAPL removal process before the application of vacuum.

Oil tensiometers were inserted into soil within the 2-D chamber to measure the tensions of the oil held within the soil pores. By monitoring dodecane tensions in the 2-D chamber, it might be possible to monitor relative dodecane distribution within the soil. Theoretically, regions of soil from which dodecane is removed would display higher dodecane tensions since remaining dodecane would be held more tightly.

Oil tensiometers were constructed by attaching oleophilic membrane disks to the ends of glass tubes. Each glass tube had a 9 mm O.D., 6.5 mm I.D., and a length of 10 cm. Each tensiometer was attached to a manometer and then both were filled with dodecane. The tensiometer tip was held at the elevation of the 2-D chamber port into which it would be inserted and allowed to equilibrate to atmospheric pressure.

After this process of being zeroed, the tensiometers were inserted into the 2-D chamber ports and adjusted
to insure contact between soil and membrane tips. A small volume of dodecane flowed into or out of the tensiometers depending on whether the pressure of the dodecane held within the soil was higher or lower than atmospheric pressure.

To insure that dodecane resided in the soil region between the top and bottom rows of tensiometer ports, dodecane was added through a perforated insertion tube (3 mm O.D., 1 mm I.D.) positioned horizontally in the soil, midway between the middle and bottom row of ports.

Following charging of the chamber, dodecane was allowed to distribute and tensiometer readings were monitored. When dodecane tensions became relatively steady, gravity drainage of dodecane through the screened well in coarse sand was initiated. When this drainage ceased, gravity drainage through the extraction device was allowed.

Vacuum extraction of dodecane then began. Vacuum pressure was applied step-wise in an attempt to slowly remove dodecane from increasingly smaller pores. During the experiments with loam and diatomaceous earth, the vacuum pump was turned off periodically to prevent overheating of the motor.

When the experiment with diatomaceous earth ended, soil samples were removed from the chamber and analyzed for dodecane and water concentrations. Dodecane was extracted from soil samples using methylene chloride. Dodecane concentrations were determined using a Hewlett Packard 5970a gas chromatograph with flame ionization detector. Total liquid content was gravimetrically determined by comparison of wetted and dried samples. Water concentrations were calculated from total liquid and dodecane concentrations.

### Results of coarse sand experiments

The extraction device was positioned vertically so surface of the membrane was about 48 mm to the left of the center line of the nearest tensiometer ports. The water table was established 115 mm below the middle row of ports.

A total of 500 mL of dodecane was added to the soil. Gravity drainage yielded 327.0 mL of dodecane through the screened well and 31.6 mL through the extraction device. Of the remaining 141.1 mL of dodecane in coarse sand, 17.3 percent was recovered by vacuum extraction. The rate of recovery eventually decreased and became essentially zero even as vacuum pressure was increased.

It is theorized that the number of connected, dodecane filled soil pores in contact with the membrane decreased rapidly as dodecane was removed from the larger soil pores and snap-off occurred. Consequently, the percentage of dodecane that can be recovered by OSL in coarse grain soil appears to be limited by soil pore size distribution and a further step-wise increase in the applied vacuum pressures does not have any beneficial effect.

Continues on page 24 →

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**Figure 4: Properties of soils used in experiments**

<table>
<thead>
<tr>
<th>Soil</th>
<th>Median Particle Diameter (mm)</th>
<th>Bulk Density (g/cm³)</th>
<th>Particle Density (g/cm³)</th>
<th>Porosity (cm³/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse sand</td>
<td>0.520</td>
<td>1.61</td>
<td>2.64</td>
<td>0.39</td>
</tr>
<tr>
<td>loam</td>
<td>0.160</td>
<td>1.51</td>
<td>2.59</td>
<td>0.41</td>
</tr>
<tr>
<td>diatomaceous earth</td>
<td>0.015</td>
<td>0.32</td>
<td>2.32</td>
<td>0.86</td>
</tr>
</tbody>
</table>

1 Data was obtained from soil analyses provided by Daniel B. Stephens & Associates Inc., 1994
Selective, from page 23

Results from tensiometer data were inconclusive as changes in oil conductivity were not apparent. Dodecane tensions generally increased gradually during experiments at each tensiometer location in experiments with all three soils. Dodecane tensions were not noticeably higher near the membrane than in regions of soil located further from the membrane.

Results of loam experiments

A water table was established 25 cm below the middle row of tensiometer ports. Of 1000 mL of dodecane added to the soil, none drained by gravity through the extraction device. It was theorized that increasing the vacuum pressure before the rate of dodecane recovery had become asymptotic, could cause dodecane snap-off and result in decreases in oil conductivity near the membrane. Higher dodecane tensions near the membrane might be indicative of lower oil conductivity. Therefore, in loam and subsequent diatomaceous earth experiments, the extraction device was positioned about 13 mm from the midpoint of the nearest tensiometer ports so that oil tensions near the membrane could be monitored.

Generally, when vacuum pressure was increased, recovery of dodecane began again. Vacuum pressure was applied for about 900 hours and the length of the entire experiment was about 1350 hours due to the pump being turned off periodically. It is likely that low rates of dodecane recovery from the loam, generally less than 1 mL per hour of applied vacuum, were due to a small percentage of interconnected, dodecane filled pores. A total of 31.7 percent of the residual 1000 mL of dodecane were recovered.

Results of diatomaceous earth experiments

Of 1500 mL of dodecane added to the soil, none drained by gravity through the extraction device. An initial vacuum pressure was applied and increased step-wise. After 46.25 hours, only 8.1 mL of dodecane had been recovered. The experiment was interrupted and an additional 975 mL of dodecane was added through the perforated insertion tube. Percent recovery is therefore based on a total of 2475 mL of dodecane added.

A vacuum pressure was applied until the rate of dodecane recovery from the soil had slowed. The experiment was terminated before the rate of recovery had approached zero during the period when a vacuum pressure of 71 cm of water was applied. The percentage of dodecane recovered was 13.8 percent after 1300 hours of applied vacuum pressures. Although the rate of recovery at the end of the experiment was higher than recovery rates achieved at lower applied vacuum pressures used in this experiment, it was thought that ultimately the rate of dodecane recovery would become asymptotic and continuing the experiment would not have resulted in an overall recovery percentage of dodecane significantly greater than 13.8 percent.

Contours of dodecane saturation were determined as the volume of dodecane divided by the volume of voids. Dodecane saturation contours running within the region of soil up to 180 mm above the chamber's bottom and out to 230 mm to the right of the membrane were essentially vertical. Based on the orientation of these contours it appears that dodecane moved horizontally toward the membrane. Other dodecane saturation contours ran essentially horizontally and showed that dodecane saturations generally increase when moving down from the soil surface to the bottom of the chamber. This is likely a result of gravity drainage.

The vertical dodecane saturation contours near the membrane decrease in value from 0.50 to 0.40 dodecane saturation about 63.5 mm to the right of the membrane. Dodecane saturations in the vicinity of the membrane are higher than saturations in most other locations; therefore, it appears that, at the end of the experiment, the conductivity of oil in this region had not decreased to a point at which it was limiting the recovery of dodecane.

If the experiment had continued, dodecane saturation near the membrane likely would have decreased further. Although dodecane had
redistributed toward the membrane, the rate of recovery had been too low to warrant continuation of the experiment.

Water saturation contours also ran vertically near the membrane. Water saturations generally decrease where dodecane saturations increase and increase in regions where dodecane saturations decrease. This may be the result of complimentary redistribution of water as dodecane was recovered.

**Conclusions drawn from these experiments**

When this investigation began it was expected that high vacuum pressures would be applied to the membrane to remove NAPL held at high tension in small soil pores. However, after performing dodecane recovery experiments, it became apparent that much lower vacuum pressures should be used in practice to avoid snap-off and decreases in soil conductivity.

Recovery of dodecane from coarse sand was low — 17.3 percent — which was expected given the soil’s relatively large pore sizes. Loam, which had a greater percentage of small pore sizes, provided slightly higher recovery at 31.7 percent. The highest recovery from diatomaceous earth was 13.8 percent, which was disappointing since it had the smallest pore sizes. On the other hand, it may not be realistic to expect to recover residual NAPL from the vadose zone as a liquid.

Analysis of soil samples removed from the 2-D chamber at the end of an experiment with diatomaceous earth indicates dodecane distributed toward the membrane during OSL. It appears that water within the soil pores redistributed rather than blocked the movement of dodecane toward the membrane.

Dodecane recoveries appear to be too low to make OSL attractive as an in situ soil remediation technology. It is theorized that OSL can only remove limited quantities of NAPL before snap-off occurs within soil pores, limiting further NAPL mobilization. Snap-off limits the radius of influence and quantity of NAPL that can be recovered using OSL technology. On the other hand, it is unrealistic to have expected that OSL could recover a high percentage of the added NAPL. The fact that it successfully recovered some of the residual NAPL not recoverable by gravity drainage demonstrates that suction-enhanced recovery did occur.

Acknowledgement: This research was initiated and funded by the Research and Development Program of ENSR Corp., Acton, Mass.
### Eighth Annual West Coast Conference

**Contaminated Soils and Groundwater**

Analysis, Fate, Environmental and Public Health Effects, and Remediation  
March 8-12, 1998  
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Attracting over 400 participants in 1997, the West Coast Conference on Contaminated Soils and Groundwater is a highly successful and nationally known conference focusing on important and timely environmental issues related to soil and groundwater contamination. Attendees are drawn from a wide variety of professions including state and federal regulatory agencies, environmental engineering and consulting communities, environmental scientists in the petroleum and chemical industries, and academia. Past/present conference sponsors and supporters include Port of Los Angeles, Levine-Fricke-Recon, Inc., Gas Research Institute, Shell Oil Company, Foster Wheeler Environmental Corp., Naval Facilities Engineering Service Center, Southern California Gas, Texaco, Earth Tech, McLaren/Hart, and others.

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The rental fee for an 8' X 10' exhibit booth space is $995.00. Exhibitors reserving space by November 1, 1997 qualify for a special rate of $895.00.
For remediation, living parts of soil must be considered

By Alfred R. Conklin Jr., Ph.D.

Soil is the loose material on the earth’s surface made of sand, silt and clay size particles acted upon by soil forming factors. These are parent material, vegetation, climate, topography and time. While these components are sufficient for much of the work soil scientists do, it is not sufficient for remediation and bioremediation. The abundant living component of soil must be included in such work. This includes plants, animals and microorganisms in soil. It is important to include both decomposed and undercomposed organic matter.

Soil contains horizons, a result of the soil forming factors working on the loose material on the earth’s surface. Horizons are horizontal layers differing in characteristics such as color, texture and structure. Horizons are most easily identified by changes in color although other characteristics are used to differentiate horizons of the same color. In some soils, horizons with high density and low permeability are found. In this way, and many others, horizons have an effect on the way soil is handled during remediation.

A well developed soil profile contains several easily recognized horizons. The uppermost horizon is the A horizon. It is darker in color and higher in organic matter than lower horizons. Lower in the profile is the B horizon, which is generally redder in color and higher in clay. Below this is the C horizon, the parent material from which the soil is forming. Each of these horizons can be subdivided to designate additional features of the profile. Often transition horizons are also present. See Figure 1, page 29.

One must keep all these components in mind if one expects to work effectively with soil. The parent material is the decomposed or ground rock from which the soil is forming. The temptation is to assume that soil has characteristics from underlying parent material or rock. In some cases, sandy soils have developed from sandstone. However, it is more common to find that the soil is drastically different from the rock that provided the parent material and even the parent material from which it is forming.

Soil in much of Ohio, Indiana and Illinois have formed from glacial till which is overlaid by loess, wind blown silt size particles. The surface of these soils is acidic while the till is basic. The blue grass soils in and around Lexington, Ky., formed from the residues left behind by the decomposition of limestone. These soils are acidic and low in phosphate while the limestone is basic and high in phosphate. Many more similar examples exist throughout the world.

Soil is dynamically interactive with vegetation. It is common to find A and B horizons in soils throughout the world. The A horizon is relatively high in organic matter and contains most plant roots. In areas where there is dense grass sod cover, the A horizon is very dark and thick. In areas with trees, the A horizon has an E horizon under it. The E horizon is lighter in color and coarser in texture than the A or B horizon. Vegetation also affects other soil characteristics such as permeability.

Climate controls vegetation, but it also has an effect on soil characteristics quite separate from vegetation. Development of a soil results from decomposition and

Continues on page 28 >
Using Bioremediation?

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Characterize the total microbial community.
Metabolic status:
growth/starvation/toxicity

Academix, from page 27

synthesis of inorganic matter in the soil profile.
Inorganic components, salts and clays are transported through the soil by water movement. Thus, the amount of rainfall is a controlling factor in soil development.

Temperature is also important. The rate of chemical reaction increases as the temperature increases. In climates with high temperatures throughout the year, one expects to find an increase in the decomposition and synthesis of inorganic materials in the soil profile.
Topography is the lay of the land — its slope and its aspect. That is, does it face north, west, south or east? The steeper the slope, the greater the tendency of water is to flow across the surface rather than infiltrate the soil. This means there is less water moving through the profile thus less degradation and synthesis and less soil formation. In addition, water flowing over the surface causes erosion. Eroded soil is not available for profile or soil development. A slope facing south warms up faster in the spring. Thus, soil development, chemical reactions and life are more active longer than on slopes facing other directions.

The last factor in soil development is time. Soil parent material or presoil must stay in one spot for some time to become soil. It can easily take 1,000 years for 2.5 cm of soil to form. Soil erodes at 1.1 metric tons/hectare year under normal circumstances. This is geologic erosion and is natural. Erosion at higher rates does not allow time for new soil to develop to replace that which is lost. Plants, particularly grass or sod crops, are effective in stabilizing soil and preventing erosion.

When soil on a slope is contaminated, erosion presents the potential for the movement of contamination into streams, rivers and lakes. Protecting the soil surface is essential in controlling erosion. Raindrops hitting the soil surface starts the erosion process. This is splash erosion. Water movement over the soil surface is the second step in the erosion process as it carries soil away. If rain does not hit the soil surface and water does not run over the surface then erosion cannot occur.

Even if a material meets all of these characteristics, it might not be considered soil. First, it must be made up of sand, silt and clay size particles. Particles larger than 2 mm in diameter are no: sand by the soil scientist’s definition. Under normal conditions, sand silt and clay particles will not act alone. They will be connected to each other in such a way as to form aggregates called peds. Peds are a common development in soil and increase its permeability.

A sample of soil will have about 50 percent void space and 50 percent solid space. About one percent of the solid space is organic matter. The void space will be about half air and half soil solution. This is soil water. However, soil water always has inorganic and organic ions and molecules dissolved in it.

Researchers needing to do research with soil will get
much better results if they stop at this point. However, their results will have little relevance to real soil. The reason is that soil is alive and contains organic matter. The life is plants, animals and microorganisms. These are important in the physics and chemistry of soil. They are responsible for the absorption, decomposition and synthesis of both inorganic and organic compounds and ions.

Organisms in soil carry out myriad chemical reactions, some quite exotic. Nitrogen fixation carried out by free living microorganisms and in symbiotic relationships is common in soil. The production of methane under anaerobic conditions and the oxidation of ammonia to nitrite and nitrate under aerobic conditions are other common reactions occurring in soil. The conversion of metals such as iron and manganese and nonmetals such as sulfur between their various oxidation states occurs readily in soil under a wide variety of conditions.

Some examples of common reactions and the organisms that carry them out in soil follows.

\[
\begin{align*}
\text{NH}_4^+ + 1.5 \text{O}_2 & \rightarrow \text{NO}_2^- + 2\text{H}^+ + \text{H}_2\text{O} & \text{Nitrosomonas} \\
\text{NO}_2^- + 0.5\text{O}_2 & \rightarrow \text{NO}_3^- & \text{Nitrobacter} \\
\text{S} + 1.5\text{O}_2 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{SO}_4 & \text{Thiobacillus} \\
4\text{Fe}^{2+} + \text{O}_2 + 4\text{H}^+ & \rightarrow 4\text{Fe}^{3+} + 2\text{H}_2\text{O} & \text{T. ferrooxidans}
\end{align*}
\]

Organisms also excrete enzymes into the soil solution. These enzymes catalyze a host of reactions often involving the decomposition of complex insoluble compounds such as cellulose and other polymers. Free enzymes do not survive long in soil, however their existence is easily demonstrated.

Organic matter is also very important in defining both the physical and the chemical characteristics of soil. It can absorb a wide variety of inorganic and organic compounds. Humus — the material remaining when organic matter added to soil is decomposed — has a cation exchange capacity higher than clay. Thus it is important in any discussion of the cation exchange reactions of soil. A soil lacking organic matter will not have the same cation exchange characteristics as a soil with organic matter.

Soil used in research on remediation and particularly bioremediation should be a real live soil. It should be a mixture of sand silt and clay size particles bound together. It must have been acted upon by the soil forming factors and should be about 50 percent solid and 50 percent void space. The solid space should include a significant amount of organic matter, generally one to 10 percent. The void space must include both air and water. There must be a diverse group of organisms in the soil including plants, animals and microorganisms. This is indeed a complex medium in which to work but it is the only way that results meaningful in the real world can be obtained.
Bio-Rad Laboratories, Sadler Division, Philadelphia, has released IR Mentor Pro™, designed to assist both novice and experienced spectroscopists to interpret spectra and confirm the presence or absence of functional groups. The program features an expanded knowledge base comprising characteristic group frequency ranges and intensities along with associated bar charts and structural fragments of 200 IR functional groups.

Write in 643

Bioscience Inc., Bethlehem, Penn, offers the CONTRAL® Bioprocess control system, a software package which provides operational, design and management strategies for biotreatment system. It is a menu-driven software package consisting of seven separate, but related, computational routines. There are five spreadsheet programs, one curve-fitting program and one modeling program. Oxygen uptake results, along with other waste degradation data, are converted into recommendations for design, operation and management of a biotreatment or bioremediation system.

Write in 644

EnviroMetrics Software Inc., New Castle, Del., has released its PlantWare® MSDS and Inventory modules. PlantWare MSDS supports MSDS authoring in multiple formats and languages. PlantWare inventory is a material management system for tracking materials movement both on site and between sites.

Write in 645

Environmental Profiles Inc., Columbia, Md., offers IHT™, a software tool to manage industrial hygiene data and prepare reports. The Windows™ based software will search, sort and provide reports on: exposure information; employee information; facility information; and equipment inventory and calibration. IHT runs as a standalone product or across an organization’s network for multiple users. Also available is SPARQT™, an integrated process using Windows based software for self assessment of most types of compliance programs or company policy.

Write in 646

Environmental Software, Huntington Beach, Calif., offers SitePro™, an integrated database, CAD, GIS, mapping, graphing, analysis and reporting software for environmental management. Feature include GIS with hotlinks to the database, mapping, gridding and contouring. The software includes a chemical database of more than 10,000 compounds and a graphical user interface.

Write in 647

Environmental Systems & Technology, Blacksburg, Va., has developed BIOVENTINGplus, a Windows 95 program for air injection and extraction system design. The software evaluates design options for air-based in situ remedial technologies including soil vacuum extraction bioventing, air sparging and bioslurping. The program performs airflow rate and radius of influence, composition and recovery versus time, time to meeting specified cleanup criteria, and total cost versus number of wells. The program considers leakage from the ground surface, multiphase, multi-component partitioning, oxygen-limited biodecay, air turnover rate or intrinsic soil limitations, effects of air turnover rate as a function of distance on removal efficiency, and vacuum enhanced free product recovery.

Write in 648

GBA Technologies, Huntington Beach, Calif., has introduced Well Logger, a computer application for creating soil boring and well construction logs. It features customized layouts, user-definable fill patterns, adjustable scaling, and on-screen print-preview.

Write in 649

Intergraph Corp., Huntsville, Ala., offers environmental management and visualization software. The Environmental Office provides fully integrated, Windows based software for 2D and 3D environmental data management reporting, geoscientific analysis, groundwater modeling, environmental GIS, geostatistical analysis and engineering/site design. Five specific products are also available. ERMA Data Manager provides data capture, management, visualization and reporting capabilities for 2-D and 3-D environmental information. ERMA Site Geologist provides geological interpretation capabilities for subsurface analysis. ERMA Groundwater Modeler provides graphical user interfaces for data input, analysis and visualization for flow modeling, particle pathway tracking and contaminant transport modeling. Voxel Analyst provides true volume modeling, analysis and visualization for 3-D distributed scientific data. Geostatistical Evaluator provides graphically interactive tools for spatial analysis, interpolation and extrapolation of sample data values using classical statistics and kriging.

Write in 650
Justice Innovations, Mountain View, Calif., has released Chrom Perfect for HP GCs, the newest version of the Chrom Perfect for Windows chromatography data system. The software acquires and analyzes data directly from up to eight Hewlett-Packard 6890 or 5890 gas chromatographs. The software allows users to control all temperatures, pressures, and setpoints directly from the PC. Each GC can have its own method, printer and data directory. The GCs can be located up to 50 meters away from the computer without loss of signal quality. The software can log data to a network field server for review by other Chrom Perfect users on a network.

Write in 651

Kencon Environmental Inc., Cherry Hill, N.J., offers the Risk-Based Soil Screening Level Power Tool Kit. The software features automatic generation of conceptual site models, calculation of site-specific, risk-based SSls, generic soil screening levels, state-by-state cleanup standards, standardized electronic forms and worksheets and a geostatistical package. Other features include an integrated database system with point-and-click interface, chemical/toxicological databases for more than 600 chemicals and guidance on soil parameter estimation methods.

Write in 652

Mentor Software Inc., Thornton, Colo., offers CS-MAP, a coordinate system mapping library which serves as the coordinate conversion engine for MicroStation GeoCoordinator™ by Mizar Systems Limited, Vancouver, B.C. The latest version of CS-MAP enables MicroStation users to reproject reference maps in any coordinate system.

Write in 653

RegScan Inc., Williamsport, Penn., offers monthly updates on CD-ROM that contain all regulatory changes that were published in the Federal or State Register through the first day of that month. All the information is fully codified and changes are clearly noted.

Write in 654

RockWare, Golden, Colo., has released LogPlot97, a log plotting software package for Windows. The program reads text files and plots the log information based on customizable keyword and lithologic pattern files. The program is user-modifiable, and includes a log format designer, and symbol, lithologic pattern, and lithologic keyword editors. Log entities include lithologic patterns and descriptions, scale bars, BMP graphics, curves, histograms, fill bars, text, symbols, and lithologic percentages. Up to 40 curves and 40 histograms can be included in linear or logarithmic format.

Write in 655

Solutions Software Corp., Enterprise, Fla., has introduced EPA Methods and Guidance for Analysis of Water on CD-ROM. The CD-ROM features the official EPA Series 500, 600, 1600 Methods, plus the complete Title 40 CFR Parts 136-145. It contains more than 330 EPA drinking water and wastewater methods, as well as guidance from more than 50 EPA documents. It also includes Methods of Chemical Analysis of Water and Wastes; Metals, Inorganic and Organic Substances in Environmental Samples; and Whole Effluent Toxicity Methods. Each document includes all text, tables, diagrams, flow charts, and figures.

Write in 656

Veeer-Root Co., Simsbury, Conn., has released an upgrade to RemoteControl, a communication software for monitoring fuel inventory, alarms, and leak detection reports from remote sites. Improvements to the program include reduced site connect time, compatibility with the latest TLS software version and with Wireless Pressurized Line Leak Detection, and alarm reporting that allows customized alarm reports.

Write in 657

![Tier2 RBCA Tool Kit](image)

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tel. 713/522-6300 fax 713/522-8010
http://www.gsi-net.com/RBCAtools/

Write in 021

Soil & Groundwater Cleanup October 1997 31
November, 1997

"Due Diligence at Dawn: ASTM E 1527 The Devil is in the Details." Nov. 11, Hyatt Regency Denver, Colo; Nov. 12, Houston Marriott West Loop, Texas; Nov. 13, Fort Lauderdale Marina Marriott, Fla.; Nov. 18, Cobb Galleria Centre, Atlanta, Ga.; Nov. 19, Embassy Suites Hotel, Washington D.C.; and Nov. 20, Sheraton Newark Airport, Edison, N.J. Call Janelle Falcone, 800-352-0050.

November 12-14

November 13-14

November 17-18, 1997

November 17-19, 1997

November 18-20, 1997

November 18-20, 1997
47th CPI Exposition/’97 Chem Show, Javits Convention Center, New York City. Call Mark Stevens, 203-221-9232.

November 19-21, 1997
"Implementing Natural Attenuation for Sites Contaminated with Hydrocarbons or Chlorinated Solvents." University of Wisconsin-Madison. Call 800-462-0876.

November 19-21, 1997
Environmental Technology Expo and OSHA Compliance Expo. Georgia World Congress Center,
December 1-5, 1997
The RCRA Compliance Institute.
The Polo Towers, Las Vegas. Call Katjie Swangren, 301-921-2345.

December 2-5, 1997
The Site Remediation and Restoration Institute· Adams Mark Hotel, Denver, Colo. Call Katjie Swangren, 301-921-2345.

December 2-4, 1997

December 8-9, 1997

December 8-11, 1997

December 12, 1997

March 4-5, 1998

March 8-12, 1998
8th Annual West Coast Conference on Contaminated Soil and Groundwater. Embassy Suites, Oxnard, Calif. Call Barbara Knowles, 413-549-5170 or 888-540-AEHS.

March 16-19, 1998
The CFR Course: Understanding and Using Environmental Regulations with Confidence .

Atlanta, Ga. Call Harry Alexander, 423-691-9825.

April 1-2, 1998
20th International Madison Waste Conference. Madison, Wisc. Call Phil O'Leary or Kris Winneke at 608-262-0493 or 800-462-0876.

April 8-9, 1998

April 8-10, 1998

April 20-22, 1998

April 20-23, 1998
Eighth Symposium on Environmental Toxicology and Risk Assessment: Standardization of Biomarkers for Endocrine Disruption and Environmental Assessment. Atlanta, Ga. Call Dr. Diane S. Henshel at 812-855-4556 or Dr. Marsha C. Black at 706-542-0998 or Dr. Michael C. Harrass at 312-856-5116.

April 26-May 1, 1998

May 5-7, 1998

May 11-15, 1998
17th International Conference on Incineration and Thermal Treatment Technologies. DoubleTree Hotel, Salt Lake City, Utah. Call Tina Haddad, 714-824-7066.

May 18-21, 1998
First International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Doubletree and Marriott Hotels, Monterey Conference Center, Monterey, Calif. Call 800-783-6338 or 614-424-5461.

June 9-11, 1998
EMAT. The New Atlantic City Convention Center, Atlantic City, N.J. Call 216-891-2695.

Send your calendar listing including name, date and location of event along with a contact name and phone number to: Soil & Groundwater Cleanup, "What's Happening", 204 W. Kansas, Ste. 103, Independence, MO 64050.
Analyzer designed for field surveys

The RGA3 Reduction Gas Analyzer, from Trace Analytical, Menlo Park, Calif., determines low parts per billion levels of free hydrogen in groundwater. The instrument consists of a microprocessor controlled gas chromatograph with a reduction gas detector. The unit operates on the principle of absorption of UV light from mercury vapor, released by reaction of the separated hydrogen with a heated mercuric oxide bed.

Skimmer handles grease, oil in water

The Grease Grabber™, a mechanical skimmer that removes floating grease and oil from water, is available from Abanaki Corp., Chagrin, Falls, Ohio. The skimmer features ceramic wiper blades and reinforced polyfiber belts. With available belt lengths of 30.5 meters or more, belts can be customized to suit specific application requirements. The unit discharges at a rate of 605 liters per hour.

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AMS PowerProbe TC
Direct push technology takes the next step

Art’s Manufacturing & Supply Inc., American Falls, Idaho, has introduced the PowerProbe 9600TC. The tractor-mounted PowerProbe features 16,800 kg of pull and 13,600 kg of push, weight dependent. The unit features 20 cm of side to side movement, a variable probing ratio plus or minus 15 degrees from vertical and optional drill and hammer capabilities.

Unit combines line boring, bore welding

Tectran Technology Transfer, Santa Rosa, Calif., has introduced the Wolverine Super-Combi, a machine tool which combines both line boring and internal bore welding in one portable unit. The unit can bore up to 60 cm diameters. Rotational speed and advance are separately controlled in the bore welding process.
New line of water treatment systems launched

Zentox Corp.'s NEPCCO Equipment Division, Ocala, Fla, has launched a new line of packaged ozone water treatment systems. The TurbOzone series of systems are skid-mounted and capable of treatment of cooling towers from 250 to 10,000 plus cooling tower tons. All models are equipped with ozone generator, oxygen preparation system, skid pump, electric panels, ORP sensing and control loops.

Tubing designed for soil sample probe liners

MOCAP Inc., St. Louis, Mo., has introduced Clear Tec, a line of round crystal clear semi-rigid tubing for soil sample probe liners. The tubing is stocked in 1.2 meter lengths and diameters from 6 mm to 89 m. Special sizes are available. Snug fitting caps in a variety of colors are also available. The tubing contains no plasticizer.

Probe measures water velocity

Global Water, Gold River, Calif., offers the Global Flow Probe, a water velocity instrument. The probe consists of a protected Turbo-Prop positive displacement sensor coupled by an expandable probe handles to a digital readout display.

Device handles seven operations with one probe

The MicroPurge FC4000 Flow Cell is available from QED Environmental Systems Inc., Ann Arbor, Mich. The device simultaneously measures, displays and records seven purge water parameters, including pH, dissolved oxygen, temperature, ORP - redox, conductivity, TDS, and salinity. The unit uses a single probe and meter. The device can be operated from its hardshell, weatherproof carrying case. The analyzer features automatic storage, recall and downloading of up to 30,000 data points.
THE EPA RESULTS ARE IN AND MBS WON BIG!

I’m Joe Theismann and I know winners when I see them. That’s why I joined the Solucorp team. Solucorp’s Molecular Bonding System (MBS) is now proven to be a cost efficient and permanent solution for stabilizing heavy metals in soils and industrial wastes. That sidesteps the risk of future liability better than I dodged linebackers!

What’s the proof? The EPA’s test results. Solucorp’s innovative MBS process was tested on the EPA’s three highest priority wastes at the Midvale Slag Superfund Site. MBS blitzed even the proposed UTS criteria!

The Solucorp team now leads the way in permanently and cost efficiently cleaning up the toughest heavy metals contaminated sites across all of North America and Europe.

Beat your heavy metals problem with MBS.
Call Solucorp for a free consultation.

Following is an update to our 1997 Buyer’s Guide. These companies missed the 1997 deadline or have moved or changed phone numbers since April 1997. If you would like to be included in our 1998 Buyer’s Guide, please fax the following required information: your company’s name, contact person, phone number and fax number to 816-254-2128 as soon as possible. We will begin the process of preparing the 1998 Buyer’s Guide in early January.

Adirondack Environmental Assoc. Inc.
9 Kasinen Road
Plattsburgh, NY 12901
Phone: 518-563-5726
Fax: 518-562-0789
E mail: AEA@Together.net
Contact: Guy Fenwick

Anguil Environmental Systems Inc.
& Global Technologies Inc.
8855 North 55th St.
Milwaukee, Wisc. 53223
Phone: 414-365-6400
Fax: 414-365-6410
E mail: sales@anguil.com
Website: www.anguil.com

Blackhawk Environmental Co.
21 W. 159 Hill Road
Glen Ellyn, Ill. 60137
Phone: 630-469-4916
Fax: 630-469-4896
Contact: Mark Bertane

Control Instruments Corp.
Phone/fax: 973-575-9114

The Critter Co. of Ohio Inc.
P.O. Box 276
Westerville, OH 43086-0276
Phone: 614-794-9775
Fax: 614-794-9481
Contact: Scott Klingsmith

36 October 1997 Soil & Groundwater Cleanup
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Soil & Groundwater Cleanup October 1997 37
Bubbles spell trouble for chlorinated solvents
C-Sparging reduces PCE in groundwater in Massachusetts

By William B. Kerfoot, Ph.D., Lsp.

A system called C-Sparging™ which uses ozone/air injected periodically in conjunction with a pulsing pump has been demonstrated by K-V Associates to reduce PCE-contaminated groundwater from 1000 ppb to less than 1 ppb in three weeks. The rate of decay was found to be a tenfold reduction per week in monitoring wells located 1.5 to 4.5 meters from the sparging well. The site treated was a 18 meter wide, 4.5 meter deep and 46 meter long plume of tetrachloroethylene (PCE) extending from an urban dry cleaner. Three treatment wells were installed. See Figure 1, page 39. Monitoring from seven wells was performed weekly during and after treatment.

The process appears capable of operating without vapor control. The balancing of ozone concentration to rate of extraction by the microbubbles resulted in hardly detectable levels of PCE in the vapor control system. In addition, by the use of microbubbles, the rate of ascent of the bubbles was designed to allow oxidation reactions to be completed before the bubbles reached the unsaturated vadose zone.

What is C-Sparging?

The K-V Associates Inc. process of C-Sparging™, in-situ air stripping with micro-encapsulated ozone,

William B. Kerfoot, Ph.D., is president and an LSP with K-V Associates Inc., Falmouth, Mass.
combines two unit operations. First, fine bubbles with a high surface to volume ratio are injected into the saturated zone to extract dissolved chlorinated solvents out of contaminated groundwater. Second, ozone contained within the bubbles reacts extremely rapidly in the gaseous phase to decompose the solvents into end products consisting of carbon dioxide, very dilute hydrochloric acid and water.

The reaction detoxifies groundwater containing VOCs like PCE, TCE, and 1,1 DCE rapidly to below drinking water standards without producing harmful byproducts. The reaction is accomplished with very low ozone concentrations — molar ratios — compared to VOC concentrations in groundwater.

The treatment system injects fine bubbles below and into the main VOC plume. Pulsed injection of air/ozone through a micro-channeled diffuser, or Spargepoint®, introduces fine bubbles into the bottom of the plume region, which move upward through the contaminated water.

Within the central core area of the plume, a second Spargepoint, combined with the intermittent operation of a submersible pump, displaces the vertically-moving bubbles sideways to maximize dispersion and contact. By periodically pulsing this process, groundwater is circulated from top to bottom of the sparge well, allowing effective capture and treatment of the VOC affected saturated zone.

Going to the cleaners

The site is located in a downtown shopping center on Main Street in Falmouth, Mass. The region was formed on a glacial outwash plain and contains a 75 meter plus deep sand and gravel sole source aquifer. Surface area mainly consists of a large asphalt-paved parking lot behind the Main Street businesses. Depth of groundwater ranges 3.7 to 4 meters, depending upon rainfall which averages 110 cm per year.

The subsurface soils consist of predominantly fine to medium sand, occasionally laced with cobblestone and coarse sand layers. Coarse sand and gravel account for about 31 percent of weight, medium sand for 31 percent and fine sand for about 35 percent of total weight. Fine soil fractions of silt and clay account for less than three percent by weight.

Continues on page 40→

![Figure 1: C-Sparger](image)

| Figure 2: Well and groundwater elevations, April 1, 1991 |
| Well | Depth to groundwater (m) | Groundwater Elevation (m) |
| MW-1 | 5.1 | 3.8 | 1.3 |
| MW-2 | 4.8 | 3.6 | 1.2 |
| MW-3 | 4.9 | 3.7 | 1.2 |
| MW-4 | 5 | 3.7 | 1.2 |
| MANHOLE | 5 |

<p>| Figure 3: Flow direction and rate |</p>
<table>
<thead>
<tr>
<th>Well</th>
<th>Depth</th>
<th>Direction</th>
<th>Flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-3</td>
<td>5</td>
<td>242°</td>
<td>71 cm</td>
</tr>
<tr>
<td></td>
<td>5.3</td>
<td>250°</td>
<td>63.5 cm</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>317°</td>
<td>25.4 cm</td>
</tr>
</tbody>
</table>

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- Large volume soil remediation.

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Write in 262
Figure 4: Groundwater Samples Analyzed by EPA Method 8010

<table>
<thead>
<tr>
<th>Compound</th>
<th>Before Treatment</th>
<th>After Continuing Treatment</th>
<th>Rebound Test Turned Off After 45 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetrachloroethene (PCE)</td>
<td>12-29-95</td>
<td>02-02-96</td>
<td>04-01-96</td>
</tr>
<tr>
<td>Concentrations (ppb) in Monitoring Well MW-1</td>
<td>430</td>
<td>11</td>
<td>BRL</td>
</tr>
<tr>
<td>Trichloroethene (TCE)</td>
<td>50</td>
<td>2</td>
<td>BRL</td>
</tr>
<tr>
<td>CIS-1,2 Dichloroethene (DCE)</td>
<td>14</td>
<td>2</td>
<td>BRL</td>
</tr>
<tr>
<td>Concentrations (ppb) in Monitoring Well MW-3</td>
<td>12-13-95</td>
<td>02-02-96</td>
<td>04-01-96</td>
</tr>
<tr>
<td>Tetrachloroethene (PCE)</td>
<td>7</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Trichloroethene (TCE)</td>
<td>4</td>
<td>8</td>
<td>BRL</td>
</tr>
<tr>
<td>CIS-1,2 Dichloroethene (DCE)</td>
<td>6</td>
<td>5</td>
<td>BRL</td>
</tr>
<tr>
<td>Concentrations (ppb) in Monitoring Well MW-4</td>
<td>12-13-95</td>
<td>02-02-96</td>
<td>04-01-96</td>
</tr>
<tr>
<td>Tetrachloroethene (PCE)</td>
<td>50</td>
<td>77</td>
<td>38</td>
</tr>
<tr>
<td>Trichloroethene (TCE)</td>
<td>19</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>CIS-1,2 Dichloroethene (DCE)</td>
<td>79</td>
<td>45</td>
<td>22</td>
</tr>
<tr>
<td>trans-1,2 Dichloroethene</td>
<td>1</td>
<td>BRL</td>
<td>BRL</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>BRL</td>
<td>BRL</td>
<td>BRL</td>
</tr>
<tr>
<td>Concentrations (ppb) in Monitoring Well MW-7</td>
<td>05-95</td>
<td>02-02-96</td>
<td>04-01-96</td>
</tr>
<tr>
<td>Tetrachloroethene (PCE)</td>
<td>4400</td>
<td>180</td>
<td>38</td>
</tr>
<tr>
<td>Trichloroethene (TCE)</td>
<td>1400</td>
<td>65</td>
<td>7</td>
</tr>
<tr>
<td>CIS-1,2 Dichloroethene (DCE)</td>
<td>28</td>
<td>190</td>
<td>28</td>
</tr>
</tbody>
</table>

Bubbles, from page 39

Groundwater elevation was measured by surveying the well elevation relative to the sewer system manhole cover and then measuring depth to groundwater in each well. See Figure 2, page 39. Direction of groundwater flow is southeast. The gradient at the site varies from .005 to .0015.

Groundwater flow direction and rate were measured in well MW-3 using the KVA Model 40 GeoFlo groundwater flowmeter. The flowmeter works on a heat-pulse methodology. Recommended protocol is to take three measurements per well: top, middle and bottom. Magnetic declination for the area is 15°. See Figure 3, page 39.

Site specific system set up

A single C-Sparger master unit with three in-well units was installed along the historical plume region. The first installation was a double Spargepoint with a dual screen. The second consisted of a dual-screened 100 mm well with casing between, but no lower spargepoint. The third was a double spargepoint/dual screen, but no in-well unit was used and only air/ozone supplied to the lower spargepoint.

The general construction consisted of 100 mm casing leading to a 1.5 meter screen with 0.5 meter above the water table, a blank casing which was bentonite-sealed
in the annular space to prevent short circuiting, and a lower 1.5 meter screen (10 slot). Placed below this was a support section, 1.5 meters of 50 mm PVC, holding a 50 mm spargepoint 46 cm long with a compressing fitting and 13 mm polypropylene tubing leading up to the wellhead region.

Procedure gets results

Initial results of the treatment were monitored by three procedures.
• Groundwater samples taken at weekly intervals from purged monitoring wells and analyzed on a gas chromatograph using the 25 percent headspace procedure developed by Spittler, et. al.
• Groundwater samples obtained by purging monitoring wells and submitting samples to certified analytical laboratories by EPA procedure 8010 for volatile organics. See figure 4, page 40.
• Groundwater samples obtained from purging the monitoring wells and analyzed for selected cations and anions: alkalinity, TDS, chloride, sulfate and nitrate.

A rapid decrease in PCE, trichloroethene (TCE) and cis-dichloroethene (1,2 DCE) was observed in the monitoring wells. The rate was related to proximity of the monitoring wells to the sparging wells. The rate of decrease was more rapid with higher molecular weight: PCE>TCE>DCE. The headspace analyses showed a quicker response than did the laboratory samples, but both were closely correlated.

A relationship between rates of PCE removal and changes in anion/cation balance was observed. The proximity of monitoring wells to sparging wells allowed them to be segregated into heavy moderate, and light C-Sparging treatments. Sparge well C and monitoring wells MW-1 and MW-4 were closest to C-Sparging sources. A significant increase in alkalinity, TDS, chloride and sulfate was observed.

Generally, heavier C-sparging shows elevated hardness (carbonate production), chloride, sulfate and TDS. The total amount of increase of chlorides in the dissolved fraction exceeded the rise expected up to 40 mg/1 ppm from decomposition of PCE from 1000 ppb to non detect. This suggests some adsorbed liquid reacted with decomposition products of C-Sparging. Hardness measures equivalent CaCO₃ concentrations as mg/1. Alkalinity is the measurement of capacity of water to accept protons, usually imparted by bicarbonate compounds of natural water.

A concentrated region, located in the center of an abandoned cesspool, resisted reduction. After two months of maintaining a concentration near 250 ppb PCE, two injected Spargepoints were placed in and slightly below the septic unit. Within two weeks of treatment, water samples showed less than 5 ppb.

Conclusions for chlorinated solvents

Three dissolved chlorinated solvents were observed on the site: PCE, TCE anc DCE. The TCE and DCE were breakdown products of anaerobic bacterial activity generated near the septic system. All three dissolved chlorinated solvent products rapidly decreased with treatment without any transfer from one compound to another. Cessation of treatment for 1.5 months did result in significant rebound in concentration VOCs within the abandoned cesspool and downgradient from a catchbasin which had received liquid solvent at some point.

The technique of cessation of treatment to check for rebound was a powerful means of locating secondary sources on the site, as well as a means of rapid removal of dissolved HVOCs.

Water sampling was performed across the site to determine if any unwanted degradation products occurred. A slight rise in pH occurred, from 6.0 to 5.5. Breakdown products were very dilute HCl and CO₂. No evidence of epoxide formations with dichloro acetate or formaldehyde were observed.

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42 October 1996 Soil & Groundwater Cleanup
Enzyme Technologies DO IT system

- A new system called Dissolved Oxygen Insitu Treatment, or DO IT, from Enzyme Technologies, Troutdale, Ore., combines scientific principles with proprietary biological products for soil and groundwater treatment.

The DO IT system uses affected groundwater from downgradient sources which passes through a treatment tank and an oxygen mixing chamber that supersaturates the water with dissolved oxygen.

Once the water contains sufficient oxygen, it is reinjected through a set of lateral and vertical upgradient injection points to diffuse the entire site with high levels of oxygen, which increases the aerobic activity.

As the oxygen rich waters act as a carrier for the biological products or enzymes, all pathways through which the contaminants have migrated are contacted and immediate degradation begins. The DO IT system can be used as stand alone technology or augmented where conventional pump and treat, air sparging or vapor extraction systems are currently in use.

While indigenous or augmented biological cultures rely on at least three ppm of oxygen to oxidize every one ppm of hydrocarbons, there is always sufficient oxygen available for the transformation process.

The DO IT system allows for complete saturation of oxygen to the groundwater table in small micron sized bubbles. As the oxygen is released from the water molecule, it diffuses upward into the capillary fringe and vadose zone, allowing for the microbial action to remove the more difficult contaminants which have bonded to the soil molecule to be remediated simultaneously.

Write in 638
HydroTechnics In Situ Flow Sensor

- The In Situ Permeable Flow Sensor from HydroTechnics, Albuquerque, N.M, uses a thermal perturbation technique to directly measure the three-dimensional groundwater flow velocity in unconsolidated, saturated, sandy sediments.

  The instrument consists of a cylindrical heater 76 cm long by 5 cm in diameter with an array of 30 calibrated temperature sensors on its surface. The probe is installed like a 5 cm PVC monitoring well and connected to the surface by cables housed in 25-50 mm SCH40 PVC.

  The probe is buried in direct contact with the formation where the measurement is to be made and the heater is activated with about 80 watts of continuous power. The sediments and groundwater surrounding the probe are warmed by 20 to 30°C.

  In the absence of any flow past the instrument, the temperature distribution on its surface is independent of azimuth and symmetric about the vertical midpoint of the probe. When there is flow past the tool, the surface temperature distribution is perturbed as the heat emanating from the probe is advected around the probe by the moving fluid.

  Relatively cool temperatures are observed on the upstream side of the tool while relatively warm temperatures are observed on the downstream side. PC-based software is available which converts the measured probe surface temperature distribution into the direction and magnitude of flow velocity.

  Sensor operations, data collection, and data transfer can be remotely controlled via data acquisition system and modem from an office computer with HTFLOW software.
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