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Abbreviations and acronyms used throughout articles include:
EPA Environmental Protection Agency
ppm parts per million
UST Underground Storage Tank
ppb parts per billion

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essir, I love the gatherings! And the environmental gatherings are the greatest gatherings in the world. No other industry that I know of puts on so many wonderful, useful, impressive conferences, trade shows, workshops, gatherings—as the environmental industry. And, we not only have quantity, we have quality gatherings. Don’t take this valuable resource for granted. Get out there—attend, learn, rub elbows, (maybe even bend an elbow, if you’re so disposed), make contact, pick up the literature. We have Superfund, the 10th Annual Conference on Contaminated Soils at the University of Massachusetts in Amherst, HazMat West, and countless others. I see on my calendar that my next outing is the Mighty Hornet Women Blowout—oops, that’s my high school gang reunion. Even so, I expect to “grow,” (I gained almost 2 kilos at last year’s blowout) and further polish my karioke skills.

If you picked up your copy of this magazine at a conference, let me know. I’d like to hear your impressions. What did you gain? What was your role—attendee, exhibitor? Do you have suggestions to improve environmental gatherings? More focus or broader coverage? Different sessions? Open bar? How do you translate your conference experience to your co-workers when you get back home? Drop me a line and let me know what you think.

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Write in 261

Soil & Groundwater Cleanup October 1995
Passive survey yields dynamic results

Two week test collects data over time

By William Messner, John Thompson and Jay Hodny

![Figure one: schematic of soil gas collector.](image)

Active soil vapor surveys provide a snapshot of site conditions on a particular day. Although this method can provide fast results, it has been of limited utility on sites with wet or low permeability soils, or where semi-volatile organic compounds are the principal constituents of interest. As soil moisture increases and decreases, vapor content tends to decrease and increase.

That is why W.L. Gore & Associates Inc., Elkton, Md., developed a passive soil vapor screening system, GORE-SORBER® Screening Survey, to measure, report and map the relative distribution of vapors originating from volatile and semi-volatile organic compounds over time in soil and groundwater. A simple diagram of the soil gas collector is shown in figure one, left. To test the system, Gore chose an operating bulk fuel storage facility, owned and operated by Mobil Oil Corp., that stores and dispenses gasoline, #2 fuel oil, diesel and jet fuel. The objective of the test was to evaluate the effectiveness of the system, as compared to known groundwater quality data, and to the results of the active soil vapor survey conducted previously at the site.

The area of the facility selected for the evaluation is located directly downgradient from a light product fuel loading rack. The area is about .25 hectare in size, and encompasses the general location of the active soil gas.
survey, as in figure two, left. Depth to groundwater at the site ranges from about 1 to almost 2 meters below surface grade with an inferred westerly direction of flow. Site lithology consists of fill material with wet sands and clays. Soil permeability measurements range from $10^{-4}$ to $10^{-6}$ square centimeters. Impact to groundwater quality by petroleum hydrocarbons is evidenced by separate-phase floating petroleum products in two of the four monitoring wells located in the study area.

The sampling design included three transects, with up to nine modules per transect, spaced 9 to 18 meters apart, and placed perpendicular to the groundwater flow direction. These 25 sample locations approximated the active soil vapor survey grid as in figure three, above. Pilot holes were drilled with a rotary hammer drill, fitted with an 18 mm, carbide tip, solid-stem auger bit. The soil gas collectors were inserted to depths just short of one meter below surface grade using a 6 mm diameter stainless steel insertion rod. The surface end of each module was attached to a cork, placed into the hole and tamped flush with the ground surface, sealing it at grade. It took about four hours to install the 25 modules, and about an hour to retrieve them after a two week subsurface exposure time. The modules were packed on ice and shipped to Gore's lab for analysis and computer mapping.

The modules were analyzed using automated thermal desorption and gas chromatographic separation with mass selective detection. Results were quantified in terms of mass recovered per sorber, expressed in micrograms, and presented in a tabular format, as well as in color contour overlays on a map of the site. Figure two shows the relative mass distribution of BTEX (benzene, toluene, ethylbenzene and xylenes) compounds reported by the passive survey. Analysis of the modules located near and directly downgradient from

Continues on page 8→

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Soil & Groundwater Cleanup October 1995 7
Passive survey results, from page 7

monitoring well GT-40 yielded the highest BTEX levels at the site, exceeding 450 µg. Well gauging data from GT-40 indicated an apparent thickness of 355 mm of separate-phase petroleum hydrocarbons—the most significant groundwater impact in the area surveyed. Considering the inferred westerly direction of groundwater flow, the well data and the passive soil vapor survey results compared favorably.

Results of the active soil vapor survey in figure three agree favorably with results of the passive survey in figure two—with one significant exception. The active survey results depict an apparent decrease in BTEX concentrations (µg per liter of soil vapor) reported directly downgradient from well GT-40. In contrast, the passive method indicated significant subsurface impact by BTEX constituents in the same area. Further investigations revealed that this particular area has a near-surface soil permeability of 10⁻² square cm, whereas the balance of the site exhibits higher permeability measurements ranging from 10⁻³ to 10⁻² square centimeters. This demonstrates the effectiveness of the passive technology in overcoming one of the limitations of the active technique—application at sites with low and/or varying soil permeabilities.

The time-integrated, passive approach not only allows for application in low permeability soils, but can also detect and collect low volatility, high molecular weight organic compounds. Figure four, above, illustrates the distribution of a typical PAH (polynuclear aromatic hydrocarbon), phenanthrene, which is considered to be a relevant indicator compound of #2 fuel oil. Modules with significant levels of phenanthrene were reported in the area of two wells with separate-phase floating petroleum hydrocarbons, GT-40 and GT-72.
A hydrocarbon distillation analysis of the separate-phase floating product from the wells indicate a combination of gasoline range hydrocarbons and fuel oil constituents in GT-40. The analysis of the product in GT-72 shows fuel oil constituents only. Total ion chromatograms (TICs) from a soil vapor module located near each well are shown in figure five, right. The TIC from the module near GT-40 contains peaks in the range of both gasoline and fuel oil. The TIC from the module near GT-72 contains peaks in the range of fuel oil, with an absence of significant peaks in the range of the higher volatility gasoline constituents. Thus, the analytical results of the passive soil vapor survey from these two modules confirms the hydrocarbon distillation analysis.

Results of this study indicate that passive soil vapor screening not only matches well with long term monitoring results, but that the technology works well in low permeability soils, as low as $10^{-9}$ square cm. Detection of volatile organic compounds by active screening was adversely affected by soil permeability in an area of significant groundwater impact. And, the PAHs were not reported as part of the active soil vapor results due to their lower vapor pressures. Passive techniques can delineate soil or groundwater impact by low volatility, high molecular weight organic compounds, as well as more volatile organics typically detected by active soil vapor methods. The GORE-SORBER module installation and retrieval is achieved with hand tools in a relatively short time.

Write in 824 for more information
Horizontal wells tilt industrial site pollutants

Multiple challenges spawn innovative solutions

By Michael Lubrecht

Remediation of subsurface contamination at a busy industrial facility is never easy. Each site presents its own set of challenges for the designer and remediation contractor. The most interesting remediation projects tend to be those with the largest collection of challenges.

FlowMole Environmental Services Corp., Kent, Wash., recently completed such an "interesting" project at a chemical warehouse and distribution facility in Seattle. The site is listed on the Washington State Department of Ecology hazardous sites list for soil and groundwater releases. Hart Crowser, a Seattle consulting firm, performed extensive investigations at the site to define the nature and extent of the contamination. FlowMole was contracted to install horizontal soil vapor extraction wells and groundwater extraction wells as part of a comprehensive site cleanup plan.

The primary contaminants of concern at the site include chlorinated solvents, such as tetrachloroethylene, in concentrations of 500 to 1,000 ppm. This contamination reached the upper aquifer, which is separated from lower aquifers only by a thin silt aquitard. At one spot on the site, free DNAPL (dense non-aqueous phase liquids) pooled on the surface of the silt horizon. A plume of contaminants also migrated downgradient into a nearby waterway.

Hart Crowser designed an installation that included two, 50 mm diameter, high-density polyethylene soil vapor extraction wells; and two 100 mm diameter stainless-steel, pre-packed groundwater extraction wells. The soil vapor wells, located in the vadose zone, are connected to a vacuum system to extract volatile contaminants that permeate the interstices between soil particles in the unsaturated zone. The groundwater extraction wells remove free product and contaminated groundwater, with the resulting drawdown exposing additional unsaturated soil to the vacuum from the soil vapor extraction system.

Stainless steel was selected for the groundwater wells because of concerns that the relatively high concentrations of chlorinated solvents could degrade polyethylene or other synthetics. A prepack configuration was chosen for the well screen, a factory-assembled combination of a 50 mm diameter, pipe-based well screen inside a 100 mm wire-wrapped screen, with graded silica sand filling the annulus between the screens. This screen type provides excellent filtration to develop and maintain the well, but stiffens the assembly considerably, making installation difficult.

The geo-hydrological setting and physical constraints of the work area make it an ideal candidate for horizontal drilling. Several factors contributed to this choice:

- Access—All the wells are located in a narrow alley, adjacent to the site property line and a loading dock. Since the water table is 3.6 meters deep, trenching operations would require extensive shoring and complicated spoils management in order to avoid trench collapse without disrupting access to the loading dock, or hindering remediation efforts. Horizontal drilling requires relatively small work areas at the launch and exit points, which are covered with steel plates when not in use, permitting full site access.

- Hydrogeology—A major concern is the potential for perforating the thin, silty clay layer at the base of the uppermost aquifer. With a nominal thickness of only 300 mm, any overexcavation could result in the immediate release of free DNAPL that was ponded on the surface of the aquitard into the lower aquifers. However, placing the casing at too high an elevation would not remove pooled product from the aquitard surface, and would also reduce the effectiveness of the dewatering operation. FlowMole’s guided horizontal drilling method can

Continue on page 12→
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Write in 090
Horizontal wells, from page 10

accurately bore a tunnel at the design elevation along this layer without fear of a significant breach.
•Spoils management—Trenching would generate a large volume of contaminated spoils. The on-site management and eventual disposal of these spoils, either via on-site treatment or hauled to a landfill, would add substantially to the project cost. Horizontal drilling generates limited volumes of spoils, which are pumped to a rolloff disposal container to filter out the solids. Then, the fluid portion is pumped to a tank for storage until the groundwater treatment is constructed.

FlowMole mobilized an intermediate size, F-series drill rig for this project, with nearly 15,000 kilograms of pullback power—more than enough to pull in the stainless steel casing, which weighs more than 900 kilograms. The drilling is guided by the company’s Flocator™ guidance system, which relies on radio signals transmitted from the drillhead to provide a readout of depth and lateral location to the Flocator technician, who walks along the borehole path. The technician directs the driller to steer the drill in the desired direction. In deeper wells, a wireline system is used to boost the signal from the drillhead, as well as to provide a readout of the tool’s pitch, which helps to drill a borehole with smooth, gradual curves that facilitate casing installation.

One initial challenge that faced the crew was to steer the relatively stiff F-drill rods in the loose, silty sand layer where the groundwater extraction wells were to be installed. The F-drill, originally designed to install long utility cable runs, is supplied with heavy duty drill rods that withstand high tensile loading during pullback. This increased strength is welcomed for pulling back the stainless steel casing, but it decreases the flexibility and steerability of the rods for drilling the initial pilot hole. In softer soil materials, the rods resist deflection forces for steering, and simply dive vertically under their own weight.

The crew quickly addressed the diving problem by building a reaction plate for the drill bit with a large surface for the rig to push against, thus multiplying the deflection force applied to the drillhead. Engineers also designed and constructed a drill sub to adapt smaller diameter drill rods to the stout F-series rods. By attaching 9 meters of these more flexible lead rods to the drill string, steering was improved, while retaining the extra tensile strength needed for the casing installation.

Each of the four pilot bores, ranging from approximately 36 to 55 meters in length, was typically drilled in two to three hours. Each of the holes involved compound curves—the borehole profile included not only launch and exit sections with vertical transitions, but snaked laterally through an area populated with several vertical monitoring wells. Careful steering of the pilot bore slightly above the design screen invert helped assure that the aquitard would not be breached, and that the screen would be located at the correct final elevation after the borehole was reamed.

After the pilot bore was completed, the hole was preamed to final size. The casing was pulled in behind a second reamer used to help clean drill cuttings from the borehole. Casing installation took from two to four hours per well, with the stainless steel wells requiring great care to assemble the threaded casing couplings to avoid thread damage and possible joint failure.

Despite the assurances from design engineers and pipe manufacturers that the stiff stainless steel casing would accommodate the 75 meter radius bends in the well bore, everyone was elated to see the first glimpse of the gleaming stainless pipe in the access pit at the end of the first run.

The crew completed each well with a packer installation to prevent migration of grout into the screened interval, and grouted the borehole annulus from the packer to the ground surface. An enzymatic viscosity breaker was introduced to quickly degrade the polymer drilling mud, followed by jetting and pumping.

Although the remediation is just getting underway, initial observations of well performance suggest that the system will perform well, as Hart Crowser completes construction of the on-site treatment facilities for the groundwater and soil vapor.

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- The new version of VISITT is out. Vendor Information System for Innovative Treatment Technologies version 4.0 from the Technology Innovation Office of the EPA’s Solid Waste and Emergency Response division is like “a free electronic Yellow Pages of innovative treatment technologies and vendors,” according to the announcement.

It contains data on 325 innovative technologies, 70 percent of which are commercially available, provided by 204 vendors. The user-friendly database features customized search capabilities. EPA estimates the database is used by over 10,000 users in 76 countries.

A free software and user manual is available on the Internet-accessible Clean-Up Information Bulletin Board System (CLU-IN), call 301-589-8366, or CLU-IN.EPA.GOV. VISITT software is also available from EPA’s FTP site on the Internet (FTP.EPA.GOV). It can also be obtained from America Online, Defense Environmental Network for Information eXchange (DENIX) (Telnet: 128.174.5.510), with plans to put it on CompuServe, the Garbo FTP site and the Simtel FTP site in the near future.

For instructions on downloading VISITT from these resources, contact the Help Line at 800-245-4505 or 703-883-8448.

If you want your company to be listed as a technology vendor in the next update of VISITT 5.0 for release next summer, you must complete a vendor information form. Forms are available by mailing your request to US EPA/NCEPI, Box 42419, Cincinnati, OH 45242. Be sure to include your return address. Or, fax a request to 513-489-8695. Or, call the help line. You are eligible to promote your technology in VISITT if it is designed to remediate groundwater or nonaqueous phase liquids in situ, soil, sludge, solid-matrix waste, natural sediments and off-gas. Technologies not eligible for VISITT include incineration, aboveground wastewater or groundwater treatments, solidification, stabilization, or treatments for industrial waste.

- In August, EPA Region 5 recently notified more than 12,000 Illinois underground storage tank owners and operators that the Illinois UST Fund is no longer an acceptable financial assurance mechanism, and that they had to find another mechanism by the end of September. EPA says the Illinois fund, which has more than $30 million in unpaid claims, no longer provides effective coverage for cleanup costs and compensation of third parties for bodily injury and property damage.

- On September 7, EPA issued a rule that will ease the regulatory burden and limit the liability of lenders financially involved in properties with USTs. The rule is expected to result in expanding credit to gas station owners and operators and other small businesses that have such tanks on their property.

The new rule limits the regulatory obligations of financial institutions and others who hold security interests in properties with USTs. Secured creditors (lenders) have been reluctant to extend loans to these small businesses for fear of incurring UST cleanup liability in situations where the business goes bankrupt, and the lender takes possession of the property through foreclosure. By reducing the regulatory obligations of lenders, EPA aims to remove this potential barrier to extending loans to small businesses intending to operate USTs.

Under the rule, a lender is eligible for an exemption from all federal UST regulatory requirements both prior to and after foreclosure, if it holds an ownership interest in a UST or in a property on which the UST is located, in order to protect its security interest. A lender typically holds property as collateral as part of the loan transaction. The lender is not liable for cleanup costs from a contaminated property, provided it does not engage in petroleum production, refining, marketing, managing or operating the tank or store petroleum in the tank after foreclosure.

The rule specifies a range of activities, including foreclosure, which lenders can undertake to protect their collateral without being held responsible for compliance. Lenders are allowed to regularly monitor or investigate borrowers’ collateral, business condition and financial health. The lender may also require that the property be maintained in an environmentally sound manner. For a copy of the Federal Register notice, contact the EPA RCRA/Superfund Hotline at 800-424-9346.
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Write in 244
Avoid unnecessary remediation—
Give attenuation a chance

Save big money at petroleum release sites

By Nicholas De Rose, P.G.

Most petroleum products naturally attenuate in the environment. This is largely due to the volatility of many of the lighter distillates, including petroleum based solvents and motor fuels, and the biodegradability of most of the simpler petroleum compounds which make up motor fuels and lighter heating oils. Often, a shallow groundwater condition provides the required ingredients for biodegradation, including indigenous petroleum degrading bacteria, and oxygen as a metabolizer and electron receptor. Comprehensive characterization of the unsaturated zone and underlying shallow aquifer should determine the relationship between the plume and contaminant source. Recent experience with petroleum hydrocarbon releases from underground storage tank sites shows that completing an accurate and detailed Source Impact Zone Evaluation yields a functional characterization of the subtleties of the site as regards natural attenuation. Often, by completing an effective Source Impact Zone Evaluation and plume delineation, very little additional analysis is needed to demonstrate natural attenuation. Experience on many petroleum release sites has shown that natural attenuation can be demonstrated as the appropriate remediation by relying on basic characterization techniques. The need for complicated sampling and analytical programs is often not necessary or appropriate.

The assessment of natural attenuation requires combining fundamental hydrogeology with the analysis of the plume’s biological and geochemical dynamics.

Source impact zone evaluation
In the early days, UST site assessments consisted of limited post-closure soil sampling, often followed by the immediate installation of a groundwater monitoring system. The monitoring system was typically located immediately surrounding the former UST excavation. The detailed interaction of the excavation (Source Impact Zone) with the overall site and regional subsurface conditions was not considered. This often resulted in erroneous determination of site groundwater flow conditions and incorrect conclusions about the contamination. Furthermore, if results of these investigations indicated non-compliance, active groundwater remediation was often initiated without a complete or accurate hydrogeologic assessment, resulting in ineffective, and sometimes unnecessary remedial programs.

To some extent, this approach was justified as a cost saver for owners of large tank populations. However, anticipated long-term cost savings of this “boiler plate” approach were often gobbled up by remedial costs.

The current status of risk-based site assessment, which supports natural attenuation as the preferred remedial option, offer a more cost-effective UST management approach.

Failure to conduct a thorough and accurate Source Impact Zone Evaluation can result in:

• incomplete or incorrect hydraulic characterization of the impacts of the excavation on the site groundwater flow,
• incomplete or incorrect assessment of unsaturated zone soils, geology and flow conditions,
• incorrect interpretation of shallow groundwater flow direction and gradient by improper well design,
• incorrect interpretation of shallow groundwater flow direction and gradient by failure to consider temporal fluctuations in groundwater elevations,
• incomplete or incorrect assessment of impacts of shallow fill deposits, site construction modifications, subsurface barriers or preferential flow paths on contaminant migration pathways from the source.

From any one of these data gaps, it would not be possible to accurately assess natural attenuation as a remedial option. Limitations to the

Nicholas De Rose, P.G., is vice president of Langan Engineering and Environmental Services Inc., Doylestown, Pa. This article is based on a paper presented at the 27th Mid-Atlantic Industrial and Hazardous Waste Conference.
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assessment process include:
- not determining reliable temporal or spatial data trends from the monitoring well system,
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- not completing the plume delineation and,
- missing a release pathway from the source area.

**Natural attenuation checklist**
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The checklist considers source characterization, evaluation of the Source Impact Zone, analysis of migration pathways, natural attenuation assessment and groundwater monitoring. There are five levels of site assessment for natural attenuation:
- Level one: Source Control and Removal Verification
- Level two: Source Impact Zone Evaluation
- Level three: Contaminant Migration Analysis
- Level four: Natural Attenuation Assessment
- Level five: Groundwater Monitoring.

Level one, source control and removal verification is typically the first action to be taken at a leaking site. Removal of obvious separate phase product and grossly contaminated soils is typically accomplished during or soon after tank removal. In many cases, reliance solely upon post-closure sampling and limited groundwater monitoring may not be adequate to confirm the effectiveness of source removal. For example, at sites where USTs were situated within bedrock formations, the investigation of soil underlying the tank

Continues on page 18→
excavation may not reveal contamination or free phase product. This could lead to the conclusion that source removal has been accomplished. But, it is possible that the petroleum product may have migrated from the soils into underlying fractured bedrock. The objective of the source impact zone evaluation is to characterize the immediate environment, the tank excavation proper, and evaluate release pathways to the environment. Doing this will also confirm the effectiveness of the source removal and control activities of level one. The findings can also help characterize contaminant migration. In the case of the tank situated in bedrock, the evaluation might reveal that the excavation has created a relatively impermeable sump within the top of the bedrock. In this case, removal of all contaminated material within the excavation may be all that is required to restore the site. Open, fractured bedrock may not act as an impermeable sump, but instead may act as a permeable dry well, so the evaluation should identify the likely release pathways.

The goal of the level three, contaminant migration analysis is to establish the lateral and vertical extent of the plume and identify potential receptors. The efficiency of this step is directly affected by the accuracy of the level two evaluation.

The use of screening techniques, including non-destructive, site-wide soil gas surveys is effective in the early stages of the contaminant migration analysis. In the immediate vicinity of the source zone, the effects of hydraulic mounding, preferential release and migration pathways, and fluctuating, shallow saturated zone conditions may require detailed analysis. The installation of piezometers to aid in distinguishing between regional groundwater flow patterns in the site vicinity and localized hydraulic effects from the excavation must be considered.

Once the plume is delineated, level four, the assessment of natural attenuation is accomplished by characterizing plume conditions and assessing the risk to potential receptors. If source removal has been accomplished, accurate plume delineation is achieved, and the impacts to potential receptors eliminated, then natural attenuation should be an appropriate remedial approach.

In general, based on the calculation of travel times using groundwater flow velocities and contaminant properties, the downgradient extent of plume migration can be estimated, and the duration of the contaminant in the

---

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environment can be predicted. This information is used to assess potential impacts to identified receptors by determining the extent and duration of the plume.

Favorable conditions for natural attenuation include dissolved oxygen levels in excess of 2 ppm, and moderate hydraulic conductivities and flow gradients. Spatial trends which indicate an inverse relationship between dissolved oxygen levels and contaminant concentrations are typically indicative of active natural bioattenuation. Temporal trends of increasing dissolved oxygen levels and decreasing contaminant levels also indicate natural bioattenuation is taking place.

Plume dimensions generally are limited by aerobic biodegradation which occurs at plume fringes. Over time, this will be evident by a limit to the lateral downgradient and transverse migration of the plume. In addition benzene, toluene, ethylbenzene and xylenes migrate and degrade at varying rates, resulting in varying plume chemistry over time. Geochemical indicators of natural bioattenuation can also be evaluated by conducting sophisticated monitoring programs, and analysis of other electron acceptors, including iron, sulfate and nitrate.

Level five monitoring must account for short term and long term fluctuations in groundwater elevations at a site, variations in natural groundwater quality, the distinction of multiple contaminant plumes, and background impacts. Trends cannot be reliably established and interpreted without sufficient data points, which typically requires a period of regular, semi-annual monitoring of several well locations.

Incorporation of statistical techniques is also occasionally useful. The effectiveness of natural attenuation is demonstrated by favorable monitoring results which confirm estimates of maximum plume extent and the expected duration of the plume. These results should also demonstrate protection of any potential receptors.

For final site closure, monitoring should be proposed to confirm complete plume attenuation. The successful approach to natural attenuation relies on completing a source impact zone evaluation of the petroleum release. By conducting a proper characterization of the release and its potential impact using risk-based techniques, natural attenuation can be efficiently evaluated as a remedial approach. Confirmation of natural attenuation processes can typically be incorporated into site characterization and monitoring programs.

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Density provides a pore role model

Bulk density of soil affects remediation

By Alfred Conklin, Ph.D.

Soil density is easy to measure and is important to any remediation effort. The density of soil is actually referred to as its bulk density (BD) because it is the density of the solid and gaseous portions of the soil combined. BD is always based on the dry weight of a known volume of soil, and is related to a soil’s structure. It is measured by taking a known volume of undisturbed soil and determining its dry weight and volume. The bulk density can then be calculated. From the BD, it is possible to determine a soil’s pore space. Once this is known, steps can be taken to increase or decrease the bulk density as the remediation protocol demands.

BD is taken with a drive head, and a series of brass rings that hold the sample, as shown in figure one, next page. The tool is made so that the soil is not compacted during sampling. The weight and volume of each brass ring are measured, they then are slipped into the drive head at which point a sample can be taken.

The assembled sampler is driven into the soil. The sampler is removed and the rings pushed out of the drive head. Soil is scraped off level with the top and bottom of the ring. The sample (the ring plus the soil) is dried for 24 hours at 110°C, then weighed. The volume and weight of the ring are known, and are subtracted from the weight of the soil and ring together, leaving the weight of the soil. The results are plugged into the equation below to determine the bulk density:

\[
BD = \frac{\text{weight (g)}}{\text{volume (cm}^3\text{)}} = \frac{\text{(soil + ring weight) - (ring weight)}}{\text{volume}}
\]

Commonly, soil densities range from 1.00 to 1.70 grams per cubic centimeter. Soil scientists take 2.65 g/cm³ to be the average density of the rock from which soil is formed. Soil is always significantly less dense than rock. As strange as it might seem, it is possible to have a soil BD of less than 1. This happens in soils with high organic matter and high percentages of pores. Organic matter is usually lighter than water—the density of water is 1—and soil may have more than 50 percent pore space (see sample calculation). The air in the pore space has a density of approximately 0.1226 g/cm³. Thus, in high organic matter, high porosity soils, it is common to have a BD of less than 1.

From this, one might conclude that some soils would float. Some organic soils do tend to float when they are first wetted. This is particularly noticeable when working with such soils in the laboratory. However, soils with low BD have many pores that rapidly fill with water during a rain. Very low density air is displaced, and the resulting wet soil has a bulk density greater than 1, so soil does not float away.

One might also conclude that soil high in organic matter would be more prone to wind and water erosion than soils low in organic matter. In the natural state, soils high in organic matter generally have good structure or ped formation. In addition, such peds are water stable. Peds are usually too large to be easily moved by wind or water. Also, high organic matter soils tend to form in wet, low-lying conditions where

Alfred Conklin, Ph.D., is a professor in the agriculture department of Wilmington College, Wilmington, Ohio.
there is thick vegetation. Under these conditions, they are not subject to a great deal of erosion. When they are dried, and worked in a way that destroys structure, and are left without vegetative cover, they become highly susceptible to both water and wind erosion.

At the other end of the spectrum, some soils have BDs between 1.65 and 1.90. A soil with a BD greater than about 1.65 is considered to be compacted. This means that the pore space is decreased with a corresponding decrease in the ability of the soil to conduct air and water. This can be an advantage if an aspect of a remediation plan is to prevent the movement of pollutants or polluted water through soil. But, if soil washing is the plan, compacted soil becomes a disadvantage. Compacted soils also make bioremediation more difficult because it is difficult to keep such soils aerobic during the remediation effort.

In the field, high density layers in soils are called pans. Some are natural, some are man-made. Often, pans form as a result of traffic or plowing. Pans are easy to identify. They are difficult to penetrate with sampling tools, and roots do not grow through them. Roots stop at the top of the pan. Such soils also exhibit poor drainage, even when they are located on a high spot that would be expected to drain readily.

The percentage of pores in a soil indicate how easily extractants, air, water and pollutants move through it. Percent pore space is calculated using BD and the average rock density, also called particle density (PD), which is taken to be 2.65 g/cm³. The BD divided by the PD, times 100 gives the percent of solid space in the soil. Solid space plus the void space must equal 100 percent, so subtracting the solid space from 100 yields the void or pore space:

\[
\frac{BD}{PD} \times 100 = \text{ % Solid space} \\
100 - \text{ % Solid space} = \text{ % Void space}
\]

Continues on page 22→

The ring in the illustration has a radius of 2.7 cm and height of 3 cm. Its volume is found by the following equation:

\[ V(\text{cubic centimeters}) = \pi r^2 h \]

Where:

\[
\begin{align*}
\pi &= 3.141 \\
r &= 2.7 \text{ cm} \\
r^2 &= 7.3 \text{ cm}^2 \\
h &= 3 \text{ cm}
\end{align*}
\]

Then: The volume is \(3.141 \times 7.3 \text{ cm}^2 \times 3 \text{ cm} = 69 \text{ cm}^3\)

The weight of the drying can and ring before sampling is also needed. Then, the weight of soil in the ring after drying can be determined by subtraction.

If:

\[
\begin{align*}
\text{ring weight} &= 72.53 \text{ g} \\
\text{drying can weight} &= 32.79 \text{ g} \\
\text{wet weight of soil + ring + drying can} &= 178.56 \text{ g} \\
\text{dry weight of soil + ring + drying can} &= 176.32 \text{ g}
\end{align*}
\]

\[
\begin{align*}
\text{dry weight (ring + soil + can) minus} \\
\text{dry weight (ring + can) = dry weight of soil} \\
(176.32 \text{ g}) - (72.53 \text{ g} + 32.79 \text{ g}) = 71.00 \text{ g}
\end{align*}
\]

Thus:

\[
\begin{align*}
\text{density} &= \frac{g}{\text{cm}^3} \\
\text{density} &= \frac{71}{69} = 1.03
\end{align*}
\]

The density of this soil sample is 1.03 g/cm³. Also note that if the wet weight of soil, plus ring, plus can is known, then the % moisture at the time of sampling can be determined. Two pieces of data must be calculated:

\[
\begin{align*}
\text{(weight of wet soil + ring + can) minus} \\
\text{(weight of ring + can) = weight of water} \\
178.56 \text{ g} - (72.53 \text{ g} + 32.79 \text{ g}) = 73.24
\end{align*}
\]

\[
\begin{align*}
\text{(weight of dry soil + ring + can) minus} \\
\text{(weight of ring + can) = dry weight} \\
166.32 \text{ g} - (72.53 \text{ g} + 32.79 \text{ g}) = 71.00 \text{ g}
\end{align*}
\]

\[
\begin{align*}
\% \text{ moisture} &= \frac{(\text{wet weight} - \text{dry weight}) \times 100}{\text{dry weight}} \\
\% \text{ moisture} &= \frac{73.24 - 71.00}{71.00} \times 100 = 3.2\%
\end{align*}
\]

The percent pore space can be found using the following relationships:

\[
\begin{align*}
\% \text{ solid space} &= \frac{\text{BD}}{\text{PD}} \times 100 \\
\% \text{ solid space} &= \frac{1.03}{2.65} \times 100 = 39\% \\
100 - \% \text{ solid space} &= \text{ pore space} \\
100 - 39\% &= 61\%
\end{align*}
\]
Pore role model, from page 21

So, the smaller the BD, the more void space. The first assumption is that a soil with a high percentage of void space will have rapid air and water movement. However, the void space behavior is a little more complex than this simple calculation indicates. The complexity is due to the fact that soil pores are actually divided into micro-, meso-, or macro-pores—depending on well-defined size limits. For most environmental projects, the classification as micro- and macro- is sufficient.

Macro- and micro-pores are both important in remediation efforts. Macro-pores are large enough that water drains rapidly from them, so these are the pores that allow air movement through soils. For a soil to be aerobic, it must have an abundance of macro-pores. Macro-pores predominate in sandy soils, which explains why they drain well. Remediation processes such as washing work particularly well with soils that have nearly 100 percent macro-pores. However, for bioremediation to work efficiently, a balance of macro- and micro-pores is needed.

Macro-pores hold air, and micro-pores hold water. Because bioremediation requires both air and water, it works best in soils that have a balance between the two pore types. Macro-pores provide air movement, which keeps soils aerobic. Micro-pores hold water needed for the bioremediation process.

Pores in soil are a result of the aggregation of primary particles. Aggregation is the cementing of sand, silt and clay in such a way as to form larger, secondary particles. These aggregates are called pedds. The cementing agents are multivalent cations, such as Ca⁺⁺, organic matter and microbial gums. Keeping a high level of calcium and organic matter in soil encourages ped formation. Sod crops, such as grass and clovers also encourage the formation of pedds. Soil scientists describe a soil as having good structure or poor structure depending on whether the pedds are strong and well formed, or weak and poorly formed.

Different compounds are used to add calcium to soil, depending on its pH. If a soil is acidic, lime—Calcium Carbonate (CaCO₃) is added to increase calcium content and pH. If a soil is basic, calcium can be added as Calcium Sulfate (CaSO₄). Calcium Sulfate adds Ca⁺⁺ with little change in pH.

In situ remediation, one must work with the soil structure that is available. It is possible to apply calcium and organic matter to the surface, and plant sod crops to improve structure or ped formation. Improvement of air and water movement will be slow because the calcium and organic matter must be carried into the lower soil layers by water. This is a long term process, taking perhaps three or four years. Sod crops, grasses and legumes also help improve the structure. Such crops cause a dramatic and rapid increase in soil permeability and can be highly beneficial to remediation efforts.

In situ projects, the biggest problem is compaction of the soil. This can happen by working the soil, primarily digging, when it is either too wet or too dry. Also, repeatedly driving heavy machinery over soil destroys the structure. Even light machinery passing over the same area frequently causes compaction. The addition of calcium and organic matter when soil is being moved will help maintain and even improve structure. Keep machinery and vehicles off the soil as much as possible.

Measurement of bulk density is simple, yet provides valuable information about soil in terms of air and water movement. A low BD indicates that the soil will have good aeration and be easy to work. A high bulk density indicates that the soil will be more difficult to work, and will transmit air and water slowly.

"The percentage of pores in a soil indicate how easily extractants, air, water and pollutants move through it."
Proper backfill protects tanks

This step is more complicated than it looks, but can prevent future problems

By John Hartmann

One of the most vexing problems in a tank installation is how to specify and control backfill materials for tank and piping excavations. Millions of dollars in damage have resulted from the use of improper materials, inadequate placement and compaction of material around UST systems. Misunderstanding of the function of backfill material often results in difficulty in establishing a clear definition of acceptable material in codes, standards, recommended practices, construction documents and regulations. Heightened concern about the consequences of tank leaks has resulted in owners, contractors and system designers becoming more concerned with this aspect of tank installation.

Backfill has three functions: to isolate the tank from surrounding materials that could damage its outer shell or coating; to provide a secure foundation and support to the tank structure; and to provide a firm base for paving over the tank. Experienced system designers typically use such wording as: “backfill materials must be carefully placed, well compacted and free of debris, frozen material, rocks or boulders.”

Inadequate compaction generally results in uneven settlement (subsidence) and leads to cracking of the pavement over an excavation. It’s the same principle that causes sidewalks in residential neighborhoods to settle unevenly and crack because home builders typically use the poorly compacted soil from the excavations to backfill foundations. Construction documents may specify the degree of compaction required in terms of the desired density, as 95 percent Procter density, but field testing of tank backfill compaction is seldom done.

Placement requires moving many tons of sand, pea gravel or crushed rock from delivery trucks into the excavation without damaging or dislodging the tank. Care in placement is essential to prevent voids that adversely affect compaction and support to the tank.

Installation of larger tanks requires larger and deeper excavations, complicating backfill placement.

Increased awareness of excavating safety has resulted in larger excavations, sloping sidewalls and, in some cases, requirements for confined space entry procedures.

We have seen instances where excavating machinery was permitted to drive over tanks to place backfill, a practice that risks damage to the tank, its coating or piping. We have seen cave-ins caused by operating excavating machinery too close to the edge of the excavation. In the event of a cave-in, all the loose,...

Continues on page 24>

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caved-in material must be removed because it is not acceptable backfill and is difficult or impossible to adequately compact. A cave-in could even require reinstallation of the tank.

To overcome placement problems and help ensure the quality of the installation, some contractors use ready-mix trucks and troughs, cranes with concrete hoppers and conveyor systems normally used to transport ready-mix. Savings in time offset higher equipment costs. Regardless of the method of placement, it is essential that backfill materials be well-granulated and free-flowing to facilitate placement and compaction.

A common misconception is that surrounding a tank with dry, inert sand "insulates" the tank and piping from potentially corrosive surrounding soil. While dry sand may be inert and electrically nonconductive, tank excavations are seldom dry through the life of the tank. The backfill will be wet due to periods of high groundwater, infiltration of surface water during heavy rain, and the "bathtub effect" created when tanks are installed in porous backfill in dense clay soils. In any case, the backfill takes on the electrical and corrosive characteristics of the surrounding soil, even temporarily, when saturated. Backfill does not serve as a long-term electrical insulator.

In poor soil, peat bog, landfill, swamps and other porous soils, the backfill must be isolated to prevent it from migrating into the less compacted native soil. Similarly, when more than one type of backfill is used, the different materials must be separated. Geotextiles, or filter fabrics, permit water to pass through while resisting the migration of one material into another.

Steel, composite and fiberglass tanks all derive part of their structural integrity from the surrounding backfill. Voids or uneven compaction deprive the tanks of this necessary strength and may permit unacceptable movement. The granular characteristic of acceptable backfill permits the free flow of water, preventing the development of unequal pressures against the tank walls.

Backfill containing clay fines may provide excellent compaction, but may create other problems. Clay-laden sand absorbs water and swells in volume. If it is extremely well compacted, the result might be unacceptable, vise-like pressure against the exterior of the tank. This phenomenon is a probably the cause of the failure of several UL1746 thin-wall composite tanks. The granular nature of acceptable material eliminates this problem.

The selection of backfill materials is as essential to tank system design as the type of tank and piping to be used. Selection should be based on availability and installation costs. The installer should provide a sample of the material proposed, as well as a generic description of the material and its source. Compliance should be confirmed at the time of installation.

Definitions used in industry, recommended practices and manufacturers’ installation instructions are sometimes vague and subject to misunderstanding. Establishing a consistent terminology and defining terms could be a great asset to the industry in establishing quality assurance. Adopting definitions for acceptable backfill material terminology would help simplify specification writing and provide a basis for inspections.

The most widely used reference, Recommended Practices for Installation of Underground Liquid Storage Systems, of the Petroleum Equipment Institute, PEI/RP100-94, differentiates between backfill for steel and composite tanks, from that for fiberglass tanks.

4.3 Backfill Materials: Steel or Composite (Fiberglass-clad Steel) Tanks.

Backfill material should be clean, well-granulated, free-flowing, non-corrosive, inert material: sand, crushed rock or pea gravel. The largest particle should not be larger than 3/4 inch. It should be free of debris, rock, ice, snow, or organic material, all of which could damage the tank or its coating and adversely affect compaction.

4.5 Backfill Material for Nonmetallic Tanks.

Materials for backfilling nonmetallic tanks should be free of ice and snow; not more than 3% (by weight) should pass through a #8 sieve, and the material should conform to ASTM C-33, Paragraph 9.1 requirements. Approved materials are:

1) Pea gravel: Naturally rounded particles with a minimum diameter of 1/8 inch and a maximum size of 3/4 inch.
2) Crushed rock of gravel: Washed and free-flowing angular particles between 1/8 inch and 1/2 inch in size.

The American Petroleum Institute (API) 1615, Installation of Underground Petroleum Storage Systems, states:

10.3.2.1 Steel and Fiberglass-clad Steel Tanks.

Backfill for steel and fiberglass-clad steel tanks must be free of ice, snow, debris and organic material, which adversely affect compaction and may damage the tanks.

10.3.2.2 Fiberglass reinforced Plastic Tanks.

All backfill material should be in accordance with the manufacturer’s specifications. Such backfill is generally pea gravel or crushed stone that meets the requirements of ASTM C-33.

Xerxes Corp., a tank manufacturer in Minneapolis, Minn., permits use of either pea gravel or crushed rock in their installation instructions:

General: The material is washed and free flowing and conforms to the specification of ASTM C-33 paragraph 9.1, sizes 6 though 8. No more than 5% (by weight) of the material may pass through a #8 sieve. Pea Gravel: Mix of rounded particles—sizes between 1/8” and 3/4”. Crushed Rock: Mixed angular particles—sizes between 1/8” and 1/2”.
ASTM C-33 Standard Specification for Concrete Aggregates:

Paragraph 9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled, blast furnace slag, or crushed hydraulic cement concrete, or a combination thereof, conforming to the requirements of this specification.

Air-cooled blast furnace slag, or crushed hydraulic cement concrete, or combinations of materials are not acceptable as tank system backfill. Gravel, crushed gravel, or crushed stone may be acceptable if they meet the other criteria—properly graded, inert, free of ice and snow, and so on.

PEI discontinued use of the term washed in the 1990 edition of RP100. Washing is one method of removing fines and non-inert materials from the backfill. The committee felt that other methods could be used to achieve satisfactory results. PEI requires that all the other criteria be met, whether or not materials are washed.

Fines, defined by ASTM as materials which pass through a #200 sieve, may prevent backfill materials from being free-flowing, may not be inert, and can be compacted to the point of damaging the tank structure. Tightly compacted clay fines swell in volume when they absorb water, placing a tank in a virtual vise, and could impose unacceptable force on the sides of a tank. Materials with fines may also inhibit the free flow of groundwater and impair equalization of hydrostatic pressure. The presence of fines in backfill above the frost line allows lenses of frost to act on the surrounding pipe. The effect below the frost line is less significant if the presence of fines does not restrict the free passage of water. Materials containing more than 5 percent by weight of fines are not considered clean, and are not acceptable as backfill for tanks or piping.

Large particles, corrosive materials and debris can damage the tank's protective coating or hold ground moisture against steel tanks. This may cause differences in oxygen concentrations and can promote corrosion. Fiberglass and plastic tank shells must be cushioned from the surrounding soil and isolated from rock and other foreign material. The goal, to evenly support all parts of the tank surface, is best accomplished with pea gravel.

ASTM D2487-93, Definition of Soils Used in Construction, defines gravel as "particles of rock that will pass a 75 mm sieve and be retained on a No. 4 (4.75 mm) sieve." Coarse gravel is defined as "larger than 19 mm" and fine gravel as "smaller than 19 mm." The standard defines sand as "particles of rock that will pass a No. 4 (4.75 mm) sieve, and be retained by a No. 200 (75μm) sieve," with subdivisions for sand as follows:

- **coarse sand** passes a No. 4 (4.75 mm) sieve and is retained on a No. 10 (2.00 mm) sieve
- **medium sand** passes a No. 10 sieve and is retained on a No. 40 (425μm) sieve
- **fine sand** passes a No. 40 sieve and is retained on a No. 200 (75μm) sieve

Specifications for acceptable fines and fine sand backfill typically limit materials smaller than those which pass a #100 sieve to less than 3 percent. While the local name for acceptable sand may vary, it is often referred to as "#2 Torpedo Sand."

Native soil is taken directly from the ground without processing, grading or washing. In rare instances, native soil may be acceptable backfill, but it should be tested to assure it complies with all parts of the definition of acceptability.

The minimum acceptable size for pea gravel and crushed rock is 3.2 mm. Fines may be considered any material smaller than 3.2 mm, and are limited to less than 3 percent. Fines in crushed rock which are a product of the crushing process may be allowable up to 7 percent.

The conventional definition of pea gravel, as clean, inert, naturally rounded particles between 3.2 mm and 19 mm, and crushed stone, as clean, inert angular rock particles between 3.2 mm and 12.7 mm, fit neatly into the framework of the ASTM standard.

Some words could be dropped from the present definitions. For example, "non-corrosive" and "inert" have similar meanings. "Washing" is a process to remove fines to make material clean, so "washed" could be eliminated from the definitions. Material which meets the size limits will be, by definition, free flowing. Banning rocks is unnecessary, since they are unacceptable because they exceed the maximum size.

To help ensure an installation that will last for the life of a tank and pipe system, the proper material must be specified and delivered to the site, and proper installation procedures must be followed. I

Write in 827 for more information
Bubbles tattle on leaks
Mass measurement detects small leaks in ASTs

By Jimmy Wolford

Detection of leaks in large aboveground storage tanks (ASTs) is technically challenging. Using the EPA threshold criteria of .38 liters per hour in a 38,000 liter underground tank, the threshold would equate to a 127 liter per hour detection level in a 12,700,000 liter tank. Given the limited number of systems capable of meeting the EPA underground threshold of .38 liters, the reality of detecting leaks in aboveground tanks at a full magnitude below, (less than 4 liters per hour), in an exposed environment must be seriously considered.

There are five major applications for AST detection systems:
1. Use of accurate leak detection qualification methods to determine the existence and quantify the size of a suspected leak. Typically these tanks come under suspicion because of inventory inconsistencies, noted results of manual tank sticking or presence of leaked product at or near the surface.
2. Use of leak detection to classify existing tanks with no known leak history for future repair. This enables the operator to set priorities for bottom replacement, and double bottom installation projects.
3. After any repair projects, which may require a hydrostatic test or leak detection test to document the tank’s containment integrity.
4. Leak detection investigation to protect the environment, avoid litigation, preempt regulation, reduce liabilities and maintain control of product inventory.
5. Situations where regulations or company policy dictate leak detection testing.

Mass measurement technology offers proven performance in detecting small leaks in ASTs. One provider of such a system is Mass Technology Corp., Blue Bell, Pa.

Practical application of mass measurement involves lowering a bubbler unit through the gauge hatch to the bottom of the tank. A differential reference is placed just above the liquid surface. A low pressure, inert gas is conveyed to the bubbler unit at a precisely controlled rate to generate a steady stream of bubbles at the bottom of the tank, which corresponds to the differential pressure as a result of the fluid mass. An additional tube is attached which eliminates the flowing friction and subsequent back-pressure effects in the differential pressure transducer as a result of this friction. The flow rate is controlled by a regulator, allowing concentric bubbles to be transmitted to and released at the tank bottom. Pressure is measured by a micro-sensitive differential pressure transducer, recorded on a real time basis, and data are analyzed to calculate any changes in the mass of fluid in the tank to determine if there is a loss. See figure one.

The transducer used by Mass Technology is capable of pressure measurement with an error of less

<table>
<thead>
<tr>
<th>Threshold liters/hour</th>
<th>Probability of Detection %</th>
<th>Probability of False Alarm %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.33L</td>
<td>95%</td>
<td>5%</td>
</tr>
<tr>
<td>5.11L</td>
<td>99%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Figure two: Results for typical 36 hour test time

Jimmy Wolford is vice president of engineering and operations for Mass Technology Corp., Blue Bell, Pa.
than ± 0.00254 of a millimeter of water column on a real time basis. This accuracy enables the company to detect leaks at a threshold of less than 3.4 liters per hour, with a probability of detection of 95 percent in a 16,000,000 liter tank.

Mass Technology submitted their system to a third party evaluation. The evaluation was performed on a 12,768,000 liter tank, 35 meters in diameter, holding 8.5 meters of 49.1 API gravity crude oil. The tank featured an internal floating roof with and external fixed roof. A peristaltic pump connected to a tank port pulled a controlled volume from the tank at a rate fixed by the evaluator. The leak detection system operator was blind to the controlled leak rate. Sixteen tests were run in a variety of weather conditions. Since EPA currently has no protocol for evaluating AST leak detection systems, an adaptation of the EPA protocol for evaluating UST leak detection systems was used. The results shown in figure two are typical for a 40 hour test time.

Direct measurement of the mass of fluid in the tank eliminates errors that can result from real world variations, such as the consistency of the soil acting as the tank foundation, temperature stratification of product, extraneous noise sources, thermal expansion of tank contents, water table level, previous soil contamination and tank shell dynamics.

Vertical and horizontal temperature stratification in the liquid contents throughout a tank can cause accuracy problems for a volumetric method to detect leaks. Unknown tank bottom to soil strata interfaces can compromise the accuracy of acoustic emissions detection systems. Use of soil vapor monitoring to detect leaks is subject to varying vapor diffusion patterns for varying products, as well as variations in soils and groundwater. The precision of flow measurements in and out of the tank, fluid temperatures and fluid properties affect the accuracy of volume measurements in inventory reconciliation systems.

A mass measurement system overcomes the effects related to tank shell variations through data collection and correction techniques. Data are collected round the clock, with leak rate calculations taken only at night to eliminate the effect of the sun’s radiant energy. Night data are corrected for atmospheric conditions and temperature variations in the tank shell. These measures allow the system routinely to achieve the stated accuracy in real world conditions. Typically, a determination of the tank’s integrity can be made in 40 to 72 hours of testing.

Mass Technology Corp. is cooperating with the American Petroleum Institute, the EPA and the U.S. Department of Energy to create a facility and conditions to evaluate leak detection systems in real world applications. The company is contributing engineering expertise to assist in facility design and in the development of testing criteria and protocols. The company is also evaluating ways to apply mass measurement techniques to ultra large underground tanks.

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Write in 001
Soil and Groundwater Cleanup October 1995 27
Secondary containment is a primary safety measure

Aboveground tank protection technology advances

By Paul McWhorter and Mary Planek

Aboveground storage tanks have undergone an evolution of safety options since the early 1980s. The latest advances include secondary containment, fire protection and protection from physical damage.

Historically, secondary containment, insulation and physical protection have been optional, but events such as the Exxon Valdez spill, the Monongahela River spill of 3.8 million liters of petroleum, as well as such natural disasters as hurricanes and earthquakes have heightened awareness of the need for safety measures. Regulators now anticipate and specify such measures as the last barrier to prevent a primary tank from leaking directly into the environment or into the path of a fire. As a result, regulatory authorities allow two alternatives to deal with leak concerns for the storage of flammable and combustible liquids: (a) single-stage, primary tank only containers which must have such accessories as sophisticated alarms, placed in guarded locales within a dike, and inspected on a regular schedule, and (b) secondary containment, which affords regulators the opportunity to deal with a leak by noting that the primary vessel is leak-tight, or is captured entirely within a secondary containment chamber.

Regulatory authorities typically recognize secondary containment as a safer method to store hazardous materials, and tend to subject such systems to fewer environmental and fire code inspections and allow less expensive leak detection methods, such as manual dipsticks within the interstitial space. The owner or operator of an AST system must decide whether to install a metallic secondary container or a nonmetallic chamber system.

Traditional methods for metallic secondary containment offer a double-wall steel vessel able to capture 100 percent of the primary vessel's content with a maximum capacity of 45,600 liters per National Fire Protection Association rules, and 38,000 liters per Uniform Fire Code. These methods for secondary containment involve different levels of effectiveness and expense. The double wall steel tank, also known as a secondary containment tank, comes in many configurations: a primary steel tank encased in a thermal insulation material placed inside a second steel tank; a primary steel tank, surrounded with concrete inside a second steel tank; or a primary steel tank within a second steel tank surrounded by a polyethylene liner with the entire system encased in concrete.

While providing a rigid construction, and therefore a conveniently pressure testable system, the downside of the metallic secondary containment option includes:
- it can be up to three times more costly than single-wall or nonmetallic secondary containment;
- such a system is not resistant to multi-directional corrosion, except for the option of using a poly liner...
between the steel tank and the concrete;
• there is a hidden cost in cathodic protection to
  insure that the steel does not oxidize; and
• damage or any breach to the exposed metallic sec-
  ondary containment could invalidate the integrity of the
  entire assembly which could generate expensive repairs.

There are two types of leak-tight dike systems, earthen
dikes, which may allow leaking product to seep into the
ecosystem, and concrete dikes, which are more effective,
but also more expensive. While concrete dikes are more
effective than earthen dikes, they are still porous to
some less viscous materials. And, over time, concrete
can crack, causing channels of leakage in the dike to
develop. Some fire officials have experienced leaks of
flammable and combustible liquids being retained in the
dike, exposed to an ignition source, and creating a pool
fire.

One variation is to situate the steel tank within a
retaining structure that has integral concrete walls, floor
and roof which are lined with high density polyethy-
lene. Such an enclosed system currently affords the best
nonmetallic method to insure that a leak is contained
until authorities can determine how to dispose of the
hazardous material. Another benefit of this closed sys-
tem is that rainwater and snow do not accumulate with-
in the dike, creating a freeze/thaw hazard.

Another nonmetallic alternative is fiberglass tanks.
Since fiberglass is inherently non-corrosive, it can serve
both as a barrier to corrosion on an inner steel tank, as
well as a primary and secondary containment vessel
within a vault. However, fiberglass is nearly as expen-
sive as steel, and must be enclosed in concrete or some
other material to withstand ultraviolet damage, as well
as exposure to fire. Fiberglass technology is presently
being evaluated by the national fire codes for limited
aboveground use. The obstacle is the stipulation within
the fire codes that prevents the use of a combustible
material in the construction of an AST, and there is con-
cern regarding the structural stability and integrity of an
underground storage tank being used in an above-
ground application. UL Standard 1316, “Glass-Fiber-
Reinforced Plastic Underground Storage Tanks for
Petroleum Products, Alcohols and Alcohol-Gasoline
Mixtures,” is being used to determine the acceptability
of the fiberglass material to contain combustible liquids.

Use of the poly liner within a concrete shell provides a
dual function by isolating the corrosive concrete from
the primary steel tank, as well as providing the barrier
necessary to protect the environment from a leak. The
use of enclosed forms of nonmetallic secondary contain-
ment, although more recent in development than metal-
lic technology, can offer the same level of safety at a
reduced cost.

To determine the overall safety of each of these tech-
nologies, third-party investigations have been conduct-

Continues on page 50→

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Write in 144
West coast plant focuses on safety

L.A. area plant set for large capacity

For years, Los Angeles area producers of petroleum contaminated soil had no soil recycling facility in the county. That changed last summer when American Remedial Technologies (ART) opened for business in the city of Lynwood, Calif., less than 10 kilometers from L.A.

The 13,500 square meter indoor facility has the capacity to process more than 180,000 metric tons of soil annually, and processed nearly 11,000 metric tons in its first month of operation.

According to Enrique Tomeu, company president and CEO, the ART facility, with the new Super 7 plant from Tarmac Environmental Co., Kansas City, Mo., was conceived with the highest standards for safety. “We wanted to establish a facility that would become the model for California and the rest of the country,” Tomeu says. “As the largest, most dynamic and most visible market on the West Coast, Los Angeles was the obvious location choice. This initial facility will serve as our own standard to create two more facilities elsewhere in the country within the next year. We have gone way beyond anything that has come before in terms of safety and quality assurance.”

The facility’s EPA-approved thermal desorption and enhanced bioremediation system begins with an operation platform consisting of 150 millimeter thick, nonporous, steel-reinforced concrete. Beneath this platform is a leachate prevention system made from two Permalon X-210 liners separated from each other and from the platform by 50 millimeter layers of sand.

The soil is heated in a rotary kiln to evaporate the hydrocarbons. Vapors are destroyed in a thermal
oxidizer with 99 percent destruction efficiency. The oxidized gases then pass through a cooling air-to-air heat exchanger, a baghouse and a wet scrubber for particulate matter and sulfur oxides emissions control before they are exhausted. Fresh water is added to the treated soil as it passes through a soil conditioner unit to enable its reuse as construction fill or planting soil.

For added safety, the facility also has a vapor monitoring and detection system installed between the Permalon liners, a series of fume hoods for fugitive emissions and a dust-suppressing mist system.

Tomeu’s 15 years experience in the environmental and construction industries include ownership and operation of American Asphalt Co., an asphalt manufacturing and road construction firm, and Siboney Contracting Co., a contract hauling business, both located in Florida. Siboney was recognized by the Army Corps of Engineers for outstanding work as the major subcontractor removing debris generated by Hurricane Andrew three years ago.

Brett MacDonald, executive vice president of ART, has been responsible for the treatment of more than 360,000 metric tons of petroleum hydrocarbon contaminated soil in the Port of Los Angeles.

The city of Lynwood welcomes the new jobs the plant has brought in, as well as access to as much clean soil as they need for municipal development. In the near future, the company plans to offer a soil stabilization process to treat inorganic contaminants such as lead, and a mobile thermal system to treat chlorinated and non-chlorinated hydrocarbon contaminated soils in outlying areas.

Write in 830 for more information
Fast track to non-detect

Surface Technology Co., Vista, Calif., says their Cleanup Pentanonic product can be used in situ to remediate hydrocarbon contamination at service stations, storage facilities and other industrial sites. Once the depth of contamination is determined, holes are drilled directly on the surface on 150 mm centers to the lowest point of contamination. A 150 to 250 millimeter berm is made, using either non-contaminated topsoil from the site, or plastic sheeting. The berm holds the process water and Pentanonic mixture in place to prevent runoff. Surface Technology recommends a solution of 209 liters of Pentanonic mixture for each 910 metric tons of soil to be processed in cases where the level of TPH does not exceed 5,000 ppm.

The mixture is applied to the surface with a garden hose or small pump unit. After 48 hours, lab analysis should test soils and process water as Non-Detect for hydrocarbons. Cost of the Cleanup Pentanonic is about $2 per metric ton of treated soil.

The product does not add any bacterial agent, but works in conjunction with naturally occurring bacteria present on the site. The end product is CO₂ and H₂O.

For areas with medium to high clay concentrations, the company offers an aqueous solution that breaks down the electrical bond in clay, to allow for the penetration of water which mechanically forces the disassociation of clay particles. The product, X-Clay, also contains trace elements and nutrients to stimulate naturally occurring bacterial action from dormant microorganisms present in the contaminated soil.

When used in conjunction with Cleanup Pentanonic, 19 liters of X-Clay is required for each 3,800 liters of water. Boreholes are drilled to the lowest level of contamination. Both products are injected into the boreholes. Random measurements should be taken every 24 hours to confirm results of the remediation.

In aboveground applications, use of the products eliminates problems of fines fouling equipment, says the company.

For more information please call John Stone at: 800 695-7771

Write in 308

Write in 831 for more information
Sensor detects tiniest leaks

EPA sources indicate that vapors can travel up to 50 times faster through soil than liquid. That is why vapor monitoring can be an effective leak detection technique for underground storage tank sites.

One company, FDR Services, Lakewood, Colo., has developed a sensitive gasoline leak detection system, GasPakTM that can detect fuel vapors as minute as one ppm in soil. The system uses a small hydrocarbon sensor suspended in a sampling well, according to Bill Stroman, president of the company. To users, this level of sensitivity translates to rapid detection of even tiny leaks— as small as a few teaspoons per hour.

James Rakers, engineering supervisor with the state’s Department of Labor and Employment, says GasPak meets state and federal monitoring requirements. Monthly monitoring also meets the 1998 EPA mandate for monthly leak detection compliance.

“The Texas Water Commission accepts this instead of tank tightness testing,” says Al Lyons, president of Lyons Gulf Service Inc., in Dallas. The system also helps Lyons keep responsible parties responsible. “When I bought this station in 1992, it had contaminated soil. I needed the backup and paperwork to show that we haven’t done additional damage,” he says.

The GasPak system helps Lyons prove this, because it can differentiate between old and new leaks, providing precise diagnosis.

Stephen Martin, vice president of Martin Eagle Oil Co., Denton, Texas, likes the fact that monthly samples are collected and analyzed by Fayette Environmental Services Inc., Fayette, Mo., so that no burden is placed on the tank owner. “It’s handled by someone else. I don’t have to use my people. They repeat the test every month, and you don’t concern yourself with it.”

The system was developed by Rhys Thomas, Ph.D., chief analytical chemist for Fayette Environmental Services. “The fundamental idea took 10 to 15 minutes, working out details took a couple of days. The simplest ideas work best. And, it’s cheap. You can do the same thing with more expensive equipment, essentially transporting the lab to the site.”

The system can also be calibrated other substances, such as natural gas. It has scored 99 percent accuracy and dependability in independent tests that surpass EPA stringency, by two separate labs.

Write in 832 for more information

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Write in 255

October 1995 Soils & Groundwater Cleanup 33
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“Aerial photographs, an ASTM E 1527-94 accepted standard historical source, are an increasingly popular tool to help document past land use for an environmental site assessment,” says Peter Cashman, chairman of Environmental Data Resources Inc., a Southport, Conn.-based firm that provides nationwide map-based reports that indicate the potential for environmental contamination at a target property and its adjoining sites.

EDR just bought National Aerial Resources to complement its environmental information products line to enhance site assessments. According to Robert Shuey, National Aerial’s general manager, NAR management will remain in their current positions. “We lack the resources to market ourselves to a large group of people. Now, we’ll be able to serve a large client base, thanks to EDR,” he says. “Our combined customers will have access to EDR’s top-of-the-line reports, as well as NAR’s extensive aerial photo coverage.”

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Write in 062
Secondary containment, from page 29

ed by such laboratories as Underwriter’s Laboratories Inc. (UL), Southwest Research Institute (SWRI), and Omega Point Laboratories (OPL). Listing by these labs indicates that the system has been strenuously tested, and can be expected to perform specific objectives for containing hazardous material. According to Alan Flandez, P.E., of UL’s Santa Clara, Calif. office, UL tries to adopt informed performance requirements, rather than construction requirements, in order to accommodate innovative advances such as a nonmetallic liner as a secondary containment option, or a concrete shell for physical protection. If the material satisfies performance requirements, it should be listed. Further requirements may be needed to evaluate different materials or innovative constructions.


Technological advances in AST designs have occurred which incorporate parts of various national environmental codes, fire codes as well as third party standards and test results. The highest level of safety available in an AST presently carries the UL 2085 listing, “Insulated Secondary Containment Aboveground Tank for Flammable Liquid, Protected Type, Vehicle Impact Resistant, Projectile Resistant,” or the SWRI 93-01 listing, “Two-Hour Rated Insulated and Protected Aboveground Storage Tank for Flammable and Combustible Liquids, Projectile Penetration and Heavy Vehicle Impact.” The protected tank requirements are the end result of the iterative process the AST industry has undergone with the IFCI. Fire protection authorities, code consultants, tank manufacturers and tank users have identified the criteria necessary to achieve the highest level of assurance of safety and resistance to catastrophic events. These requirements include secondary containment, either metallic or nonmetallic, fire protection, and protection from physical damage.

The fire protection or insulation portion of the designation represents the tank’s ability to withstand the heat exposure for a prolonged period of time before the material in the tank reaches auto-ignition temperature of 204°C—followed immediately by a hose stream test to insure the integrity of the tank after exposure to fire conditions; and a leak test to show complete primary containment after exposure to fire.

The protection from physical damage portion of the designation includes completion of additional tests: vehicle impact resistance, ballistic and projectile protection. All these tests are designed to provide users and emergency personnel with enough data to predict how a particular tank design will hold up in a worst case scenario.

Protected aboveground storage tanks have endured Hurricane Andrew, the 1989 Loma Prieta earthquake, an impact from a C-130 aircraft, collapse of a 135 metric ton silo onto the tank, and numerous attempts at ballistic vandalism without a system failure, whether using the nonmetallic or metallic secondary containment option.

According to Rick Thornberry, P.E., of The Code Consortium Inc., the future of aboveground fuel storage tanks includes fire code changes to allow for reduced setbacks and separation distances for protected tanks, as compared to fire-resistant tanks, which have less fire protection and lack physical protection. Protected tanks will also be recognized for aboveground storage and dispensing uses other than fueling motor vehicles—such as general storage of flammable and combustible liquids, and liquid hazardous materials storage.

There is no substitute for installing a high quality tank, conducting scheduled inspections of sites, testing the tank content to confirm that it is maintaining its stability, and training employees in the use and care of the containers which house these materials. Mother Nature’s willingness to allow corrosion, severe climates and natural disasters to occur on a regular basis, mandate that those who store hazardous materials must always be on guard to protect the containers and their contents.

Write in 829 for more information
Firms combine soil washing technology

Delta-Omega Technologies Inc., Lafayette, La., is purchasing Tuboscope Vetco Environmental Services of Houston, Texas. The Tuboscope technology is a soil washing system that can remediate petroleum wastes, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, mixed wastes and low level radioactive materials.

The Tuboscope system uses a countercurrent soil washing auger design which pushes contaminated soil toward the left side of a covered metal trough, then directs wash water containing dispersed contaminants down the right side of the auger and out for further treatment. (See Soils, November 1994, page 6.)

Delta-Omega plans to combine their expertise in chemicals and cleaning technology with the Tuboscope systems to offer a comprehensive soil washing package.

Delta-Omega specializes in cleaning fine clays and silts which are the most difficult-to-clean components of most contaminated soils.

Delta-Omega develops, manufactures and markets environmentally safe specialty chemicals for use in soil remediation, cleaning and fire suppression applications. Their products replace many hazardous, flammable, toxic and ozone depleting chemicals in specific applications for commercial, military and industrial users, according to Donald Carlin, president of Delta-Omega.

Write in 863 for more information

Plant travels to Superfund site

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The Environmental Show to Remember
Bioslurping enhances free product recovery

Technique combines bioventing with vacuum enhancement

By Jack Parker

Due to the regulatory emphasis on free product removal before addressing residual product, hydrocarbon spill site remediation is generally a phased operation. When free product exists at the water table, it is initially recovered by bailing or skimming, or by pumping of water and product to increase the hydraulic gradient. After mobile product is recovered, residual product is addressed by soil vacuum extraction, bioventing or other technology. Although free product recovery rarely exceeds 25 percent of the total hydrocarbon volume, the phased approach in applying remedial technologies is widely used in the industry.

There are various models available for evaluating and designing hydrocarbon remediation systems. Numerical models such as ARMOS or analytical models such as SPILLCAD may be used to design free product recovery systems. The model VENTING is applicable for soil vacuum extraction systems. No models have been documented to consider variants of soil vacuum extraction, such as bioventing or bioslurping. Bioventing involves extraction or injection of air in the subsurface to overcome oxygen limitations to biodegradation. This generally entails much lower flow rates than are used in more conventional soil vapor extraction systems.

Vacuum-enhanced free product recovery is an adaptation of the practice of vacuum dewatering used in construction projects. Applying a vacuum to a well increases the piezometric gradient for water and hydrocarbon without increasing the physical drawdown at the well or the plane of zero capillary pressure in the soil, as in figure one, page 54. The higher gradient increases water and product recovery rates, while the reduced physical drawdown minimizes product smearing. Potentially higher asymptotic recovery of free product is therefore possible, since residual product is minimized in the smear zone.

In addition to the effect on free product recovery, vacuum wells remove volatile constituents in captured soil vapors, and dissolved constituents in recovered groundwater. Soil aeration is also increased, which concurrently enhances biodecay if microbial activity is oxygen-limited. Vacuum-enhanced recovery represents a shift away from phased applications of technology to a more efficient approach that can remove free product while addressing residual product remediation.

Bioslurping is a technique that balances free product recovery while enhancing biodegradation. It essentially combines bioventing technology with vacuum enhanced free product recovery. In bioslurping, air and liquid are pumped from a well that is screened above and below a suction tube inlet. The suction tube is connected to a vacuum pump as well as to air-liquid and oil-water separators and to air and water treatment or discharge systems.

The assessment and design of bioslurping remediation could be conducted using numerical models that can simulate multiphase flow and transport. However, such models are too numerically intensive for routine use.

A practical modeling approach uses three submodels: 1) a steady-state, air-water flow model, 2) a model to estimate recoverable free product and time to reach asymptotic free product recovery, and 3) a model to estimate mass removal and change in composition over time due to vapor recovery and biodecay.

The flow model considers areal flow of air and water with vertical air leakage from the ground surface to estimate water and air pumping rates and local gradients for various well configurations, wellhead vacuums and suction tube elevations (well bore water level). The model ARMOS/Air is run in a transient mode until steady-state is reached. At locations with free oil, the water piezometric head is corrected to account for the presence of free product.

ARMOS/Air considers the effects of vacuum on soil capillary pressure distributions to estimate the asymptotic free product recovery. The method

Continues on page 54→
Vacuum Enhanced Product Recovery

Figure one: How vacuum enhanced product recovery works—Z_{ac} and Z_{ow} represent air-water and oil-water levels in a static well. \( \psi_0 \) and \( \psi_w \) represent oil and water piezometric levels, which control flow. \( P_o \) is the air vacuum.

Bioslurping, from page 53

involves computing the residual oil in the smear zone, based on the flow model solution and summing the residual to estimate nonrecoverable and recoverable oil volume. The estimate of recoverable volume determined by this method is valid only if the imposed pumping results in capture of the phase separated hydrocarbon plume—that is, groundwater flow vectors on the plume perimeter are inward. To estimate the time to reach asymptotic free product recovery, oil streamlines and travel times are computed from the steady-state flow model results. The recovery time is assumed to correspond to the longest travel time along any streamline that starts at the plume perimeter and ends at a well.

The final submodel solves space-averaged multispecies mass balance equations to compute species mass reductions due to vapor extraction and biodecay. BIOVENTING is a vapor recovery model with modifications to consider zero-order biodecay. This method considers equilibrium partitioning of multiple species among the air, water, liquid hydrocarbon and solid phases over time. An efficiency factor accounts for nonequilibrium phase partitioning effects. The maximum total biodecay rate, which may be determined from an in situ respiration test, is allocated among individual species in proportion to their current equilibrium dissolved phase concentrations. During the period in which free product recovery occurs concurrently with vapor extraction and bioventing, species mass is updated at each time step to account for free product recovery, assuming an exponentially decreasing recovery rate.

In an example problem to evaluate the effects of wellhead vacuum and wellbore water level in a bioslurping well, gasoline has spilled in a fine, sandy soil with saturated hydraulic conductivity of 2 meters per day. Seven pumping configurations are considered with physical drawdowns (drawdown in the well fluid level) of zero, 0.6 meters or 1.2 meters, and a well bore vacuum of zero, 0.6 meters or 1.2 meters of water. The corresponding total water piezometric drawdown, which is equal to the sum of the physical drawdowns plus the well bore vacuum ranges from 0.6 meters to 1.8 meters. Computed water and air pumping rates for the various cases are summarized in figure two, page 55. The water pumping rate is controlled by the total piezometric head, and the air flow rate is controlled by the air pressure.

From computed drawdown and initial well product thickness, the asymptotic recoverable product volume, unsaturated residual product volumes and time to reach asymptotic free product recovery are computed taking into account the effect of vacuum on the capillary pressure distribution.

Finally, component mass recovery over time is computed using the multicomponent mass balance model. Product composition typical of weathered gasoline is used. A venting efficiency of 20 percent is assumed to have been determined from a pilot vacuum test. A maximum biodecay rate of 5 milligrams of contaminant per kilogram of soil per day is assumed to have been determined from an in situ respiration test. Termination of system operation is assumed to occur when the dissolved concentration of benzene in equilibrium with the separate phase hydrocarbon drops below 1 \( \mu g/L \). This is a conservative value for the unsaturated zone, but it does not take into consideration possible continued dissolution of residual hydrocarbon in the saturated zone. The model assumes that the estimated final unsaturated
<table>
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<th>$\Delta H$ (m)</th>
<th>$Q_w$ (lpm)</th>
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Figure two: Wellhead vacuum ($P_a$), wellbore water level drawdown ($\Delta Z$), total water piezometric drawdown ($\Delta H$), water pumping rate ($Q_w$) and air pumping rate ($Q_a$) for selected cases.

zone residual product and recoverable free product volumes are susceptible to remediation by bioslurping.

Cases involving concurrent water and air pumping (all cases except 1 and 4) are assumed to recover free product as long as it exists while simultaneously removing mass due to vapor recovery and biodecay. In cases 1 and 4, free product recovery systems are assumed to operate until asymptotic recovery is achieved. For case 1, asymptotic product recovery was predicted in 750 days, after which a vacuum of 0.6 meters was applied while maintaining the same water level drawdown as in case 2. This system will be referred to as case 1/2. For case 4, product recovery was also followed by bioventing with a 0.6 m vacuum and the same water level as in case 5. This system will be referred to as case 4/5. Note that for cases 1/2 and 4/5, the water pumping rate increased by about 11 liters per minute when the vacuum was applied to maintain the water level in the well.

The times to reach the shutdown criteria of less than 1 μg/L dissolved benzene concentration in the unsaturated zone, as computed by the model, are summarized in figure three, page 56. Also tabulated are total water and air pumped over the durations of the remedial system operation. The conventional systems involving serial application of product recovery and bioventing technologies are predicted to take two to three times longer than concurrent vapor enhanced recovery/venting systems—

Continues on page 56→

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case 6, bioslurping, and case 1/2, serial recovery is shown in figure four, below. The slower stepwise attainment of the stopping criterion for the serial product recovery / vapor extraction system is evident. The predicted total water pumping ranges from 50 million liters for case 4/5, which has the highest piezometric drawdown of 1.8 meters and the longest recovery time, to only 7.2 million liters for case 6, which has the lowest piezometric drawdown and the shortest recovery time. Total air pumping varies over a much narrower range, with a minimum value of 459,000 cubic meters for case 6.

The results suggest that bioslurping may allow recovery times to be cut substantially compared with conventional systems that involve serial application of free product recovery and vapor extraction technologies. Furthermore, the total water volume pumped, hence water treatment costs, may be substantially less with bioslurping than with conventional serial technology applications.

Residual product in the saturated zone is not addressed through bioslurping, or any of the other technologies discussed in this article. The highest saturated zone residual product volume was predicted to occur in case 6, which otherwise appeared to be the most cost effective option. Analyses of natural attenuation in groundwater may be undertaken using models such as BIOTRANS to assess the impact of saturated zone residual product and determine if other technologies should be considered to address this problem.

Figure three: Summary of time to reach 1 μg/L aqueous benzene concentration in soil, total water pumped and total air pumped.

Bioslurping. The shortest remediation time is predicted for case 6, which imposes a vacuum of only 0.5 meters and uses a water pumping rate just sufficient to maintain the water at the well at the initial static level. This minimizes smearing of product in the unsaturated zone.

A comparison of predicted mass recovery vs. time for

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Figure 4: Predicted mass removal from soil vs. time due to product recovery, vapor extraction and/or biodecay for a bioventing system (case 6) and for serial application of product recovery and bioventing technologies (case 1/2).

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**Meyer blower power paks wear many hats**

Meyer Blower Power Paks, from Wm. W. Meyer & Sons, Skokie, Ill., are available as either a pressure blower with up to 15 PSI or a vacuum blower with 16” Hg. All packages are assembled with premium brand motors and silencers, filters, controls and accessories, and are pre-piped for immediate installation. Units are suitable for soil remediation applications, as well as for pneumatic conveying, wastewater treatment, vacuum hold-down positioning, combustion and gas boosting.  

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**Andersen units fry wastes**

Skid-mounted, pre-wired, pre-piped and fully instrumented incinerator and scrubbing systems are available from Andersen 2000, Peachtree City, Ga., for medical, hazardous and municipal wastes. Units can continuously process up to 2,350 kilograms of waste, says the company. Systems are guaranteed to remove up to 99.5 percent of acid gas emissions and outlet particulate as low as 0.01 gr/sdcf. Systems are available with optional natural gas fired reheater for plume supression from stack.  

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**Solinst makes a point**

Solinst Canada Ltd., Georgetown, Ontario, model 660 drive-point profiler offers multiple discrete zone sampling in a single drive. Downward drag is avoided while driving between sampling zones by flushing the 660 with deionized water, says the company. Designed with one distinct level of screened inlet holes, the drive offers contaminant vs. depth profiling and detailed plume delineation. A grouting tip is available as an option. This profiler is an addition to Solinst's 600 series, drive-point piezometer line.  

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Global expands vapor treatment line

Global Technologies Inc., Milwaukee, Wis., introduces the Model 1 Remed-Cat to satisfy demand for a small oxidizer capable of handling between 100 and 200 scfm of VOC-laden air from vapor extraction and groundwater treatment systems. The unit is a vapor treatment module that provides destruction efficiency of 97 percent or higher using catalytic oxidation in a square meter footprint. A number of options are available, says the company.

QED offers system in a building

QED Treatment Equipment™ of Ann Arbor, Mich., offers UpTime™ certified treatment systems in a variety of structures: enclosed building, open-air or trailer-mounted. Process elements include cleanup pumps, oil/water separators, removable-tray air strippers, vapor extraction, air sparging, carbon systems—plus booster blowers, transfer pumps and other accessories, says the company.

Sparkler filter polishes wastewater

Sparkler Filters Inc., Conroe, Texas, offers the MCRO line of filters for wastewater treatment where suspended solids are very low, sometimes because liquid already has passed through a filter process. The Sparkler MCRO vertical plate polishing filter has up to 216 square meters of filter area with tank diameters up to 1.8 meters. MCRO filters can be installed in parallel with the option of multiple filters for high volume polishing applications. Cake discharge is automatic, and enclosed dry discharge systems are available.
Foxboro sniffs it out
The Foxboro Co., East Bridgewater, Mass., announces the addition of a precision light measurement systems line of open path IR flammable gas detectors to its product line. Models 4001 and 4001 are capable of line-of-sight gas detection up to 109 meters, to protect chemical and petroleum plants from hazardous flammable gas leaks, says the company. Model 4003 is designed for use in ducts and turbine units. Write in 871 for more information.

Delumper Twin chews it up
The Delumper Twin™ from Franklin Miller Inc., Livingston, N.J., has two counter-rotating parallel shafts with sharp-edge teeth to crack dry, caked feed with pick-like action, says the company. The individually interchangeable teeth rotate through a heavy bar grating with a low friction design. Flanges are provided for easy connection, says the company. Write in 872 for more information.

Eclipse burns it up
Eclipse Combustion Inc., Rockford, Ill., releases the Minnox Gas Burner System, a direct-fired gas burner guaranteed to emit less than 20 ppm NOx and less than 50 ppm CO, as corrected to 3% O2, says the company. In straight or H-shape configurations, the burner is suitable for any industrially available gas with turn-down ratio of 10:1 and single burner range to 7000 kW. Write in 873 for more information.

Work of ART
ART’s Manufacturing & Supply Inc., American Falls, Idaho, introduces the new Power Probe 9600 for deep probing with over 16,000 kg of pullup force for easy tool removal, says the company. The 9600 can collect 36 X 1200 mm core samples, and AMS has developed a variety of new tools to work with the probe. Write in 874 for more information.

Gast combines electronics with pneumatics
Gast Manufacturing Corp., Benton Harbor, Mich., says their new Smart Air™ technology uses electronic sensing and control to enhance the performance of air pressure and vacuum devices, and expand their range of applications by combining electronics and pneumatics. An example is the development of various controls that provide greater precision and more constant air pressure or vacuum. According to the company, the underlying objective of Smart Air is to provide pneumatic solutions to respond to design challenges for Gast’s manufacturing customers. An electronically controlled solenoid valve concept allows compressors or vacuum pumps to restart efficiently under load. A monitoring and control system detects subtle changes in system conditions and compensates for them. Write in 875 for more information.
Software roundup

Christmas is coming—make your wish list!

FastRegs software offers quick reference searches

FastRegs 4.0 software from ACHIEVE! Technology Inc., Amherst, N.H., is a regulations management program that allows users to insert their company-specific policies into the database. The software allows users to search and print state and federal government regulations. Also available is a FastRegs Compliance Library with Code of Federal Regulations (CFR) text and supporting documentation, and state-specific regulations. Users can add company-specific manuals and documents to the program for the purposes of company compliance efforts and audit processes. Offered on CD-ROM or diskettes, FastRegs is available for Windows and DOS operating systems. It is available in multi-user network versions. Monthly, quarterly or annual subscriptions for regulation updates are available.

Write in 837 for more information.

Autodesk acquires key GIS technology

The recent acquisition of key geographic information system (GIS) technology by Autodesk Inc., San Rafael, Calif., allows the company to enhance its offering of PC-based mapping and GIS products. Among the company's current offerings is AutoCAD, a computer aided design/drafting program. The acquisition of assets of Automated Methods (Pty) Ltd. of the Republic of South Africa puts Autodesk in a position to expand its offerings with the development of a family of new products during the next year.

Write in 838 for more information.

Unit cost database added to Composer Gold

The Composer Gold cost and analysis system from Building Systems Design, Atlanta, Ga., now has ECHOS, a new environmental restoration cost database. The programs work together to perform cost estimates for restoration site cleanup. The cost databases provide information for planning, construction, operations, maintenance, sampling, analysis, personal protective equipment, decontamination and labor. It also offers condition modifiers for safety, environmental and geographical constraints, and customized estimating forms and strategic formatting. Assemblies database and unit database are cross referenced for accurate analyses.

Write in 839 for more information.

Soil's hydraulic parameters rendered with DAEM package

Estimating hydraulic parameters in soil is the purpose of SoilPara Version 1.0 software from Draper Aden Environmental Modeling Inc., Blackburn, Va. The estimator is based on statistical pore/particle size distribution models. It allows estimation of the unsaturated zones of variably saturated soils from retention data and/or conductivity or diffusivity data based on the public domain RETC model by M. Th. van Genuchten with a Windows native preprocessor; from soil texture by clicking on a soil texture diagram to return percentage of sand, silt and clay within the pre-processor; or by selection of USDA recommended typical parameter values for various texture classes available in the SoilPara database.

Write in 841 for more information.

Calculating software offered by Eagle Point

The construction division of Eagle Point, Dubuque, Iowa, has created a couple of calculating programs for pollution monitoring, ocean engineering, pond and fish studies, wildlife studies, and civil engineering. The software uses object-oriented technology to allow the user to enter data from field sampling, databases, spreadsheets and 2D and 3D CAD drawings to create 3D visualizations. It creates iso-shells, surfaces, fence diagrams and table views. The software runs of Windows 3.1 personal computers with at least 16 MB of RAM and 20 MB of swap space. It can run on Windows 95 and Windows NT and is available for SunSPARC systems.

Write in 840 for more information.
use with windows. One is Bidcalc for Windows, a PC based system for estimating. This product has automatic overtime calculations, a project copy utility and the ability to incorporate R.S. Means data or have it bundled with the Bidcalc for Windows module. The software features a graphical user interface. Advanced SiteCalc for Windows reduces the time spent performing volume calculations with software features such as Grid Cell, Prismatical or Average End, 3D imaging, automatic drawing set-up and site balancing adjustment. Eagle Point HP 48 solutions, specific to the HP 48SX/GX field calculator, allows surveyors, civil engineers and construction crews to do stakeout, data collection, alignment layout and coordinate geometry. It integrates with the AutoCad, MicroStation and StandAlone Eagle Point software packages.

Write in 844 for more information.

Compliance software keeps tabs on health, safety, environment

Environmental Compliance Services Inc., Atlanta, Ga., is marketing the ECAS Environmental Compliance Assurance System program for use in establishing site compliance. The PC based system is designed to track and schedule activities integral to compliance with all environmental, health and safety requirements. The software compiles all site-specific environmental, health and safety responsibilities into one program. It allows facility responsibilities to be assigned to specific personnel. It alerts managers of upcoming regulatory due dates and provides a means for determining a facility's compliance status.

Write in 843 for more information.

EnviroWin's catalog has 100-plus software packages

The 1995 spring catalog from EnviroWin Software Inc., Chicago, Ill., features more than 100 software packages in categories ranging from electronic methods and regulation databases, risk and hazard assessment, electronic reporting forms, modeling and mapping tools, waste management and remediation, and industrial safety. Also available are a number of computer-based employee training and training program management tools. Software products are available in both Windows based and Macintosh formats.

Write in 844 for more information.

Sample label package supports 15 label types

Sample Labeler from Eventide Software Co., Harvard, Mass., is a software product for labeling containers used for environmental samples. The latest version, 2.2, features several enhancements, including the ability to export the label data to a structured text file format that can be imported into databases or data management systems. Fifteen label sizes are supported. Labels can include a variety of data created by merging user-defined sample names and medium information with a group of user-defined analytes (laboratory test methods). Version 2.2 is shipped with 21 analyte data files with more than 400 pre-defined analytes with associated preservative information and the typical number of containers.

Write in 845 for more information.

Riskpro upgrades two of its packages

Two software programs are available from General Sciences Corp., Laurel, Md. Riskpro's enhanced version of AT123D for Windows, an analytical groundwater transport model, includes a post-processing function that allows the output data to be sliced so a subset can be extracted. The subset can then be transported to a graphing program for imaging or a spreadsheet program for analysis. SESOIL for Windows has been enhanced to allow the user to specify the initial adsorbed-soil concentrations at any sublayer, allowing for the instantaneous loading option while having concentrations from layers other than the top one. The Summers mode was added to SESOIL to allow the user to estimate the average concentrations in the groundwater, and the interface was modified to allow the user to specify 9,999 years of simulation, rather than the previous 99-year period.

Write in 846 for more information.

GIS\Key generates variety of analytical reports

GIS\Key 2.0 from GIS\Solutions Inc., Concord, Calif., will aid consultants, engineers, analysts, and managers connected with environmental data monitoring and management with a means of tracking and cross referencing data. (See box, page 62.) GIS\Key integrates data to create numerous reports, including graphs, geologic cross-sections, boring logs, contour maps and statistical tables. The latest release features a network version, additional compliance capability, and full metric capabilities. The software compiles geologic, hydrologic and chemical data through single/double key or electronic input. More than 4,00 chemical names are included in its library. The program can directly interface with the Groundwater Modeling System (GMS) for groundwater flow and transport models, and users have access to graphic output capabilities through the use of a customized AutoCAD interface. Training seminars are offered at the user's place of business.

Write in 847 for more information.

EnvironQuant works with HP 4500 spectrometer system

ICP-MS EnvironQuant from Hewlett-Packard Co., Palo Alto, Calif., is designed to increase the productivity and reporting accuracy of environmental labs engaged in analysis of metals in wastes and waters for EPA Methods 6020, 6030 and 6040.

Continues on page 62→
Atlantic Environmental is a Connecticut environmental consulting firm that needed a way to streamline its data management system. They turned to GISKey, an integrated environmental data management system from GISolutions Inc. Mike Nejdl of Atlantic began using the GISKey system on a long-term project for a government transportation agency. Half a dozen sites of several hectares were to be monitored over several years, with samples taken quarterly from more than 50 wells.

"The sites under scrutiny were salt sheds, where road salt is stored for use on the highways during snowy weather," says Nejdl. Salt had leached into the groundwater, producing high levels of sodium and chlorides. Complicating this contract was the need to incorporate measurements of chemical concentrations dating back seven years before Atlantic Environmental became involved in the project. Old data were needed to show regulators a clear picture of the groundwater problem from past to present, but entering the information in a database would have been time consuming and very expensive, said Nejdl.

GISKey organizes 4,000 compounds by CAS number (a U.S. numeration standard), since many compounds have more than one common name. When entering data for the first time on the salt shed project, Nejdl started with a blank template constituent list (TCL). He used the first site sampling report from his lab to input the constituent names while GISKey automatically entered the CAS number. He also entered the detected constituent levels and other site data relevant to the job. The next time he opened the TCL file to input new lab findings, all he did was go down the list and enter the new concentration. The TCL file kept all the previous information in the same order.

When it came time to enter the historical data, reports from different labs didn't necessarily contain the lists of constituent concentrations in the same sequence or under the same compound names. Nejdl entered the names from the lab reports one by one and GISKey automatically recognized the compound name, matched it with a CAS number, and jumped Nejdl to the correct constituent record. With each new sampling round, Nejdl was provided with a hard copy of the lab results. He selected the project file and entered information about the sampling round such as the time and date the sample was taken, any chain-of-custody information, and any changes in the analysis routine. GISKey then brings up the TLC screen, where the user enters the new concentration results.

"It's not just the chemical names and concentrations that we need, it's the other information we're interested in. For example, if we sample a well 10 times in one day, the time listed is very important, as is the well identification. Our TCL on this project will let us customize the transportation agency project database by site, relevant compounds, sampling methods and detection limits," Nejdl says.

"Generating a GISKey report is as simple as asking it to 'Print out all the field blanks for April 12, 1995,'" says Nejdl. "Analysts especially like to see printouts of blind duplicates; GISKey prints these out side by side using an additional, user-defined column."

Another way Nejdl designed his queries was to instruct GISKey to report only on those wells when target limits were exceeded. "Consultants are usually interested in producing tables of those results that are positive. In the body of a report to our client," says Nejdl, "that's the meat, because it shows whether there has been any improvement."

When Nejdl wanted to customize a report, he sent the output file not to his printer but exported it to his Lotus program instead. The same data used to provide tables or graphs of constituents versus time at certain wells were extracted and used in contour maps output using the AutoCAD interface. On the salt shed project, Nejdl also output isopleth maps that displayed numeric values next to the wells, while contour maps displayed the same information using color shading to represent constituent migration and elevation.

The flexibility of the system made it easier for Atlantic Environmental to give the transportation agency clear, unambiguous documentation that showed improvement in the groundwater immediately beneath the salt sheds since the installation of new roofs that prevent the effects of rainwater leaching. Atlantic Environmental is now using GISKey on 10 other projects. Time and cost reductions of 50 percent have been estimated.

"Write in 847 for more information."
toward electronic document management. DM2 features DM/Server, a server with object oriented technology and industry-specific data modeling; DM/View and DM/Redline, with viewing and redlining capabilities; full-text retrieval searches; a client interface; graphical workflow definition and management; and a mechanism to capture and manage product structures and integrate with supporting product definition data. Environmental Resource Management Applications (ERMA) for Windows includes ERMA Data Manager, ERMA Site Geologist and ERMA Groundwater Modeler. Data Manager, based in an open GIS concept, can capture, analyze, map and report 2D and 3D environmental data. Site Geologist assists the geologist in developing a comprehensive geologic site model. Groundwater modeler provides an intuitive graphical interface and modeling software for MODFLOW, MODPATH and MT3D.

Write in 850 for more information.

Justice Alarm message screen
Process/QC software relies on chromatography
The Alarm! software/hardware package is available from Justice Innovations Inc., Mountain View, Calif. The program allows a chemist to create fully automatic real-time monitoring systems that use the results of the chromatographic analysis to initiate quality or process control actions. The actions can consist of throwing a switch and/or issuing an auditory message to the operator. The software can check up to 100 “alarm events” such as out-of-range peak amount or width. It can check system suitability values such as resolution, skew and noise, and can be used for environmental monitoring, automatic quality control checks, and on-line process control.

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Tracking allows permits to be tracked on an ongoing basis for users with tracking software (HAZMIN or LogiTTrac). The tracking menu schemes and documentation have been reorganized, too, and most selection screens and menus on Logical PC-based products can now be accessed from a One-Line Help menu. Write in 852 for more information.

**Coordinate conversion software speeds up mapping process**

Three new versions of mapping and coordinate conversion software systems have been introduced by Mentor Software Inc., Denver, Colo. DLG2MIF software converts DLG (Digital Line Graph) data directory to MapInfo (Map Interchange Format) file formats according to the user’s specifications. The use controls many of the conversion aspects. The manufacturer claims that large batches of DLG maps can be converted to MIF formats using batch mode. CS-MAP release 6.01 is the latest version of geographic coordinate conversion software for “C” programmers. This version contains more than 200 modules so users can incorporate comprehensive coordinate system/datum conversions in their own programs. The software also includes support for the Bursa/Wolf Datum (Seven Parameter Transformation) transformation technique and dynamic byte swapping. It also adds five new projections, bringing the total to 14. DLG2DWG file format conversion system release 3.01 operates three times faster than previous versions. The upgraded software supports overpassing and underpassing entities, and complete support for hypsography (contours) and has a number of utility programs for effective conversions. DLG2DWG is available in two models: Lite or Professional. Write in 853 for more information.

**Photovac upgrades software for IOS portable chromatograph**

The IOS Plus Portable Gas Chromatograph from Photovac, Inc., Markham, Ontario, has been enhanced with the new 10S Comm Plus Windows based software package. The unit is used for field measurement of VOCs from sub-PPB to PPM range in air, soil and water. Chromatographic data files can be stored and retrieved from disk in either tabular or graphed format. Unattended, continuous monitoring and bi-directional communications can be accomplished using a modem. Write in 855 for more information.

**HazProfile provides databases for environmental marketing**

HazProfile, a database marketing system, has been introduced by PI Environmental Data Services, a division of Petroleum Information Corp. (PI), Houston, Texas. The system provides users a means of identifying, qualifying and contacting prospects in the U.S. environmental management industry. HazProfile contains more than 200,000 detailed company profiles on a single CD-ROM. The information is a compilation of PI's HazSearch Database Subset, Toxic Release Inventory (TRI), Resource Conservation Recovery Information System (RCRIS), and Superfund priority clean-up list (NPL). The system also interfaces to Windows-based ACT! manager contact software. The system is available on DOS operating systems. With ACT! it is also available for Windows-based applications. HazProfile allows sorting of companies by waste volume, emission type and location. The program can generate personalized letters, mailing labels and standard custom reports. Users can quantify market needs for their products and services, identify market opportunities and demand, and develop direct marketing programs and lists. Write in 856 for more information.
Rockware’s 1995 catalog
Rockware catalog features environmental software
Rockware Inc., Golden, Colo., offers a number of computer software programs and packages for the environmental industry. Among them: WellCAD for Windows, for all well log data management and reporting functions; and Geographic Reference/Tracker/View, for creating relationships and images between source data coordinates and geographic coordinates, and for display and manipulation of maps. Flowpath is an integrated groundwater flow and path line analysis package including wellhead protection and featuring a complete graphic-user interface. MODFLOW 386 is the current version of the U.S. Geological Survey MODFLOW 3-dimensional groundwater flow model. SOILPROP is used for estimating soil hydraulic properties and their uncertainty from particle size distribution. SpillCAD is designed for hydrocarbon spill site assessment and remedial design evaluation. TWODANUS a two-dimensional analytic groundwater flow model based on the Analytic Element Method described by Strack. Venting software can be used for estimating hydrocarbon recovery by in-situ vacuum extraction. TDLume and TwoDFlume are hydrogeologic programs that predict spatial and temporal contaminant fate, considering convection, dispersion, adsorption and decay. LANDesign is a coordinate geometry program for use in any surveying, land planning, site design, road layout or civil project.
Write in 857 for more information.

Matching NMR curves is the goal of gNMR software SoftShell International Ltd., Grand Junction, Colo., has released gNMR, a Macintosh application that helps spectroscopists match NMR curves to structures. The software simulates one-dimensional NMR spectra or molecules or mixtures with up to 12 NMR-active nuclei. Users may start with imported structures from common drawing programs. Data can be imported in these formats: Win-NMR, Lybrics, GE-Sun, VNMR, and others. gNMR does full-lineshape iteration using a generalized least squares procedure to fit the calculated spectrum to the observed one. The software can also perform chemical exchange calculations of the intra- and inter-molecular type.
Write in 858 for more information.

State-specific topo maps available from Sylvan Ascent
Topographic maps for AutoCAD are now available on CD-ROM from Sylvan Ascent Inc., Santa Fe, N.M. Each CD/Maps CD-ROM contains all the 7.5 minute quadrangles for a specific state in DWG format. Version 3 includes AutoCAD release 13 compatibility, DXF file conversion, borders, latitude and longitude tic marks, map legends, EdgeFix LSP routine,
Continues on page 66→
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SOFTWARE ROUNDUP

NAD27 to NAD83 enhancement to coordinate conversion utilities, installation utility, quad lookup and double line routine improvements.

Write in 860 for more information.

CRS estimating software available from Tempest
Construction Reporting System (CRS) estimating software is available from Tempest Co., Omaha, Neb., for contractors, subcontractors, owners, developers and designers. The CRS package has assemblies, global adjustments to pricing, and system generated takeoff sheets. It can be used to estimate functions from feasibility and budget through detailed bid and change orders. The system includes a 14,000 item database. Single and multi-user PC based systems for DOS, CS/2, UNIX and XENIX are supported. The software requires 640k RAM and 15 Mb hard drive space.

Write in 861 for more information.

Software monitors tank conditions, stores data
TankControl software from Watson General Corp., Irvine, Calif., monitors underground storage tanks at remote locations for leaks and alarm conditions. Release 4.0 provides gasoline inventory control, delivery routing and scheduling, and sales information. It also collects data necessary for Statistical Inventory Reconciliation analysis. The software is applicable in many situations, including gas stations, utilities, fleet operations, airports, state and local governments, and military facilities.

Write in 862 for more information.
The Mobile Groundwater Treatment System from Remtech Engineers of Marietta, Ga., is constructed of lightweight cross-linked polyethylene and thermoplastics to enable it to be easily towed with a conventional half-ton pickup truck. The treatment train consists of a coalescing oil/water separator with removable coalescing elements, followed by twin, low-profile air sparge cells with removable, cleanable diffusers. It is powered by a 2.3 HP regenerative blower. Additional sparge cells can be added as an option. Flow through the reactors is by gravity, thereby reducing energy transfer costs. Effluent from the sparge chambers is collected in a 190 liter poly sump equipped with a 0.5 Hp submersible float-activated pump which transfers waste to a 63 kilogram carbon aqueous phase adsorber unit. The activated carbon cell is designed to be easily opened by perimeter clamps to allow for spent carbon removal and replacement.

Free product drains from the separator into a 114 liter poly collection vessel. An optional auto skimmer is available for large volume product recovery. Aeration rates may be varied for different air-to-water ratios via a bleeder valve located between the two aeration cells. Off-gases may be collected and passed through an optional gas treatment train consisting of carbon canister adsorbers. The system is mounted on a 3 metric ton open trailer with dual axles and electric brakes that also can serve as equipment utility trailer with the treatment system removed. An optional enclosed trailer is available. The system is powered by a 10 kw portable generator. The system can achieve contaminant removal efficiencies up to 99.5 percent for benzene, toluene ethylbenzene and xylenes, and up to 98 percent for TPH 5030 at a rate up to 57 liters per hour, says the company.

Write in 835 for more information.
Geoprobe® Direct Imaging Soil Conductivity System

- The Direct Image Soil Conductivity System made by Geoprobe® Systems of Salina, Kan., measures soil conductivity for determination of site lithology. The system employs percussion type direct push technology to advance a probe into the formation. The probe has a tapered design composed of steel contact rings isolated by an engineering plastic. The probe design gives it the strength to be driven using a Geoprobe® percussion hammer. During a push, uphele instrumentation applies an alternating current excitation to the probe and collects data from the probe and a depth measuring stringpot mounted on the probe unit. Direct Image software is run on a laptop computer which mounts inside the instrumentation case. The system provides a real-time display of soil conductivity versus depth and probing speed versus depth and stores the data in a spreadsheet compatible data file for later display and analysis.

To apply the system, an initial Direct Image conductivity log is performed and then compared with a sample log or with soil samples to confirm and refine interpretation. Discrete, as opposed to continuous soil sampling can often be used as confirmation. Subsequent logs on the same site then require little or no confirming samples to determine lithology unless drastic changes in the conductivity profile are obtained. The resulting data are used to pinpoint permeable zones for groundwater or gas sampling, to identify confining clay units and determine their continuity and to detect boundaries to flow or zones for aeration.

The conductivity system can be applied to depths of 24 meters and provides a 2 cm resolution. Either a Wenner array or two electrode dipole array can be used. The software runs under MS Windows on a user-supplied IBM compatible 386 or later PC with a math coprocessor.

Write in 836 for more information.
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