

## THE ACWA PROGRAM: AN ALTERNATIVE APPROACH, PROGRAM MANAGER ASSEMBLED CHEMICAL WEAPONS ALTERNATIVES

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### INTRODUCTION

The Army's technologies for destroying stockpiles of chemical weapons have been debated for many years by environmentalists, community members living near the stockpile sites, scientists, government and regulatory agencies, and other interested parties. The Department of the Army historically has supported incineration as its preferred method for the disposal of chemical weapons.

The Program Manager Assembled Chemical Weapons Assessment (PMACWA), which was charged with assessing alternatives to incineration for assembled chemical weapons, developed a process for evaluating, selecting and demonstrating technologies with significant, diverse public participation. PMACWA brought together key stakeholders from private and industrial sectors, various Army agencies, and regulatory communities in an open and collaborative process. As a result, all participants reached a consensus and supported the decisions and conclusions of the program as both technically sound and publicly acceptable.

### THE ORIGINS OF ACWA

In 1985, the U.S. Congress directed the disposal of all stockpiled U.S. chemical weapons and agent. As a result, the U.S. Army Program Manager Chemical Demilitarization (PMCD) was established and charged with the responsibility for the destruction of the nation's chemical weapons stockpiles, located at nine sites across the country. To accomplish its mission, PMCD began preparations to implement the proven incineration technology at each of these sites. Over several years, this effort was met with opposition from various environmental advocacy groups at many of the stockpile sites.

"Opponents began using the environmental permitting process to mount legal challenges to the use of the incineration, which started to impact the Army's schedule, budget, and it increased the public risk associated with the continued storage of chemical weapons," recalled Program Manager Michael A. Parker. "Congress recognized this and reacted with a plan, which I think benefited both the public and the Army."

In 1996, Congress passed Public Law 104-208, which charged the Under Secretary of Defense for Acquisition and Technology with designating a program manager to identify, demonstrate, and evaluate not less than two alternative

technologies to baseline incineration and report the conclusions of the assessment to Congress. Congress also suspended the funding to construct baseline incineration facilities at the Blue Grass Army Depot in Kentucky and the Pueblo Chemical Depot in Colorado pending receipt of the findings and subsequent Congressional actions. The first result of this law was the selection of Michael Parker as program manager and the establishment of the Assembled Chemical Weapons Assessment (ACWA) program.

### THE ACWA APPROACH

PMACWA realized early on that a public participation program would be as critical as its technical program in ensuring the success of its mission. To facilitate the process of working with various stakeholders the program enlisted the support of a non-profit public policy organization specializing in mediation to convene the various stakeholders into what became the Dialogue on Assembled Chemical Weapons Assessment (hereafter referred to as "the Dialogue"). The non-profit organization identified key stakeholders from the Department of Defense (DOD); state, and federal regulators; national activist groups; and a diversity of citizen interests from all nine stockpile sites. The group of some 35 stakeholders that comprised the Dialogue worked side-by-side with the PMACWA staff from the outset of the program, through the original procurement process, continuing with the testing, evaluation, and reporting of the technologies being demonstrated, and culminating in the decision-making process for technology selection at Pueblo and Blue Grass. The group's overall goal was established as the following:

*"Draw on a wide range of experience, perspectives and expertise in support of efforts to identify, demonstrate and deploy safe, effective and broadly acceptable methods for disposing of chemical munitions and any resulting materials and/or waste streams."*

To accomplish its goal, the Dialogue planned to fulfill the following objective:

*"Solicit stakeholder input into the Congressionally-mandated program at key decision-making points during the process, including but not limited to: assisting with the development of criteria for comparing technologies, providing input into the assessment of alternative technologies, and aiding in the determination of appropriate locations for technology demonstrations."*

Dialogue meetings were open to the public, and the group gave all attendees the opportunity to provide comments for consideration. Meetings were held at or near stockpile sites to encourage local residents to attend, or in Washington, D.C., to facilitate DOD and congressional participation.

In addition to meetings, ACWA supported various outreach initiatives since the program's inception. These initiatives focus on two primary objectives: 1) to provide information, and 2) to provide opportunities for public involvement. The goal was to provide the public with as much information as possible about the technologies, given the constraints of a procurement-sensitive evaluation process, and to encourage them to provide input into the decision making process.

One key mechanism that helped PMACWA conduct a successful program was a combination of four Dialogue members and a support contractor comprising a Citizens' Advisory Technical Team (CATT). The CATT became integral to the process and provided an independent review of the program for the Dialogue. CATT members signed confidentiality agreements allowing them to serve as the Dialogue's "watchdog" at many PMACWA internal meetings, including those dealing with procurement-sensitive information. By participating in meetings normally open only to PMACWA staff, the CATT provided Dialogue members with assurances that the technical program was being executed according to the commitments PMACWA had made to the Dialogue. The CATT also provided a mechanism for stakeholder input into the program's technology selection and evaluation process. The CATT thus ensured maximum communication between PMACWA and stakeholders while respecting the government's legal and ethical responsibility to protect proprietary and trade secret information contained in proposals and other documents submitted by technology providers.

### THE ACWA PROCESS

PMACWA set out to accomplish several milestones in order to achieve this larger mission. With the Dialogue and public participation program in place, the program began to focus on three programmatic phases:

**1. Development of criteria by which to solicit and select technologies for evaluation.** This challenging process was completed in less than three months with program staff drafting the initial document based on their expertise and public documents gathered from various Chemical Demilitarization Citizens' Advisory Commissions (CACs) and other groups noting the attributes they desired in alternative technologies. The draft was then worked with the public and technology providers until the criteria were finalized. The complex process comprised three tiers of criteria, including:

**Threshold Criteria:** For use in screening proposed technologies, this set of criteria outlined the minimum requirements technologies had to meet to be considered by the program.

**Demonstration Selection Criteria:** For the detailed evaluation of specific technologies, this set of criteria was used by PMACWA to select technologies for demonstration and included technical and business factors. The technical factors were sub-divided into process efficacy, safety and human health and environment.

**Implementation Evaluation Criteria:** For the assessment of the demonstrated technologies, this criterion was similar to Demonstration Selection Criteria and was used as the basis for all recommendations to Congress.

**2. Assessment of technologies for demonstration.** The goal of this phase was for PMACWA to evaluate proposed technologies using available data, and to incorporate additional data requested from the technology providers. In October 1997, task order contracts were awarded to seven companies with promising technologies. Based on a technology evaluation process that assessed the submitted proposals, the initial awards funded work by the technology providers to fill in identified data gaps, so that more robust evaluations could be conducted. An evaluation of the completed data sets led to the award of a second

task order to six of the technology providers that required the offerors to submit demonstration work plans.

**3. Demonstration of technologies.** Due to funding limitations, only three technology providers were awarded demonstration contracts in July 1998, which initiated "Demonstration I." On October 25, 1999, Public Law 106-79 provided additional funding and allowed PMACWA to conduct demonstrations for the remaining three technology providers, which initiated "Demonstration II." Demonstrations were designed to be a series of validation tests for the critical unit operations of each technology as determined by PMACWA. Test plans focused on the means by which to validate performance of the technology processes, to characterize the process intermediates and final effluents, and to establish confidence that they could be incorporated into an overall system or "total system solution." Government personnel conducted all tests using existing government facilities. The program staff worked in an iterative process with test installation representatives, support contractors, members of the CATT, and the technology providers in performing detailed planning activities. The performance of the process demonstrations and the analytical results were reviewed and evaluated using the Implementation Criteria. Collectively, two supplemental reports were submitted to Congress and indicated that four technologies to demilitarize assembled chemical weapons were validated during Demonstration I and Demonstration II. In each of these reports, the Dialogue drafted and agreed to a several page consensus letter that noted recommendations for Congress regarding the ACWA program.

Once it became clear that alternative technologies could be demonstrated successfully, Public Law 105-261 was passed, which directed that PMACWA carry out "activities necessary to ensure that an alternative technology for the destruction of lethal chemical munitions can be implemented." As a result, PMACWA expanded its focus. In order to establish program requirements, to prepare procurement documentation, to develop environmental documentation, and to prepare to award a contract for the design, construction, and operation of a pilot facility for the technology, a series of Engineering Design Studies were initiated for the four validated technologies. These studies were designed to obtain further data required to support the certification decision of the Under Secretary of Defense for Acquisition, Technology, and Logistics, as well as to support solicitations for a full-scale pilot facility.

PMACWA worked with environmental regulators throughout the technology assessment and selection process to ensure environmental compliance and public safety under the purview of the National Environmental Policy Act. An Environmental Assessment was developed during the demonstration phase, the result of which produced a finding of no significant impact. Site-specific environmental strategies were implemented in compliance with federal and state laws governing transportation of materials, handling and disposal of waste, and potential air and water emissions. Environmental Impact Statements were developed at several stages of the process. In May 2002, the program's final programmatic EIS, Environmental Impact Statement for the Design, Construction, and Operation of One or More Pilot Test Facilities for Assembled Chemical Weapon Destruction Technologies at One or More Sites, was published.

In addition to preparing its own programmatic EIS, PMACWA provided support to PMCD as that program prepared site-specific EISs for Pueblo and Blue Grass.

In July 2000, the Under Secretary of Defense for Acquisition, Technology and Logistics, in his role as the DoD Acquisition Executive (DAE), requested a review of all aspects of the Chemical Demilitarization Program, including the ACWA program. In 2001, it was determined that the technology selection decision for the Pueblo and Blue Grass stockpiles would be a Defense Acquisition Board (DAB) decision. *An Overarching Integrated Product Team (OIPT) reported to the DAE the status of the Chemical Demilitarization Program and whether the ACWA technologies could meet the certification requirements and the findings of the Pueblo and Blue Grass Final EIS. The DAE considered all the information presented, including input from the affected communities, and documented and confirmed the resulting DAB selection in an Acquisition Decision Memorandum for each site. The DAB designated neutralization followed by biotreatment as the preferred alternative at Pueblo. The following identifies and describes the actions taken during each step.*

- **Removing the Energetics:** Robotic equipment will remove the weapon's energetic components, including the fuse and the burster.

- **Removing the Mustard Agent:** To remove the chemical agent, the body is mechanically accessed and then the agent is washed out with pressurized water.

- **Neutralizing the Energetics and Mustard Agent:** After the energetics and chemical agent have been separated from the metal parts, they will be treated in separate tanks with a caustic solution and water, respectively. The by-product from this process is called hydrolysate. The energetic hydrolysate and chemical agent hydrolysate are then combined and further processed.

- **Biotreatment:** The hydrolysates will go through the biotreatment process, which consists of large tanks containing microbes that digest and further break down the solution. Water released from the process will be recycled, leaving various salts and biosludge. Biosludge, which is made up of microbe waste products and other bacterial matter, will be filtered to remove water and shipped off-site to a permitted treatment, storage and disposal facility.

- **Disposing of the Metal Parts:** Although the metal parts were cleansed of energetics and chemical agent at the beginning of the process, they still may contain energetics and agent and need to be decontaminated to a higher level. This level is called "5X," a military standard of decontamination that ensures the metal is clean and safe for disposal. To reach this level of decontamination, the metal parts will be heated to 1,000 degrees Fahrenheit for a minimum of 15 minutes. The metal can then be recycled.

The DAB designated neutralization followed by supercritical water oxidation (SCWO) as the preferred alternative for Blue Grass. Below is a description of neutralization followed by SCWO:

- **Removing the Chemical Agents and Energetics:** Munitions are disassembled by modified reverse assembly. Chemical agent and energetics are separated.

- **Neutralizing the Chemical Agents and Energetics:** Chemical agent and energetics are chemically decomposed and neutralized by caustic or water hydrolysis. The resulting chemical compounds are known as hydrolysates.

- **Supercritical Water Oxidation:** The chemical agent and energetic hydrolysates are destroyed using SCWO units. SCWO subjects the hydrolysate to very high temperatures and pressures, breaking them down into primarily carbon dioxide, water and salts.

- **Treating the Metal Parts and Solid Effluents:** Metal parts are thermally decontaminated by heating to 1,000 degrees Fahrenheit for a minimum of 15 minutes. Solid effluents are recycled or tested prior to disposal in permitted landfills. Gas effluents are recycled or filtered before released to the atmosphere.

The final activity necessary to ensure that an alternative technology would be implemented involved preparation for acquisition of a pilot plant facility. PMACWA issued a Request for Proposal for a Pueblo systems contractor on July 17, 2002, and subsequently awarded the contract during the following September; a Request for Proposal for Blue Grass was issued on February 28, 2003 and awarded on June 13, 2003.

## THE FUTURE

PMACWA met its initial mandate from Congress by ultimately demonstrating six technologies in less than five years after the program was created. With this mission accomplished, PMACWA is looking towards the future and has moved into the implementation phase. In light of this shift, PMACWA has changed its name to Program Manager Assembled Chemical Weapons Alternatives, to better reflect its evolving mission. However, despite this changing mission, the program is committed to its approach to active, open public participation.

PMACWA regards public participation as a critical key to its past and future successes. From its inception, the program has established a new standard for the degree of openness and coordination with affected local communities and stakeholders. When the Dialogue process began, the Colorado and Kentucky Citizens' Advisory Commissions and community groups were divided regarding the path forward. Over the course of the process, the Colorado community, including the CAC and more than 30 other major groups unanimously supported neutralization followed by biotreatment at their site. At the start of the Dialogue process in Kentucky, a CAC member noted that his community was "at absolute stalemate." After working through the Dialogue, the Kentucky CAC is in favor of PMACWA and the agency's preferred alternative for the disposal of chemical weapons at the Blue Grass Army Depot. Today, PMACWA is continuing to encourage public involvement through the development of community forums in both Kentucky and Colorado. Local residents and other stakeholders will continue to have a voice in decisions made about plans for chemical weapons disposal in their communities.

"We accomplished our mission through partnership, partnership with the government, the military and the public," said Parker. "I think that speaks volumes, not only for our approach, but also for the future."

## ECONOMICAL DELIVERY OF DISSOLVED ORGANIC CARBON FROM PEAT AND WASTE WOOD PRODUCTS FOR USE AS ELECTRON DONORS

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### PROBLEM STATEMENT

In order to plate or paint metal, it must be free from dirt and grease. Numerous solvents and procedures have been developed to accomplish this task. For many years, flammable solvents were employed to clean metal. While flammable solvents worked they presented fire, safety, and health concerns that eventually became unacceptable. Chlorinated solvents like trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA) were developed to overcome fire concerns and were employed for decades as degreasing agents. Leaks, spills, and past industrial disposal practices of chlorinated hydrocarbons have left a legacy of groundwater contamination. Several engineering approaches have been developed to remove chlorinated solvents from groundwater such as mechanical pump and treat systems, but most of these have been very expensive to start and operate. These short-comings inspired microbiologists and geochemists to investigate other remedial approaches.

Geochemists and microbiologists have found that most chlorinated solvent plumes can undergo reductive dechlorination in anaerobic environments. The bioremediation of these plumes requires a source of carbon to serve as electron donors and appropriate nutrient conditions (Chapelle 2001). These sources of carbon can exist in many different physical forms and chemical compositions. Recently, several approaches have been taken to enhance *in-situ* bioremediation of chlorinated solvents in aerobic aquifers through the delivery of various electron donors such as wood mulch, vegetable oil, molasses, lactate, and polylactate esters (ITRC 1998, Magar et al. 2001). The problem to date has not been the lack of suitable electron donors but their sustained and economical delivery to the subsurface. Delivery of electron donors usually entails injection, drilling, trenching, or some other mechanical disturbance of the subsurface. Existing delivery methods are often subject to biofouling and a limited range of influence due to subsurface heterogeneity. Field experiments with biobarriers consisting of wood mulch have been established at several sites in America with TCE contaminated groundwater. The results of these wood barriers have been promising. What is needed most is a method to deliver inexpensive and sustainable electrons like peat and wood mulch to the subsurface with minimal mechanical alteration. Is it possible to deliver

enough electron donors derived from either peat or mulch to promote reductive dechlorination without trenching or other anthropogenic subsurface intervention? The answer to this question may come from studies on waste wood covers employed in the remediation of uranium mining wastes in Ontario and Quebec, Canada conducted by (Tasse et al 1997) and (Reardon et al. 1984). Both Reardon and Tasse and Germain found that deposits of fine woods chips were able to generate enough dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) to promote anaerobic conditions at depths greater than 50 cm and influence the geochemistry of the underlying groundwater.

### „Technical Maturity“

The study of humic substances is a century old scientific activity with regard to soil chemistry. In the past twenty years, research on humic substances in aquatic systems has provided a much better understanding of the chemistry and ecological significance of these substances.

Tranvik and Bertilsson (2001) studied the net effect of UV irradiation on DOC bioavailability and report that old humic material supports increased bacterial growth upon UV exposure. The emplacement of peat in ponds is anticipated to capitalize on these photodegradation processes and provide a bioavailable form of DOC to the underlying aquifer during periods of recharge. Although the DOC in peat soils may or may not benefit from photodegradation processes, Lorah et al. (1997) observed methanogenic conditions and the disappearance of TCE across a thin (approximately 6 feet) unit of peat at Aberdeen Proving Ground, Maryland. The emplacement of a layer of peat / peat soil in topographic depressions is anticipated to capitalize on similar processes. Fujii et al. (1998) report concentrations of DOC in peat soils ranging from 46.4 to 83.2 milligrams/liter (mg/L). These concentrations are well in excess of the DOC concentrations (1.6 to 1.8 mg/L) that were observed to support *in-situ* reductive dechlorination of TCE at a phytoremediation site within the plume proposed for study (Eberts et al. 2002); background concentrations of DOC in the Terrace Alluvial aquifer at the Carswell Phytoremediation Site, where no biodegradation is observed, range from 0.9 to 1.1 mg/L.

Additional bench scale and field scale evidence exists for the viability of using peat for remediation of chlorinated solvents. At the bench scale, Kao and Lei (2000) report that one half gram of peat has the potential to convert 1.5 mg of perchloroethylene (PCE) to ethylene. At the field scale, Buss et al. report that VOC concentrations in a chlorinated solvent plume were decreased from 100,000 ug/L to less than 10 ug/L after traveling a distance of less than 350 feet through peat rich subsurface. In addition, Bradley et al. (1998) observed that humic acids can also act as electron acceptors for the anaerobic microbial oxidation of DCE and VC. These researchers conclude that in the presence of humic acids, efficient mineralization of VC without the accumulation of reduced intermediates can occur.

The subsurface transport of DOC in relation to rain events also has been studied. Jardine et al. (1990) concluded that a significant flux of DOC through the subsur-

face environment during storm events can be expected. Winter (1995) notes that ground water recharge is highly variable and is initially focused where the vadose zone is thin, particularly near surface water bodies.

It is anticipated that it is possible to economically deliver DOC to an underlying aquifer by combining what is known about the ability of peat to promote biodegradation of TCE with what is known about ground water recharge and event driven DOC flux into the subsurface. The proposed study will document to what extent the emplacement of peat in ponds and / or topographic depressions can support the in-situ biodegradation of chlorinated solvents in an initially aerobic aquifer.

### PROJECT DESCRIPTION

A possible technology solution is the combined use of peat or wood mulch and the natural or existing hydrologic / topographic setting to deliver sustained, inexpensive, and readily bioavailable dissolved organic carbon (DOC) to a shallow (less than 10 feet below ground surface) trichloroethylene (TCE) contaminated aquifer, and to serve as a source of electron donors for *in-situ* biodegradation of the TCE. Applications of the use of peat and mulch to increase the DOC in the underlying aquifer need to be investigated. For example sphagnum peat or wood mulch could be placed in the bottom of a pond and, in the other instance, sphagnum peat (or peat soil) will be placed in a topographic depression where water ponds in response to storm events. The purpose of the peat or wood mulch emplacement in each of these settings is to carry DOC enriched recharge to the contaminated aquifer during and immediately after periods of precipitation. This technology is innovative because it is a passive technology that capitalizes on the natural / existing hydrologic and topographic setting of a selected site and requires no operation or maintenance costs after initial peat emplacement; this is desirable for the long-term delivery of DOC to a contaminated aquifer. A team comprised of hydrologists, geochemists, and microbiologists would then monitor concentrations of DOC in the shallow ground water upgradient, beneath, and down gradient of the emplaced peat or mulch. This team would study associated effects on microbial communities that degrade chlorinated solvents. The affect of peat and mulch photodegradation products of peat humic substances, typically low molecular weight organic acids, on the formation of TCE daughter products (dichloroethylene (DCE), vinyl chloride (VC), and ethane and the consumption or production of geochemical indicators of *in-situ* biodegradation (dissolved oxygen, nitrate, ferrous iron, sulfate, sulfide, methane, carbon dioxide and dissolved molecular hydrogen) in the aquifer also will be determined.

### Technical description

Sphagnum peat could be placed in the bottom of any existing pond located above a TCE ground-water plume. In addition, sphagnum peat / peat soil or wood mulch will be placed in a topographic depression where water ponds in response to storm events above the same plume. Grass will be planted

over the peat soil in the topographic depression to prevent the loss of the peat during periods of overland flow associated with storm events, as well as to minimize interference with golf course operation. These two sites, as well as a control pond and a control topographic depression in which no peat is emplaced, will be monitored for changes in DOC in the pore water of the pond sediments and in the aquifer. Samples for analysis of DOC in the pore water of the pond sediments will be collected by squeezing water out of sediment samples scooped from the bottom of the ponds. Samples for DOC in the aquifer upgradient and down gradient of the ponds will be collected from a line of well nests located parallel to the direction of ground water flow at each site. Samples for DOC in the aquifer upgradient, beneath, and down gradient of the selected topographic depressions also will be collected from a line of well nests located parallel to the direction of ground water flow at each of these sites. Samples for analysis of volatile organic compounds (VOCs), including TCE, DCE, VC, and ethene, and dissolved oxygen in the pore water of the pond sediments will be collected by use of water-diffusion samplers that will be buried in the sediments (<http://ds.itrcweb.org/common> accessed March 14, 2002).

Samples for analysis of VOCs, geochemical indicators of in-situ biodegradation, and a conservative tracer such as chloride will be collected from all wells using traditional well-purging techniques. Samples for determination of microbial ecology will be collected from sediment core. An analytical solute transport model, such as BIOCHLOR (Aziz et al. 2000), will be used to compute biodegradation rates for each sampling event. Water samples will be collected once prior to peat emplacement and four times per year for two years following peat emplacement. Three sampling events per year will be associated with precipitation events. One sampling event per year will take place during an extended dry period. A precipitation gage, soil tensiometers, pond stage gages, and pressure transducers in selected wells, including the well nests, will be used to help identify ground-water recharge events and determine the timing of sampling. Sediment core samples for determination of microbial activity will be collected once prior to peat emplacement and twice during the second year of the project. One of these sampling events will occur during a wet season and one will occur during an extended dry period. Samples of sediment core will be collected from coreholes drilled upgradient and down gradient of each site for the purpose of sediment sampling. Physical properties of the pond sediments and vadose zone sediments beneath the topographic depressions will be characterized prior to peat emplacement to aid in technology transfer. Such properties affect the ability of DOC enriched pond water or precipitation to reach the water table. Specifically, core will be collected from the pond sediments and analyzed in the laboratory for determination of vertical hydraulic conductivity. The grain-size distribution of core from beneath the selected topographic depressions will be determined for classification of the vadose zone soils. Water levels in each well and the stage of the pond will be recorded during each sampling event to record the depth to ground water and hydraulic gradient across each site.

### ***Potential issues of concern and technical risks in taking the technology from the lab to the field***

It is anticipated that minimal technical risks will be presented by taking this technology from the lab to the field. One potential concern is that excessive placement of peat into existing ponds may compromise the dissolved oxygen levels enough to impact the fish present. Other technical concerns are that not all waste wood products and mulch decay at the same rate. Some woods for example cedars (*Juniperus virginiana*), redwoods (*Sequoia sempervirens*), and osage orange (*Maclura pomifera*) are very resistant to decay and may not provide the amount of electron donors needed to promote reductive dechlorination.

### ***Approach for determining performance and expected cost of the technology***

The hydrological and geochemical data from a demonstration could be incorporated into a 2-D solute transport model, such as BIOCHLOR, to quantify changes in *in-situ* biodegradation rate constants that can be attributed to the emplaced peat. Changes in the distance of stabilization of the plume that can be attributed to the emplaced peat also will be calculated using the method of Chapelle and Bradley (1998). A 2-D ground water flow model, such as MODFLOW (McDonald and Harbaugh 1998), may be used to estimate the amount of

ground water recharge received at each site during the two year period of demonstration. There are minimal costs associated with this technology. It is expected that the peat will cost no more than \$ 1,000 per acre. The labor associated with peat emplacement is also estimated at \$ 1,000 per acre. No operation and maintenance costs are anticipated once the peat or mulch is in place.

### **EXPECTED BENEFIT**

Persistent plumes of chlorinated solvents are an enormous liability to owners of industrial sites with groundwater with chlorinated solvents. The economical delivery of sustained electron donors to the subsurface zone has proven problematic. If it is possible to deploy readily available and inexpensive peat humic substances or waste wood products such as mulch to provide a source of carbon and electron donors to groundwater discharge/recharge areas via ponds and existing topographical drainage features, a low technology, then a passive affordable method will be available to remedial project managers. Both mulch and peat are commercially available, easy to handle, and widely accepted by both the public and other parties. It may also be possible to deliver DOC to the subsurface from other sources of cheap carbon, such as grass clippings or agricultural wastes, in a similar fashion.

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