# IMPACT OF LANDFILL CLOSURE DESIGNS ON LONG-TERM NATURAL ATTENUATION OF CHLORINATED HYDROCARBONS

**Doug Downey**
Parsons
1700 Broadway, Suite 900, Denver, CO 80290
Phone: (303) 764-1941, Email: doug.downey@parsons.com

Coauthor:
John Hicks, Parsons

The purpose of this landfill-closure evaluation project is to assist the Environmental Security Technology Certification Program (ESTCP) and their United States (US) Department of Defense (DoD) technology-transition partners in developing alternative landfill closure designs and management strategies that can enhance the long-term natural attenuation of chlorinated aliphatic hydrocarbons (CAHs) (i.e., chlorinated solvents) in landfills and landfill-leachate-contaminated groundwater. The project was divided into three primary tasks:

- **Task 1 – Literature Review/Landfill Data Review**. This task involved completion of a literature review that focused on determining how alternative landfill closure designs and landfill management strategies can impact the natural attenuation of and long-term risk associated with CAH groundwater plumes.
- **Task 2 - Conceptual Landfill-Design Model**. This task involved preparation of simple decision-logic diagrams (Initial Landfill Screening, Remedial Alternatives Evaluation, and Cover Type Selection) and several design alternatives that could be used to optimize CAH biodegradation while minimizing plume migration.
- **Task 3- Final Technical Report.** The technical report (Parsons, 2002) describes the decision-logic diagrams and is intended to provide DoD engineers with a useful tool for evaluating the potential for enhancing CAH biodegradation at landfills undergoing final closure planning and design.

**Background and Potential Benefits**

The ‘enhanced-leaching’ theory of landfill treatment challenges the conventional philosophy of ‘infinite containment,’ and could move the waste industry toward more permanent and efficient waste-management solutions. These solutions could include a greater reliance on evapotranspiration (ET) landfill covers using natural vegetation, and greater emphasis on natural attenuation rather than expensive leachate collection and treatment systems.

At some landfills, surface infiltration may accelerate the leaching of the “source” and reduce the time required for biological stabilization of the landfilled waste. Recirculation of landfill leachate could also be used to accelerate the source-leaching process and promote reductive dechlorination within a “closed loop” *in-situ* bioreactor. This could reduce the time required for a CAH plume to stabilize and degrade, thereby reducing the long-term risk posed by the site. More rapid waste stabilization also will reduce long-term monitoring (LTM) costs because most regulatory agencies require rigorous post-closure monitoring activities as long as wastes pose a potential threat to water quality.

**Regulatory Environment**

In 1993, the US Environmental Protection Agency (USEPA) established source containment as the presumptive remedy for municipal solid waste (MSW) landfills regulated under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). In 1996, USEPA stated that this presumptive remedy, including installation of a landfill cap to minimize infiltration, should also be applied to all appropriate military landfills. Therefore, the concept of facilitating *in situ* degradation of landfilled wastes is at odds with the implicit intent of waste isolation and infiltration minimization. Implementation of an alternative landfill management strategy would require profound changes in the current regulatory paradigm.

However, recent actions by USEPA indicate that the regulatory climate may be changing, thus making regulatory approval of more innovative MSW landfill closure strategies more likely. For example, in recent years USEPA has been focusing on risk-based/performance-based corrective action approaches that encourage technical and administrative innovation to achieve environmentally protective cleanups on a facility-specific basis. The Resource Conservation and Recovery Act (RCRA) Reforms of 2001 promote use of innovative approaches, accelerate changes in regulatory culture, and focus on remediating to capitalize on long-term development potential. These paradigm shifts appear to create a more favorable framework within which to explore innovative management strategies for MSW landfills that are intended to degrade and/or minimize the potential long-term threat of landfilled wastes.

**Initial Landfill Screening**

A Landfill Screening Decision Tree was developed to assist Department of Defense remedial program managers in determining if engineered remediation of CAHs in groundwater is required, or if cleanup goals can be met within an acceptable time frame via natural attenuation. The initial screening process involves determining the presence/absence of contamination, and (if significant contamination is present) performing a natural-attenuation treatability study (TS), contaminant fate and transport analysis, and risk analysis.

If site assessment results indicate that significant contamination is not present, then it is unlikely that a final cap consisting of a low-permeability cover is required. If contaminant fate and transport analyses indicate the potential for the CAH plume to migrate off government-controlled property, and downgradient receptors are potentially at risk, then a detailed remedial alternatives assessment should be completed, using the decision tree developed herein for this purpose, to select an appropriate remedy that will mitigate risks posed by the plume. Conversely, if cleanup goals can be met within an acceptable time frame via natural attenuation, then a remedial alternative consisting of monitored natural attenuation (MNA) of groundwater should be pursued.

**Remedial Alternatives Assessment**

The Remedial Alternatives Decision Tree guides the user in selecting an appropriate remedial alternative when risk or time considerations dictate a more aggressive approach than MNA alone, and indicates the conditions under which operation of the landfill as a bioreactor, with collection and recirculation of leachate-contaminated groundwater, is an appropriate alternative. Elements of this decision tree include:

- <u>Source Identification and Removal</u>: If an active, continuing source likely is present, then reasonable efforts to locate and remove/remediate significant sources may provide a significant payback in terms of reduced plume migration and persistence.
- <u>Determining the Feasibility of Plume Capture and Recirculation</u>: Site-specific hydraulic models can be developed to design plume capture systems and determine optimal leachate recirculation rates. If the dissolved CAH plume can be contained by extracting flow from the impacted aquifer, which can then be reapplied within the landfill without adversely affecting the site, then recirculation of leachate-contaminated groundwater and operation of the landfill as a bioreactor should be considered. This *in situ* bioremediation alternative can potentially accelerate the waste-stabilization and contaminant-mass-reduction processes at problematic landfills for a relatively low cost. For older landfills such as those maintained by the DoD, leachate recirculation may enhance degradation of persistent chemicals by providing more favorable conditions for the microorganisms of interest. If recirculation of leachate-contaminated groundwater or MNA is not a feasible remedial alternative, then use of a permeable reactive barrier and/or enhanced bioremediation of dissolved CAHs should be considered. Enhanced bioremediation can include creation of anaerobic zones for tetrachloroethene/trichloroethene (PCE/TCE) degradation, and/or creation of aerobic zones for dichloroethene/vinyl chloride (DCE/VC) degradation.
- <u>Bioreactor Options</u>: Bioreactor landfills can conceivably be managed to promote either anaerobic conditions (for PCE and TCE) or aerobic conditions (for DCE and VC), or sequential zones of both conditions. Aerobic conditions can be created or maintained by recirculation of naturally aerobic or mechanically aerated groundwater, or via addition of oxygen or an oxygen source into the subsurface. Anaerobic conditions can be created or maintained by recirculation of anaerobic, organic-rich groundwater, with or without amendments such as electron donors. Anaerobic microbial degradation processes that can be artificially enhanced, depending on site-specific conditions, include direct and cometabolic reductive dechlorination, and direct anaerobic oxidation. Aerobic processes that can be enhanced include direct and cometabolic oxidation. Creation or enhancement of sequential anaerobic and aerobic treatment zones represents the most promising scenario for successful biodegradation of the full range of CAHs that may be present at landfill sites. In addition, pH adjustment or addition of nutrients

may be desirable to maintain a healthy microbial population. Successful implementation of leachate recirculation depends on:

- Collecting and controlling leachate as it is generated;
- Effectively redistributing leachate throughout the landfill without creating leachate seeps or other exposure-related issues;
- Controlling recirculation in a fashion that promotes robust microbial activity; and
- Containing and collecting gases produced as a result of biodegradation (typically not of concern at most DoD landfills due to their age and relatively stabilized nature).

**Landfill Cover Designs**

Three general types of covers are recommended for consideration at DoD landfills, depending on site-specific characteristics: low-permeability covers, ET covers, and capillary-barrier covers. In some cases, maintenance or enhancement of the existing soil cover may be adequate to achieve remedial goals. The experimental nature of capillary barriers, and mixed results from prior applications of this cover type, suggest that they should not be used alone, but could be incorporated into an ET cover design.

Low-permeability covers should be considered if the contaminant source material generally remains above the seasonally high water table, and/or the climate is characterized by abundant rainfall that would overwhelm the capacity of an alternative cover to adequately control infiltration. In all other cases, alternative (e.g., ET) covers should be considered when it is desirable to eliminate or reduce infiltration of water. If highly chlorinated solvents such as PCE and TCE are the primary risk drivers in the groundwater plume, an organic (e.g., mulch) layer can by incorporated into an alternative landfill cover to scavenge available oxygen and enhance anaerobic biodegradation processes within and beneath the landfill.

**Recommendations**

Completion of a pilot-scale demonstration of the bioreactor and landfill cover design concepts developed for this project at an inactive, unlined DoD landfill is recommended. The demonstration would consist of retrofitting the landfill to operate in bioreactor mode, including collection and recirculation of leachate-contaminated groundwater, and installation of an ET cover (possibly with an organic layer). The test cell would be instrumented to measure infiltration rates below the ET landfill cover, and temporal changes in the chemical and geochemical characteristics of water in the vadose and saturated zones would be assessed. Based on an initial review of limited site data, landfills at three Air Force Bases have been identified as potential pilot-test candidates.

**References**

Parsons, 2002, Impact of Landfill Closure Designs on Long-Term Natural Attenuation of Chlorinated Hydrocarbons. Prepared for the Environmental Security Technology Certification Program. March.