Remediation of Contaminated Groundwater at Complex Sites: Overview of Alternative Endpoints and Approaches – 14400

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ABSTRACT

The goal of United States (U.S.) Department of Energy's (DOE)'s environmental remediation programs is to restore groundwater to beneficial use, similar to many other Federal and state environmental cleanup programs. Based on past experience, groundwater remediation to pre-contamination conditions (i.e., drinking water standards or non-detectable concentrations) can be successfully achieved at many sites. At a subset of the most complex sites, however, complete restoration is not likely achievable within the next 50 to 100 years using today's technology. This presentation describes several approaches used at complex sites in the face of these technical challenges.

Many complex sites adopted a long-term management approach, whereby contamination was contained within a specified area using active or passive remediation techniques. Consistent with the requirements of their respective environmental cleanup programs, several complex sites selected land use restrictions and used risk management approaches to accordingly adopt alternative cleanup goals (alternative endpoints). Several sites used long-term management designations and approaches in conjunction with the alternative endpoints. Examples include various state designations for groundwater management zones, technical impracticability (TI) waivers or greater risk waivers at Superfund sites, and the use of Monitored Natural Attenuation (MNA) or other passive long-term management approaches over long timeframes.

This presentation will focus on findings, statistics, and case studies from a recently-completed report for the Department of Defense's Environmental Security Technology Certification Program (ESTCP) (Project ER-0832) on alternative endpoints and approaches for groundwater remediation at complex sites under a variety of Federal and state cleanup programs. The primary objective of the project was to provide environmental managers and regulators with tools, metrics, and information needed to evaluate alternative endpoints for groundwater remediation at complex sites. A statistical analysis of Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites receiving TI waivers will be presented as well as case studies of other types of alternative endpoints and alternative remedial strategies that illustrate the variety of approaches used at complex sites and the technical analyses used to predict and document cost, timeframe, and potential remedial effectiveness.

This presentation is intended to inform DOE program managers, state regulators, practitioners and other stakeholders who are evaluating technical cleanup challenges within their own programs, and establishing programmatic approaches to evaluating and implementing long-term management approaches. Case studies provide examples of long-term management designations and strategies to manage and remediate groundwater at complex sites. At least 13 states consider some designation for groundwater containment in their corrective action policies, such as groundwater management zones, containment zones, and groundwater classification exemption areas. Long-term management designations are not a way to "do nothing" or walk away from a site. Instead, soil and groundwater within the zone is managed to be protective of human health and the environment. Understanding when and how to adopt a long-term management approach can lead to cost savings and the more efficient use of

resources across DOE and at numerous other industrial and military sites across the U.S. This presentation provides context for assessing the use and appropriate role of alternative endpoints and supporting long-term management designations in final remedies.

INTRODUCTION

The U.S. DOE's Office of Environmental Management (EM) has made significant progress in its restoration efforts at many sites. However, the remaining 18 sites in the DOE EM Program are some of the most complex. Closure of these sites will require remediation of 1.7 trillion gallons of contaminated groundwater, 75 million cubic yards of contaminated soil, and deactivation & decommissioning (D&D) of over 3,000 contaminated facilities. In addition to the sheer mass of contamination, the nature of contamination, type of hydrogeologic setting, time elapsed since the historical releases, and other factors have created some of the most challenging conditions for the technical remediation community.

A recent report published by a National Academy of Sciences National Research Council (NRC) expert panel concluded that about 10 percent of the remaining 126,000 sites across the U.S. would not achieve restoration within the next 50 to 100 years due to technological limitations (NRC, 2012). Using today's technology, it is impossible to completely restore groundwater at these sites to pre-disposal conditions. The NRC expert panel also found that there were no new technology innovations that appeared promising for overcoming these challenges within the near time horizon (NRC, 2012). Remedial efforts at these complex sites are costly and are often financed using public funds, because the remediation of many complex sites is the responsibility of Federal or state governments.

Due to technical limitations of restoration and the cost of remedial efforts, it may be beneficial to consider alternative endpoints that are protective of human health and environment and are consistent with existing environmental policy and regulations. The overall purpose of environmental remediation is the protection of human health and the environment. Remedial objectives are developed based on site-specific understanding to meet this overall goal. Remediation is complete when these remedial objectives have been met. Typically, unrestricted use is desired and the endpoint or cleanup goal is meeting drinking water standards or background concentrations throughout the aquifer. Alternative endpoints may be allowed in conjunction with land use restrictions and/or long-term management of residual groundwater contamination.

LONG-TERM MANAGEMENT DESIGNATIONS

Long-term management or containment approaches may need to accompany various legal designations in order to satisfy regulatory requirements. These designations vary depending on the cleanup program. At sites regulated under the Resource Conservation and Recovery Act (RCRA), on-site containment and long-term management is widely accepted. The idea of a containment or management zone with a defined point of compliance is inherent in RCRA corrective action regulations and in the RCRA approach to managing landfills and other Solid Waste Management Units (40 Code of Federal Regulations [CFR] 264.95). Waste Management Units can be designated to manage wastes in place and meet cleanup requirements at an agreed-upon downgradient point of compliance (40 CFR 264.95). Because of this flexibility in RCRA regulations, additional designations are rarely needed at RCRA sites that are using long-term management/containment approaches.

In contrast, final remedies at CERCLA sites are expected to meet Applicable or Appropriate and Relevant Requirements (ARARs) everywhere throughout the plume. Therefore, if the remedy is not expected to meet long-term cleanup requirements within a reasonable timeframe, an ARAR waiver would be required (40 CFR 300.430(f)(1)(ii)(C)). State Superfund programs and other State cleanup programs may have additional designations that are needed in order to support long-term management.

Examples of these designations and case studies illustrating their application are provided in the following sections. Where DOE sites are part of these cleanup programs, similar long-term management designations will be needed. Case studies may also provide DOE officials and policy-makers with food for thought in creating reasonable and cost-effective precedents for managing residual contamination over the long-term in ways that are consistent with current policy and regulations and are protective of human health and environment.

Long-Term Management Designations and Case Studies in State and RCRA Cleanup Programs

Several state cleanup programs require an approval process for areas where groundwater contamination will be managed over long timeframes. Some of these designations are primarily intended to help states implement and track land use controls and other institutional controls until long-term cleanup goals are reached within the zone. Examples include Groundwater Management Zones in Illinois and New Hampshire. Other designations are alternative endpoints as they waive or replace the final cleanup standard. For example, the term Groundwater Management Zone is also used in Delaware’s Voluntary Cleanup Program and Hazardous Substances Control Act sites. This state designation prevents the use of groundwater and restricts drilling any new potable water supply wells. This designation also may be used to describe an area where technical impracticability exists for groundwater remediation and contamination will be present for a long time (Delaware, 2008). This designation has been used at 105 sites throughout the state of Delaware as of January 2009 (Delaware, 2009).

The Texas Commission on Environmental Quality (TCEQ) has a Plume Management Zone designation which modifies groundwater cleanup requirements within any area where cleanup is not technically or economically feasible. This designation is needed at Texas sites where a long-term groundwater management approach is being used. Note that any dense non-aqueous phase liquid (DNAPL) that is present at the site must be removed to the extent practicable before approving a Plume Management Zone. In California, sites under the jurisdiction of the State Water Resources Control Board need to designate a Containment Zone if groundwater will be managed over the long-term without meeting long-term cleanup goals. Containment Zones are appropriate at sites where residual contamination is not expected to degrade significantly over time and will remain indefinitely, i.e., where cleanup to water quality objectives is technologically and/or economically infeasible, per Resolution No. 92-49. Several other states (e.g., Georgia, New Jersey and Wyoming) require Technical Impracticability zone designations at highly complex sites along with any type of long-term management/containment zone approach. To determine whether a state cleanup program has a comparable designation, state-specific policies and regulations should be reviewed.

Several sites in Texas have designated groundwater Plume Management Zones, including the Naval Weapons Industrial Reserve Plant in Dallas, Texas, USA (Navy, 2008). NWIRP Dallas is a RCRA facility with chlorinated solvents in groundwater. Contamination was being addressed by three boundary pump-and-treat systems for over 10 years (Navy, 2008). The Navy proposed installing two permeable reactive barriers, designating a Plume Management Zone, conducting monitoring, and maintaining institutional controls. The remedy was supported by the partnering team and implemented. Long-term monitoring is being conducted to ensure that the plume remains within Plume Management Zone boundaries. Other sites with designated Plume Management Zones include the Red River Army Depot Ordnance Training Center Landfill, Spector Salvage Yard, Pioneer Oil Refining Company, Mountain Creek Industrial Center (proposed Plume Management Zone) and State Highway 123 PCE plume (state Superfund sites). More details on these sites are presented in original site-specific documents (Texas Register, 2007; TCEQ, 2007; TCEQ, 2004; Reed and James, 2010).

The California State Water Resources Board (SWRB) has a website (California SWRB, 2011) listing all sites with Containment Zones: J.H. Baxter site in Weed, Edwards Air Force Base South Air Force Research Laboratory in Kern County, Edwards Air Force Base Arroyos Air Force Research Laboratory in Kern County, and Georgia-Pacific (former Peterbilt Motor Co.) site in Newark, California. More information on these sites is provided in the links posted on the California website (California SWRB, 2011).

Two other facilities, Intel Fab 1 in Santa Clara, California and Norge Cleaners in Napa, California had Containment Zones at one time but these were rescinded (California SWRB, 2011). The Intel Fab 1 site received an order from the California Regional Water Quality Control Board (RWQCB) establishing the Containment Zone in 1999 for chlorinated solvents in groundwater that had reached asymptotic concentrations but were still above Maximum Contaminant Levels (MCLs) after years of pump-and-treat. In 2005, the RWQCB determined that the site met criteria for low-risk closure and the order was rescinded. Further groundwater monitoring is no longer needed (RWQCB, San Francisco Bay Region, 2005).

The distinction between Containment Zones and low-risk closure, and between MNA remedies and low-risk closure, was recently summarized by the San Francisco Regional Board (California RWQCB San Francisco Bay Region, 2009). This document described low-threat closures as potentially applicable before groundwater has been fully restored to beneficial uses, as long as stakeholders have concluded that the site will reach cleanup standards under natural conditions within a reasonable timeframe. Other states have adopted similar low-threat closure guidelines including the Colorado Department of Public Health and Environment (Colorado DPHE, 2010). Low-threat closure is not typically considered at highly complex sites; however, this is an alternative approach that can be used at sites that are approaching cleanup standards.

Some of the difficulties associated with approving Containment Zones are illustrated by the Fairchild Semiconductor Corporation South San Jose site (San Jose, California). The site had been operating a pump-and-treat system (as well as maintaining a slurry wall) to address chlorinated solvent contamination in groundwater. When contaminant removal by the pump-and-treat system approached asymptotic limits, stakeholders considered a Containment Zone designation. However, the site is located in a sensitive hydrogeologic area (classified as a recharge zone for groundwater by the local Santa Clara Valley Water District). To avoid potential conflicts with local groundwater management policies, stakeholders decided not to implement any official Containment Zone policy; however, the approach taken is, in fact, a containment zone system. According to a recent state five-year review report, the slurry wall present at the site is containing contamination above MCLs. Institutional controls are preventing exposure to contamination. Overall, the remedy is protective, despite several new developments including the detection of 1,4-dioxane inside the slurry wall at concentrations up to 850 µg/L and the evaluation of potential vapor intrusion risks. This is an example of an informal groundwater management/containment approach without a formal Containment Zone designation.

Based on conversations with Navy representatives, the Navy has considered Containment Zones and does not accept the procedural requirements outlined in Resolution 92-49. Referencing this resolution and using Containment Zone language would give the state an expanded role in the remedial decision-making process. The Navy has therefore used other alternative endpoints and approaches.

Long-Term Management Designations and Case Studies in the CERCLA Program
Objectives and expectations for remedial actions at CERCLA sites, as described in the NCP, translate into two threshold criteria that all final remedies must meet: Overall protection of human health and the environment and compliance with ARARs over the long-term. Seven other criteria (five “primary balancing criteria” and two “modifying criteria”) are used in comparing and selecting the final remedy: long-term effectiveness and permanence; reduction in toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; cost; state acceptance; and community acceptance.

Two different approaches have been taken within the CERCLA program for designating long-term management approaches. Some decision documents state that the final remedy will eventually meet all ARARs, including Federal ARARs and any state ARARs which are more stringent than Federal ARARs. The final remedy is then described, which may include a combination of active and passive long-term management approaches. For example, at the Solvents Recovery Service of New England site, a CERCLA site located in Southington, Connecticut, hydraulic containment with pump-and-treat is being used in conjunction with MNA over a long timeframe. Millions of gallons of waste solvents and oils were handled, stored and processed at the site for over 30 years. The site has multiple historical potential release areas including two unlined lagoons, drum storage areas, and truck loading/unloading areas. Approximately 84% of the subsurface contaminant mass is thought to be present as non-aqueous phase liquid (NAPL) in the overburden. NAPL is also known to be present in the bedrock. The Record of Decision (ROD) (U.S. EPA, 2005a) describes the selected remedy for groundwater in the overburden and bedrock. The overburden remedy includes in situ thermal treatment in the NAPL source zone, excavation and capping of soils and wetland soils, pump-and-treat for dissolved plume containment, MNA for areas outside of the pump-and-treat system containment zone, and institutional controls to prevent human exposure. The remedy for the bedrock consists of hydraulic containment using pump-and-treat and MNA in the NAPL area. The pump-and-treat system will be modified as appropriate based on expected reductions in dissolved volatile organic compound (VOC) concentrations due to MNA. The timeframe for restoration of the bedrock plume was estimated to be approximately 225 years to reach ARARs in the bedrock aquifer. This timeframe was considered reasonable relative to the timeframe of other remedial alternatives at the site.

At other CERCLA sites, decision documents state that the long-term management approach will not comply with ARARs. An ARAR waiver is included as part of the final remedy. The only grounds for waiving an ARAR are the following six options (40 CFR 300.430(f)(1)(ii)(C)):

- Technical impracticability (TI) – if compliance with ARARs is technically impracticable from an engineering standpoint, within a reasonable timeframe
- Greater risk – if compliance with the ARAR would result in greater risk to human health and environment compared with an alternative which does not comply with ARARs

- Interim measure – if the remedy is an interim action, ARARs need not be met. However, the final remedy still needs to achieve ARARs
- Equivalent standard of performance – if the selected remedy will attain a standard of performance that is equivalent to the ARAR. This waiver is typically used for action-specific or location-specific ARARs
- Inconsistent application of state standards – if the ARAR is a State standard that has not been consistently applied to other remedial actions within the State
- Fund balancing – if compliance with the ARAR would threaten the ability of the Fund to respond to and achieve protectiveness at other sites

Sites incorporating ARAR waivers into final decision documents must ensure that the final remedy is protective of human health and the environment. With the exception of the temporary ARAR waiver for interim remedies, TI waivers are the second most widely-used of the six types of ARAR waivers. Per EPA guidance, a written evaluation of technical impracticability (TI evaluation report) must be prepared prior to TI waiver approval to identify ARARs for which the TI decision is being sought, the three-dimensional volume subject to the TI waiver (the TI zone), the conceptual site model, evaluation for the potential for restoration, cost estimate, and other parts of the final remedial strategy (U.S. EPA, 1993a). Outside of the TI zone, traditional cleanup objectives will still remain as the final cleanup goal. Details on the TI evaluation process at CERCLA sites are described in U.S. EPA guidance (U.S. EPA, 1993a). Sites adopting a long-term management/containment approach ensure that contamination will remain within the TI zone.

Research efforts have identified 77 CERCLA sites that have received TI waivers for groundwater as of November 2010 (Malcolm Pirnie, Inc., 2011). Recently, a TI waiver was approved at Edwards Air Force Base South Air Force Research Laboratory, California, USA (ROD dated 9/24/2007). This site has a large TI zone, extending over 16 square miles. Solvent releases occurred during historical rocket motor/fuel testing and subsequent cleaning and disposal into sumps and dry wells. Contaminants include PCE and TCE. There are suspected DNAPL source zones in fractured rock. The geology at the site consists of a thin zone of unconsolidated soil (silty sand) overlying granitic bedrock. The depth to first groundwater ranges from 20 to 200 ft, averaging 120 feet, flowing through a network of fractures. Hydraulic conductivity has a similarly broad range, from 10-7 to 10-1 centimeters (cm) per second (3.3 x 10-9 to 10-3 feet per second). Wells generally pump at less than 0.5 gallons per minute.

The Air Force made significant effort over the past decade to characterize the site and evaluate remedial technologies through treatability studies. Site characterization techniques included the installation of monitoring wells, preparation of boring logs, quarterly water level measurements, surface fracture and mapping of lineaments, high-resolution three-dimensional seismic reflection survey, aquifer tests, tracer studies, and rock coring. Treatability studies evaluated dual phase extraction, pump and treat, soil vapor extraction, blast fracturing, in-situ bioremediation, thermal treatment and steam injection. A model was developed to simulate contaminant transport over a large area (the three plumes cover approximately 7.7 square miles). The closest town of Boron, CA, USA is approximately two miles from the base and the contaminated groundwater is not expected to reach it. Other potential future receptors include production wells located on- and off-base (6 and 2 miles from plumes, respectively). Based on the conceptual site model substantiated by the significant level of effort and documented field studies, stakeholders supported a ROD that included a TI decision.

The E.I. du Pont de Nemours & Co. site, located in Newport, Delaware received two types of ARAR waivers – an ARAR waiver for groundwater based on greater risk and a TI waiver for surface water ARARs. This site includes a paint pigment production facility, a chromium dioxide production facility, and two industrial landfills separated by a river. The selected remedy for groundwater consisted of long-term monitoring, installation of a public water supply line and establishment of a groundwater management zone. Based on data collected during the remedial investigation and feasibility study, attempts to remediate chlorinated solvents in the lower (Potomac) aquifer would draw more contamination into this aquifer from the more contaminated upper (Columbia) aquifer. Remedial attempts in the upper aquifer would adversely affect wetland areas. More details on the site background and selected remedy can be found in the original 1993 ROD (U.S. EPA, 1993b) and the second five-year review report (U.S. EPA, 2005b).

Long-term management/containment approaches have also been used at CERCLA sites in conjunction with a "greater risk" ARAR waiver. This waiver will apply if activities undertaken to meet an ARAR would result in greater risk or harm to human health or the environment than waiving that ARAR and choosing another alternative. The nature of the potential greater risks may vary with the site circumstances. Some examples include the following:

- Greater risk to drinking water aquifer(s) due to potential contaminant mobilization during remedial activity. This line of reasoning might be particularly applicable at a site with DNAPL
- Greater risk to nearby wetlands, agriculture, and/or ecosystems of implementing pump-and-treat remedies that lead to dewatering or land subsidence
- Greater risk to sensitive ecosystems in areas where remediation activities would be a disturbance
- Greater risk posed by explosive hazards or other health and safety hazards associated with particular remedial technologies. If the only technologies suitable for meeting ARARs were determined to pose a greater risk than other technologies, this waiver would be applicable
- Greater risk to ecosystem of sediment disturbance during dredging or excavation. This waiver would more likely be applicable to sediments or surface waters than groundwater
- Liner or capping requirements that affect the amount of natural flushing that occurs could potentially extend the time for groundwater to reach ARARs, resulting in greater risk.

At the Moss-American Superfund site, located in Milwaukee, Wisconsin a greater risk waiver was initially applied to RCRA Subtitle C capping requirements and State requirements for a double-liner/leachate collection system as part of the original 1990 ROD (U.S. EPA, 1990). Installing an impermeable cap and liner would have reduced the natural flushing and prolonged the treatment time for remediating groundwater contaminated by wood-treatment operations. This greater risk waiver was later revoked by a 1998 ROD amendment (U.S. EPA, 1998), based on new information that indicated a greater presence of DNAPL. Source control measures were then taken for soils in the area.

An ARAR waiver for groundwater based on greater risk was approved for the Onondaga Lake site in Syracuse, New York, USA. This site was a manufacturing facility for sodium hydroxide and liquid chlorine using a mercury cell process, followed by subsequent manufacturing of hydrochloric acid and bleach. The primary groundwater contaminant is elemental mercury DNAPL. The groundwater remedy selected in 2000 consisted of a barrier wall installed in the top 55 feet down to glacial till, hydraulic containment within the barrier using pump-and-treat, long-term monitoring, and deed restrictions. A timeframe of 30,000 years to reach ARARs was estimated, indicating that complete restoration of groundwater was also technically impracticable. However, groundwater ARARs were waived on the basis of greater risk, citing losses of wetlands from dewatering if a more aggressive pump-and-treat system were installed. Greater risks from on-site soil excavation and treatment included lots of truck traffic, fugitive dusts and air pollution, lack of community acceptance, and increased traffic accidents.

ARAR waivers based on interim measures have been used at many sites. At some complex sites operating under interim remedies, an alternative endpoint or approach is likely to be a component of the final remedy. For example, the Hastings Ground Water Contamination site, OU 19 (located in Hastings, Nebraska) selected an interim remedy for groundwater which primarily consists of institutional controls and groundwater monitoring. Contaminants include PCE, TCE, daughter products and other chlorinated solvents, 1,4-dioxane, carbon tetrachloride, benzene and other fuel constituents, and PAHs. Various sources have been discovered, including a grain storage facility, vapor degreasing process, manufactured gas plant, municipal/industrial waste landfill, and grain fumigant operations. Nearly all of the soils are deep and are formed in calcareous loess, eolian sands and mixed silty/sandy alluvium (U.S. EPA, 2001a). As stated in the 2001 ROD (U.S. EPA, 2001a), none of the alternatives that were evaluated could achieve ARARs and therefore could not be selected as a final remedy. U.S. EPA stated that monitoring would be conducted to determine if it would be technically impracticable to meet ARARs.

In response to public comment, the ROD stated that alternative endpoints (TI waiver or Alternate Concentration Limits [ACLs]) might be considered as part of the final remedy (U.S. EPA, 2001a): “However, EPA would not consider an application for a TI waiver or ACLs appropriate until response actions have indicated that contaminant concentrations have leveled off after a period of time, or further improvement in ground water quality using available technologies is shown to be impractical.” At Hastings, data were not sufficient to support a final ROD incorporating a TI decision; therefore, an interim remedy was proposed instead (U.S. EPA, 2001a). U.S. EPA’s recommendation to consider TI early in the CERCLA cleanup process and to continually refine the conceptual site model during the RI phase may be useful for avoiding further delay of final remedies (U.S. EPA, 1993a).

Site SS-01 of Brandywine Defense Reutilization and Marketing Office, Andrews AFB, Maryland, USA is another complex site operating under an interim remedy (US Air Force and U.S. EPA Region 3, 2006). The interim ROD stated that it is impractical to treat groundwater within the source zone area to MCLs, due to the presence of DNAPL, incomplete characterization of the DNAPL source area and the heterogeneity of the shallow groundwater aquifer (US Air Force and U.S. EPA Region 3, 2006). Data from the interim remedy (hydraulic containment, institutional controls, enhanced bioremediation, and bioaugmentation) will be used to evaluate the remediation potential of the final remedy.

MONITORED NATURAL ATTENUATION OVER LONG TIMEFRAMES

Some highly complex sites have selected or transitioned to a passive remedy to slowly remediate contamination over a long timeframe. Passive remedies generally rely on MNA. Capping, permeable reactive barriers, and infrequent injections of long-lived remedial agents such as edible vegetable oils may also be considered passive technologies. In addition, containment, monitoring, periodic reviews and/or institutional controls may be put in place to protect human health and the environment.

MNA is a fairly well-accepted component of groundwater remedies, as evidenced by the U.S. EPA report “Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites” (U.S. EPA, 1999) and several technical reports published in the late 2000s on MNA of inorganic contaminants in groundwater (U.S. EPA, 2007a, 2007b; U.S. EPA, 2010a; ITRC, 2010). Per U.S. EPA, implementation of source control measures in conjunction with MNA is almost always necessary (U.S. EPA, 1999). MNA can be used downgradient of the source area, as a supplement to source control measures, or (in some cases) as the primary component of a limited action remedy in the source area. MNA may provide several benefits when compared to active technologies, including reduced ecological disturbance of sensitive areas, reduced energy consumption, less waste generation and lower remediation costs. Remedial timeframes for MNA and active remediation technologies may be similar, due to rate-limiting processes such as diffusion and dissolution.

Institutional controls are often used in conjunction with MNA over long timeframes. Examples of institutional controls include zoning restrictions, building/excavation permits, prohibition of well drilling, fencing and other methods to control exposure pathways. The appropriate role of institutional controls and limited action alternatives was described in a June 2009 memorandum published by U.S. EPA. The memorandum restated the NCP expectations that institutional controls are generally not substitutes for active remediation but are intended as supplementary protective measures during the implementation of groundwater remedies (U.S. EPA, 2009). Detailed guidance on institutional controls, including full life-cycle planning recommendations, effective implementation, maintenance recommendations and enforcement tools is summarized in recent interim guidance (U.S. EPA, 2010b).

MNA and other limited action remedies over long timeframes at complex sites can be used without an alternative endpoint. NCP Section 300.430(a)(iii)(F) states that U.S. EPA expects to “return usable groundwater to beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site”. As long as these expectations are achieved, an alternative endpoint is not needed. There is no standard definition of “reasonable timeframe”; instead, the definition of reasonable is assessed for each site. The lack of a definition of “reasonable timeframe” has increased the flexibility of site stakeholders to accept longer timeframes to reach cleanup requirements allows for the use of MNA rather than considering remediation to be technically impracticable. Therefore, if longer timeframes are warranted for remediation and are accepted by stakeholders, no alternative endpoint is needed. In interviews conducted in 2003, several U.S. EPA and state regulators referred to MNA as another option at complex sites that are considering TI waivers (Malcolm Pirnie, Inc., 2004).
At site SA-17 of the Former Naval Training Center (NTC) in Orlando, Florida, USA, trichloroethylene (TCE) was present in the source area at concentrations indicative of DNAPL (up to 577,000 micrograms per liter). TCE in the source area has already been addressed by several remedial technologies, including ISCO with Fenton’s Reagent followed by enhanced bioremediation. ISCO was unable to treat some portions of the aquifer due to a lack of hydraulic connection, preferential flow paths and back-diffusion. Enhanced bioremediation has been operating using a recirculation well field design (Favara et al., 2006). The site is now in the process of transitioning to MNA. Multiple lines of evidence support a transition to MNA, including the following:

- Favorable geochemical conditions
- The presence of functional genes for dehalogenation (as measured using molecular biological tools)

- The presence of daughter products cis-1,2-dichloroethylene and vinyl chloride downgradient of the source zone
- Total concentrations of chlorinated VOCs that are within one to two orders of magnitude above MCLs, approaching Florida's default criteria for natural attenuation
- Natural Attenuation Software estimates indicating that remedial timeframes for the downgradient plume would not be further reduced through active remediation in the source zone. Remedial timeframes for MNA range from 60 to 70 years for the downgradient plume area.

An alternative endpoint was not necessary at the former NTC site. However, passive approaches also can be used in conjunction with alternative endpoints. At McKin Co (located in Gray, Maine, USA), chlorinated solvents were present at concentrations indicating DNAPL in bedrock. A 2001 amendment to the final remedy approved transitioning from pump-and-treat to MNA and institutional controls, in conjunction with a TI waiver. Pump-and-treat remained a contingency response in order to protect surface water. The transition to MNA was supported by the conceptual site model which indicated that residual DNAPL was likely present in bedrock, but it was extremely difficult to locate. Finally, an analysis of remedial timeframes indicated that pump-and-treat was not helping to achieve ARARs faster than natural attenuation.

SUMMARY AND LESSONS LEARNED

Sites with remedial timeframes estimated to be many decades, centuries, or even longer may need to implement a long-term management approach due to the limitations of current technology to restore groundwater to pre-disposal conditions. The appropriate selection and implementation of long-term management strategies is critical to DOE's ability to achieve cost-effective and sustainable programmatic solutions for addressing residual contamination at complex sites. This process can be facilitated by DOE activities that enhance a broader understanding and acceptance of the following:

- Technical limitations to site cleanup and predictions of remedial timeframes
- Land use restrictions
- Current regulations regarding long-term management approaches under various cleanup programs and a variety of alternative endpoints and other designations used in conjunction with long-term management
- Continued development and demonstration of systems-based tools, monitoring programs and policies to ensure protectiveness of human health and environment despite the presence of residual contamination
- Precedents of long-term management approaches used at other complex sites in a manner that is consistent with current regulations.

Defining technically achievable endpoints for complex sites is critical for meeting DOE's cleanup goals. Alternative endpoints can formally acknowledge the technical limitations to achieving remedial goals and ensure that residual contamination will be managed in the interim in ways that are protective of human health and environment. Formally acknowledging long remedial timeframes can be a basis for establishing common expectations for remedy performance, thereby minimizing the risk of re-evaluating the selected remedy at a later time. An acknowledgement of the long timeframe for complete restoration and the need for long-term management can also help a site transition from the process of pilot testing different remedial strategies to selecting a final remedy and establishing a long-term management and monitoring approach. After the expectations for long-term management are in place, remedial efforts can be directed towards near-term objectives (e.g., reducing the risk of exposure to residual contamination) instead of focusing on long-term cleanup requirements that cannot be achieved within any reasonable period of performance.

Familiarity with the analyses and case studies presented above will prompt DOE site managers and program managers to establish long-term management objectives, use alternative endpoints and other designations where appropriate, and more carefully consider alternative, beneficial, and cost-effective cleanup objectives and metrics that can be achieved over the short-term (while eventually meeting long-term cleanup objectives or demonstrating the applicability of alternative endpoints).

It would benefit DOE to develop technically-defensible guidance for determining and implementing appropriate land use restrictions at complex DOE sites and in developing and implementing systems-based monitoring and management approaches to detect relevant changes in site conditions that may change the conceptual site model or otherwise trigger a change in a long-term monitoring and management program. Moreover, because residual contamination could pose a risk to human health or environment if the site were used for a different purpose, most complex DOE sites will require continued use restrictions such as land use controls, water use restrictions or other institutional controls after remediation is complete. As such, closure solutions must utilize integrated approaches that consider potential contaminant transport from residual sources to receptors (e.g., water resources). Defensible alternative endpoints can benefit the DOE environmental remediation programs by providing cost-effective, sustainable long-term monitoring strategies, remediation and site transition decision support, and effective, forward-thinking long-term management approaches.

REFERENCES

1. California RWQCB San Francisco Bay Region. 2005. Executive Officer’s Report. September 14. Available at: www.swrcb.ca.gov/rwqcb2/board_info/agendas/2005/september/09-21-05-4eosr.doc. Accessed October 2011.

2. California RWQCB San Francisco Bay Region. 2009. Assessment tool for closure of low-threat chlorinated solvent sites. Draft Final. July 31. Available at: www.swrcb.ca.gov/ust/luft_taskforce/lowthreat_closure080609.pdf. Accessed October 2011.

3. California State Water Resources Control Board. 2011. GAMA – Groundwater Ambient Monitoring Program. Sites with Containment Zones. Available at: www.swrcb.ca.gov/water_issues/programs/gama/containment_zones.shtml. Accessed October 2011.

4. Colorado DPHE. 2010. Draft guidance for the closure of low-threat sites with residual ground water contamination. First edition. August 13. Available at: http://www.cdphe.state.co.us/hm/nfalowthreat/lowthreat.pdf. Accessed October 2011.

5. Delaware. 2008. Coordinated state agency response policy to detections of volatile synthetic organic contaminants in ground-water and/or drinking water. February. Available at: www.awm.delaware.gov/SIRB/Documents/State%20Response.pdf.

Accessed October 2011.

6. Delaware. 2009. HSCA, VCP, and NPL Sites with Groundwater Management Zones (GMZs) Requirements. January. Available at: www.awm.delaware.gov/SIRB/Documents/GMZ_sites.pdf. Accessed October 2011.

7. Favara, P.J., Singletary, M.A., Nwokike, B. and Tsangaris, S. 2006. Using a treatment train to optimize DNAPL source zone remediation. Fifth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California. May. Battelle Press, Columbus, Ohio.

8. ITRC. 2010. A decision framework for applying monitored natural attenuation processes to metals and radionuclides in groundwater. APMR-1. December. Available at: www.itrcweb.org/Documents/APMR1.pdf. Accessed October 2011.

9. Malcolm Pirnie, Inc. 2004. Technical impracticability assessments: Guidelines for site applicability and implementation. Phase II report. Prepared for the Army Environmental Center. March. Available at: http://aec.army.mil/usaec/cleanup/techimprac.pdf. Accessed October 2011.

10. Malcolm Pirnie, Inc. 2011. Alternative endpoints and approaches selected for the remediation of contaminated groundwater. Environmental Security Technology Certification Program (ESTCP) report number ER-0832. Prepared by Malcolm Pirnie, Inc. Available at www.serdp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-200832. Accessed October 2011.

11. Navy. 2008. Plume management zone to manage chlorinated solvents, Naval Weapons Industrial Reserve Plant, Dallas, Texas, USA. Department of the Navy Environmental Restoration Program 2008 progress report, p. 32. Available at: https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/resourceerb/don_er_rpt_2008_(2006-2007).pdf. Accessed October 2011.

12. NRC, 2012. Alternatives for Managing the Nation’s Complex Contaminated Groundwater Sites. National Research Council Committee on Future Options for Management in the Nation’s Subsurface Remediation Effort; Water Science and Technology Board; Division on Earth and Life Studies.

13. Reed, S. and James, J. 2010. Environmental Restoration Overview, Mountain Creek Industrial Center. July 16. Available at: http://mountaincreekindustrialcenter.com/downloads/MCIC_Industry_Day_Environmental_Presentation.pdf. Accessed October 2011.

14. TCEQ. 2004. Proposed Remedial Action document for State Hwy 123 PCE plume,

Proposed state Superfund site, San Marcos, Hays County, Texas. December 9. Available at: http://www.tceq.texas.gov/assets/public/remediation/superfund/statehwy123/pdf0303.pdf. Accessed October 2011.

15. TCEQ. 2007. Proposed Remedial Action document for Spector Salvage Yard, Proposed state Superfund site, Orange, Orange County, Texas. January. Available at: http://www.tceq.texas.gov/assets/public/remediation/superfund/spector/pdf0369.pdf. Accessed October 2011.

16. Texas Register. 2007. Notice of intent to designate a groundwater plume management zone, Spector Salvage Yard, Orange, Texas. 32 Texas Register 966-967. February 23. Available at: http://www.tceq.texas.gov/remediation/superfund/state/spector.html. Accessed October 2011.

17. US Air Force and USEPA Region 3. 2006. Interim Record of Decision for Site SS-01, Brandywine DRMO, Andrews AFB, Maryland. September. Available at: www.epa.gov/superfund/sites/rods/fulltext/r2006030001338.pdf. Accessed October 2011.

18. USEPA. 1990. Record of Decision for the Moss-American Site, Milwaukee, Wisconsin, September 27. Available at: www.epa.gov/superfund/sites/rods/fulltext/r0590142.pdf. Accessed October 2011.

19. USEPA. 1993a. Guidance for evaluating the technical impracticability of ground-water restoration. OSWER Directive 9234.2-25, EPA/540-R-93-080. September. Available at: www.epa.gov/superfund/health/conmedia/gwdocs/techimp.htm. Accessed October 2011.

20. USEPA. 1993b. Record of Decision. E.I. du Pont de Nemours & Co., Inc. (Newport Pigment Plant Landfill), OU 01. EPA ID DED980555122. Newport, Delaware. EPA/ROD/R03-93/170, September 29. Available at: www.epa.gov/superfund/sites/rods/fulltext/r0393170.pdf. Accessed October 2011.

21. USEPA. 1998. Record of Decision Amendment for the Moss-American Co., Inc. (Kerr-McGee Oil Co.), EPA ID: WID039052626, OU 1, Milwaukee, Wisconsin. September 30. Available at: www.epa.gov/superfund/sites/rods/fulltext/a0598157.pdf. Accessed October 2011.

22. USEPA. 1999. Use of monitored natural attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P. April 21. Available at: www.cluin.org/download/reg/d9200417.pdf. Accessed October 2011.

23. USEPA. 2001a. McKin Co. Superfund Record of Decision Amendment, OU 2, Gray, Maine. EPA/AMD/R01-01/015. March 30. Available at: www.epa.gov/superfund/sites/rods/fulltext/a0101015.pdf. Accessed October 2011.

24. USEPA. 2001b. Record of Decision for Hastings Ground Water Contamination Superfund Site OU 19. EPA ID NED980862668, EPA/ROD/R07-01/511. Hastings, Nebraska, June 25. Available at: www.epa.gov/superfund/sites/rods/fulltext/r0701511.pdf. Accessed October 2011.

25. USEPA. 2005a. Record of Decision for the Solvents Recovery Service of New England, OU 3, Southington, Connecticut. EPA ID CTD009717604. September 30. Available at: www.epa.gov/superfund/sites/rods/fulltext/r0105008.pdf. Accessed October 2011.

26. USEPA. 2005b. Second five-year review report. E.I. du Pont de Nemours & Co., Inc. (Newport Pigment Plant Landfill) Superfund site (a.k.a. DuPont-Newport Site), Newport, Delaware. Prepared by EPA Region 3. March 31. Available at: www.epa.gov/superfund/sites/fiveyear/f0503006.pdf. Accessed October 2011.

27. USEPA. 2007a. Monitored natural attenuation of inorganic contaminants in ground water. Volume 1. Technical Basis for Assessment. EPA/600/R-07/139. October. Available at: http://epa.gov/ada/gw/mna.html. Accessed October 2011.

28. USEPA. 2007b. Monitored natural attenuation of inorganic contaminants in ground water. Volume 2. Assessment of non-radionuclides including arsenic, cadmium, chromium, copper, lead, nickel, nitrate, perchlorate and selenium. EPA/600/R-07/140. October. Available at: http://epa.gov/ada/gw/mna.html. Accessed October 2011.

29. USEPA. 2009. Summary of key existing EPA CERCLA policies for groundwater restoration, EPA OSWER Directive 9283.1-33. Available at: www.epa.gov/superfund/health/conmedia/gwdocs/pdfs/9283_1-33.pdf. Accessed October 2011.

30. USEPA. 2010a. Monitored natural attenuation of inorganic contaminants in ground water. Volume 3. Assessment of radionuclides including tritium, radon, strontium, technetium, uranium, iodine, radium, thorium, cesium, and plutonium-Americium. EPA/600/R-10/093. September. Available at: http://epa.gov/ada/gw/mna.html.

31. USEPA. 2010b. Institutional controls: A guide to planning, implementing, maintaining, and enforcing institutional controls at contaminated sites. Interim final. EPA-540-R-09-001. USEPA, Washington, DC, USA. November. Available at: http://www.epa.gov/superfund/policy/ic/guide/icgdraft.pdf. Accessed October 2011.