A TECHNICAL REVIEW OF GROUNDWATER REMEDIAL ACTIONS AT MASSACHUSETTS MILITARY RESERVATION

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INTRODUCTION

On October 23, 1998, the Inspector General (IG) for the Department of Defense (DoD) released a report evaluating the program management practices that have been implemented in the Installation Restoration Program (IRP) at the Massachusetts Military Reservation (MMR), since the U.S. Air Force assumed overall site management in 1996 (Evaluation Report, Office of the Inspector General). This report recommended, among other things, that an independent technical review team, consisting of appropriate experts, should perform a comprehensive peer review of the MMR IRP. Based on this recommendation, the Air Force Center for Environmental Excellence (AFCEE) retained Booz-Allen & Hamilton to coordinate the formation of a Technical Peer Review Team (TPRT) with the goal of completing an independent assessment of the groundwater remediation strategies that have been or are planned to be implemented at the 13 groundwater plumes identified to date at the MMR. Specifically, the statement of work asked the TPRT to:

- Evaluate and validate the credibility of the MMR IRP cleanup decision-making process;
- Evaluate and validate the rationale used in reviewing and selecting remedial actions;
- Evaluate and document the extent to which established and recognized risk assessment concepts and site-specific and risk-based methodologies were utilized in remedial decision making processes; and,
- Review and evaluate the technical feasibility of selected remedies to achieve the stated remedial goals on a site-by-site basis.

In response to this statement of task, the TPRT team, composed of six experts, determined that the decision processes used at the MMR could be best evaluated by assessing the role of three key factors: community involvement, risk, and technology. The TPRT has thus prepared three reports assessing the adequacy of the processes used at MMR from these three perspectives with an executive summary to be prepared by Dr. Stan Hewins, Texas Center for Applied Technology (a subcontractor to AFCEE's GSE&I Contractor, Waste Policy Institute) presenting the main findings/conclusions and recommendations of the TPRT. The report concentrates on IRP activities conducted after 1996, when AFCEE assumed primary site management responsibility.

This technology report presents the evaluation of the remedial decision-making process at MMR primarily from the viewpoint of a technology assessment. The questions we address in this report include the following:

1) Has the IRP program management team employed the appropriate technical analyses and selected the appropriate technology for cleanup of each of the 13 groundwater contaminant plumes?

2) Are the recommended or implemented technologies technically feasible and are they likely to achieve the remedial action goals within the time frames and costs currently projected?

The authors of the technology report recognize that technology or technical factors are not the only drivers for the selection of groundwater remedial measures, and we recognize the limitations of purely technical analyses of groundwater cleanup strategies. The relative degree of influence in the decision process for these three factors (community involvement, risk, and technology) will vary from one site to another. As has been clearly documented in the two companion TPRT reports that discuss MMR-related **community involvement** and **risk,** community values and community input have had a dominant role in the decision processes at the MMR. Nonetheless, technical considerations play a significant role in determining the appropriate mix of technologies that should be selected to meet the cleanup goals. More importantly, technical considerations will play an increasingly important role in the future as the performance of the groundwater cleanup remedies, from both an efficiency and cost perspective, are revealed through plume monitoring programs. In fact, achieving a "win-win" solution at MMR that meets community needs and concerns at the least cost to the taxpayers, requires the use of the best engineering and scientific tools available. The results of those analyses must then be presented in a manner both comprehensible and credible to the public. The importance of this communication process has been clearly documented in the companion report on community involvement.

In an important sense, technical considerations are value neutral. That is, given any specific groundwater cleanup goal for a site, as determined by the agreed upon decision process, technical considerations should provide an unbiased assessment of the technical feasibility of selected remedial technologies, and the expected life cycle costs to meet that cleanup goal. Uncertainties in determining feasibility and life cycle costs should be documented and discussed for each selected alternative. Technical considerations thus provide a basis for decision makers to compare the suitability of any alternative within the inherently complex and messy public setting. It is at this point in the decision process, however, where technical considerations may become of secondary importance, and stakeholder acceptance is controlled by other factors, as discussed in the community involvement report.

This technology report should thus be considered as a peer review of the technical processes that have been applied at MMR since the transition to AFCEE management. We begin with a brief overview of the site, and of the groundwater cleanup program currently in place or planned. We follow this with our findings, the basis for these findings, and finally our recommendations. We have also included as an attachment more comprehensive assessments of the technical dimensions of decision processes at six of the 13 plumes. These plumes were selected to be representative of the key technical issues faced by the IRP in implementing groundwater remediation programs in the aftermath of the “60 percent” design submittal to the community (as described in the Comprehensive Plume Response Plan and Schedule, MMR IRP Strategic Plan, September 24, 1997). As noted in other reports, time and budget constraints did not permit an in-depth evaluation of technical considerations at all of the plumes and we make no claim for comprehensiveness in this review. Nonetheless, we have reviewed a sufficient number of documents and interviewed key AFCEE and contractor staff such that we are confident that our technology assessment accurately reflects the current state of technical aspects of the IRP.

BACKGROUND

Site Description

MMR was established in the 1930s. Comprised of approximately 22,000 acres, it lies within the community boundaries of Bourne, Mashpee and Sandwich, and abuts Falmouth, Massachusetts. The site overlies a groundwater aquifer used as the sole-source drinking water supply for several communities in Cape Cod. Additionally, the groundwater aquifer underlying MMR naturally discharges to ponds, bogs and ultimately, the ocean. Commercial cranberry production takes place in bogs located in the vicinity of MMR. The community places great value on the groundwater resource and is concerned about MMR groundwater contamination based on potential present or future human health and ecological impacts as well as on property values.

Site History

MMR activities included operation of aircraft runways, aircraft and vehicle maintenance, landfilling of waste materials and firefighter training. Soil and groundwater contamination occurred at MMR as a result of these historical activities. The U.S. Air Force managed the base until the end of 1973 when base management was transferred to the Air National Guard. In 1978, the town of Falmouth detected detergents in a drinking water well located south of the MMR wastewater treatment plant. In 1979, the U.S. Geological Survey (USGS) identified a chemical plume extending into the Ashumet Valley area of Falmouth. The MMR IRP began in 1982. Volatile organic compounds (VOCs) were detected in both base and private off-site wells (1985 to 1986). Between 1982 and 1985, 73 MMR sites were identified that had the potential to adversely impact the environment. In 1989, MMR was added to the U.S. Environmental Protection Agency’s (EPA’s) National Priorities List as a Superfund Site. Since that time, a variety of decision-making processes have been used at MMR to direct the remediation activities associated with soil contamination sites and groundwater plumes. Remedial action has either been completed, is in progress, or will be taken at all of the MMR sites identified as requiring remediation.

Remedial Action Goals

The MMR IRP Strategic Plan (September 24, 1997) states that the plume response management goal is “100 percent capture of all plumes above maximum contaminant levels (MCLs) or other risk-based levels and treatment of contaminants and cleanup of plume(s) to background levels if technically and economically feasible”. Generally three technologies have been or are planned to be used at MMR to achieve groundwater cleanup goals: (1) extraction, treatment and reinjection (ETR) systems, usually described in the technical literature as “pump and treat” systems, (2) recirculating well technology (RWT), which is an in situ form of “pump and treat”, or (3) a combination of ETR, RWT, long term monitoring (LTM) and monitored natural attenuation (MNA). The strategic plan also indicates that the remedy selection process involves “the continual re-evaluation and integration of hydrologic and ecological investigations, risk assessments, monitoring programs, modeling, planning, pilot testing, construction, implementation and other activities”.

MMR Remediation Program Status

Beginning in the late 1970s and continuing to the present, hundreds of potential source area investigations and groundwater investigations have been conducted at MMR. Site investigation and remediation are in various stages. Soil cleanup at several source areas began in 1994. Groundwater plume characterization activity began in 1992 and the first groundwater treatment system was installed at the Chemical Spill 4 (CS-4) area in 1993. As of August 1999, thirteen significant groundwater plumes have been identified at MMR. By the end of calendar year (CY) 1999, remedial treatment systems at nine of the 13 identified plumes will include 70 groundwater extraction wells and two recirculating wells. These remedial systems are expected to treat more than 9.5 million gallons (MG) of groundwater per day. By the end of calendar year 2002, MMR remedial systems are projected to treat approximately 15.7 MG of groundwater per day.

Summary of Expenditures

The Inspector General’s Report states that over $200 million dollars has been spent to date for cleanup at MMR and that the total cost estimate for the entire cleanup could exceed $800 million. Projected costs in 1999 dollars for groundwater remediation alone are greater than $300 million, based on data provided to the team during the peer review.

Overview of Current Groundwater Remediation Activities

Table 1 summarizes the TPRT’s understanding of the current status of remedial actions at each of the 13 significant MMR groundwater plumes. Information provided in the table comes from MMR fact sheets and technical reports. The TPRT created Table 1 (MMR Groundwater Plume Technology Evaluation) to provide a summary of relevant site data for use during the review process. However, we believe that it may also be of interest to the readers of this document as a reference table, thus it was included in this report. Additionally, Mr. Jim Snyder of AFCEE provided some of the data. The table provides the following information for each of the thirteen MMR plumes:

- Decision Process. Remedial measures implemented or planned for the 13 significant MMR groundwater plumes were established under three decision-making processes: interim action Record of Decision (IROD), remedial investigation and Record of Decision (RI-ROD), or a combination IROD and MMR-specific Decision Criteria Matrix (DCM) process.

- Contaminants of Concern (COCs). The contaminants of concern at in the groundwater at MMR include halogenated volatile organics and petroleum hydrocarbons. The major indicators of the petroleum hydrocarbon plumes are ethylene dibromide (EDB), benzene, and isomers of trimethylbenzene. Five of the thirteen plumes contain only halogenated organics (for example, trichloroethylene [TCE] or tetrachloroethylene [PCE]), three of the plumes contain a mixture of halogenated and petroleum organics, and the remaining five plumes are petroleum hydrocarbon plumes. Inorganic compounds (including nitrates and phosphorous) are also COCs in the Ashumet Valley plume.

- Sources. This column identifies the presumed sources of the MMR plumes and includes, among others, such sources as historical chemical use and disposal activities at the reservation, fuel spills and pipeline leaks, as well as landfilling activities.

- Estimated Plume Volume. The volume of affected groundwater is estimated from groundwater monitoring data that define the three dimensional boundaries of the plumes. Estimated volumes of the MMR plumes range from 180 MG to 12 billion gallons.

- Remediation Goal. As previously stated, the MMR plume response management goal is 100 percent capture of all plumes above MCLs or other risk-based levels, and treatment of contaminants and cleanup to background levels, if technically and economically feasible. Therefore the 13 significant MMR plumes will at minimum be contained, and restored if technically and economically feasible.

- Remedial Actions. Most of the MMR plumes will be remediated using the ETR technology. In addition to ETR, source removal will be implemented at four plumes to reduce contaminant mass. MNA will be used at two of the plumes in conjunction with the ETR system. Long-term monitoring will be implemented at the Fuel Spill-29 (FS-29) and FS-13 plumes.

- Actual or Projected Extraction Rate. The rate of groundwater removal is presented based on the capacity of the pumps in the ETR system. The actual extraction rate will vary due to hydrogeologic conditions and efficiency of the system. The projected flowrates range from 230 gallons per minute (gpm) for the smallest plume to 3,620 gpm for the largest plume.

- Annual Pore Volumes Extracted. A pore volume is defined as the volume of groundwater contaminated above the cleanup goal. The number of pore volumes removed per year is based on the extraction rate and estimates of the plume volume. The number of pore volumes provides an approximate basis to estimate the time necessary to achieve a given cleanup goal.

- Estimated Time to Achieve Remedial Goals. Contractors have estimated the time needed to achieve remedial goals at each plume based on site specific groundwater flow and contaminant transport modeling. Based on the current or proposed remedial actions, the MMR plumes are projected to be remediated between 6 to 35 years after initiation of the ETR systems.

- Estimated Mass of COCs. The mass of organic contaminants in the plume is calculated from the concentration profiles of each chemical and the volume of groundwater containing that concentration. The estimated total mass of contaminants in each plume ranges from less than 1 pound to 12,000 pounds, with a total estimated contaminant mass of organic contaminants in MMR groundwater of over 15,000 pounds. We report here the numbers provided to us, and make no claim as to accuracy.

- Projected Annual Operations and Maintenance (O&M) Costs. Operational and maintenance costs are a function of the size of the remediation system and the contaminant concentrations being removed.

- Projected Annual Long-term Monitoring and Ecological Assessment (ECO) Costs. The annual costs for long term monitoring of the plumes and on-going ecological assessments are provided.

- Projected Life Cycle Costs. The total cost of each remedial action is given based on the cost of the remediation system, the time to achieve remedial goals, and the annual O&M and monitoring costs. The projected cost to achieve the remedial goals for all plumes at MMR is over $300 million (in 1998 dollars). This projected cost is not a present worth cost, and is based solely on the cumulative O&M costs for each plume site.

FINDINGS

Based on review of documents from the MMR Administrative Record, interviews conducted during the week long site visit, and our knowledge of groundwater remediation, we have developed overarching findings related to the remedial decision process and technology feasibility issues associated with the 13 significant MMR groundwater plumes. We grouped our findings in the following general categories:

- A retrospective view of the groundwater remedial decision-making process from a technical perspective, and,
- A prospective view of technical feasibility issues related to the selected technologies, remedial system design and implementation of these technologies.

Decision-Making Process Findings

1. **With the exception of the removal actions at FS-1 and FS-28, remedial decisions were not driven by quantitative estimates of risk; instead, they are driven by aquifer restoration to achieve background levels.**

   The groundwater cleanup goal for the 13 plumes is aquifer restoration. This cleanup goal is considered an applicable, relevant or appropriate requirement (ARAR) as defined by the Superfund process, because it meets the state standards for a sole source aquifer. The U.S. Air Force has also agreed to this cleanup goal as documented in the 1997 Strategic Plan, and in various public statements made since 1996.

2. **The primary technology selected for remediation of MMR groundwater plumes, namely, extraction, treatment and reinjection of contaminated groundwater, the ETR system, is appropriate.**

   The generic strategy for groundwater remediation encompasses removal or isolation (containment) of the source of the contamination; implementation of a technology, or technologies to contain and ultimately remove, immobilize or destroy contaminants of concern in the plume; and implementation of a monitoring system that provides a basis for system optimization and final site closure. At Superfund sites and most other chlorinated solvent sites, the most prevalent technology used for plume remediation is "pump and treat", followed by discharge or reinjection of the treated groundwater. A wider variety of technical approaches are being implemented for source remediation, however.

   Selection of appropriate technologies for groundwater cleanup depends on a large number of factors too lengthy to discuss here in detail. In the case of the MMR plumes, however, certain factors limit the technical options significantly. First the plumes are quite large and deep. Contaminants released from the base have impacted well over 40 billion gallons of groundwater. Secondly, the concentration of contaminants in the plumes are generally low, relative to the solubility limits of the contaminants, or relative to the concentrations of the contaminants in the immediate vicinity of the point or area of initial release. Both of these factors limit the applicability of various innovative or recently demonstrated technologies that rely on in situ processes to achieve remedial goals. Examples of these technologies include engineered in situ biodegradation, chemical oxidation, and in situ air sparging. Finally, the hydrogeologic characteristics of the Cape Cod aquifer provide a setting where the ETR technology has a high likelihood of achieving at least MCL levels of cleanup for the organic COCs within the projected time frames. The aquifer is highly permeable, and appears to exhibit a relatively low level of heterogeneity. The geology consists primarily of sands or silty sands, containing a low level of natural organic carbon, thus causing minimal retardation, or slow transport of the organic chemicals. Thus, we find that the ETR technology is appropriate for the MMR plumes.

3. **Groundwater remediation system implementation has proceeded quickly since AFCEE assumed primary management responsibility for the MMR IRP.**

   When AFCEE assumed the management of the IRP, groundwater remediation was under consideration, but only one system (CS-4) had been installed. AFCEE moved quickly to respond to stakeholder concerns on the inadequacies of the 60% design submittal. Building on the engineering and scientific studies that had been completed, AFCEE was able to achieve rapid acceptance from stakeholders of remedial strategies for the FS-12, FS-1, and Storm Drain-5 North (SD-5N) plumes. An ETR system for FS-12 was installed and operating by September 1997. Remediation decisions were reached on four of the major plumes using the DCM process. As of year-end 1999, ten ETR systems are expected to be pumping and treating more than 9 million gallons per day (MGD) of contaminated water, and plume containment has been documented at several plumes. In contrast to the slow pace of implementing remedial measures prior to the management transition, AFCEE has moved aggressively to install remedial systems and has accelerated the remediation process at MMR substantially. However, as noted elsewhere in this report, the speed of AFCEE's response due to the urgency of the situation may be the cause of some deficiencies in process documentation, and in the quality of the technical analyses used as the basis for technology selection, risk assessment analyses and public communications of these technical analyses.

4. **The DCM process uses the same nine criteria as CERCLA but is more transparent to non-technical audiences and is more comprehensive.**

   The DCM process was developed by AFCEE with significant input from many stakeholders to provide a more comprehensible process for selecting a remedial strategy from several alternatives for an individual plume. This process uses the same 9 criteria established in the National Contingency Plan under the Superfund program, but provides a level of detail not seen in the normal feasibility process conducted at other Superfund sites. The DCM contains a more quantitative assessment of many technical issues, such as the amount of mass that may be removed, and the extent of plume capture for each alternative. These data are then displayed in a manner that is much more understandable to the community, using ranges of values, and symbols that are more accessible to a non-technical audience. The combination of more quantitative comparisons of alternatives, and a unique communications format provides a more transparent and understandable decision making process that could serve as a model at other DoD sites where community stakeholders have a major influence over the decision process. We understand that the DCM process may be more cumbersome that the CERCLA process, but given the magnitude of expenditures required for groundwater cleanup, the additional costs associated with the DCM process appear justified.

5. Plume depictions in MMR Fact Sheets and reports do not always reflect monitoring data.

A common procedure to illustrate the nature and extent of groundwater contamination is to prepare two-dimensional diagrams that provide a plan view of the so-called groundwater plume at a single point in time. The boundaries of the plume are based on the analytical results of groundwater monitoring, and the numerical values of these boundaries are then established. This technique has been widely used at MMR to communicate the dimensions of groundwater contamination to stakeholders in reports, fact sheets, public presentations, and other communications formats. Because of the importance of accurate communication of plume dimensions, we reviewed the underlying basis for depiction of plume size, reviewing where available the actual groundwater monitoring data, and comparing those data to the plume maps.

We found that at several of the plumes, the accuracy of the plume map was uncertain, that the supporting data were not readily accessible, and that the basis for a number of critical design parameters could not be easily verified. Plume depictions often do not display data, making verification of the plume dimensions difficult. In some instances where data are displayed, the depicted plume boundaries do not reflect sampling results. In other cases, the contours encompass many non-detect values, giving the incorrect impression that a continuous plume is present where a discontinuous or fragmented plume may exist.

We do not know if the plume maps show plumes that are smaller or larger than the actual dimensions, although review of data at a few of the plumes suggested that the plume maps probably overestimate the actual size of the plumes. An overestimate of the plume size would mean that the estimate of chemical mass present may be overestimated. This would then lead to an overestimate of the potential health and ecological risks, an excessively conservative design of the ETR system, predicted time frames for remediation that may be too high, and cost estimates exceeding probable life cycle costs. Another important consequence of inaccurate reporting of the data is loss of credibility for MMR management, and a public perception that the problem may be much larger than it actually is.

6. Continuous pumping of remediation system extraction wells has resulted in pumping and treating of relatively clean groundwater.

We reviewed the current operation of the ETR systems for plumes FS-12 and SD-5N. In the SD-5N ETR system, we noted that the levels of contaminants in extracted water from some of the extraction wells was quite low, suggesting that the current pumping sequence may not be achieving the maximum mass removal of contaminants for each gallon of water extracted.

Specifically, during our site tour on 20 July 1999, we noted that water entering the SD-5N treatment plant had estimated concentrations (J values) for each constituent that were less than 1 µg/L. Therefore, continuous pumping of these wells is currently not efficiently removing mass from the plume. Cycled pumping is likely to prove more effective, essentially providing time for the plume to "catch up" to the ETR system. We did not review pumping data or monitoring results at all of the operating ETR systems, but the finding for SD-5N indicates that more careful attention to optimum operation of ETR systems now and in the future should provide operational efficiencies and lower overall costs of remediation.

7. **In general, formal, independent technical peer review of key documents (e.g. groundwater models, project implementation plans, remedy designs, etc) is lacking.**

The IRP at MMR is a large and complex remediation program, with current expenditures in excess of $200 million dollars. In the past two years alone, nearly $130 million has been expended. We did not undertake a rigorous review of how these funds were allocated between plume remedial programs and other aspects of the IRP. However, we did not find that independent peer review was commonly used to ensure the most efficient use of these funds. For example, as far as we can tell, AFCEE relies on an ad hoc, informal review process to review major site documents. The only group identified was the Technical Review and Evaluation Team (TRET), which was formed following the uproar over the 60% design submittal. While the current contractor and subcontractors may have adequate internal quality control systems in place (an issue that we did not evaluate), the lack of a formal program to use external independent peer review is a missed opportunity for AFCEE and the DoD to achieve potential significant cost savings in system design and operations while still meeting the intent of the selected remedial system. Given the small AFCEE staff, and the many demands on the time of the AFCEE personnel, a more formal independent peer review process would provide an important management tool to AFCEE. At the time when AFCEE assumed primary IRP management responsibility, such an external peer review program would not have been feasible, because of the demanding schedule constraints imposed by the crisis atmosphere. Peer review processes often lead to substantial savings, but the review process can be cumbersome and time consuming. As this acrimonious environment has subsided, AFCEE now has the opportunity to use effectively an external peer review process.

8. **Site-specific groundwater modeling approaches, where examined, are not consistent with the available field data, complexity of the site, intended use of the model, and the question the model is supposed to address.**

A key technical strategy at the MMR has been the development, calibration and application of numerical groundwater flow and transport models to simulate the effectiveness of various technical alternatives for groundwater remediation. The modeling approach has relied on state-of-the-art computer models calibrated in three dimensions, and with time and length scales that require hundreds of thousands to millions of individual nodes in the computer code. We did not undertake a careful peer review of each site model to assess, among other issues, whether appropriate codes are being used, whether the model assumptions are appropriate for the site conditions, and whether the submodels used to predict the fate and transport of the contaminants of concern are scientifically valid. It is our impression, however, that the size and complexity of the models used is inconsistent with the relatively homogeneous stratigraphy that characterizes the Cape Cod aquifer. As stated by technical representatives during our weeklong site visit, the hydraulic properties of the aquifer (porosity and hydraulic conductivity) are relatively uniform compared to most Superfund sites with groundwater contamination. Given this geologic environment, use of a three-dimensional model with upwards of 20 multiple layers does not appear justified. Using a more complicated model than is necessary greatly impacts the cost of a project, substantially increasing the costs associated with the modeling effort. In addition, to implement complex models such as these with confidence, a tremendous amount of hydrogeological data is required. It is not apparent to the authors that the data exist to justify such a complex model.

For example, in 1996, while evaluating SD-5N, the TRET observed that the plume is shallow, the groundwater flow directions are almost horizontal, and the hydrogeology is not complex. The remedial goal was hydraulic containment, so all one needed to consider was the ETR impacts on the flow system. Yet, a complex model with 800,000 nodes was used for plume simulation when a simpler approach would have been adequate. Similar modeling decisions appear to have been made at other plume sites. Here is an example where external independent review of the modeling program would have likely provided a more cost effective modeling program, with sufficient accuracy to meet the objectives of the modeling efforts, namely to predict the effectiveness of the ETR systems, and to predict the time frames for achieving cleanup goals.

9. **While models have played an important and useful role in decisions since 1996, it appears that there is inappropriate use and/or over-reliance on modeling predictions (e.g., the DCM compares plume capture for different ETR designs – number of wells, location of wells, etc).**

Modeling, while conceptually valuable, should not supplant, and cannot substitute for field data analyses. As pointed out by the expert panel on groundwater circulation wells, modeling has an important, but limited value. The use of models is a valuable exercise in the conceptual evaluation of various remedial options; however, over-reliance on models should be avoided. Modeling is not a substitute for data in the vicinity of the ETR. As an example, a million-plus-node model was used to simulate the FS-12 plume; however, the treatment plant was designed based on the maximum EDB concentration found in the plume. This negated the use of such a complex model.

10. **Given the size and complexity of some plumes, additional time devoted to field studies (months) may be justified to ensure thorough technology evaluation and optimized final designs.**

The plumes at MMR are very large, both in terms of length and depth. Given the size of these plumes, technology evaluations may require more time to complete, particularly if the technology is innovative. For example, MNA was evaluated for implementation at Landfill-

1 (LF-1). This plume is 17,300 ft long, 5,500 ft wide, and as much as 125 ft thick; however, relatively few (less than 10) new wells were installed that were designed for discrete interval sampling, and the new wells that were installed generally had only one or two depth intervals. Although MNA is likely to be feasible at this site, the community and regulators may have been more comfortable if more definitive data could have been presented. Installation of additional wells, and collection and analyses of additional data would have required more time and money, but the overall cost would be small compared to the total remedial cost.

Technical Feasibility Issue Findings

1. Transition from active remediation (pumping) to long-term aquifer management is conceptually defined. Practical details/procedures for implementing this concept have not been developed.

As documented in the Strategic Plan and in various fact sheets, AFCEE has proposed a three-step process for managing the closure of each of the plume remediation programs. As noted, this three-step process begins with the operation of the cleanup technology until MCLs are achieved. Active remediation will continue if it is shown that it is not technically or economically feasible to achieve complete aquifer restoration, defined as achieving below detection levels for all COCs throughout the entire volume of the COC plume. At that time, a decision will be made to rely on monitored natural attenuation, long term monitoring, or a new or innovative technology to achieve the restoration goal. At this time, based on the information provided, this transition plan is in conceptual stages only, and the formal details of how these decisions will be made have not yet been articulated. We provide our recommendations for developing this process in the next section.

2. Estimates of times to achieve cleanup goals (e.g. restoration) are overly optimistic.

The estimated cleanup times for the ETR systems, as summarized in Table 1, appear overly optimistic. The design pumping rates are low relative to the size of the plumes, in order to minimize impacts on surface features (e.g., ponds). For example, as shown in Table 1, the number of pore volumes to be extracted each year for the 13 major plumes range from a low of 0.04 to a maximum of 0.76 per year. Where multiple pore volumes of aquifer plumes need to be pumped in order to restore the aquifer, cleanup times will be extended if the annual extraction rate is below 0.5 pore volumes extracted per year. Depending upon the initial average concentration of a contaminant compared to the MCL cleanup goal, and the magnitude of retardation, between 5 and 50 pore volumes of contaminated water may need to be extracted to meet cleanup goals. At an extraction rate of 0.5 pore volumes per year, the duration of cleanup could range between 10 to 100 years.

Furthermore, the predictions for cleanup times provided in fact sheets and DCM documents rely on site-specific groundwater flow and transport numerical models. Although the models are quite detailed, as noted earlier, it is unlikely that the models accounted for various factors know to limit the effectiveness of ETR. These factors include the potential continual presence of isolated pockets of residual pure-phase organic solvents in the aquifer, the slow desorption of some contaminants that may adsorb to aquifer materials in inaccessible (i.e. no flow) regions in the aquifer, and the potential for vertical migration of some contaminants. The generally low concentrations found in most of the plumes, the detachment of some plumes from source areas, and the general tracking of plumes with the three-dimensional flow system are consistent with dissolved contamination. However, the use and disposal of chlorinated solvents, as well as the large source areas suggest the potential for dense non-aqueous phase liquids (DNAPLs). The presence of DNAPLs could be masked by the rapid groundwater flow system and high recharge, yielding low dissolved concentrations a short distance downgradient from a continuing DNAPL source. The possible presence of DNAPL would extend the time to cleanup, making aquifer restoration impractical in the source area.

These factors lead to considerable uncertainty in the accuracy of cleanup time predictions. While there are other factors that may cause an overestimate of the cleanup times, such as an overestimate of plume size, mentioned earlier, it is likely that the current estimates are overly optimistic. This appears to be the case for the chlorinated solvent plumes (see Table 1) in particular.

3. **Performance assessment of ETR systems should be based on a comparison of actual to predicted field data.**

For three of the plumes where active treatment is on-going (CS-4, FS-12 and SD-5N), we assessed the level of analysis prepared by AFCEE contractors to support performance assessment. In general, the groundwater monitoring reports contained all relevant hydrologic and chemical data obtained during the reporting period. However, a careful review of plume maps and other depictions of the nature and extent of groundwater contamination revealed inconsistencies between actual field data and the boundaries of presumed plume volumes presented in these reports. Although we did not do an exhaustive analysis of this issue, we found an uncomfortable number of examples where plume delineation was more of an interpretation of the graphic analyst than boundaries grounded in actual groundwater samples. (See for example, Figure 1-3, December, 1998, 3rd Quarter Performance Monitoring Evaluation Data Report, FS-12). We were not able to verify many of the statements in these reports regarding the performance assessment of the ETR system. Finally, given the significant investment in groundwater modeling at MMR, the lack of comparative analysis was surprising. Comparison of changes in groundwater monitoring results to model predictions would be a useful analytical approach to performance assessment at MMR.

4. **Capital and annual costs of remediation systems and future or life cycle costs need to be reported in an accessible format.**

The management team for the MMR IRP has prepared many documents containing actual or projected costs for all activities at the MMR. Various formats have been used. For example, the DCM fact sheets compare the expected costs of different technical alternatives for groundwater cleanup. Costs are provided as total projected costs to achieve the cleanup goals. The projected life cycle costs for the 13 major plumes are summarized in Table 1 in this report. These costs apparently represent a simple cumulative total of annual costs times the projected lifetime of the cleanup project. We did not have sufficient time to evaluate the accuracy of these cost estimates or to determine whether the basis for these cost estimates was technically sound. However, we were surprised that documentation for these cost estimates was difficult to obtain and could not be easily provided to the peer review team during our site visit. Our conclusion at this point is that the relative costs of alternative remediation systems have been of greater importance to AFCEE and the stakeholders rather than the absolute costs of these systems. Presentation of the cost data and cost analyses in a format accessible to both technical and non-technical audiences apparently has not been a priority at MMR.

5. **Containment monitoring must rely on monitoring water quality downgradient of ETR systems.**

   Because of the permeable groundwater system and the low pumping rates, drawdowns in the vicinity of extraction wells are on the order of a few tenths of a foot or less, making hydraulic monitoring and definition of a capture zone difficult or impossible, especially because seasonal water levels vary by as much as 3 feet. As a consequence, performance assessment regarding the efficacy of the ETR system to contain and remediate the contaminant plume must rely on water quality monitoring data downgradient of the ETR system. These water quality data will provide a more reliable assessment of the effectiveness of the ETR system, since groundwater elevation data are likely to be imprecise.

6. **Although scheduled milestones are important to keep the MMR remediation process moving forward, consideration should be given to some schedule slippage when there is technical justification.**

   Although groundwater at MMR is relatively fast moving, even at a groundwater velocity of one foot per day, a retarded plume will move less than 30 feet in a month. Therefore, a few months slippage will not result in a significant difference in overall plume size. The authors are aware that the ability to change the schedule is not completely in AFCEE’s control. However, when warranted based on technical issues, AFCEE should mount a strong case to the regulators/community for schedule extension.

RECOMMENDATIONS

The technical peer review team has developed overarching recommendations related to the remedial decision-processes and technical feasibility issues associated with the 13 significant MMR groundwater plumes. These recommendations include the following:

1. Make all site data readily accessible and ensure that it is comprehensible and complete.

The IRP has produced a small library of documents that present the results of studies, designs, and engineering construction reports. The amount of information provided in the more than 8,000 documents produced is overwhelming, and difficult to access. In addition to these formal documents that have been released to the public, we understand that a substantial amount of documentation materials are stored in individual files of contractor personnel. While it is impossible to make all of these materials available to the public, we recommend that the IRP management review document control and document access policies. Having all relevant site data in a format that is accessible to all stakeholders would increase the transparency of decision making at the MMR, and would provide relevant support to many of the decision documents related to remedy selection, cost estimates, and risk calculations. Verification of the statements made by IRP management will become even more critical in the future when decisions will have to be made on whether to continue groundwater remediation systems once MCLs are reached, or once the contaminant levels reach a limit that may be higher than MCLs. The current Geographic Information System (GIS) provides a basis for improving the accessibility of site data. We further recommend that the IRP provide a roadmap to relevant documents for each of the major groundwater sites. Stakeholder involvement in the development of this roadmap is essential.

2. Define the appropriate qualifications and skill mix needed for the next phase of groundwater cleanup.

The IRP at MMR is nearing a crossroad. Once active remediation systems have been installed to achieve the cleanup goals at the 13 groundwater plumes, success of the program will depend on the capabilities of the contractor(s) to optimize system performance. This phase of the cleanup is not simply operation and maintenance of the ETR systems, although that function will need to be completed effectively. Rather, system operation will require continual assessments of the system performance to demonstrate plume capture, mass removal, and adequate progress towards achieving cleanup goals. This phase of the cleanup will also require thorough documentation of system performance, and comprehensible and clear technical communication to the community.

For example, it is likely that the current ETR systems will require some modifications to ensure cost effective operation. As we have noted, continued pumping of wells where contamination has decreased below detection limits is not an efficient use of resources. On the other hand, the current system may not be effectively capturing a plume, and modifications will be needed. System modifications could include varying pumping regimes, installing new extraction wells, and reinjecting the treated water in new patterns compared to the original design. This is the essence of the "observational approach" for groundwater remediation, which reflects the fact that only through applying hydraulic stress to an aquifer, via the ETR system, can the ultimate effectiveness of the remediation system be assessed. This is further discussed in Recommendation 4 of this section.

Finally, in the operations phase of the groundwater cleanup, the IRP manager will have to address two controversial and complex issues, namely, 1) the appropriate extent to which monitored natural attenuation should be used for plume management and remediation, and 2) evaluating and implementing closure strategies for each plume. Based on these needs, MMR should consider whether the current contractor team has the requisite mix of technical personnel and experience to meet the analytical demands of the next phase of the project. The current contractor team has effectively implemented engineering construction projects, and achieved remarkable success in meeting schedule milestones. Future actions will require a more intense level of scientific analysis and effective technical communication, and future contractors must be capable of providing these capabilities.

3. Establish a formalized peer review process for various aspects of the projects on a periodic basis.

As noted in our findings section, the IRP has not used an independent peer review process to ensure quality and cost effectiveness in engineering design, construction and operations. Given the historical conditions at the facility, this is understandable. We now believe that the climate has improved to the point where such independent external reviews of major cleanup decisions will provide significant value. In particular, we see the need for a formal value-engineering process to review all future engineering designs. We are convinced, based on personal experience, that such reviews will lead to significant life cycle cost savings without reducing the effectiveness of the overall groundwater remediation system. MMR should consider the establishment of a standing peer review team consisting of independent experts who could provide technical advice to AFCEE's management team and to the U.S. Air Force regarding the effectiveness of the ETR systems, the need to consider alternative technologies, and effective strategies for plume closures. This expert panel would complement the TRET, whose composition includes representatives from stakeholder groups, namely, site regulators.

The cost of the formal review process is justified given the projections of over $300 million to implement the groundwater cleanups at MMR. Even a modest five percent reduction in this figure would easily pay for this formal external peer review process which is likely to cost less than 1 percent of the projected costs.

4. Utilize the observational approach and monitoring data to update and improve groundwater remedial systems.

One of the characteristics of groundwater cleanup is the uncertainty associated with measuring and monitoring the effectiveness of a subsurface technology. The performance of the ETR systems will require continual review of monitoring data, which provides the basis for inferring whether the system is operating as designed, and whether it is technically and economically feasible to achieve the cleanup goal. We strongly support the continued use of the so-called "observational approach" in evaluating the performance of the ETR systems and the recirculating well technology. This approach is an essential part of the overall groundwater management plan that will need to be continued well into the future at most of the major plumes at the MMR. It requires careful review of monitoring data, and the determination of the need for and type of system modifications (e.g., new wells, or alternative pumping strategies for installed extraction wells, or upgrades of the treatment or reinjection systems) to insure optimum system operation.

5. **Develop a more comprehensive, routine performance assessment program of the plume remediation programs based on actual field data as reported in the quarterly monitoring reports.**

Quarterly monitoring reports currently contain hydrogeologic and contaminant chemistry data collected during the quarterly sampling events to meet legal requirements. We recommend that the scope of these reports be expanded to encompass a more extensive analysis of system performance. This scope should include, among other components, periodic assessments of the projected time to achieve cleanup goals, at least on an annual basis, recommendations on ETR system optimization to improve system efficiency, recommendations on specific studies that should be undertaken to enhance system performance, and a continuous evaluation of the extent, if any, of natural degradation of contaminants as compared to mass removal by the ETR system. Estimates of mass of contaminants remaining should be compared to original mass estimates, and discrepancies discussed.

The performance of the treatment systems should also be carefully assessed. For example, at SD-5N, the original treatment sequence included both an advanced oxidation process as well as granular activated carbon (GAC). Because influent concentrations to the treatment system were much lower than projected, only the GAC process has been used regularly. Future optimization studies of treatment processes may also reveal cost saving opportunities.

Although the CS-4 ETR predates AFCEE, it is the ETR with the most history having started operation in November 1993, and is another example of the importance of regular and systematic performance assessment. By March 1996, five of the 13 extraction wells were pumping water with non-detectable concentrations of VOCs and EDB. Evaluation of the system in 1997 raised questions as to whether the system is effectively capturing the western part of the plume or whether the plume is moving downward just before the containment fence.

Cost effectiveness will be one of the advantages of this continual performance assessment; however, the primary benefit will be more effective and transparent technical communication to the community regarding the progress of cleanup.

6. **Consider contributions of less traditional approaches for site remediation.**

Although currently the ETR technology appears to be the best technology for site remediation at MMR, it is certainly a slow and costly process. Innovative technologies are continually being developed, some of which may prove to be a feasible alternative to ETR. It would be of benefit to MMR and the community to have an on-going process for keeping abreast of new remedial technology developments and perhaps pilot-testing the most promising technologies at sites if they appear to be applicable. These technologies could be tested on a small-scale without interfering with the current ETR technology and remedial process.

7. **Although transition from active remediation (pumping) to long term management of plume restoration is conceptually defined, develop the practical details/procedures for implementing this concept.**

As noted in our findings, AFCEE operates under a three-step process for decision making as the cleanup goal of MCLs is approached. Essentially, this process, as described in an MMR IRP Fact Sheet entitled "Proposed Plan for the Southwest Operable Unit" (June 1999) consists of the following: 1) active remediation until federal MCLs and state drinking water standards are achieved, 2) when MCLs are achieved and before the system is shut off, to determine if unacceptable risks are present (if so continue system operations and /or pursue additional measures as required to achieve acceptable risks) and, 3) once acceptable risks have been achieved, evaluate the technical and economic feasibility of additional remediation to approach or achieve background concentrations. We strongly recommend that AFCEE begin the process of defining explicitly how these decisions will be made in the future. Such a process needs to consider some of the following questions:

1. If the ETR system does not perform as predicted, and cleanup times are projected to exceed substantially the initial estimates, what decision process should be followed to determine the correct course of action?

2. If the contaminant levels in the plume do not decrease below MCLs, but rather stabilize at a level above MCLs, what decision process should be followed to determine the correct course of action?

3. If MCLs are achieved (and the authors have serious doubts that this will occur) and acceptable risks have been achieved, what factors will be considered in determining the definition of "technically and economically feasible"?

4. If it is determined that complete restoration is not achievable either due to technical or economic constraints, how will decisions be made on long-term management, addressing such factors as monitoring programs, reporting programs, long-term institutional control, and so on?

Achieving consensus on these issues between the community, regulators and the DOD will be challenging, and thus, the process should be initiated as soon the ETR systems are in place, and some period of operation (at least one year) has been completed.

8. **Report capital and annual costs of remediation systems and future or life cycle costs in an accessible format.**

The current IRP lacks a consistent approach to reporting and documenting capital, annual O&M, and life cycle costs for remediation systems at the MMR, as noted in the findings. We recommend that MMR develop a consistent process for cost estimating and reporting that is accessible to non-technical audiences, and is relatively easily verified. The importance of consistent methodologies for cost reporting should be obvious. Without consistency, cost information can be misleading, and reduce the credibility of MMR management with the public as well as DoD. While we recognize that cost has been a secondary factor in decision making to this point, given that aquifer restoration is the main driver, future costs will become an issue, given the low level of human health and ecological risk associated with most of the plumes, and the continual debate over resources within DoD. Consistent cost information is also essential for implementation of creative offset programs, such as the nitrate program, described in detail in the community involvement report. Finally, we recommend that MMR develop protocols for addressing the issue of uncertainty in future cost estimates, both with respect to the time value of money (i.e., some consistent discount rate should be used to permit present worth comparisons of alternatives) as well as technical uncertainties in system performance. Such considerations are especially important if long-term institutional controls are the only option for those plumes where it is not technically feasible to achieve complete restoration.

9. **Consider establishing a center for research at MMR on community outreach, risk and technology communication, and evaluation of innovative technologies to develop effective strategies for federal facilities to achieve site closure in a manner acceptable to the impacted community in the most cost effective manner achievable.**

REFERENCES

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ATTACHMENT

CASE STUDIES - GROUNDWATER REMEDIAL ACTION

The TPRT has chosen six of the 13 identified significant plumes at MMR as case studies. The six plumes chosen (Ashumet Valley, FS-12, SD-5, FS-28, CS-10 and LF-1) are believed to be representative of the overall plume population. Additionally, the case study plumes include four that have undergone the MMR-specific DCM process.

ASHUMET VALLEY PLUME

In addition to Fact Sheets, a number of documents were reviewed that include discussions on the Ashumet Valley Plume. These documents include the MMR IRP Management Action Plan, the ROD for Interim Action, the MMR 5-Year ROD review, the Ashumet Valley Plume DCM document, the project execution plan, and the draft Ashumet axial fence data gap technical memorandum.

Brief Site Description

The Ashumet Valley plume originates at the former Firefighter Training Area 1 (FTA-1) with contribution from the decommissioned MMR sewage treatment plant (STP). FTA-1, in use from 1958 to 1985, is located 500 ft north of Kittredge Road near the southern boundary of MMR. The former sewage treatment plant (Chemical Spill Areas 16 and 17) is located approximately 1,000 ft south and down-gradient of FTA-1. This facility operated from 1936 to 1995. More than 46,000 tons of contaminated soil were treated at FTA-1. This work was completed in 1997 and this source area no longer contributes to the Ashumet Valley plume. Cleanup of contaminated soils at the former sewage treatment plant is scheduled to begin in summer 2000.

The Ashumet Valley plume, as defined by MCL exceedance of any contaminant, is approximately 24,000 ft long, 2,600 ft wide and over 150 ft thick. The plume extends from MMR's southern boundary to the south-southwest near Ashumet Pond and past Carriage Shop Road in Falmouth, towards Route 28. Flow within the aquifer is predominantly horizontal with gradients ranging from 0.001 to 0.002 ft per ft (ft/ft). Horizontal flow velocities range from 1 to more than 4 ft per day (ft/day) (Ashumet Valley Project Execution Plan, September 1998).

The primary contaminants in the Ashumet Valley plume are TCE, PCE, and 1,2-dichloroethene (1,2-DCE). Maximum concentrations reported to date are 83 ppb TCE, 137 ppb PCE and 143 ppb 1,2-DCE. EDB has also been detected sporadically in excess of its MCL in a number of wells near Carriage Shop Road. Inorganic constituents associated with the plume include nitrate and nitrite, ammonia, phosphorus, boron, arsenic, iron and manganese. As of 1997, none of these inorganics were detected in concentrations exceeding primary MCL values. However iron and manganese were detected near the head of the Ashumet Valley plume in excess of secondary MCL values. Additionally a small phosphate plume exists near the former sewage treatment plant source.

The estimated volume of the Ashumet Valley plume is 4 billion gallons. The estimated organic chemical contaminant mass is approximately 1,600 pounds.

Remedial Selection Process

Ashumet Valley is one of four plumes in 1997 to go through the "decision criteria" process, a public process that enables the remedial project managers and the public to compare and evaluate cleanup alternatives. The remedy selected through this process in September 1997 consisted of (1) an axial extraction fence to provide restoration of the Falmouth well field, (2) an extraction fence to protect Ashumet Pond from phosphorus, (3) a "nitrates offset" program, and, (4) further investigation in the southwest portion of the plume between Hayway Road and Carriage Shop Road to determine if there are higher concentrations of halogenated organic compounds in this portion of the plume (Alternate I, with modifications). A capture system was intentionally not recommended south of Carriage Shop Road to avoid neighborhood impacts and because the uncaptured plume is stated not to pose human or ecological risks. Natural attenuation of the uncaptured portion of the plume would be monitored, and fate and transport modeling conducted. According to AFCEE (Ashumet Valley Plume Response Decision Fact Sheet, September 1997), this alternative was selected based on its ability to best balance the objectives to restore the aquifer for use as a public water supply within a reasonable time frame, to provide significant mass capture, and to reduce human and ecological risk. This alternative also minimizes pumping rates on the aquifer and construction and operations impacts on neighborhoods. AFCEE estimates that this approach is expected to capture approximately 70 percent of the contaminant mass through active treatment systems and capture in silts. Modeling suggests that pumping stress will change the water table approximately 0.2 ft at the Falmouth Conservation Wetland, 0.4 ft at Ashumet Pond, and no change at Flax Pond (Ashumet Valley Project Execution Plan, September 1998).

AFCEE apparently is reconsidering the necessity of installing the phosphorus extraction fence associated with Alternative I (Ashumet Valley Groundwater Plume and Source Update Fact Sheet, February 1999). AFCEE's conclusions based on evaluation of phosphorus transport and its effect on pond ecology include:

- An ETR approach is inefficient in that phosphorus is largely bound to aquifer media;

- USGS bench-scale and field-scale tests indicate that operating an ETR system may result in overall increases in phosphorus loading to the pond rather than reductions; and,

- Aquifer and pond data collected over the last six years indicate that phosphorus concentrations are in a steady state in wells near the pond.

The February 1999 Fact Sheet indicates that AFCEE recommends a change in the phosphorus approach but "does not predetermine that nothing more should be done".

According to Jim Snyder (AFCEE Remediation Program Manager), the DCM process associated with the Ashumet Valley plume cost $330,000, modeling costs were $1.4 million, design costs were $670,000, construction costs were $7,545,000, annual O&M is projected to be $570,000, and annual monitoring and ecological assessment costs are $650,000. Twelve years of active groundwater extraction and treatment, and twenty years of MNA are estimated to achieve Ashumet Valley aquifer restoration. The projected life cycle cost associated with this project (based on 1998 dollars) is $32.24 million.

Analysis

The remedial goal for Ashumet Valley is restoration. The Ashumet Valley plume cleanup is being carried out under a complex set of remedial objectives (i.e., restoring the aquifer for use as a public water supply within a reasonable timeframe, significant contaminant mass capture, reduction in potential human and ecological risks, low pumping rates to minimize hydraulic and ecological impacts and sensitivity to remedial system impacts on residential communities). The decision-making process for the Ashumet Valley plume is well documented via the DCM process. Based on an average groundwater extraction rate of 1,200 gpm, 0.16 plume pore volumes are anticipated to be extracted annually. The estimated time (12 years) to achieve the remedial goal for the Ashumet Valley plume is overly optimistic, however the hydrogeological setting (high flow and recharge) and natural attenuation should accelerate the rate of plume cleanup.

AFCEE's proposed change in approach regarding the phosphorus extraction fence associated with Alternative I of the DCM process is supported by the technical analysis. It is important that the regulatory agency / community involvement process of changing the planned remedial alternative be similarly well documented.

Findings

Technology Evaluation and Selection

- Given the large dissolved plumes and their location below the water table in a permeable aquifer, the remediation technologies selected and evaluated at Ashumet Valley, i.e., ETR and MNA, are appropriate. Most current innovative technologies focus on source area remediation, which generally are not appropriate for a large, low-concentration dissolved plume. AFCEE has not overlooked an appropriate technology. The TPRT is unaware of other technologies for this setting, with the possible exception of enhanced bioremediation.

- The $8.5 million nitrates trade-off program associated with the planned Ashumet Valley remedial alternative is a positive and creative step in creating greater environmental benefit.

Technology Feasibility

- The estimated time to achieve the remedial goal for the Ashumet Valley plume is overly optimistic (based on an annual pore volume extraction rate of 0.16). Using the observational approach and monitoring data to update and improve the remedial systems and cleanup time estimates is appropriate.

- For the Ashumet Valley plume (and overall MMR plume management), a periodic re-evaluation of the projected O&M costs and the overall projected groundwater remediation life cycle costs would be useful in re-defining remedial approaches (i.e., within the context of the full range of remedial decision-making factors).

FS-12 PLUME

In addition to Fact Sheets, a number of documents were reviewed that include discussions on the FS-12 Plume. These documents include the ROD for Interim Action, the MMR 5-year ROD review, the performance monitoring evaluation plan, 3rd quarter 1998 performance monitoring evaluation data report, action memorandum for Area of Concern (AOC) FS-12 source removal, and the FS-12 study area remedial investigation (RI) report.

Brief Site Description

The source of the FS-12 groundwater plume is a confirmed leak during the early 1970s in a now-abandoned fuel pipeline located west of Route 130 and north of Snake Pond in the Township of Sandwich. The abandoned fuel pipeline runs along the north shoulder of Greenway Road. As a result of the FS-12 pipeline leak, approximately 70,000 gallons of aviation fuel entered the soil at or near the unpaved road providing access to artillery range "L". Since 1995, over 44,580 pounds of contaminants have been removed from soil in the FS-12 AOC, an area of approximately 11 acres, by means of vapor extraction and air sparging. Confirmation testing is being conducted to ensure that the FS-12 source area has been cleaned up (MMR 5-Year ROD Review, March 1999).

The FS-12 plume, as defined by MCL exceedance of any contaminant, is approximately 4,800 ft long, a maximum of 2,000 ft wide and 60 to 130 ft thick. The areal and vertical extent of the EDB plume is larger than the areal and vertical extent of the benzene plume and encompasses the benzene plume. The FS-12 plume underlies most of Camp Good News, a privately owned summer camp facility. Groundwater is unconfined with an average depth to groundwater of 70 ft. The water table is exposed at the surface in Snake Pond to the southwest of the FS-12 area. Flow within the aquifer is generally south to southeast. The horizontal flow gradient ranges from 0.00025 to 0.0006 ft per ft (ft/ft). Data indicate that the vertical gradient shifts from downward to upward flow as groundwater approaches Snake Pond (FS-12 Performance Monitoring Evaluation Plan, April 1998).

The primary contaminants in the FS-12 plume are EDB and benzene. Maximum concentrations to date are 600 ppb EDB and 1,600 ppb benzene. The estimated volume of the FS-12 plume is approximately 1.7 billion gallons. The estimated organic chemical contaminant mass is 350 pounds. A model consisting of more than one million nodes was used to simulate the FS-12 plume.

Remedial Selection Process

The FS-12 plume remedial system, consisting of an ETR system, was part of a 60% design prepared for the National Guard Bureau for plume containment at MMR. This design was based on criteria set forth in the Record of Decision for Interim Action (IROD), utilizing extraction well fences at the leading edges of plumes. The system, consisting of 25 extraction wells, GAC treatment, and 23 reinjection wells began operating in September 1997. During public review, the 60% design for remediating MMR groundwater plumes was determined to be unacceptable by all parties because of its likely adverse impacts on Cape Cod's sensitive ecosystems and sole-source aquifer. The AFCEE took over responsibility for the remediation program in April 1996, and by May 15, 1996 had signed a Federal Facility Agreement (FFA) that contained enforceable milestone dates.

The original FS-12 ETR system was designed to maintain hydraulic control, defined as 100% capture of groundwater flow within the area where EDB exceeds its MCL. AFCEE, based on TRET recommendations in 1996, modified the remedial objective to capture as near as 100% of the plume as possible while minimizing ecological impacts to the Snake Pond area. According to AFCEE, the current system's total pumping rate, 800 gpm, is expected to have a minimal impact on the hydrologic system, i.e., drawdown of less than 0.5 ft at each extraction well (FS-12 Performance Monitoring Evaluation Plan, April 1998). As of September 1998, the FS-12 system has treated more than 400 million gallons of groundwater and removed an estimated 80 pounds of EDB and 72 pounds of benzene (MMR 5-Year ROD Review, March 1999).

According to Jim Snyder (AFCEE Remediation Program Manager), the modeling costs associated with the FS-12 plume were $496,000, design costs were $1,405,000, construction costs were $14,830,000, annual O&M is projected to be $720,000, and annual monitoring and ecological assessment costs are $580,000. Fifteen years is estimated to achieve aquifer restoration at FS-12. The projected life cycle cost for this project (based on 1998 dollars) is $34.3 million.

Analysis

The remedial goal for FS-12 is both containment and restoration. As presented in the MMR 5-year ROD Review (March 1999) and Final Performance Monitoring Evaluation Plan for Fuel Spill-12 (April 1998), the intent is to capture as near to 100 percent of the groundwater flow as possible within the area where EDB exceeds MCLs while minimizing ecological impacts to the Snake Pond area. The FS-12 plume cleanup is being carried out under a complex set of remedial objectives (i.e., containing, capturing and remediating the plume while minimizing impacts on Snake Pond and the adjacent J. Braden Thompson plume, and minimizing disturbance to private property).

MMR quickly designed and installed a groundwater ETR system. As part of the system design, hydraulic modeling was conducted and the designed system was conservatively based on the maximum EDB concentration found in the plume. Construction began in November 1996 and system startup began in September 1997 (6 days ahead of the US EPA milestone). Based on an average groundwater extraction rate of 800 gpm, 0.25 plume pore volumes are anticipated to be extracted annually.

The FS-12 3rd Quarter Performance Monitoring Evaluation Data Report (December 1998) states that the FS-12 ETR system is operating as designed and is containing the FS-12 plume; no changes in the ETR system are necessary. The report states that slight changes were made in the extraction rate (i.e., to maintain appropriate hydraulic control) based on the 2nd Quarter performance monitoring report and a recalibration of the groundwater model.

The performance evaluation reports do not appear to present summary information regarding contaminant mass removal per given volume of extracted groundwater. This information would be useful in evaluating progress towards achieving remedial objective (i.e., reduction of EDB concentrations to below drinking water standards) or in possibly redefining the overall remedial strategy.

Findings

Technology Evaluation and Selection

- Given the large dissolved plumes and their location below the water table in a permeable aquifer, the remediation technology selected at FS-12 (ETR) is appropriate. Most current innovative technologies focus on source area remediation, which generally are not appropriate for a large, low-concentration dissolved plume. AFCEE has not overlooked an appropriate technology. The TPRT is unaware of other technologies for this setting, with the possible exception of enhanced bioremediation.

Technology Feasibility

- Groundwater remediation system implementation at FS-12 proceeded quickly.

- The estimated time (15 years) to achieve the remedial goal for FS-12 appears optimistic (based on an annual pore volume extraction rate of 0.25). The hydrogeological setting (high flow and recharge) should help plume cleanup; however, removal of multiple pore volumes may still be required to achieve aquifer restoration. Using the observational approach and monitoring data to update and improve the remedial systems and cleanup time estimates is appropriate.

- For the FS-12 plume (and overall MMR plume management), a periodic re-evaluation of the projected O&M costs and the overall projected groundwater remediation life cycle costs would be useful in re-defining remedial approaches (i.e., within the context of the full range of remedial decision-making factors).

SD-5 PLUME

In addition to Fact Sheets, a number of documents were reviewed that include discussions on the SD-5 Plume. These documents include: the source RI report, project execution plans, performance monitoring evaluation data report, and modeling reports.

Brief Site Description

The source area for the SD-5 plume is located 3,000 ft from the southern MMR boundary and includes a fuel spill that occurred in the early 1960s, tank flushing from the former Eastern and Western aquafarms, the former Non-Destructive Inspection Laboratory (NDIL), the former Corrosion Control Shop, and the Permanent Field Training Site (PFTS) hangar. An estimated 450 gal/y wastes were generated at the NDIL. From 1955 to 1970, these wastes were discharged to the NDIL leaching well, a weakened brick-lined dry well.

The resulting plume followed the Central Drainage Swale as it ran south from the source area. The entire SD-5 groundwater plume is approximately 10,000 ft long, a maximum of 1,000 ft wide, and 20 to 100 ft thick. The plume extends off the base toward Ashumet and Johns Ponds. The majority of the SD-5 plume is migrating through fine- to coarse-grained sands, although fine sands, silt, and clay characterize the geology at the distal end of the plume. The plume plunges; its bottom is about 35 ft below the water table near the source, about 70 ft below the water table at the base boundary, and about 120 ft below the water table near the leading edge. The estimated volume of the SD-5 plume is 22.75 million cubic ft (170.17 million gallons); the estimated mass in SD-5 north of the base boundary was 12.8 kg (Technical Memorandum on Groundwater Modeling and Preconstruction Investigation, August 1998). As discussed below, for remediation purposes, the plume has been divided into a northern half and a southern half.

The primary contaminants in the SD-5 plume are TCE and PCE. The northern portion of the plume also contains 1,2-DCE whereas the southern portion contains sporadic detections of EDB. Maximum concentrations to date are 82 ppb TCE, 6 ppb PCE and 220 ppb 1,2-DCE. These maximum concentrations generally are found near the source area and decrease down gradient.

Remedial Selection Process

AFCEE's preferred alternative for the SD-5 source area, which has been documented in a September 1998 Record of Decision, consists of excavating the contaminated soils and mixing them with a cold asphalt emulsion - a process called asphalt batching. Based on remedial actions, the SD-5 plume has been divided into a northern portion, SD-5N, located north of the base boundary (on site), and a southern portion, SD-5S, located south of the base boundary (off site).

SD-5N

The SD-5N plume was part of a 60% design prepared for the National Guard Bureau for plume containment at MMR. This design was based on criteria set forth in the IROD, utilizing extraction well fences at the leading edges of plumes originating on MMR. During public review, the 60% design was determined to be unacceptable by all parties because of its likely adverse impacts on Cape Cod's sensitive ecosystems and sole-source aquifer. The AFCEE took over responsibility for the remediation program in April 1996, and by May 15, 1996 had signed a FFA that contained enforceable milestone dates.

After review, it was decided to continue with the boundary containment for SD-5N, consequently, the remedial goal for SD-5N is containment. The decision was based, in part, on the TRET findings in 1996 that, for SD-5N, the plume is shallow, the groundwater flow directions are almost horizontal, and the hydrogeology is not complex. In addition, pumping at low rates will not impact sensitive ecological areas (i.e., surface water bodies). A model consisting of 12 layers and 800,000 nodes was used to evaluate extraction alternatives for SD-5N.

The remediation selected for SD-5N was ETR. The ETR system that was installed consists of 10 extraction wells and 8 reinjection wells located on base near the MMR border. The treatment plant uses activated carbon canisters. Construction began in February 1997 and the system began operation on August 4, 1997, two days ahead of the EPA-enforceable deadline. It is designed to pump 355 gpm. The influent concentrations of total chlorinated VOCs have declined, and fluctuated over the fourth quarter 1998 from 1.2 to 1.8 ppb. During this same time period, benzene, toluene, ethylbenzene and total xylenes (BTEX) concentrations (source of which is thought to be the Western Aquafarm area and the Petroleum Fuel Storage Area) declined from 8.7 to 5.3 ppb. EDB was not detected. Other chemicals detected included: iron – 1390 to 1530 ppb, manganese – 192 to 214 ppb, and naphthalene - 1.2 ppb. During the TPRT site tour on July 20, 1999, water entering the SD-5 North treatment plant contained estimated concentrations (J values) for each constituent of less than 1 µg/L. Based on review of performance data, the SD-5N ETR appears to be containing the northern portion of the plume.

According to costs provided by Jim Snyder (AFCEE Remediation Program Manager), the modeling costs associated with SD-5N were $196,000, design costs were $1,100,000, construction costs were $8,580,000, and annual operation and maintenance is projected to be $560,000. These costs do not include those associated with field investigations. Seven years has been estimated as the time to achieve the remedial goal for SD-5N. The projected life cycle cost associated with this project (based on 1998 dollars) is $15.3 million.

SD-5 South (SD-5S)

SD-5S is one of four plumes in 1997 to go through the "decision criteria" process, a public process that enables the remedial project managers and the public to compare and evaluate cleanup alternatives. The remedy selected through this process in December 1997 consisted of using five recirculating wells (Alternate E). Recirculating wells were chosen to remove mass while causing minimal impacts to neighborhoods and sensitive ecological environments. Part of this decision was to collect additional data to fill perceived data gaps. A year later, December 1998, having collected additional data, AFCEE made the following conclusions: (1) virtually the entire SD-5S plume (95-98 per cent) discharges to Johns Pond, (2) all samples of water taken at the surface of Johns Pond have not shown any detectable plume-related contamination from SD-

5S, (3) the primary contaminant in the SD-5S plume, TCE, is at low concentrations varying from non-detect to 50 ppb, and (4) an area of elevated TCE found by the U.S. Geological Survey is not part of SD-5S. AFCEE further concluded that this elevated TCE was not associated with MMR.

At that same time (December 1998), AFCEE concluded that there is no added benefit to human health or the environment from installing an active treatment system for the SD-5S plume. AFCEE went on to propose a change in the remedial alternative selected from recirculating wells to long-term monitoring. In letters between AFCEE and the EPA in January 1999, AFCEE suspended the public comment period for the proposal to eliminate the recirculating wells and asked that risk evaluation be the primary basis for determining the need for active groundwater remediation for SD-5S. The EPA's response on February 11, 1999 was, "Since restoration of the aquifer has always been, and will continue to be, a remedial action objective for cleanup of the groundwater plumes on and emanating from the MMR, EPA believes that action to restore this portion of the aquifer cannot be delayed." Thus, the remedial goal is restoration based not on risk, but on a State ARAR to protect a sole-source aquifer.

Subsequently, additional information led AFCEE to conclude that the elevated TCE was associated with MMR, and was likely the leading edge of the CS-10 plume. This realization led to a modified Alternative E such that the remediation selected combined recirculating wells (two along the axis of SD-5S) with an ETR system near Johns Pond. Two recirculating well treatment systems started on June 17, 1999, five days ahead of the FFA milestone date. Construction of two extraction wells on Hooppole Road is scheduled to begin on September 13, 1999.

Advective modeling was again used as a tool to evaluate the remediation. For SD-5S, the modeling process began with a regional model that had 21 layers and 21,965 active nodes per layer. After the regional modeling exercise, the area of the model was reduced (zoom or box model) to include the SD-5S plume and surrounding features and plumes. This model consisted of 653,400 nodes per layer, where again 21 layers were used for a node count of 13,721,400 nodes. Unfortunately, the model did not focus on the area requiring remediation, and the grid discretization in the zoom model did not lend itself to a detailed simulation of the hydraulics of recirculating well systems.

Costs associated with SD-5S for the recirculating wells and the ERT, respectively, provided by Jim Snyder (AFCEE Remediation Program Manager), are as follows: conducting the DCM process ($195,000), modeling ($400,000 and $120,000); design ($845,000 and $125,000) construction ($1,617,000 and $1,208,000), annual O&M ($145,000 and $75,000) and annual monitoring and ecological assessment ($160,000). The estimated time to cleanup based on modeling is six years (i.e., for Alternative E, more than 99 percent of the contaminant mass will have been captured, or will have migrated to/under the ponds and river). The projected life cycle cost associated with this project (based on 1998 dollars) is $5.10 million.

Analysis

The complex models developed for SD-5 appear to go beyond the available field data, site complexity and the intended question(s) the model is to address. For SD-5N, the TRET observed that the plume is shallow, the groundwater flow directions are almost horizontal, and the hydrogeology is not complex. The remedial goal was hydraulic containment, so all one needed to consider was the ETR impacts on the flow system. A simple capture zone model could have been used to aid the ETR design. Yet, a complex model with 800,000 nodes was used for plume simulation when a simpler approach would have been adequate. The modeling costs for SD-5N were over 35 % of the costs for the entire design. The modeling costs for the Alternative E evaluation process (SD-5S) were over 47 % of the costs for the entire design. The model did not focus on the area of the actual remediation, and was unable to simulate the hydraulic effects of the recirculating wells, the selected remedial action. A simpler model tailored to address the remediation would likely have provided more useful results and been more cost effective.

Drawdown and mounding around the SD-5 North ETR system are generally less than 0.4 ft, and the head differences in well clusters used to detect the vertical movement of the groundwater are often as small as 0.02 ft. These drawdown effects were determined only by monitoring during a planned system shutdown (October 12 and 13, 1998). The ETR system impacts the natural flow system only slightly and locally near the extraction/reinjection wells. This makes it difficult to monitor hydraulic control. Construction of an accurate capture zone using water-level data is difficult. In addition, the assumption of uniform background water-level variation across the aquifer is not accurate based on monitoring data. Seasonal fluctuations appear to be as much as 3 ft.

Findings

Technology Evaluation and Selection

- Given the large dissolved plumes and their location below the water table in a permeable aquifer, the remediation technologies selected and evaluated at SD-5, i.e., ETR, recirculating wells and MNA, are appropriate. Most current innovative technologies focus on source area remediation, which generally are not appropriate for a large, low-concentration dissolved plume. AFCEE has not overlooked an appropriate technology. The TPRT is unaware of other technologies for this setting, with the possible exception of enhanced bioremediation (especially for this relatively narrow plume).

Technology Feasibility

- AFCEE has performed well in implementing remedies and meeting milestones.

- The TPRT was unable to confirm many of the plume depictions because data were not readily available (i.e., not posted on maps). In some instances where data are displayed, the depicted plumes do not honor the data. In other cases, the contours encompass many non-detects, giving the incorrect impression that a continuous plume is present where a discontinuous plume may exist. This could lead to over estimates of mass in place and/or over design of an ETR.

- The estimated cleanup time for SD-5S appears optimistic. Cleanup estimates are based on data with uncertainties and models that do not include all fate and transport processes. Better estimates can be made with future performance data.

- Models have played an important role in remedial decisions. As pointed out by the expert panel on groundwater recirculating wells, modeling has an important but limited value. For SD-5, models appear to be overly complex and not tailored to answer remediation questions. There appears to be a disconnect between the modeling goals and level of effort, and the remediation needs to make design decisions.

- The hydrogeological setting (high flow and recharge) should help plume cleanup; however, removal of multiple pore volumes may still be required to achieve aquifer restoration. Using the observational approach and monitoring data to update and improve the remedial systems and cleanup time estimates are appropriate.

- It was observed that the ETR at SD-5N is pumping and treating relatively clean water. As indicated, during our site tour on July 20, 1999, water entering the SD-5 North treatment plant had estimated concentrations (J values) for each constituent that was less than 1 µg/L. Therefore, continuous pumping of these wells is not efficiently removing mass. Consideration should be given to cyclic pumping while still maintaining capture of contaminants.

- Given the permeable groundwater system and the low pumping rates, drawdowns in the vicinity of extraction wells are on the order of a few tenths of a foot or less, making hydraulic monitoring and definition of a capture zone difficult or impossible, especially because seasonal water levels vary by as much as 3 ft. Therefore, containment monitoring must rely on monitoring water quality down gradient of the ETR.

FS-28 PLUME

The documents reviewed that discussed the FS-28 Plume include Fact Sheets and reports on the Southwest Operable Unit (SWOU). SWOU documents include the Remedial Investigation and Feasibility Study.

Brief Site Description

The FS-28 plume is believed to be detached from its source, although its source has not been identified. The FS-28 plume is entirely off MMR property, and extends from the Crane Wildlife Management Area (CWMA), below the western portion of Coonamessett Pond, and terminates in and below the cranberry bogs surrounding the Coonamessett River, where the plume discharges (upwells). The FS-28 plume is approximately 9,000 ft long and varies in thickness up to 100 ft and width up to 3,000 ft. Just south of the western arm of Coonamessett Pond, the FS-28 plume lies from -85 to -220 ft msl, and stays relatively deep (average depth is 150 ft) until it passes under Hatchville Road. In the area between Coonamessett Pond and Route 151, EDB has been detected generally between the elevations of -30 and -190 ft msl. There is no conclusive evidence to indicate that the FS-28 plume comes in contact with the bottom of Coonamessett Pond, although this is possible. None of the 45 water samples or 10 sediment samples collected from Coonamessett Pond during the RI contained detectable concentrations of EDB. North of Route 151, the FS-28 plume becomes laterally and vertically discontinuous, at several different elevations ranging from -20 to -220 ft msl. The trailing edge of the FS-28 plume is difficult to define because the concentrations are less than 0.1 ppb and generally close to the EDB detection limit of 0.004 ppb. The northern-most detection of EDB associated with the FS-28 plume is located approximately 1000 ft south of the MMR boundary. Discharge to the Coonamessett River appears to cause the flow field to converge, causing the plume to narrow.

EDB is the primary contaminant in the FS-28 plume. The safe drinking water standard is 0.02 ppb. EDB is a compound that was added to leaded gasoline, including aviation gasoline (AVGAS), to inhibit the buildup of lead in engines. The highest concentration of EDB in the FS-28 plume (18 µg/L) was detected in a monitoring well near the discharge area located south of Hatchville Road, with concentrations decreasing to the north. The maximum concentration just north of Hatchville Road was 14 ppb and the maximum concentration just south of the western arm of Coonamessett Pond was 4.9 ppb.

Remedial Selection Process

Because chlorinated solvents were discovered with the FS-28 plume, north of Route 151, in July 1997, the FS-28 plume investigation was folded into a larger regional effort, which is referred to as the SWOU, and became part of the Superfund process. That is, it is part of the CERCLA process and has an associated ROD. Subsequent to completion of the SWOU Feasibility Study in June 1999, the EPA, Massachusetts Department of Environmental Protection (MADEP), and AFCEE agreed that a separate Proposed Plan should be prepared to address the FS-28 plume. Consequently, the final remedy for the FS-28 plume has not yet been determined. Deleterious construction impacts to the CWMA are an issue. To minimize impacts to the CWMA, AFCEE is proposing containment as the remedial goal for the FS-28 plume.

Surface water detections of EDB in the Broad and Coonamessett Rivers have been found where the FS-28 plume is thought to discharge. EDB concentrations decrease when the nearby cranberry bogs are flooded during the winter months. Detections of EDB in Coonamessett River surface water have been found as far south as Route 28. Surface water detections have generally been at concentrations of less than 0.3 ppb. Because of the risk this completed pathway represented, AFCEE implemented a removal action, prior to making a decision on the final remedy.

The removal action was implemented to prevent long-term human exposure to EDB found upwelling into the surface waters of the Coonamessett River. The removal action was divided into a time-critical action and a non-time critical action. The time-critical action was undertaken in July 1997 for the leading edge of the EDB plume associated with FS-28. This action included installation of a deep extraction well (69EWOOOI) and an aboveground treatment system (GAC), with treated water discharged back to the river system. The well, EW-1, was installed in April 1997 and the treatment system went into continuous operation on October 14, 1997. Part of the time-critical removal action for FS-28 were the following: (1) provision of bottled water to 35 residents prior to installing connections to the public water supply, (2) 128 public water supply residential connections, (3) wellhead treatment at the Coonamessett Water Supply Well, (4) monthly collection and analysis of surface water samples along the Coonamessett River, (5) collected air samples in the areas to evaluate inhalation risks, (6) installation of EW-1, and (7) replacement of irrigation wells that may be impacted. As part of the non-time critical removal action for FS-28, the following were performed: (1) continued operation of extract, treat and discharge (ETD) system, (2) additional extraction of contaminated groundwater by shallow well points, and (3) alternate water supply for flooding the bogs by installation of piping from existing treatment plant to bogs.

Since October 1997, when the treatment system became operational, most of the FS-28 plume in this location has been captured by the extraction well, treated, and discharged to the Coonamessett River, meeting the Massachusetts Surface Water Quality Standards. The extraction well pumps groundwater at a rate of 600 gpm. In addition to EW-1, shallow groundwater extraction well points were installed as part of the Coonamessett River/Bog Separation Project. These actions appear to have eliminated the exposure pathway.

Interestingly, the successful removal action appears to have been designed without the aid of complex models. The costs of the removal action could not be determined as part of this review. Because this is a containment system, no time estimate was provided to achieve aquifer restoration.

Analysis

Subsequent to the installation of EW-1, it was simulated by two complex models (with many nodes) that gave different results. Preliminary simulations of EW-1 using the SWOU Zoom Model and the FS-28 plume shell gave a different prediction than the EW-1 Zoom Model. The EW-1 Zoom Model was calibrated to the EW-1 pump test and contained an anisotropy of 3 throughout. The anisotropy present in the SWOU Zoom Model is significantly higher, reaching 15 - 20 even in the locally highly conductive sands. The plume shell was based on a statistically-generated, three-dimensional plume. Because the data are sparsely distributed, rigorous geostatistically defensible varograms used in plume generation are not obtainable. The modeling appears to be overly complex and not tailored to answer remediation questions.

Findings

Technology Evaluation and Selection

- Given the large dissolved plumes and their location below the water table in a permeable aquifer, the remediation technologies selected and evaluated at FS-28 are appropriate. Most current innovative technologies focus on source area remediation, which generally are not appropriate for a large, low-concentration dissolved plume. AFCEE has not overlooked an appropriate technology. The TPRT is unaware of other technologies for this setting, with the possible exception of enhanced bioremediation.

- The removal action for FS-28 was risk (exposure) driven.

Technology Feasibility

- Several of the findings for SD-5 apply for FS-28 as well, and are not repeated, except for the one on modeling. There appears to be a disconnect between the modeling goals and level of effort, and the remediation needs to make design decisions.

- Monitoring surface and groundwater in the vicinity of EW-1 is appropriate. Using this observational approach and monitoring data to update and improve the remedial system is a proper technical approach.

CS-10 PLUME

A number of documents were used to evaluate the technology selection and implementation at CS-10. Documents included:

- Fact Sheet - Introduction to Additional CS-10 Plume Response Alternatives (July 1997)

- Fact Sheet - Analysis of CS-10 Plume Response Alternatives (July 1997)

- Final CS-10 Project Execution Plan, Jacobs Engineering Group, Inc. (March 1998)

- Final CS-10 ETR Pre-Design Technical Memorandum, Jacobs Engineering Group, Inc. (December 1998)

- Five-Year Review Report, AFCEE (March 1999)

Brief Site Description

The CS-10 source area is located in the southeast corner of the MMR and is currently used by the Air National Guard (ARNG) for vehicle maintenance and storage. The suspected source is for the northern and east-central portion of the CS-10 plume is the Boeing Michigan Aerospace Center (BOMARC). The Air Force maintained ground-to-air missiles in this area from 1960 to 1973. Activities conducted in association with this area are known to require substantial amounts of solvents, but the actual amount of waste and waste disposal methods have not been documented.

The CS-10 source area encompasses approximately 38 acres. TCE is the primary contaminant within the groundwater plume. The plume is approximately 17,000-ft long, 6,000 ft wide, and up to approximately 140 ft thick. In general, the plume is approximately 60 ft below the water table (approximately 120 ft below ground surface) along most of its length. It divides into an eastern and western lobe, and the eastern lobe further divides into a shallow upgradient plume, and a deeper downgradient plume slightly to the north of Ashumet Pond. The western lobe of the CS-10 plume has TCE concentrations as high as 400 μg/L spread over several depths. In the upgradient portion of the plume, TCE concentrations are generally similar to those detected in the western lobe of the plume, although a few isolated higher concentrations were detected several years ago. The downgradient portion of the eastern lobe has TCE concentrations as high as 5,000 μg/L. None of the primary contaminants of the CS-10 plume have been detected in the surface water of Ashumet Pond.

Recently, a high concentration TCE plume was detected on the southeastern side of Ashumet Pond. It is hypothesized that this plume is part of the CS-10 plume that has flowed under Ashumet Pond. However, studies are continuing to determine the source of this new plume.

Remedial Selection Process

CS-10 was one of four plumes that went through the DCM process in 1997. Eight remedial alternatives were initially proposed for CS-10:

- Alternative A — Extraction and reinjection (4 fences)
- Alternative B — Extraction and reinjection (3 fences)
- Alternative C — Recirculating wells (1fence) in combination with extraction and reinjection (4 fences)
- Alternative C1 — Recirculating wells (1fence) in combination with extraction and reinjection (4 fences with 1 fence slightly modified from that proposed in Alternative C)
- Alternative D — Recirculating wells (4 fences)
- Alternative E — Monitored natural attenuation
- Alternative F — Recirculating wells (1 fence) in combination with extraction and reinjection (4 fences with 1 fence slightly modified from that proposed in Alternative C)
- Alternative G — No-action alternative

Each alternative listed above was evaluated according to the DCM. This matrix was presented to the acceptance groups in July 1997. Upon incorporation of comments, Alternative B (with refinements) was selected as the most appropriate remedial technology for this plume.

The goal of Alternative B is to capture and treat the contaminant plume. Alternative B (with refinements) consists of an extraction fence located along Sandwich Road to capture the plume before it migrates into or under Ashumet Pond. A reinjection fence is located east of the plume. In addition, an in-plume mass removal action to expedite removal of highly contaminated groundwater was included in the remedial action. The Sandwich Road extraction fence and the in-plume extraction remedy were scheduled for installation by Summer 1999.

Two additional extraction fences are under consideration for location along the southern and southwest portion of the plume. Each of these extraction fences would have a reinjection fence immediately downgradient. These extraction fences are expected to begin operations in April 2000, but will be evaluated once the Southwest Operable Units study is completed to determine the necessity of the extraction fence.

Four recirculating wells were already in place in an area of high contamination just north of Ashumet Pond. These wells will be discontinued once the Sandwich Road extraction fence is operational.

According to Jim Snyder (AFCEE Remediation Program Manager), the projected annual O&M costs associated with the CS-10 plume are $1,500,000 and annual monitoring and ecological assessment costs are $730,000. Thirty-five years is estimated to achieve aquifer restoration at CS-10. The projected life cycle cost associated with this project (based on 1998 dollars) is $99.85 million.

Analysis

Three remedial alternatives were considered for the CS-10 plume in various configurations and combinations of the technologies. The three technologies considered were ETR, recirculating wells, and monitored natural attenuation. The recirculating well technology is unlikely to provide sufficient mass removal to stem contaminant migration. Likewise, while monitored natural attenuation may be occurring to some extent within the CS-10 plume, the natural processes are not functioning rapidly enough to prevent migration of contaminants into surface waters. Therefore, selection of ETR is the most feasible approach for plume containment at this site. Rapid installation of an ETR fence along Sandwich Road was an appropriate response to prevent contaminant migration into Ashumet Pond. In addition, installation of an in-plume treatment system was a logical approach to speed up the restoration process.

The ETR system for the CS-10 plume has only recently been operational; therefore, there is limited data to evaluate the effectiveness of the system. However, the monitoring program that is in place appears sufficient for evaluating the effectiveness of the ETR system.

The system will have a total extraction and reinjection rate of approximately 5.2 million gallons per day and is predicted to capture 98% of the contamination. A small amount (<2%) will not be captured, but is not predicted to have any adverse impact on human health or the environment. This extraction rate translates into removal of 0.04 pore volumes per year at the Sandwich Road extraction fence, 0.05 pore volumes per year at the in plume extraction wells, and 0.07 pore volumes per year at the South/Southwest extraction fence. This comes to a total removal rate of approximately 0.16 pore volumes per year.

The goal for the CS-10 plume is restoration of the aquifer and containment of the plume. Although data is not yet sufficient to evaluate the effectiveness of containment of the plume, based on previous containment efforts at MMR as well as the established effectiveness of ETR for plume containment, the installed system is likely to meet the goals for plume containment. In terms of aquifer restoration, however, there are more questions, particularly given the low pore volume removed per year. ETR systems have not been widely successful when used for aquifer restoration[1]. The use of the in-plume extraction wells should decrease the remediation time; however, the extraction wells will not necessarily address the issue of contaminant diffusion over time from less permeable zones or from sorbed contaminants. This diffusion process often results in increases in contaminant concentrations after remedial systems are discontinued, a condition otherwise known as rebound. Given that rebound is a common occurrence at sites using ETR as a remedial approach, careful consideration must be given to a monitoring program *after* discontinuation of the ETR system to ensure rebound does not occur.

The DoD currently intends to reassess the progress of the treatment system after 5 years. This re-evaluation is appropriate and necessary given that conditions may change over the course of the remedial action.

Findings

Observations concerning this site are as follows:

Technology Evaluation and Selection

- The selection of extraction and reinjection fences appears to be the most appropriate technology for this site. Monitored natural attenuation is not feasible since the natural processes are not functioning quickly enough to prevent contaminant migration into local surface waters. The recirculating well technology is unlikely to be as efficient as extraction and reinjection for mass removal.

Technology Feasibility

- A total of three extraction fences are planned for this plume. Installation of the Sandwich Road extraction line was expedited in order to prevent migration into and under Ashumet Pond. This was an appropriate response to the situation and was a sound technical decision.

- Groundwater treatment plants have previously been installed at FS-12 and SD-5 North. These treatment plants were evaluated as part of the CS-10 design process to optimize the treatment plant. Incorporation of “lessons learned” from other, similar treatment plants will favor a more efficient operation.

[1] Doty, C.B. and C.C. Travis. 1991. ONRL/TM-11866, Oak Ridge National Laboratory, Oak Ridge TN; National Research Council. 1994. National Academy of Sciences Press, Washington D.C.; Wilson, J.L. 1997. in Subsurface Restoration, Ann Arbor Press, Inc., Chelsea, MI.

- The monitoring program described appears to provide adequate oversight of treatment efficiency and environmental conditions. The monitoring program must continue after the remedial action is completed to ensure there is no rebound.

LF-1 PLUME

A number of documents were used to evaluate the technology selection and implementation at LF-1. Documents included:

- Fact Sheet - Landfill 1 (LF-1) Plume Response Alternatives (August 1997)
- Fact Sheet - Analysis of LF-1 Plume Response Alternatives (September 1997)
- Draft Proposed Response Document for Landfill-1 (LF-1), Jacobs Engineering Group, Inc. (July 1998)
- Fact Sheet - Landfill 1 (LF-1) Plume Proposed Response Document (August 1998)
- Supplement to the Draft Focused Feasibility Study for Landfill 1 (LF-1), Parsons Engineering Science, Inc. (September 28, 1998)
- Draft Landfill-1 (LF-1) Design Data Gap Technical Memorandum, Jacobs Engineering Group, Inc. (December 1998)

Brief Site Description

LF-1 was the main landfill at the MMR and is located in the south-central portion of the reservation. The landfill encompasses approximately 100 acres of open to heavily wooded terrain. The landfill began receiving wastes in 1941.

Disposal at LF-1 occurred in six disposal areas: five cells and a natural kettle hole. The cells were designated according to the approximate year of termination of waste disposal activities in that cell (1947, 1951, 1957, 1970, and post-1970). The depth of waste burial is not known; however, it has been estimated to be approximately 20-ft bgs for all five cells. There is no documentation available concerning the types of wastes in LF-1, nor is there evidence to suggest that any type of impermeable liner was used in the disposal areas.

In 1983, VOCs detected in Base water supply well G (located 4500-ft downgradient of LF-1) were linked to possible contamination from LF-1. Further investigations in 1985, 1986, and 1988 confirmed that contamination leaching from LF-1 was contaminating groundwater.

To prevent further leaching of contaminants, the remaining landfills cells (1970, post-1970, and the kettle hole) were closed and capped. Closure activities were completed in 1995.

The groundwater contaminant plume extends westward beyond the Base boundary. The plume is approximately 17,300-ft long, 5,500 ft wide, and up to 125 ft thick. The toe of the plume separates into a northern and southern lobe. The primary constituents that exceed MCLs[2] in the plume are PCE, TCE, and carbon tetrachloride (CT).

Remedial Selection Process

Seven remedial alternatives were initially proposed for LF-1:

- Alternative A — Recirculating wells (2 fences) in combination with extraction and reinjection (1 fence)
- Alternative B — Recirculating wells
- Alternative C — Extraction and reinjection
- Alternative D — Recirculating wells (2 fences) in combination with extraction and reinjection (3 fences)
- Alternative E — Extraction and reinjection in combination with monitored natural attenuation

- Alternative Y — Monitored natural attenuation
- Alternative Z — No-action alternative

Each alternative listed above was evaluated according to the DCM. Upon incorporation of comments, Alternative E (with refinements) was selected as the most appropriate remedial technology for this plume.

The goal of Alternative E is to capture and treat the contaminant plume. The treatment system consists of five extraction wells, four in the southern lobe of the plume and one in the northern lobe of the plume. Extracted groundwater is treated in a 700-gpm treatment facility and is then reinjected into the aquifer through an infiltration gallery located in the central portion of the plume.

MNA is being implemented for treatment of the plume west of Route 28.

According to Jim Snyder (AFCEE Remediation Program Manager), the projected annual O&M costs associated with the LF-1 plume are $380,000 and annual monitoring and ecological assessment costs are $480,000. Twenty years is estimated to achieve aquifer restoration at LF-1 for the portion of the plume undergoing natural attenuation. Thirty years is estimated to achieve aquifer restoration for that portion of the plume undergoing active pumping. The projected life cycle cost associated with this project (based on 1998 dollars) is $31 million.

[2] MCL values are 5 μg/L for each of these contaminants.

Analysis

Monitored Natural Attenuation

The incorporation of MNA into the remedial design for LF-1 was a unique approach to site cleanup given that MNA of chlorinated solvents is still a developing technology. A detailed study was conducted by AFCEE to determine the potential feasibility of monitored natural attenuation for this site. Two lines of evidence were used to evaluate natural attenuation: (1) historical contaminant concentration trends over time and (2) geochemical conditions as an indicator of biodegradation.

Establishing historical contaminant concentration trends over time is difficult at this site due to the variability in the number of wells sampled. Table 1 lists the number of wells sampled per sampling event.

Table 1. Number of Wells Sampled per Sampling Event

Sampling Event	Number of Wells
October 1989 – April 1990	33
February 1993 – December 1994	24
March 1995 – December 1995	38
January 1996 – December 1996	69
March 1997 – December 1997	50
January 1998 – June 1998	39

Therefore, the plumes that are drawn for each sampling event are not directly comparable from year to year. For example, in 1997, a VOC hot spot was found at monitoring well 03MW0097. This well was not sampled during any other sampling event. This would impact any mass calculations that are made and would impact a qualitative assessment of the groundwater plumes. Given that these plumes are difficult to compare, some of the conclusions may be overstated. For example:

- It is stated that the "carbon tetrachloride (CT) plume is shrinking noticeably since 1993". This is not readily apparent from the plumes shown.

- It is also stated that PCE and TCE concentrations are steadily decreasing; however, this is again not readily apparent from the data. Both contaminants appear to fluctuate. Some fluctuation of TCE would be expected given that it is believed to be a parent compound as well as a byproduct from PCE dechlorination (as shown below). This point is not well discussed in the section concerning historical contaminant trends over time.

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{DCE} \rightarrow \text{Vinyl chloride (VC)}$$

- In the overall discussion of MNA, it is stated "Based on these maps, it is apparent that the plume has reached steady-state equilibrium". This is not readily apparent from the isopleth maps. It is certainly suggested, but it is not surprising that regulators and the public may be skeptical based on this statement.

Quantitative analysis of the groundwater plume also was conducted. A comparison of contaminant mass over time was calculated. The mass was calculated based on the sampling data described in Table 1. Therefore, mass calculations cannot be assumed to be completely accurate and comparable from year to year due to the variability in sampling patterns. Again, there does appear to be a trend, but any conclusions drawn from these results should be tentative.

The measurement of total VOCs is used frequently to demonstrate contaminant removal. Given that a portion of the total VOCs being formed are derived from the parent compounds, does this value give an accurate representation of the data? This may confuse the issue given the large volume of data already available. The author is not stating that the presentation of total VOCs is without merit, but the issue should be addressed when presenting the data (i.e. given that a large component of monitored natural attenuation involves reductive dehalogenation of chlorinated compounds, some time should be spent on discussing this issue). Similarly, is the Mann-Kendall statistical analysis accurate when you have VOCs forming from VOCs? The Mann-Kendall statistical approach was used to determine the trend of VOCs in individual wells. While the contaminant concentrations in the majority of wells examined were shown to decrease over time, some contaminant concentrations increased or remained relatively stable. Formation of volatile byproducts could explain these trends.

The geochemical indicators of biodegradation generally show agreement with the shape of the contaminant plume, providing evidence that there is biological activity within the plume. This data is quite promising, but would have to be repeated over time given that there is no historical data for the biological indicators.

In conclusion, the data suggest that natural attenuation is occurring at the site; therefore, implementation of MNA is a reasonable remedial approach. The public was resistant to the use of MNA and the presentation of the results may have contributed to this. The summaries provided to the public overemphasized modeling results showing the success of natural attenuation in the future. A summary of real data may have been more useful along with a realistic discussion of the limitations of the current data and future methods to provide consistent data.

Extraction and Reinjection

The extraction wells are designed to extract groundwater from the areas of the plume containing the highest contaminant concentration before it can migrate off site. The treated groundwater is then reintroduced into the aquifer through infiltration galleries. The infiltration galleries are located approximately 5 ft bgs, much more shallow than a typical reinjection system. The design of this extraction and reinjection system will nicely complement the monitored natural attenuation. Extraction of highly contaminated groundwater will speed up the natural attenuation process without disturbing the naturally occurring process. Likewise, the use of infiltration galleries will limit the impact of introducing treated groundwater into the aquifer. Reinjection of treated groundwater directly into the aquifer could disturb the natural processes, possibly resulting in decreased biodegradation rates. Percolation of the groundwater through the vadose zone will allow for slow introduction of treated groundwater and will create much less disturbance.

Based on an extraction rate of 700 gpm, approximately 0.04 pore volumes per year will be removed. For aquifer remediation, this would translate into an extremely long cleanup time. However, given that the extraction and reinjection system is functioning in conjunction with natural attenuation processes, this low removal rate is not a great concern.

Findings

Technology Evaluation and Selection

- Given the large dissolved plumes and their location below the water table in a permeable aquifer, the remediation technologies evaluated and selected at LF-1 (i.e., ETR, recirculating wells, and MNA) are appropriate. Most current innovative technologies focus on source area remediation, which generally are not appropriate for a large, low-concentration dissolved plume. AFCEE has not overlooked an appropriate technology. The TPRT is unaware of other technologies for this setting, with the possible exception of enhanced bioremediation.

Technology Feasibility

- MNA appears to be a feasible approach for this site, although future monitoring must be consistent to obtain comparable plume maps.

- The extraction and reinjection system complements MNA without disrupting the natural processes.

- Establishing historical contaminant concentration trends over time is difficult at this site due to the variability in the number of wells sampled.

- Conclusions about MNA may have been overly optimistic given the data.

- For the LF-1 plume, a periodic re-evaluation of the projected O&M costs and the overall projected groundwater remediation life cycle costs would be useful in re-defining remedial approaches (i.e., within the context of the full range of remedialdecision-making factors).