Environmental Resources Management

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17 December 2003
Reference: 1922.09

Massachusetts Department of Environmental Protection
Northeast Regional Office
Bureau of Waste Site Cleanup
One Winter Street
Boston, MA 02108

Re: Release Abatement Measure Completion Report
In Situ Chemical Oxidation Pilot Study
Former Raytheon Facility
430 Boston Post Road
Wayland, Massachusetts (the "Site")
RTN 3-13302, Permit No. 133939

Dear Sir or Madam:

On behalf of Raytheon Company (Raytheon), Environmental Resources Management (ERM) is submitting this Release Abatement Measure (RAM) Completion Report for the above-referenced Site (Figures 1 and 2). A chronology of RAM activities is presented in Table 1. This RAM Completion Report was prepared in accordance with the requirements of 310 CMR 40.0446 of the Massachusetts Contingency Plan (MCP). The original RAM Transmittal Form BWSC-106 is attached and a copy is included as Appendix A.

BACKGROUND

The Site is an approximately 83-acre facility located at 430 Boston Post Road in Wayland, Massachusetts (Figure 1). Raytheon operated the facility from 1955 to 1995. Operations included electronic testing and research to support Raytheon's in-house prototype manufacturing. Raytheon operations were terminated in 1995, and the facility was decommissioned in 1996. The facility has since been sold and is currently utilized as commercial office space.

ERM submitted a Phase I-Initial Site Investigation (Phase I) report for the Site to the Massachusetts Department of Environmental Protection (DEP or Department) in July 1996 and a Tier Classification filing in January 1997. The Department issued Raytheon a Tier IB Permit, effective 21

May 1997. Results of Phase II assessment activities identified a potential imminent hazard condition in Site wetlands. Based on this condition, a reclassification permit application was submitted to the DEP. A new Tier IB Permit (No. 133939) was issued by DEP, effective 15 December 2000.

A Phase II Comprehensive Site Assessment (Phase II) report was submitted to the Department in November 2001. The Phase II report indicated impacts to groundwater consisting primarily of trichloroethene (TCE), with limited tetrachloroethene (PCE) and TCE degradation by-products. Since the Site is located within the Zone II for the Baldwin Pond Well Field, impacts to groundwater at levels in excess of Massachusetts Maximum Contaminant Levels (MMCLs) pose a condition of "Significant Risk" to potential future receptors, requiring abatement.

The Phase III Remedial Action Plan (Phase III) was submitted to the Department in November 2001. The Phase III report identified in situ chemical oxidation (ISCO) as the preferred remedial action alternative for abatement of TCE in groundwater.

The Phase IV Remedy Implementation Plan (Phase IV) was submitted to the Department in December 2002 and presented a conceptual design for implementation of ISCO at the Site. Upon completion of the ISCO pilot studies covered under this RAM, additional ISCO remedial activities will be conducted as part of ongoing comprehensive response actions as presented in the Phase IV.

To avoid confusion, it is important to note that this document addresses activities conducted in the two pilot study areas that are located in the southern portion of the Site. As part of ongoing comprehensive response actions, a second chlorinated volatile organic compound (CVOC) release area was identified in the northern portion of the Site. CVOC impacts to groundwater in the northern area are being addressed under Release Tracking Number (RTN) 3-22408. Preliminary Response Actions are being conducted pursuant to the MCP and a Phase I – Initial Site Investigation Report and Tier Classification submittal will be completed by December 2003.

PURPOSE AND SCOPE

The purpose of the RAM Completion Report is to summarize the ISCO remedial actions conducted at the Site. The remainder of this RAM

Completion Report is formatted consistent with the requirements of 310 CMR 40.0446(4).

SITE DESCRIPTION

Historical Release Description

Source areas in the southern portion of the Site include:

- a former hazardous waste storage area that was located near the southwest corner of the facility (vicinity of MW-33 well cluster); and
- manhole W-4 in the courtyard (vicinity of MW-43S).

As discussed in the Phase II report (ERM, 2001a), manhole W-4 was cleaned and sealed during building decommissioning activities in 1995. The former hazardous waste storage area has not been active since 1995 and was demolished in 1996. Therefore, the suspected sources of release no longer exist.

Site Conditions

The geologic sequence beneath both of these source areas is similar and consists of the following geologic units (from top to bottom):

- moderate conductivity, partially saturated, sand unit;
- low conductivity, saturated, silt unit; and
- moderate conductivity, saturated sand unit.

Following the initial release, TCE migrated downward through the sand unit and likely collected at the top of the upper, low conductivity, silt unit (i.e., an aquitard). Over time, the TCE migrated into the silt unit via advective flow or diffusion. Due to the presence of some clay minerals in this unit, TCE sorbed onto the clay minerals resulting in a residual source that continues to exist within the silt unit. In general, CVOCs have not been detected beneath the silt unit near the main building, suggesting that the silt unit is either semi-confining (i.e., an aquitard) or has an adequate sorption capacity to prevent downward vertical migration of CVOCs.

Surrounding Receptors

The Site is located in a portion of Wayland that is zoned for limited commercial/residential use. Currently, the Site is being used for commercial office space.

Surrounding land use and zoning is residential and roadside commercial. Properties adjacent to the Site include:

- North – forest and upland wetlands designated as Protected Open Space and owned by the Town of Wayland.
- East – wooded area and residential properties.
- West – wetlands and the Sudbury River.
- South – Route 20 (Boston Post Road), commercial and residential properties.

As shown in Figure 1, the Sudbury River abuts the Site to the west. An unnamed brook abuts the Site to the east-southeast, and flows into the Sudbury River approximately ¼ mile south of the Site. Wetlands are located along the banks of the Sudbury River to the west and southwest of the Site.

The MA DEP Geographical Information System (GIS) Site Scoring Map (Figure 5), indicates that the Site is located within the MA DEP-approved Zone II Wellhead Protection Area for the Baldwin Pond Well Field, located approximately 0.5-mile to the north of the Site.

RELEASE ABATEMENT MEASURE (RAM) DESCRIPTION

A RAM Plan was submitted to the Department on 11 September 2001. RAM Plan Modification #1 was submitted to the Department on 22 October 2002.

The objective of the RAM was to evaluate the ability to reduce the concentration of CVOCs in groundwater to levels that enable achievement of a Permanent Solution, if feasible. ISCO is a remedial technology that, through a series of chemical reactions, completely mineralizes contaminant mass into neutral by-products such as manganese dioxide, salt and carbon dioxide. A variety of chemical oxidants exist, including hydrogen peroxide, permanganate, persulfate

and ozone, each of which can be used to destroy TCE. Permanganate (sodium and potassium) was selected as an appropriate oxidant for the Site based upon subsurface conditions, contaminants present (i.e., chlorinated ethenes) and the amount and strength of oxidant needed. In addition, there are fewer health and safety issues associated with the use of permanganate versus hydrogen peroxide or ozone, since vapors (CVOCs or oxygen) are not generated using this oxidant.

Potassium and sodium permanganate are strong and somewhat non-selective oxidants. Therefore, in addition to CVOCs, they can oxidize other reduced soil and groundwater constituents, including natural organic carbons (e.g., humic and fulvic acids) and reduced minerals (e.g., ferrous iron). To evaluate the natural oxidant demand (NOD), ERM performed soil oxidant demand (SOD) tests using representative soil samples collected from the Site. The mass of permanganate injected as part of each pilot study was determined based on the total oxidant demand (i.e., combination of SOD and CVOC demands) within the projected volume of aquifer to be treated by the injections (i.e., based on total vertical injection interval and projected radius of influence).

Based on ERM's experience at similar sites, successful implementation of ISCO is ultimately a function of the ability to deliver oxidants to the impacted groundwater (i.e., contact) and transport oxidants within the aquifer. Therefore, the pilot studies evaluated a variety of injection techniques to determine which would be most effective.

The RAM Plans described two pilot studies designed to evaluate the efficacy of ISCO to abate CVOCs (primarily TCE) in groundwater. The two pilot areas were identified as the MW-33 Pilot Study Area (Figure 3) and MW-43 Pilot Study Area (Figure 4), and were designed to evaluate two different delivery methods for introducing oxidants to the subsurface and two different oxidant concentrations. The two injection methods were: gravity feed (i.e., passive injection; MW-43 Pilot Study Area) and high-pressure injection (i.e., pneumatic fracturing and liquid atomized injection (PFLAI); MW-33 Pilot Study Area).

The following RAM Status Reports have been submitted to the Department:

- 120-Day Status Report, 31 January 2002
- Six-Month Status Report, 25 July 2002

- Six-Month Status Report, 31 January 2003
- Six-Month Status Report, 31 July 2003

ERM conducted the following activities, in accordance with the RAM Plan (2001) and RAM Plan Modification #1 (2002).

Install Monitoring Wells

A total of 21 monitoring wells were installed to conduct a detailed evaluation of hydrogeology within the pilot study areas and to provide a detailed well network to evaluate the effectiveness of the pilot studies. A summary of monitoring well construction data within the pilot study areas is presented in Table 2. Figures 3 and 4 present the layouts of the pilot study areas. Additional information regarding monitoring well installation activities is presented in the 120-Day Status Report (January 2002) and the Six-Month Status Report (January 2003).

Conduct Bench-Scale Soil Oxidant Demand Tests

A bench-scale SOD test was performed to evaluate the NOD of the aquifer to ensure that an adequate amount of oxidant was injected to facilitate destruction of the contaminants within the pilot study areas while minimizing the amount of residual permanganate remaining after completion of the pilot studies. The seven-day permanganate SOD fell in the range of 0.033 to 0.068 grams per kilogram (g/kg) of wet soil, which translates to a required range of 0.09 to 0.18 pounds of permanganate per cubic yard of soil (assuming a soil density of 100 pounds per cubic foot and 30% porosity). The mass of permanganate injected during the pilot studies was determined by combining the oxidant demands for native soil (i.e., NOD) and the calculated mass of CVOCs within the pilot study area. Additional information regarding the SOD tests is presented in the 120-Day Status Report (January 2002) and the Six-Month Status Report (January 2003).

Establish Baseline Hydrogeochemistry

Hydrogeochemical baseline conditions were established for groundwater flow and quality within both pilot test areas prior to conducting each phase of oxidant injections (i.e., August 2001 and November 2002). Groundwater elevation and geochemical field parameters (pH, conductivity, temperature, oxidation-reduction potential (ORP) and

dissolved oxygen) were measured during sample collection (Tables 3 and 4). Groundwater samples were collected from all wells for analysis of CVOCs (Tables 5 and 6) and from selected pilot study wells for analysis of some or all of the following parameters (depending on which pilot study area and which baseline monitoring round): fluoride, chromium, hexavalent chromium, manganese, sodium and chloride. Additional information regarding baseline monitoring activities is presented in the 120-Day Status Report (January 2002) and the Six-Month Status Report (January 2003).

Apply Reagent

Initial RAM Activities

The two initial ISCO pilot studies were conducted to evaluate the efficacy of the following delivery methods:

- direct-push high-pressure injection (MW-33 Pilot Study Area; Figure 3); and
- single-well passive injection (MW-43 Pilot Study Area; Figure 4).

In October 2001, approximately 2,500 gallons of 2% potassium permanganate and 50 milligrams per liter (mg/L) of sodium fluoride conservative tracer were injected at a rate of 250 gallons per hour using the PFLAI method into a temporary injection point located north-northeast of the MW-33 well cluster (Figure 3). The injections were conducted at pressures ranging from 25 to 50 pounds per square inch (psi). Oxidant was injected into seven discrete three-foot vertical intervals, which were designed to facilitate oxidant delivery from the top of the silt unit (28 feet below grade) to slightly above the water table (12 feet below grade). The use of short vertical injection intervals was designed to enable relatively uniform oxidant delivery within the lithology. The oxidant was injected under pressure and allowed to migrate via natural advective and diffusive flow from the injection point throughout the pilot study area.

In October 2001, approximately 250 gallons of 4% sodium permanganate followed by 120 gallons of potable water were injected into MW-43S via the gravity feed injection technique at a rate of 25 gallons per hour. The oxidant was passively injected and allowed to migrate via natural advective and diffusive flow.

The PFLAI injection resulted in an apparent radius of influence of at least 20 feet. Gravity feed injection resulted in an apparent radius of influence of five to ten feet. In the MW-33 Pilot Study Area (i.e., 2% potassium permanganate), most of the permanganate was rapidly consumed. However, in the MW-43 Pilot Study Area (i.e., 4% sodium permanganate), the permanganate persisted due to the higher permanganate concentration injected. Additional information regarding permanganate injection activities conducted as part of the initial RAM is presented in the 120-Day Status Report (January 2002).

RAM Plan Modification #1

The RAM Plan Modification #1 was designed to expand the MW-43 Pilot Study in an effort to further evaluate the ability to reduce CVOC concentrations in groundwater. The expanded pilot involved application of the hydraulic fracturing and liquid atomized injection (HFLAI) technique, injection of a larger mass of permanganate, and injection at multiple locations over a larger treatment volume.

In November 2002, ERM provided oversight during the injection of approximately 9,000 gallons of 23% sodium permanganate into five temporary injection points using a combination of HFLAI and high-pressure injection techniques. The injections were conducted on the perimeter of the pilot area first to minimize potential displacement of CVOC-impacted groundwater from the treatment area. Injections were initially conducted in peripheral temporary injection points (INJ-1, INJ-6 and INJ-4), then moved inward to injection points INJ-3 and INJ-2. The injections were conducted at pressures generally ranging from 80 to 160 pounds per square inch (psi).

High pressure injection techniques were used to achieve greater injection radii and to facilitate injection of permanganate into lower hydraulic conductivity soil (i.e., fine sand and silt). HFLAI, which is similar to PFLAI, was not used exclusively due to the potential for this technique to affect the structural integrity of the nearby building due to ground heave. A 23% sodium permanganate solution was used to maximize the mass of oxidant while minimizing the volume injected, in an effort to minimize displacement of contaminated groundwater from the source area. In an effort to further minimize the potential for displacement of contaminated groundwater from the Pilot Study Area, permanganate was initially injected around the periphery of the treatment area and subsequently into the center of the treatment area. Additional information regarding

permanganate injection activities conducted as part of the initial RAM Plan Modification #1 is presented in the Six-Month Status Report (January 2003).

Install Confirmatory Borings

Following the RAM Plan Modification #1 permanganate injection in the MW-43 Pilot Study Area, four soil borings (B-1, B-2, B-3 and B-4) were advanced to evaluate the distribution of permanganate within the pilot area. Boring locations are shown on Figure 4. Soil samples were collected continuously and visually inspected for the presence of permanganate (i.e. identified by characteristic purple color).

Visual evidence of permanganate was observed in borings B-1, B-3 and B-4. The greatest evidence of permanganate presence was identified in B-4, which is located within the expected radial influence of INJ-1, INJ-2 and INJ-3. Fingers of permanganate were observed in samples collected from B-1 and B-3. No color was noted in boring B-2, located approximately 24 to 32 feet from the injection wells. Additional information regarding the confirmatory soil boring advancement and sampling activities is presented in the Six-Month Status Report (January 2003).

Post-Injection Groundwater Monitoring

MW-33 Pilot Study Area

Seventeen (17) post-injection field parameter monitoring rounds were conducted from 8 October 2001 through 15 January 2002. These monitoring rounds included measurement of groundwater elevations and field parameters and collection of groundwater samples for analysis of fluoride, a conservative tracer used in the MW-33 Pilot Study Area. Up to six rounds of groundwater samples were collected for laboratory analysis of CVOCs. Field parameter data are presented in Table 3. Groundwater analytical results are presented in Table 5. Additional information regarding post injection monitoring activities is presented in the 120-Day Status Report (January 2002) and the Six-Month Status Report (July 2002).

MW-43 Pilot Study Area

Nine post-injection field parameter monitoring rounds were conducted from 13 November 2002 through 12 February 2003. These monitoring rounds included measurement of groundwater elevations and field parameters and collection of groundwater samples for analysis of permanganate. Up to 11 rounds of groundwater samples were collected for laboratory analysis of CVOCs. Field parameter data are presented in Tables 3 and 4. Groundwater analytical results are presented in Table 6. Laboratory analytical reports for recent sampling rounds are presented in Appendix B. Field colorimetry results are included in Appendix C. Additional information regarding post injection monitoring activities is presented in all four RAM Status Reports (January 2002, July 2002, January 2003 and July 2003).

Additional groundwater monitoring will be conducted under Phase IV.

MANAGEMENT OF REMEDIATION WASTE

No Remediation Waste or Remediation Wastewater was generated as part of these RAM activities that required off-site disposal. Residual permanganate from the RAM Plan Modification #1 pilot study was transported off-site by the shipper, Synder Trucking.

Personal protective equipment (PPE) was decontaminated as needed and disposed off-site as solid waste. No drill cuttings were generated as the injection points were advanced using direct-push drilling techniques. Groundwater purged from the wells prior to collection of groundwater samples was returned to the wells following sample collection.

MONITORING DATA

Depth to groundwater, field parameters (i.e., pH, specific conductivity, dissolved oxygen, temperature and ORP) and color data for the initial RAM and RAM Modification # 1 are presented in Tables 3 and 4, respectively. Sodium permanganate concentration data are also presented in Table 4. Laboratory analytical results for the MW-33 and MW-43 Pilot Study Areas are presented in Tables 5 and 6, respectively.

Laboratory analytical reports are presented in Appendix B. Field colorimetry results are presented in Appendix C.

MW-33 Pilot Study Area

Historic evidence of permanganate (i.e., color) was observed in wells MW-109 and MW-110, and indirect evidence (increased ORP) was noted in wells MW-107 and MW-108 in the MW-33 Pilot Study Area. Direct evidence of permanganate has not been observed in this pilot study area since November 2001.

As of January 2002, TCE concentrations in six wells located within the MW-33 Pilot Study Area (MW-111, MW-112, MW-113, MW-114, MW-115 and MW-116) exhibited an average concentration decrease of 67% relative to the baseline monitoring round (August 2001). These wells were not directly affected by the permanganate injection, but likely reflect the migration of treated groundwater. Slight increases in TCE concentrations were observed in other wells in this pilot study area and are potentially attributed to the oxidation of organic matter within the aquifer material, resulting in liberation of previously sorbed CVOCs.

MW-43 Pilot Study Area

The following wells have been directly affected by oxidant injections in the MW-43 Pilot Study Area, based on the historic and/or current presence of visual or measurable permanganate: MW-43S, MW-104, MW-105, MW-105M, MW-106, MW-106M, MW-210, MW-212 and MW-212M. As of 30 September 2003, permanganate persisted at measurable concentrations in seven wells within the MW-43 Pilot Study Area.

The average TCE concentration in the MW-43 Pilot Study Area decreased by 92% as a result of the RAM activities, as of 30 September 2003 (see table below). Additional reductions in TCE concentrations may occur, based on the continued presence of permanganate in groundwater. The September 2003 average TCE concentration of 13 micrograms per liter (ug/L) exceeds the MMCL of 5 ug/L.

Summary of Average TCE Concentrations in the MW-43 Pilot Study Area

	27 August 2001 Initial RAM Baseline	12 November 2002 RAM Modification No. 1 Baseline	30 September 2003
Average TCE Concentration (ug/L)*	173	108	13

Notes:
* Average TCE concentrations were calculated using the following wells (including duplicate analyses):
27 August 2001: MW-43S, MW-104, MW-105, and MW-106
12 November 2002: MW-43S, MW-104, MW-105, MW-105M, MW-106, MW-106M, MW-210, MW-212 and MW-212M
30 September 2003: MW-43S, MW-104, MW-105, MW-105M, MW-106, MW-106M, MW-210, MW-212 and MW-212M

For samples that contained TCE at concentrations below the laboratory quantitation limit, one-half the detection limit was used to calculate the averages.

Groundwater samples were also collected for analysis of the following parameters: fluoride, chromium, hexavalent chromium, manganese, sodium and chloride. As noted in the RAM Plan Modification No. 1, groundwater samples were collected for analysis of these additional parameters during the baseline round and after all permanganate has been consumed. Since permanganate is still visually present and measurable in the majority of wells, groundwater samples from only a subset of MW-43 Pilot Study Area wells have been analyzed for these additional parameters.

Of these analytes, chromium and hexavalent chromium were detected during post-injection monitoring rounds at concentrations above applicable MCP Reportable Concentrations (RCs). During the baseline sampling event (i.e., prior to permanganate injection), chromium was not detected in groundwater at a concentration above the RC. Chromium is more soluble in groundwater under oxidizing conditions, which would be expected during and following injection of permanganate. Therefore, ERM believes that chromium detected in groundwater is a transient condition and will likely naturally attenuate once the aquifer returns to ambient oxidation-reduction conditions.

Additional groundwater monitoring will be conducted under Phase IV.

FINDINGS AND CONCLUSIONS

The ISCO pilot studies demonstrated the efficacy of permanganate oxidation. In the MW-43 Pilot Study Area, TCE concentrations have been reduced by 92% through September 2003. Permanganate persists in groundwater in this area, which may result in additional reduction in TCE concentrations. In a portion of the MW-33 Pilot Study Area, TCE concentrations were reduced by 67%.

ERM has formulated the following conclusions:

- High pressure injection techniques were more effective than gravity feed injection techniques in that they achieved a significantly larger radius of influence.
- Low volume, high concentration sodium permanganate injections were more effective than high volume, low concentration potassium permanganate injections to treat source areas. This approach minimized the potential for displacement of contaminants from the treatment zone and enhanced reaction rates by applying a stoichiometrically appropriate amount of permanganate to satisfy the NOD and contaminant demand.

DESCRIPTION OF ONGOING ACTIVITIES

Raytheon proposes to transition remedial activities from this RAM to Comprehensive Response Actions. Pilot study results indicate that ISCO is effective at reducing the mass and concentration of CVOCs in groundwater. Based on results of the pilot studies, Raytheon will develop a remedial design for implementation of additional ISCO activities in both the MW-33 and MW-43 Pilot Study Areas. Additional permanganate injections will be conducted in these and other areas to further reduce TCE concentrations in groundwater at the Site, as presented in the Phase IV RIP (2002). A draft remedial design document will be presented to the public for review and comment prior to implementation.

LSP OPINION

The response actions described in this RAM Completion Report were conducted in conformance with the RAM Plan and the requirements of the MCP (310 CMR 40.0440).

If the Department requires additional information or clarification, please contact either of the undersigned at (617) 267-8377.

Sincerely,

John C. Drobinski, P.G., LSP
Principal-in-Charge

R. Joseph Fiacco, Jr., P.G.
Senior Project Manager

attachments:

Table 1	Chronology of RAM Activities
Table 2	Monitoring Well Construction Summary
Table 3	Groundwater Elevation & Field Parameter Data
Table 4	Groundwater Field Parameter Data – RAM Plan Modification #1
Table 5	Groundwater Quality Data – MW-33 Pilot Study Area
Table 6	Groundwater Quality Data – MW-43 Pilot Study Area
Figure 1	Locus Map
Figure 2	Site Plan
Figure 3	MW-33 Pilot Study Area
Figure 4	MW-43 Pilot Study Area
Figure 5	Resource Area Map
Appendix A	RAM Transmittal Form BWSC-106
Appendix B	Laboratory Analytical Reports
Appendix C	Field Colorimetry Results

cc: Mr. Edwin Madera, Raytheon Company, Sudbury, MA 01776

Public Repository (Primary Location), Wayland Public Library, Wayland, MA 01778

Public Repository (Secondary Location), Board of Health, Wayland, MA 01778

Mr. Benson R. Gould, CMG Environmental, Inc., Southbridge, MA 01550