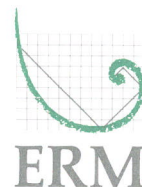


27 April 2004

Reference: 0013606.01

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



Re: Response to Public Comments
Draft Phase IV Remedy Implementation Plan (RIP) Addendum
Former Raytheon Facility
430 Boston Post Road
Wayland, Massachusetts (the "Site")
RTN 3-13574; Tier IB Permit No. 133939

Dear Mr. Gould:

On behalf of Raytheon Company (Raytheon), Environmental Resources Management (ERM) has prepared this letter providing responses to comments prepared by CMG Environmental, Inc. (CMG), consultant to the Town of Wayland, regarding the Draft Phase IV Remedy Implementation Plan (RIP) Addendum (Phase IV Addendum), dated 3 March 2004. CMG's comment letter, dated 16 March 2004, contains six comments. This response letter includes relevant portions of each comment in italics and responses in plain text.

CMG's Comments:

I) On page 7 of the Draft Phase IV RIP Addendum report, ERM states that "Under current land use conditions, risks to human health are considered negligible since the area of impact is remote from the Baldwin Pond wellfield." It is true that the contamination which is the subject of this report (i.e., the 'Southern Area' chlorinated VOC plume) is a substantial distance from the Baldwin Pond wellfield. However, this plume is still located within the DEP-approved Zone II for the Baldwin Pond wellfield and a Town Aquifer Protection District Overlay Zone. Furthermore, Russell's Garden Center operates a private production well located on their property, which is located hydraulically downgradient and proximal to this plume (although screened at a much deeper interval). Therefore, because of the current or future drinking water source area designation, neither the Town of Wayland, the DEP, nor the concerned public would characterize risks associated with this plume as "negligible."

In addition, promulgated DEP regulations and published DEP guidance

continually stress the importance of 'reasonably foreseeable' uses. Wayland believes that reasonably foreseeable use of groundwater that DEP has classified GW-1 (current or potential drinking water supply) should include consumption as drinking water. At present, some groundwater at the Southern Area of the Site significantly exceeds drinking water standards (which is, of course, why ERM has proposed the remedial strategy outlined in the Draft Phase IV RIP Addendum report).

The Town requests that ERM change their wording in this portion of Section 3.1.

Raytheon shares the Town's concerns regarding Site impacts to groundwater within the DEP-approved Zone II for the Baldwin Pond wellfield and a Town Aquifer Protection District Overlay Zone. In response to this comment, ERM will remove the following sentence from the Phase IV Addendum: "Under current land use conditions, risks to human health are considered negligible since the area of impact is remote from the Baldwin Pond wellfield."

A detailed discussion of current and potential future risks at the Site is included in the Phase II - Comprehensive Site Assessment report, dated 28 November 2001.

II) Wayland sees it as a positive sign that Raytheon plans to include dissolved chromium and hexavalent chromium analyses in both the baseline monitoring program and the post-injection groundwater monitoring program. We believe it is important to track these potentially hazardous byproducts of in-situ chemical oxidation (ISCO).

Raytheon agrees and has included dissolved chromium in the ISCO monitoring program since the original Release Abatement Measure (RAM) Plan, dated 11 September 2001. Hexavalent chromium was added to the sampling program at the request of the Town as part of the RAM Plan Modification #1, dated 22 October 2002.

It is important to note that chromium is not produced nor introduced to the aquifer as part of the permanganate applications. But rather, if insoluble chromium (III) is present in Site soil under ambient oxidation-reduction (redox) conditions, it may be oxidized to produce soluble chromium (VI) as a result of the ISCO application. This is a transient condition that is based on the presence of permanganate, a strong oxidizer, in the aquifer. Once the aquifer returns to ambient redox conditions, the chromium (VI) will be reduced to chromium (III) and precipitate from solution.

(III) Erratum: the numerical header for this section should be 4.2.2 (which also means that Section 4.2.4 should be numbered 4.2.3).

ERM will modify the Phase IV Addendum section headings as noted.

IV) The table "Summary of Permanganate Mass and Volumes for Treatment Areas" does not have consistent correlation between permanganate mass and sodium permanganate volume. ...

Please provide a better description of the sodium permanganate concentrations you intend to use, and/or state the anticipated solution molarity. Furthermore, the table in Section 4.2.3 [4.2.2] of the Phase IV RIP Addendum should explicitly state whether 'permanganate mass' refers to the total mass of sodium permanganate or permanganate ion.

ERM will modify the table in Section 4.2.2 to state "Sodium Permanganate Mass (pounds)." The mass numbers presented in the Phase IV Addendum represent the mass of sodium permanganate, not permanganate ions.

ERM typically purchases sodium permanganate from Carus Chemical under the product name of Liquox[®]. Liquox[®] is a 40 percent solution (by weight), which has a specific gravity of 1.36 grams per milliliter (g/mL) (Liquox[®] MSDS Carus Chemical Company, Rev 9/98). Based on this density, Liquox[®] weighs approximately 11.4 pounds (lbs) per gallon. Therefore, one gallon of Liquox[®] contains 4.55 pounds of sodium permanganate and 6.85 pounds of water. A 1:3 dilution of a 40 percent Liquox[®] solution with water produces a 10 percent sodium permanganate solution (by volume) or a 12.5 percent solution (by weight), as shown below.

1 gallon Liquox[®] (11.4 lbs) + 3 gallons water (25 lbs) = 4 gallons of solution (36.4 lbs)

Sodium permanganate concentration (by weight) = 4.55 lbs
NaMnO₄ / 36.4 lbs of solution = 12.5%

To calculate the molarity of a sodium permanganate solution, one must first convert from English to metric units:

4.55 lbs NaMnO₄ = 2,063.85 g 1 gallon = 3.785 liters (L)

then convert grams to moles of sodium permanganate (molecular weight of 141.93 g):

$$2,063.85 \text{ g} / 141.93 \text{ g} = 14.54 \text{ moles}$$

then divide moles of sodium permanganate by liters of solution:

$$14.54 \text{ moles} / 3.785 \text{ liters} = 3.84 \text{ moles/liter or } 3.84 \text{ M}$$

Therefore the molarity of a 40 percent (by weight) sodium permanganate solution is 3.84 M. The molarity of a 12.5 percent (by weight) sodium permanganate solution is 0.96 M.

V) Wayland requests that Raytheon provide a detailed analysis of the amount of residual sodium that will remain in the drinking water aquifer following full-scale implementation of the proposed ISCO remedy. The Town expects that you will address the ORSG value for sodium in drinking water as a 'suitably analogous standard' in your comprehensive evaluation. Given the potential health risks of elevated sodium in the drinking water supply, Wayland also requests that Raytheon provide a more detailed explanation of why you have chosen 10% sodium permanganate for ISCO over potassium permanganate.

ERM intends to apply approximately 45,200 pounds of sodium permanganate solution in five areas within the southern portion of the Site. This translates into the addition of 7,325 pounds of sodium to the aquifer. The proposed treatment volume is 95,000 cubic yards. Assuming an aquifer effective porosity of 0.30, this translates into 5,752,000 gallons of water within the treatment areas. Therefore, the proposed sodium permanganate applications in the southern portion of the Site will result in an estimated 113 mg/L increase in the sodium concentration in groundwater within the treatment areas.

During 2002 and 2003, 12 groundwater samples were collected from the MW-44 well triplet and analyzed for sodium. This well cluster is located upgradient of the MW-43 Pilot Study Area and is considered representative of background groundwater quality for the southern portion of the Site at multiple vertical intervals. Sodium concentrations in this well cluster have ranged from 2.2 mg/L to 100 mg/L, with six of 12 samples exceeding the Office of Research and Standards' Guideline (ORSG) value of 20 mg/L.

In solution, sodium is positively charged ion that is known to bind to clay minerals. Therefore, as sodium migrates in groundwater, it will

naturally attenuate with distance via advection, diffusion, dispersion, dilution and sorption. ERM does not anticipate that these levels will have an impact on water quality at the Baldwin Pond wellfield.

Over the past seven years, ERM has collected extensive groundwater elevation data that consistently indicate that groundwater in the southern portion of the Site flows generally to the west toward the Sudbury River, the regional discharge boundary. Sodium permanganate will be applied in areas where TCE concentrations are highest (i.e., known or suspected source areas). Therefore, the migration of sodium in groundwater will likely mimic the historical migration of TCE. Based on the distribution of TCE in the southern portion of the Site (see Figure 6 in the draft Phase IV Addendum), it appears that sodium will largely be confined to the former Raytheon property.

As discussed in Section 4.2.2 of the Phase IV Addendum, the mass of permanganate necessary to affect remediation in the treatment areas was calculated to satisfy the stoichiometric total oxidant demand (i.e., sum of the soil oxidant demand (SOD) and TCE demand). Potassium permanganate has an effective field solubility of approximately two percent (by weight), which is dependent upon water temperature. As noted above, sodium permanganate is manufactured at a concentration of 40 percent (by weight). ERM selected a 10 percent (by volume) or 12.5 percent (by weight) sodium permanganate solution for the following reasons:

- to satisfy the total oxidant demand of the treatment areas;
- to reduce the total volume of injectate to minimize the amount of displacement caused by the applications; and
- to apply an adequate volume of injectate to facilitate the proposed radii of influence for each injection point.

Application of potassium permanganate would require a significantly greater volume of solution, which would displace a significantly larger volume of contaminated groundwater. ERM's intent is to minimize displacement of contaminated groundwater.

VI) Wayland requests that Raytheon present a detailed and quantifiable assessment of the efficacy of sodium permanganate ISCO before proposing to substantially increase the scale of oxidant injections into the Town's drinking water aquifer.

First of all, it is important to clarify that there were two ISCO pilot study areas at the Site:

- MW-43 Pilot Study Area. This area was treated twice. In October 2001, approximately 250 gallons of 4 percent (by volume) sodium permanganate solution was injected into existing monitoring well MW-43S. In November 2002, 9,000 gallons of 23 percent (by weight) sodium permanganate solution was injected into five temporary injection points.
- MW-33 Pilot Study Area. In October 2001, 2,500 gallons of 2 percent (by volume) potassium permanganate solution was injected into a single temporary injection point.

With respect to evaluating the efficacy of ISCO at the Site, data from both pilot areas were evaluated. As noted in Section 4.1 of the Phase IV Addendum, pilot study results indicated that "low volume, higher concentration sodium permanganate injections were more effective than high volume, lower concentration potassium permanganate injections. This approach minimized the potential for displacement of impacted groundwater from the treatment zone. Pilot study results indicated that TCE concentrations were reduced by approximately 90 percent using this approach (i.e., in the MW-43 Pilot Study Area as a result of the November 2002 application).

As for the degree of concentration reduction, there is no scientific basis for the belief that chlorinated volatile organic compounds (CVOC) concentrations should decrease in a linear fashion in response to ISCO, as suggested by Charts 1A through 1D of CMG's letter. ISCO works via a multi-step process. During the initial injection phase, the oxidant solution displaces a portion of the effective porosity of the aquifer material. The oxidant comes in contact with pore water, which has not been displaced, thereby destroying the target CVOCs via a process discussed below. In addition, permanganate reacts with natural organic matter and reduced metals, commonly referred to as soil oxidant demand (SOD). The oxidant-groundwater mixture then comes in contact with the soil matrix, destroying CVOCs bound to the soil. The oxidant-groundwater mixture then flows with groundwater to downgradient zones where additional unspent permanganate oxidizes CVOCs left in the "stagnant" portion of the pores and bound to the soil matrix. At a given monitoring well, therefore, CVOC concentrations do not decrease monotonically from the start of the first injection but rather remain

relatively constant until the oxidant solution reaches the well, at which point concentrations will decrease (Figure 1).

Clearly, the TCE concentration has decreased dramatically since the 12 November 2002 baseline-sampling event (i.e., prior to the November 2002 ISCO application in the MW-43 Pilot Study Area). It is perhaps difficult to assess changes in concentration prior to November 2002, because many of the monitoring wells did not exist at that time. However, since November 2002, the arithmetic average concentration of TCE in these wells has dropped dramatically, as shown in Table 2. The RAM Completion Report, dated 17 December 2003, reported a 92 percent decrease in TCE concentrations in the MW-43 Pilot Study Area for wells that were "directly affected by oxidant injections." A list of effected wells was presented in that report. The data presented in Table 2 of this letter are more conservative in that they include two additional wells, MW-209 and MW-211, which were not directly affected by the oxidant injections, but are located along the periphery of the MW-43 Pilot Study Area.

ERM does not believe that it is appropriate to attribute concentration changes in other Site wells, since they were not affected by the November 2002 ISCO application. Therefore, any concentration changes in other Site wells (or lack thereof), do not reflect the effects of the type of ISCO approach that is proposed for the full-scale treatment design.

The point that all of the CVOCs should be included in any analysis of mass reduction is irrefutable. However, it is also the case that at the Site, TCE is by the far the predominant CVOC (see table on page 7 of the draft Phase IV RIP Addendum). For instance, Chart 1A from CMG's letter can be replotted as shown in Figure 2. Figure 2 shows the total TCE, cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC) concentrations for MW-43S. When one of the compounds was not detected, half of the method detection limit is shown. Also shown in Figure 2 is the total molar concentration of these three compounds, again using half the detection limit for undetected compounds. The resultant molar concentration of CVOCs is not exactly the same as in CMG's Chart 1A, suggesting that CMG perhaps summed the detection limits of all undetected compounds. Nevertheless, the trend is similar. The most obvious feature of Figure 2 is the extreme similarity of the TCE concentration trend and the total CVOC concentration trend. In fact, for this well, TCE comprises over 90% of the total CVOC mass except during sampling events immediately after a permanganate injection, when the detected compounds are at or near their detection limits.

Table 1. TCE Concentration in MW-43S Area Since November 2002

Well ID	TCE Concentration (ug/L) on:				
	11/12 Nov 2002	11/12 Feb 2003	22-25 Apr 2003	29/30 Jul 2003	30 Sep 2003
MW-105	190	15	17	11	35
MW-105M	37	<0.5	1	<0.5	1.1
MW-106	120	5.7	48	16	10
MW-106M	130	17	25	0.98	<0.5
MW-209	11	8.4	8	6.4	5.2
MW-210	160	<0.5	6.1	2.2	6.6
MW-211	9.1	23	1.7	0.68	0.97
MW-212	37	<0.5	0.57	<0.5	0.77
MW-212M	17	<0.5	<0.5	<0.5	<0.5
MW-43S	150	<0.5	14	8.2	28
Average TCE Concentration	86	7.0	12	4.6	8.8
% Reduction of Average TCE Concentration from 11/12 Nov 2002 Average TCE Concentration	0%	92%	86%	95%	90%

Note: If TCE was not detected, half of the detection limit was used in calculating the average TCE concentration.

Figure 2. Time Series Plot of Data from MW-43S

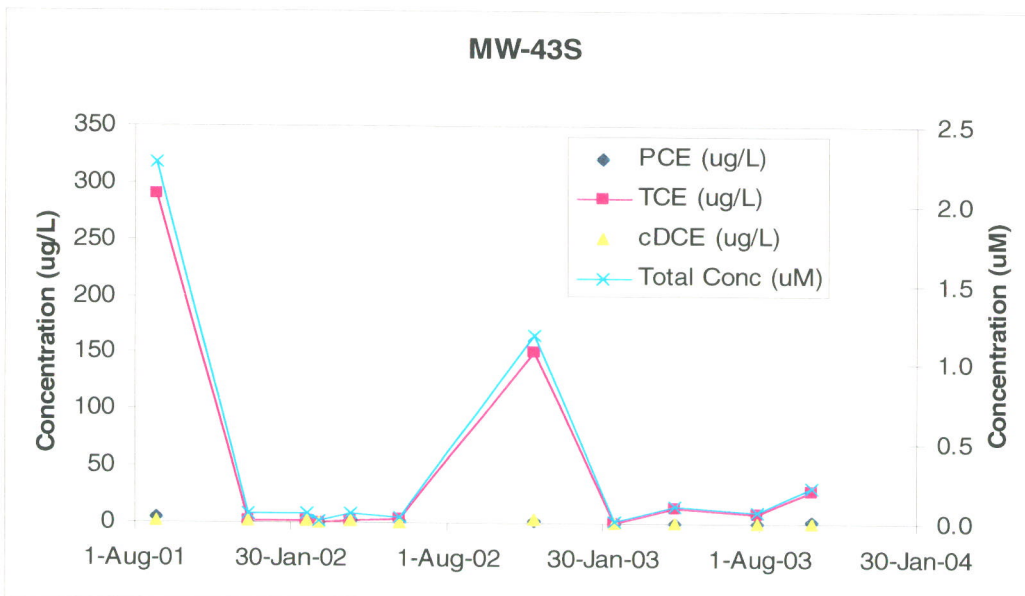


Figure 3. Time Series of TCE Mole Percentages for MW-43S Injection Are

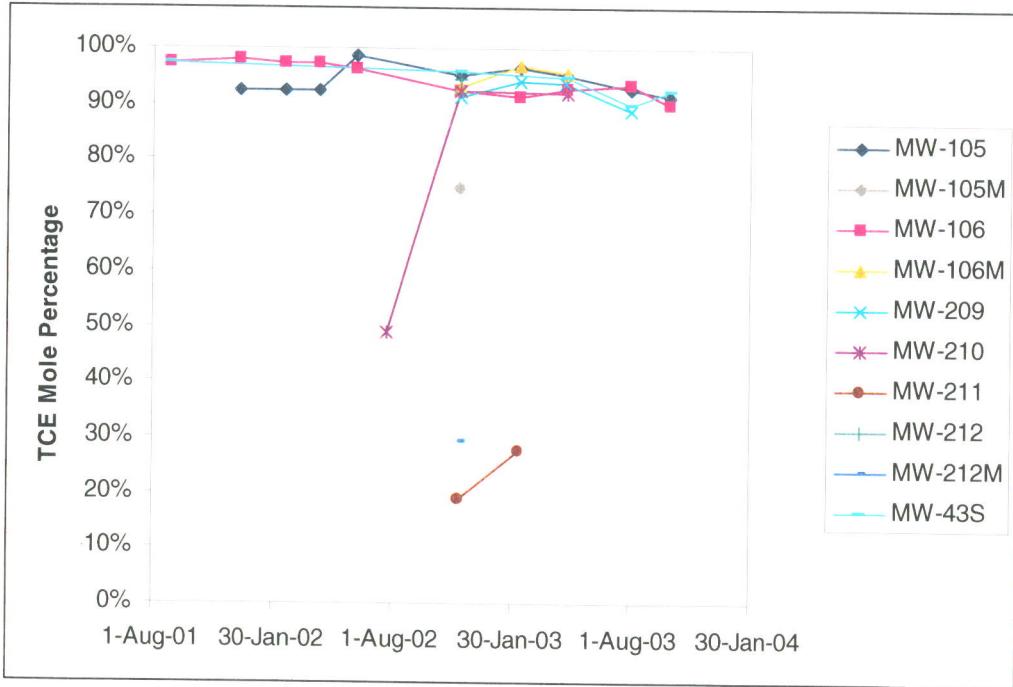


Table 2. September 2003 Data for Wells in MW-43S Area Showing Significant TCE Degradation to cDCE in 2002 and 2003.

Well ID	Concentration (ug/L)						
	Bromo-dichloro-methane	Chloro-form	cDCE	Trans-1,2-DCE	PCE	TCE	VC
MW-105M	<0.5	<0.75	<0.5	<0.75	<0.5	1.1	<1
MW-210	<0.5	<0.75	<0.5	<0.75	0.5	6.6	<1
MW-211	<0.5	<0.75	<0.5	<0.75	<0.5	0.97	<1
MW-212M	0.74	1.2	<0.5	<0.75	<0.5	<0.5	<1

From Figure 3, it is clear that the vast majority of samples have TCE mole percentages greater than 90 percent. The wells with low TCE mole percentages are MW-105M, MW-210, MW-211 and MW-212M. In all four wells, the CVOC concentrations were non-detect or nearly non-detect in 2003; data from the last sampling round from these four wells are shown in Table 2.

Finally, there appears to be some confusion regarding the various TCE degradation and destruction pathways. The Town, through CMG, posed a similar question in a comment letter, dated 8 October 2002, regarding the Draft Release Abatement Measure Plan - Modification #1. ERM provided the following response in a letter dated 7 November 2002, which summarizes ISCO processes and reactions, as well as a reference regarding this topic:

The reaction included in the text indicates the following end products: manganese dioxide precipitate ($\text{MnO}_2(\text{s})$), carbon dioxide ($\text{CO}_2(\text{g})$), hydrogen ions (H^+), chloride ions (Cl^-) and potassium ions (K^+). Similar reaction products are produced by reactions between permanganate and other chlorinated ethenes (e.g., 1,2-dichloroethene, perchloroethene, vinyl chloride). In some cases hydroxide ions (OH^-) are formed rather than H^+ . In the case of oxidation using sodium permanganate, sodium ions are produced. The H^+ and OH^- ions affect the pH of groundwater (typically by less than one pH unit) and the remaining free ions (K^+ , Na^+ and Cl^-) typically form ionic salts. The following chemical formulas are provided for reactions between other chlorinated compounds and potassium permanganate:

- PCE: $4\text{KMnO}_4 + 3\text{C}_2\text{Cl}_4 + 4\text{H}_2\text{O} \rightarrow 6\text{CO}_2 + 4\text{MnO}_2 + 4\text{K}^+ + 12\text{Cl}^- + 8\text{H}^+$
- TCE: $2\text{KMnO}_4 + \text{C}_2\text{HCl}_3 \rightarrow 2\text{CO}_2 + 2\text{MnO}_2(\text{s}) + 2\text{K}^+ + \text{H}^+ + 3\text{Cl}^-$
- cDCE: $8\text{KMnO}_4 + 3\text{C}_2\text{H}_2\text{Cl}_2 \rightarrow 6\text{CO}_2 + 8\text{MnO}_2 + 8\text{K}^+ + 6\text{Cl}^- + 8\text{OH}^- + 2\text{H}_2\text{O}$
- VC: $10\text{KMnO}_4 + 3\text{C}_2\text{H}_3\text{Cl} \rightarrow 6\text{CO}_2 + 10\text{MnO}_2 + 10\text{K}^+ + 3\text{Cl}^- + 7\text{OH}^- + \text{H}_2\text{O}$

Based on available information in the scientific literature, ISCO reactions have been shown to produce intermediates, which are short-lived due to the rapid reaction rates associated with permanganate oxidation (i.e., minutes to hours). Hydroxylation of olefins (e.g., TCE) has been known since 1895 and is accepted to occur as an initial reaction with the carbon-carbon double bond to form a cyclic hypomanganate ester (Siegrist et. al, 2001), which in turn is readily further oxidized or hydrolyzed by numerous reaction pathways.

Carboxylic acid intermediates (formic, glyoxylic and glycolic acids) have also been detected during permanganate oxidation laboratory studies, but are rapidly oxidized to form the above-listed end products.

Siegrist, R.L., M.A. Urynowicz, O.R. West, M.L. Crimi and K.S. Lowe, 2001, Principles and Practices of In Situ Chemical Oxidation Using Permanganate, Battelle Press, Columbus, OH, 348 pp.

As you can see, implementation of ISCO does not result in the production of "daughter products," as the Town suggests. Therefore, evaluation of the presence of various daughter products (i.e., cDCE, trans-1,2-dichloroethene and 1,1-dichloroethene) does not add to the understanding of whether ISCO has been effective at destroying TCE in groundwater at the Site.

With respect to microbial degradation of TCE in groundwater, the most common process is reductive dechlorination. Biologically mediated reductive dechlorination a respiratory process whereby hydrogen replaces chlorine resulting in the sequential dechlorination of TCE to cDCE, VC, ethene and ethane. The limited presence of cDCE in Site groundwater suggests that this process is occurring, but is not prevalent. Reductive dechlorination of cDCE to form VC typically occurs under highly reducing conditions (e.g., sulfate reducing to methanogenic), which do not exist in this portion of the Site. Therefore one would not expect to detect VC in groundwater under ambient Site redox conditions.

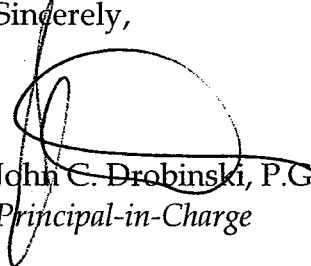
The Town is correct that a process known as biologically mediated aerobic oxidation exists. However, this process results in oxidation of chloroethenes directly to carbon dioxide without the formation of intermediates. This process is not particularly effective at oxidizing highly chlorinated compounds, such as PCE or TCE, but is effective at degrading cDCE and VC. A detailed summary of biological degradation of chlorinated ethenes via multiple pathways is presented by Bradley (2003).

REFERENCE:

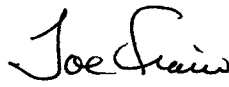
Bradley, P.M. 2003. History and ecology of chloroethene biodegradation: a review. *Bioremediation Journal*, 7(2): 81-109.

If you have any questions or comments please, contact Mr. Edwin Madera of Raytheon at (978) 440-1813.

Sincerely,



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



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

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 Office,
Wayland, MA 01778

Ms. Karen Stromberg, Massachusetts Department of
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Boston, MA 02108