REPORT



Stabilus and Honeywell International, Inc.

# Bioaugmentation Microcosm Study Report – Task 2 of the Bioremediation Evaluation

## *North Penn Area 5 Site Colmar, Pennsylvania*

June 2004

**Environmental Resources Management**
350 Eagleview Boulevard
Suite 200
Exton, Pennsylvania 19341

ERM®

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Environmental Resources Management, Inc. (ERM) and Terra Systems, Inc. (TSI) completed the Bioaugmentation Microcosm Study to evaluate the potential for enhanced anaerobic bioremediation to remediate ground water containing trichloroethene (TCE) underlying the former Stabilus property at the North Penn Area 5 (NPA5) Site in Colmar, Pennsylvania. The study is Task 2 of the Bioremediation Evaluation completed by ERM and TSI on behalf of Stabilus and Honeywell International, Inc., as described in ERM's 19 June 2003 *Revised Scope of Work and Estimated Probable Cost*.

The study consisted of the following:

- collecting ground water samples from monitoring wells RI-23 (overburden) and RI-27S (shallow bedrock), and collecting soil samples in the vicinity of RI-23 for use in the study;
- conducting 84- and 118-day microcosm studies of both overburden and shallow bedrock ground water in the laboratory to evaluate whether the addition of lactate is sufficient to stimulate reductive dechlorination of TCE to ethane/ethane; and
- conducting 84- and 118-day bioaugmentation microcosm studies of both overburden and shallow bedrock ground water in the laboratory to evaluate whether the addition of lactate, methanol, molasses, or slow-release substrate (SRS, emulsified soy bean oil) augmented with a dechlorinating enrichment (*Dehalococcoides ethenogenes* culture and nutrients) is sufficient to stimulate reductive dechlorination of TCE to ethene/ethane.

The results indicate that bioaugmentation is necessary to achieve complete reductive dechlorination of TCE to ethene in overburden and shallow bedrock ground waters at the NPA5 Site. The addition of lactate without being bioaugmented was able to stimulate growth of indigenous microorganisms and reduce TCE to cis-1,2-dichloroethene (cis-1,2-DCE), but was not able to further reduce cis-1,2-DCE to vinyl chloride and ethene.

Methanol, lactate, and SRS are potential organic substrate candidates based on the corresponding microcosms showing almost complete conversion of TCE to vinyl chloride and ethene. SRS appears to have achieved the best results based on being able to completely reduce TCE to vinyl chloride and ethene in less time than other organic substrates, and vinyl chloride concentrations showing a decreasing trend at the end of the study. Another advantage of SRS is that it will last longer in the subsurface and will not have to be replenished as often as the other soluble substrates evaluated in this study (less frequent injections for full-scale implementation).

The results indicate that enhanced anaerobic bioremediation is a viable remedial alternative to address overburden ground water on the former Stabilus property containing TCE. Further assessment of organic substrates and dechlorinating enrichments, considering implementation and cost criteria, may be conducted during the remedial design phase in order to select the appropriate organic substrate(s) and injection technique. No further laboratory studies or field-scale pilot testing are recommended. The limited size of the area targeted for treatment (less than 0.5 acre) warrants proceeding with full-scale implementation rather than conducting a pilot test. Remedial performance can be evaluated and modified as part of the full-scale implementation.

## 1.0 *INTRODUCTION*

Environmental Resources Management, Inc. (ERM) and Terra Systems, Inc. (TSI) completed the Bioaugmentation Microcosm Study to evaluate the potential for enhanced anaerobic bioremediation to remediate ground water containing trichloroethene (TCE) underlying the former Stabilus property at the North Penn Area 5 (NPA5) Site in Colmar, Pennsylvania. The study is Task 2 of the Bioremediation Evaluation completed by ERM and TSI on behalf of Stabilus and Honeywell International, Inc., as described in ERM's 19 June 2003 *Revised Scope of Work and Estimated Probable Cost.*

Objectives of the Bioremediation Evaluation were to answer the following questions:

1. Is biodegradation of TCE occurring naturally? If so, what is the process? Reductive dechlorination or other?
2. Is the optimal microorganism present?
3. Can naturally occurring biodegradation be enhanced?
4. What organic substrates and nutrients are required to enhance biodegradation?

The first two questions were answered as part of Task 1, and the results of which are summarized in Section 2.0 of this report. Task 2, the Bioaugmentation Microcosm Study, was completed to answer the remaining two questions. Sections 3.0, 4.0, and 5.0 of this report present the Bioaugmentation Microcosm Study methods, results, and conclusions.

## 2.0 JULY 2003 GROUND WATER SAMPLING EVENT

ERM completed a ground water sampling event at the NPA5 Site between 23 and 25 July 2003, which consisted of collecting ground water samples for laboratory analysis from selected monitoring wells on the former Stabilus property. The ground water sampling event was Task 1 of the Bioremediation Evaluation, and was designed to answer the following questions:

- Is biodegradation of TCE occurring naturally? If so, what is the process? Reductive dechlorination or other?
- Is the optimal microorganism present?

Ground water samples were collected from monitoring wells RI-18S, RI-18D, RI-23, RI-24, RI-25, RI-27S, RI-27D, and RI-28 using a low-flow sampling technique. The sampling procedures and results of the sampling event are presented in ERM's *July 2003 Ground Water Sampling Report*, which was submitted to EPA in December 2003. Table 1 summarizes the ground water analytical results. Figure 1 shows the approximate well locations and analytical results for TCE and cis-1,2-dichloroethene (cis-1,2-DCE) in ground water.

Based on a review of the ground water analytical results by ERM and TSI, the results indicate the following:

- The analytical data support that TCE is continuing to naturally attenuate based on decreasing ground water concentrations since 1998.
- The analytical data for VOCs and natural attenuation parameters provide evidence of naturally occurring reductive dechlorination. However, the predominant natural attenuation mechanisms for TCE in ground water at the NPA5 Site likely include dilution, dispersion, and sorption.
- The optimal microorganism for naturally occurring reductive dechlorination, *Dehalococcoides ethenogenes* (DHE), was not detected in the eight ground water samples collected as part of the sampling event. This is consistent with the ground water conditions being mostly aerobic rather than anaerobic as required for DHE to thrive. DHE may still be present at levels below the analytical detection limit, and be present in localized, anaerobic microenvironments within the subsurface at the NPA5 Site.

Based on these results and experience, ERM and TSI recommended proceeding with the Bioaugmentation Microcosm Study to evaluate whether the addition of an organic substrate (alone and augmented with a dechlorinating enrichment containing DHE) can stimulate reductive dechlorination of TCE in ground water underlying the former Stabilus property. The procedures, results, and conclusions of this study are presented in this report.

# 3.0 GROUND WATER AND SOIL SAMPLING AND ANALYSIS

Ground water and soil samples for use in the study were collected by ERM on 25 November 2003. This section summarizes the sampling procedures and analytical results.

## 3.1 SAMPLING PROCEDURES

The ground water samples were collected from monitoring wells RI-23 and RI-27S using the same low-flow sampling technique described for samples collected from these wells in July 2003 (see ERM's *July 2003 Ground Water Sampling Report* dated December 2003 for a more detailed description). RI-23 and RI-27S were selected to represent TCE-impacted overburden and shallow bedrock ground waters, respectively.

A sample of saturated soil was collected from a soil boring advanced in the immediate vicinity of RI-23. The soil boring was advanced to a depth of 13 feet below the ground surface (ft bgs) using a Geoprobe. The soil sample was collected from a depth interval of 11.5 to 12.5 ft bgs. This depth interval is where saturated conditions were encountered. A saturated soil sample was not collected in the vicinity of RI-27S because this well represents shallow bedrock ground water where no significant amount of soil would be present.

The samples were collected in sampling containers provided by TSI. The containers were filled with sample material so that there was little headspace volume, which was necessary to reduce the potential for adding oxygen to the sample that could interfere with the study results and to reduce the potential for TCE volatilization into the headspace. The containers were immediately placed into an ice-filled cooler and delivered to TSI at its facility in Wilmington, Delaware.

## 3.2 ANALYTICAL PROCEDURES AND RESULTS

TSI analyzed the ground water samples for chlorinated volatile organic compounds (CVOCs) in accordance with SW-846 Method 8021B and light hydrocarbons (i.e., ethane, ethene, methane) in accordance with a modified SW 846 Method 8015. TCE and cis-1,2-DCE were detected in both samples at the concentrations presented on the following table.

| CVOC | RI-23 (μg/L) | RI-27S (μg/L) |
|---|---|---|
| TCE | 97 | 1,020 |
| cis-1,2-DCE | 9.4 | 23 |

No other CVOCs or light hydrocarbons were detected in either sample.

TCE and cis-1,2-DCE concentrations measured in the sample collected from RI-27S are consistent with the July 2003 analytical results. TCE and cis-1,2-DCE concentrations measured in the sample collected from RI-23 are an order of magnitude less than the July 2003 analytical results (900 and 67 μg/L, respectively). TCE and cis-1,2-DCE concentrations as low as those measured in the sample collected from RI-23 in November 2003 are too low for obtaining reliable results from a microcosm study, so the RI-23 sample was spiked with TCE to increase the concentration to approximately 1,000 μg/L for the purpose of conducting the Bioaugmentation Microcosm Study.

## 4.0 MICROCOSM STUDY

TSI completed the laboratory portion of the Bioaugmentation Microcosm Study at its Wilmington, Delaware facility between December 2003 and April 2004. The study evaluated the potential for the addition of lactate alone and lactate, methanol, molasses, or slow-release substrate (SRS, emulsified soy bean oil) augmented with a dechlorinating enrichment (DE) culture containing *Dehalococcoides ethenogenes* (DHE) and nutrients to stimulate reductive dechlorination of TCE to ethene/ethane. The study procedures and results are presented in this section of the report.

### 4.1 MICROCOSM PREPARATION

Microcosms were prepared on 2 December 2003 using either a 560- or 280-milliliter (mL) serum bottles. Each microcosm was incubated for a minimum of 84 days, and several microcosms that yielded better results over the first 84 days were incubated for 118 days to ascertain if the longer incubation period would provide even better results. Table 2 summarizes the individual microcosms prepared for this study, including the quantities of ground water, soil, organic substrate, DE, and other amendments added to each microcosm. The microcosms were prepared and sampled in an anaerobic chamber containing 3% hydrogen, 5% carbon dioxide, and 92% nitrogen to ensure anaerobic conditions were maintained. The microcosms were sealed with a rubber septum wrapped with Teflon tape and incubated at approximately 22 °C throughout the study. Teflon tape was used to reduce contact between ground water and the rubber septum, and reduce potential adsorption of CVOCs and light hydrocarbons into the rubber septum.

Separate microcosms were prepared for RI-23 ground water (representing overburden ground water) and RI-27S ground water (representing shallow bedrock ground water). RI-23 ground water was spiked with additional TCE to bring the total TCE concentration to approximately 1,000 µg/L. This was done to ensure there was a sufficient mass of TCE present in the microcosms to effectively evaluate reductive dechlorination of TCE. Saturated overburden soil was added to microcosms containing RI-23 ground water to be more representative of in situ conditions compared to ground water alone.

Control microcosms included a sterile control and two unamended control microcosms. A sterile control was prepared using only RI-23 groundwater with overburden soil to account for potential TCE losses from the microcosms due to processes other than biodegradation (abiotic losses). The sterile control microcosm was autoclaved on two successive days to reduce the potential for microorganism survival. One unamended microcosm was prepared using RI-23 ground water with overburden soil and a second one using RI-27S ground water. No substrates were added to the unamended control microcosms in order to evaluate whether organic compounds in ground water or soil could support reductive dechlorination.

Organic substrates (lactate, methanol, molasses) were added at a dosage of 500 milligrams carbon per liter (mgC/L). SRS was added at a dosage of 2,000 mgC/L because it was expected to dissolve and biodegrade more slowly than the other organic substrates. Additional substrate was added to selected microcosms after 105 days to ensure there was sufficient organic substrate for the entire 118-day duration of the study.

DHE-containing cultures were added to bioaugmented microcosms. One such culture, the Pinellas Dechlorinating Enrichment (PDE) culture, was added to the bioaugmented microcosms 20 days after adding the organic substrate and other amendments to ensure the microcosms were anaerobic before adding the culture. PDE was derived from the Department of Defense site in Pinellas, Florida and has been used in both laboratory (DeWeerd et al. 1998; Harkness et al. 1999) and field studies to stimulate complete reductive dechlorination of TCE (Ellis et al. 2000). A second DHE-containing culture from a site in Rhode Island was added to the bioaugmented microcosms after 63 days. TSI recommended evaluating the second culture based on its experience with this culture in other microcosm studies indicating the culture is capable of enhancing complete reductive dechlorination of TCE. Both cultures were grown on sodium lactate and a Reduced Anaerobic Mineral Media (RAMM) containing inorganic nutrients, vitamins, trace minerals, and TCE prior to inoculation.

Each organic substrate-amended microcosm was supplied with nitrogen, phosphorus, and yeast extract at dosages of 50, 5, and 50 mg/L. Nitrogen and phosphorus were added to maintain a carbon-nitrogen-phosphorus (C:N:P) ratio of 100:10:1, which is a typical optimal ratio for biodegradation. Yeast extract was added as a source of trace elements and vitamins. Nitrogen, phosphorus, and yeast extract would be used as part of a full-scale implementation, and would be added in a mixture with the organic substrate.

Sodium bicarbonate was added to each microcosm at a concentration of 500 mg/L. This was done to buffer acid generated from biodegradation of the organic substrate. The volume of the microcosms is too small to provide sufficient buffering capacity that would be provided in the natural environment. Sodium bicarbonate will not likely need to be added as part of a full-scale implementation.

Resazurin was added to each microcosm at a concentration of 1 mg/L as a visual indicator of oxidation-reduction potential (ORP). The microcosms remain clear when conditions are anaerobic and reducing, which is necessary for reductive dechlorination to occur. A pink color is observed when the microcosm is under aerobic, oxidizing conditions. Resazurin does not affect the biodegradation process.

## 4.2 *MICROCOSM SAMPLING AND ANALYSIS*

Ground water samples were collected from each microcosm after 0, 20, 35, 49, 63, and 84 days and after 118 days for selected microcosms. On Day 20 of the study, samples were collected before and after inoculating the bioaugmented microcosms with PDE. Samples were collected from the microcosms within an anaerobic glove box to maintain anaerobic conditions. Samples were collected for CVOC and light hydrocarbon analyses through the rubber septa using a syringe. One aliquot (2 to 9 mL) of the sample was transferred directly into a 20-mL headspace vial containing 1 mL of a 25% sodium chloride solution adjusted to pH 2.0 with phosphoric acid and enough distilled water to bring the entire volume of sample and sodium chloride solution to 10 mL. This aliquot was analyzed by TSI for CVOCs in accordance with SW-846 Method 8021B and light hydrocarbons (ethene, ethane, and methane) in accordance with a modified SW 846 Method 8015. A second 4-mL aliquot of the sample was collected in an 8-mL headspace vial, amended with 1 mL of methanol, and frozen in case the analyses needed to be repeated. After sample collection, the rubber septa were removed from the microcosm bottles, the withdrawn liquid was replaced with sterile glass beads to avoid leaving a headspace for the CVOCs and light hydrocarbons to partition into, and a fresh rubber septum wrapped with Teflon tape was applied. Losses of CVOCs during this process were considered insignificant since the objectives of the study were to evaluate whether naturally occurring biodegradation can be enhanced and what substrates and nutrients are required to enhance the naturally occurring biodegradation, rather than to document that a mass balance has been maintained.

## 4.3 MICROCOSM STUDY RESULTS

Results of the bioaugmentation microcosm study are presented in this section, and are presented in terms of microcosm conditions, metabolic activity, and contaminant removal.

### 4.3.1 Microcosm Conditions

Anaerobic conditions are essential for reductive dechlorination of TCE. As described in Section 4.1, resazurin was added to each microcosm at a concentration of 1 mg/L as a visual indicator of ORP. The microcosms become clear when conditions are anaerobic, and a pink color is observed when conditions are aerobic and oxidizing. Each microcosm, except for the unamended microcosm with RI-27S ground water, was clear, which indicated that the microcosm conditions were anaerobic. The unamended microcosm with RI-27S ground water remained pink throughout the study, which indicated that this microcosm remained slightly aerobic.

### 4.3.2 Metabolic Activity

Metabolic activity refers to the level of biodegradation occurring, and has been evaluated in this study by measuring dissolved methane concentrations and the volume of gas produced (including methane and carbon dioxide) for each microcosm. The presence of methane in a microcosm is an indication that microorganisms are present and actively biodegrading the organic substrate. Increases in methane concentrations and the volume of gas produced following addition of an organic substrate to a microcosm indicate that the growth of microorganisms can be stimulated. Methane is produced when other electron acceptors (oxygen, nitrate, sulfate, iron) have been utilized, and reductive dechlorination occurs most readily under these methanogenic conditions.

Figure 2 and Table 3 present the dissolved methane concentrations for each microcosm with RI-23 ground water and overburden soil. Figure 3 presents the volume of gas produced for each microcosm with RI-23 ground water. Methane concentrations in the microcosms at the beginning of the study ranged from non-detect to 23 µg/L. Methane was detected in the sterile and unamended control microcosms, but the concentrations were low (maximum methane concentration of 56 µg/L) relative to the substrate-amended microcosms. In the substrate-amended microcosms, methane levels ranged from as high as 33,500 in the microcosm amended with lactate only to 85,900 µg/L in the microcosm amended with SRS and bioaugmented. Dissolved methane levels above its solubility (24,000 µg/L) are possible because of the high pressures created in the sealed microcosms as a result of gas production. Plastic syringes were used to collect the excess gas (includes both methane and carbon dioxide) that was generated in these microcosms. For the amended microcosms, gas volumes produced ranged from 8.2 milliliter (mL) in the microcosm amended with molasses and bioaugmented to greater than 469 mL in the microcosm amended with SRS and bioaugmented.

Figure 4 and Table 4 present the dissolved methane concentrations for each microcosm with RI-27S ground water. Figure 5 presents the volume of gas produced for each microcosm with RI-27S ground water. Methane concentrations at the beginning of the study ranged from non-detect to 19 µg/L, which are consistent with RI-23 ground water. Methane was detected in unamended control microcosms, but the concentrations were low (maximum methane concentration of 8.1 µg/L) relative to the substrate-amended microcosms. In the substrate-amended microcosms, methane levels ranged from as high as 5,350 in the microcosm amended with lactate to 72,900 µg/L in the microcosm amended with methanol and bioaugmented. The low end of the methane concentration range is 41,500 µg/L if the microcosm amended with only lactate is not included. For the amended microcosms, gas volumes produced ranged from 0.6 mL in the microcosm amended with molasses and bioaugmented to greater than 23.6 mL in the microcosm amended with SRS and bioaugmented.

The following summarize the results:

- Sterile and unamended control microcosms contained low methane concentrations throughout the study period with low gas production relative to amended microcosms, as expected.
- Growth of indigenous microorganisms can be stimulated through the addition of an organic substrate. This is based on increases in methane concentrations observed in non-bioaugmented microcosms relative to the control microcosms.
- Increased methane concentrations were measured in each microcosm between 20 and 35 days. For bioaugmented microcosms, this increase may be attributable to the microcosms being inoculated with PDE for the first time on Day 20. However, methane concentration increases were also observed in the microcosms amended with only lactate. Thus, these results suggest that between 20 and 35 days are required for the indigenous microorganisms to acclimate themselves to the changing conditions and organic substrate.
- Bioaugmented microcosms resulted in higher methane concentrations and larger gas volumes than the non-bioaugmented microcosms. This suggests that bioaugmented microcosms

experienced a higher level of metabolic activity and biodegradation than non-bioaugmented microcosms.

- Methane concentrations and gas volume production were higher in the microcosm containing RI-23 ground water amended with lactate only compared to the microcosm containing RI-27S ground water amended with lactate. This result is expected since overburden soil contains a higher microbial mass per unit volume than ground water alone.
- For RI-23 ground water and overburden soil, the highest methane concentrations and gas volume produced were achieved with microcosms amended with SRS and bioaugmented.
- For RI-27S ground water, the highest methane concentrations and gas volume produced were achieved with microcosms amended with methanol and bioaugmented. However, the microcosm amended with SRS and bioaugmented sustained higher methane concentrations throughout the study, while methane levels decreased in the microcosm amended with methanol. Decreased methane levels in the microcosm amended with methanol may indicate that methanol was depleted while SRS continued to provide carbon and hydrogen to support methanogenesis.

Based on metabolic activity alone, microcosms amended with SRS and bioaugmented achieved the highest level of sustained metabolic activity and biodegradation. However, concluding that this combination will also achieve the highest level of TCE biodegradation requires the analytical results of TCE and its daughter products, which are presented in the following section.

### 4.3.3 *Contaminant Removal*

Table 3 presents the analytical results for the microcosms containing RI-23 ground water and overburden soil. Table 4 presents the analytical results for the microcosms containing RI-27S ground water. Figures presenting the results for the various microcosms are summarized as follows:

| Figure | Microcosm | Well | Amendments |
|---|---|---|---|
| 6 | A | RI-23 | Sterile Control |
| 7 | B | RI-23 | Unamended Control |
| 8 | C | RI-23 | Lactate |
| 9 | D | RI-23 | Methanol and Bioaugmented |
| 10 | E | RI-23 | Lactate and Bioaugmented |
| 11 | F | RI-23 | Molasses and Bioaugmented |

| Figure | Microcosm | Well | Amendments |
|---|---|---|---|
| 12 | G | RI-23 | SRS and Bioaugmented |
| 13 | H | RI-27S | Unamended Control |
| 14 | I | RI-27S | Lactate |
| 15 | J | RI-27S | Methanol and Bioaugmented |
| 16 | K | RI-27S | Lactate and Bioaugmented |
| 17 | L | RI-27S | Molasses and Bioaugmented |
| 18 | M | RI-27S | SRS and Bioaugmented |

CVOC concentrations presented on Tables 3 and 4 and Figures 6 through 18 are expressed in micromolar (μM) units. This was done so that each CVOC is expressed on an equivalent mass basis for comparison purposes. The micromolar concentrations are calculated by dividing the concentration in μg/L by the molecular weight of the CVOC (PCE = 165.8; TCE = 131.4; cis-1,2-DCE = 97; vinyl chloride = 62.5; ethene = 28; ethane = 30).

The analytical results of RI-23 ground water and overburden soil microcosms and RI-27S ground water microcosms are presented in the following sections.

4.3.3.1 *RI-23 Ground Water and Overburden Soil*

The following summarizes the results for microcosms containing RI-23 ground water and overburden soil:

- Initial TCE concentrations in the microcosms ranged from 510 to 1,740 μg/L following the spiking with TCE. Initial cis-1,2-DCE concentrations ranged from non-detect to 23 μg/L. Initial ethene concentrations were below 15 μg/L. No tetrachloroethene (PCE) or vinyl chloride was detected in the initial samples.
- TCE was added to the sterile control microcosm after autoclaving on two successive days. The autoclaving process did not completely sterilize the microcosm based on the observed metabolic activity following sterilization (see Figure 6). Evidence of this metabolic activity included the decrease of TCE concentrations and increase of cis-1,2-DCE concentrations and the presence of a relatively small quantity of methane, suggesting the occurrence of reductive dechlorination and biodegradation of organics adsorbed on the overburden soil that were released by autoclaving.
- There was no detectable conversion of TCE to cis-1,2-DCE or vinyl chloride in the unamended control microcosm (see Figure 7). However, this microcosm did show an 84 percent loss of TCE from

the microcosm. The loss of TCE may be attributed to TCE partitioning into the small volume of headspace in the microcosm or adsorption onto the glass bottle, glass beads, and/or into the rubber septum. Similar abiotic losses have been observed in other microcosm studies.

- The microcosm amended with lactate showed almost complete conversion of the initial TCE to cis-1,2-DCE, but vinyl chloride was not detected and only trace levels of ethene were measured (see Figure 8). These results suggest that the addition of lactate alone was not able to achieve complete reductive dechlorination of TCE to ethene.
- The microcosm amended with methanol and bioaugmented achieved almost complete reduction of TCE to cis-1,2-DCE within 20 days, and cis-1,2-DCE was further reduced to vinyl chloride and ethene (see Figure 9). After 118 days, low concentrations of TCE and cis-1,2-DCE were detected in the microcosm, vinyl chloride concentrations were declining, and ethene concentrations were increasing.
- The microcosm amended with lactate and bioaugmented showed slower conversion of TCE to cis-1,2-DCE and cis-1,2-DCE to vinyl chloride and ethene than the microcosm amended with methanol and bioaugmented (within 49 days compared to 20 days (see Figure 10). After 118 days, low concentrations of TCE and cis-1,2-DCE were detected in the microcosm, vinyl chloride concentrations were low but stable, and ethene concentrations were increasing.
- The microcosm amended with molasses and bioaugmented showed almost complete conversion of TCE to cis-1,2-DCE within 35 days, but then produced only limited quantities of vinyl chloride and ethene over the next 49 days (see Figure 11). Cis-1,2-DCE was the predominant daughter product remaining after 84 days rather than vinyl chloride and ethene. Based on these results, molasses is not likely a good organic substrate for overburden ground water.
- The microcosm amended with the SRS and bioaugmented showed almost complete conversion of TCE to cis-1,2-DCE within 35 days (see Figure 12). Cis-1,2-DCE was almost completely converted to vinyl chloride and ethene within 84 days. After 118 days, little to no TCE or cis-1,2-DCE were detected in the microcosm, vinyl chloride concentrations were decreasing, and ethene concentrations were stable.

As evidenced by the above results, bioaugmentation is necessary to achieve complete reductive dechlorination of TCE to ethene in overburden ground water at the NPA5 Site. Methanol, lactate, and SRS are potential organic substrate candidates for overburden ground water based on the corresponding microcosms showing almost complete conversion of TCE to vinyl chloride and ethene. SRS appears to have achieved the best results based on being able to completely reduce TCE to vinyl chloride and ethene in less time than other organic substrates, and vinyl chloride concentrations showing a decreasing trend at the end of the study. The trend of decreasing vinyl chloride concentrations indicates that complete conversion to ethene would have occurred if the study duration was extended beyond 118 days.

#### 4.3.3.2 *RI-27S Ground Water*

The following summarizes the results for microcosms containing RI-27S ground water:

- Initial TCE concentrations for each microcosm ranged from 470 to 800 µg/L. RI-27S ground water was not spiked with TCE since the ground water contained TCE at a sufficient concentration for conducting the study. Initial cis-1,2-DCE concentrations ranged from 18 to 39 µg/L. Trace levels of ethene were initially measured in the microcosms. No PCE or vinyl chloride was detected in the initial samples.

- There was no detectable conversion of TCE to cis-1,2-DCE or vinyl chloride in the unamended control microcosm (see Figure 13). However, this microcosm did show a 72 percent loss of TCE and 87 percent loss of cis-1,2-DCE. The losses of TCE and cis-1,2-DCE may be attributed to partitioning of these CVOCs into the small volume of headspace in the microcosm or adsorption onto the glass bottle, glass beads, and/or into the rubber septum. Similar abiotic losses have been observed in other microcosm studies.

- The microcosm amended with lactate showed almost complete conversion of TCE to cis-1,2-DCE with no vinyl chloride and ethene production (see Figure 14). These results suggest that the addition of lactate alone was not able to achieve complete reductive dechlorination of TCE to ethene. These results are consistent with RI-23 ground water and overburden soil microcosm amended with only lactate.

- The microcosm amended with methanol and bioaugmented achieved almost complete reduction of TCE to cis-1,2-DCE within 49 days, and cis-1,2-DCE was further reduced to vinyl chloride and ethene (see Figure 15). After 118 days, low concentrations of TCE and cis-1,2-DCE were detected in the microcosm, and vinyl chloride and ethene concentrations were stable.

- The microcosm amended with lactate and bioaugmented achieved almost complete reduction of TCE to cis-1,2-DCE within 49 days, and cis-1,2-DCE was further reduced to vinyl chloride and ethene (see Figure 16). After 118 days, low concentrations of TCE and cis-1,2-DCE were detected in the microcosm, vinyl chloride concentrations were increasing, and ethene concentrations were decreasing.
- The microcosm amended with molasses and bioaugmented showed complete conversion of TCE to cis-1,2-DCE within 35 days, and almost complete conversion of cis-1,2-DCE to vinyl chloride and ethene within 63 days (see Figure 17). After 118 days, low concentrations of TCE and cis-1,2-DCE were detected in the microcosm, and vinyl chloride and ethene concentrations were stable.
- The microcosm amended with the SRS and bioaugmented showed almost complete conversion of TCE to cis-1,2-DCE within 35 days (see Figure 18). Cis-1,2-DCE was almost completely converted to vinyl chloride and ethene within 63 days. After 118 days, low TCE and cis-1,2-DCE concentrations were measured in the microcosm, and vinyl chloride and ethene concentrations were decreasing.

As with overburden ground water, the study results support that bioaugmentation is necessary to achieve complete reductive dechlorination of TCE to ethene in shallow bedrock ground water at the NPA5 Site. Methanol, lactate, molasses, and SRS are potential organic substrate candidates for overburden ground water based on the corresponding microcosms showing almost complete conversion to vinyl chloride and ethene. SRS appears to have achieved the best results based on being able to completely reduce TCE to vinyl chloride and ethene in less time than other organic substrates, and vinyl chloride concentrations showing a decreasing trend at the end of the study. The trend of decreasing vinyl chloride concentrations indicates that complete conversion to ethene would have occurred if the study duration was extended beyond 118 days.

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the Bioaugmentation Microcosm Study are as follows:

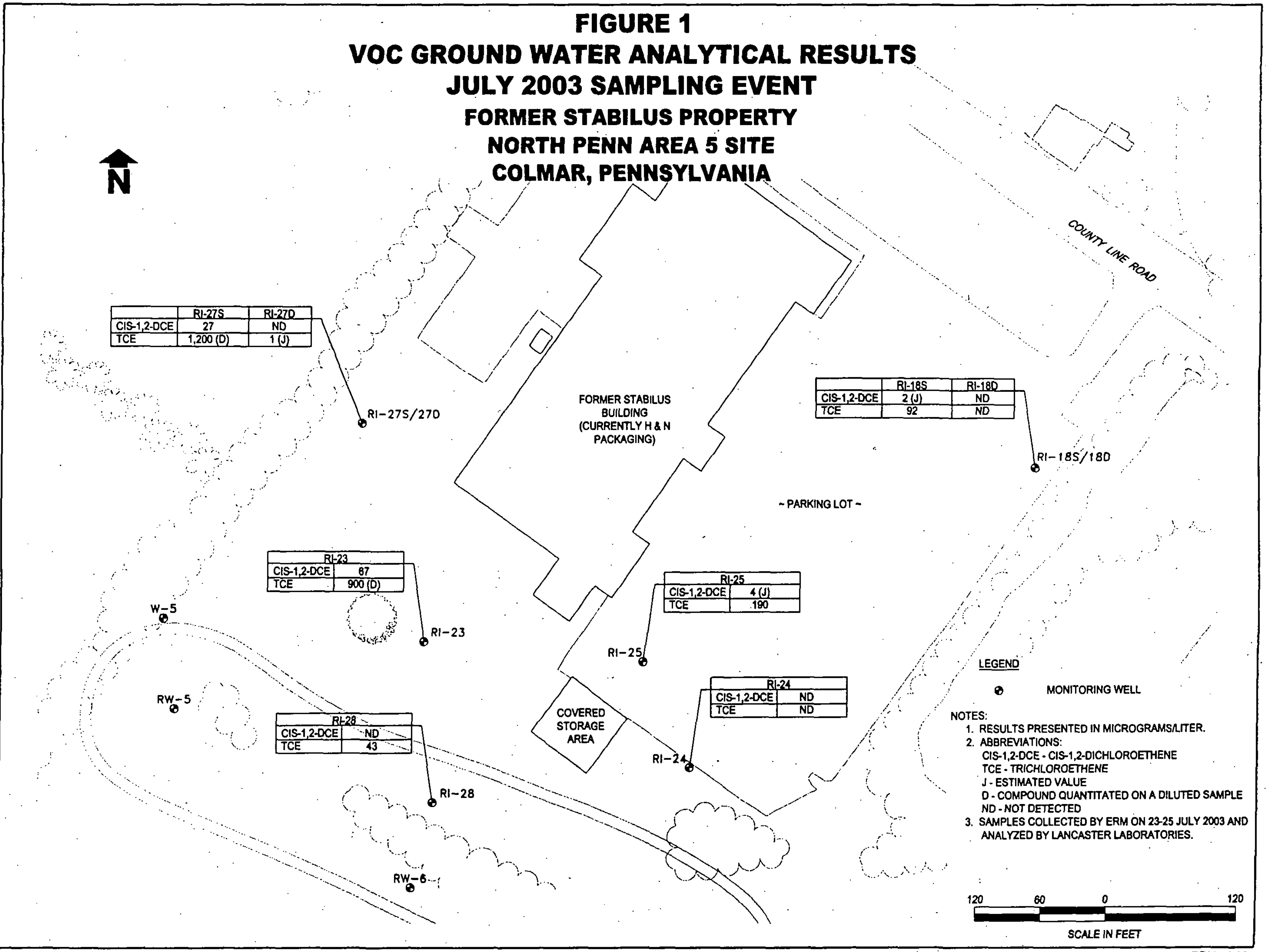
- The growth of indigenous microorganisms can be stimulated through the addition of an organic substrate. This is supported by the observed increase in metabolic activity and conversion of TCE to cis-1,2-DCE through the addition of only lactate.
- Bioaugmentation is necessary to achieve complete reductive dechlorination of TCE to ethene. Lactate-amended microcosms were able to convert TCE to cis-1,2-DCE, but were not able to convert cis-1,2-DCE to ethene. Bioaugmented microcosms achieved conversion of cis-1,2-DCE to ethene.
- Methanol, lactate, and SRS are potential organic substrates to be considered for full-scale implementation. SRS appears to have achieved the best results based on it being able to completely reduce TCE to vinyl chloride and ethene in less time than other organic substrates, and vinyl chloride concentrations showing a decreasing trend at the end of the study. Another advantage of SRS is that it will last longer in the subsurface and will not have to be replenished as often as the other soluble substrates evaluated in this study (less frequent injections for full-scale implementation).
- Molasses is not recommended for further consideration. While molasses with bioaugmentation had positive results with bedrock ground water (RI-27S), the results for overburden ground water were not favorable.
- PDE and the Rhode Island site dechlorinating enrichments can be considered for full-scale implementation. Most of the microcosms bioaugmented with these dechlorinating enrichments achieved nearly complete reductive dechlorination of TCE to ethene.

The results indicate that enhanced anaerobic bioremediation is a viable remedial alternative to address overburden ground water on the former Stabilus property containing TCE. Further assessment of organic substrates and dechlorinating enrichments, considering implementation and cost criteria, may be conducted during the remedial design phase in order to select the appropriate organic substrate(s) and injection technique. No further laboratory studies or field-scale pilot testing are recommended. The limited size of the area targeted for treatment (less than 0.5 acre) warrants proceeding with full-scale implementation rather than conducting a pilot test. Remedial performance can be evaluated and modified as part of the full-scale implementation.

# *Figures*

*Figures*

# FIGURE 1
## VOC GROUND WATER ANALYTICAL RESULTS
## JULY 2003 SAMPLING EVENT
### FORMER STABILUS PROPERTY
### NORTH PENN AREA 5 SITE
### COLMAR, PENNSYLVANIA

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MLB/05-17-04

ERM, INC.

**Figure 2**
**Methane Concentrations - Microcosms Containing RI-23 Ground Water and Overburden Soil**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

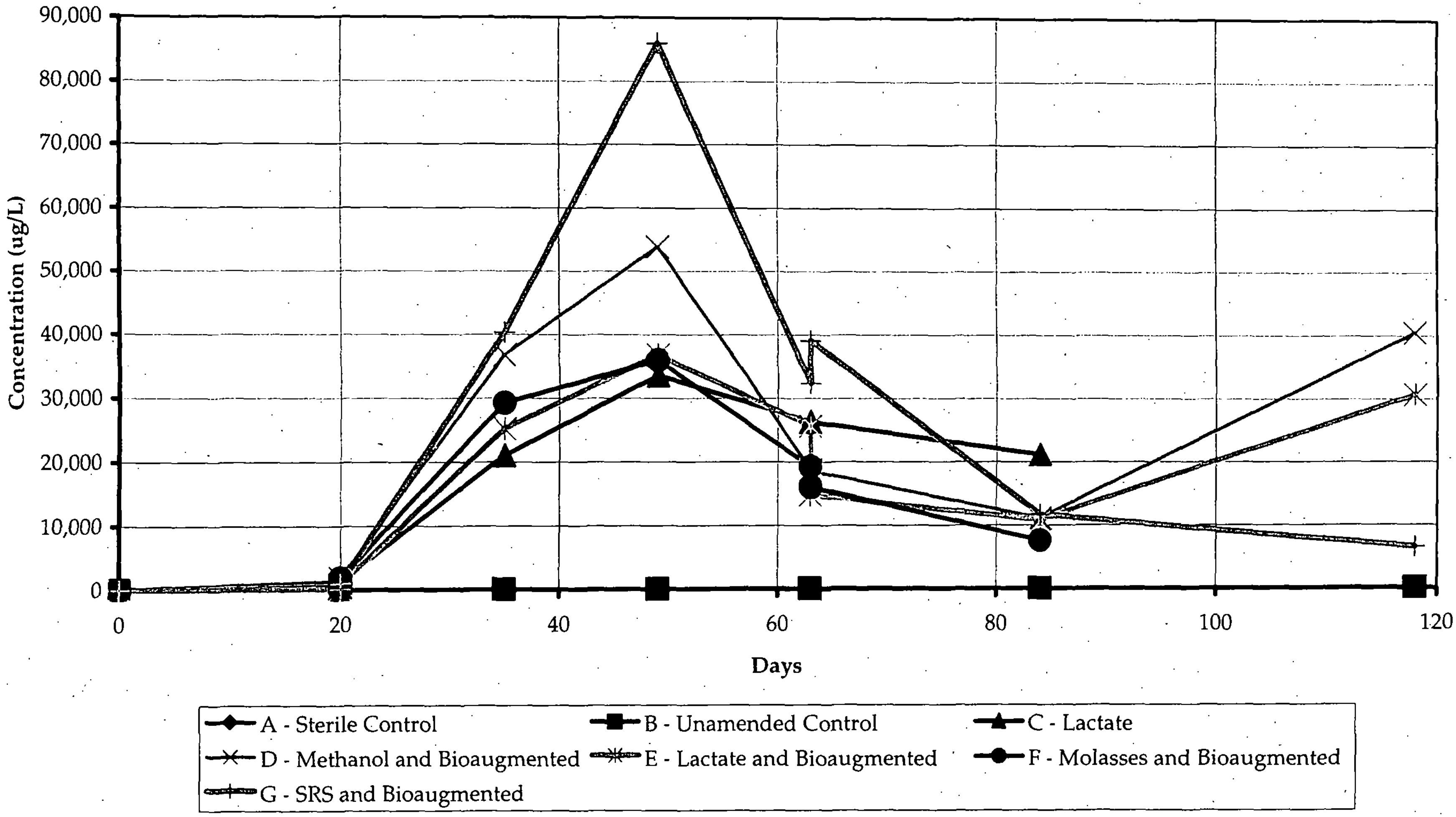

**Figure 3**
**Gas Production - Microcosms Containing RI-23 Ground Water and Overburden Soil**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

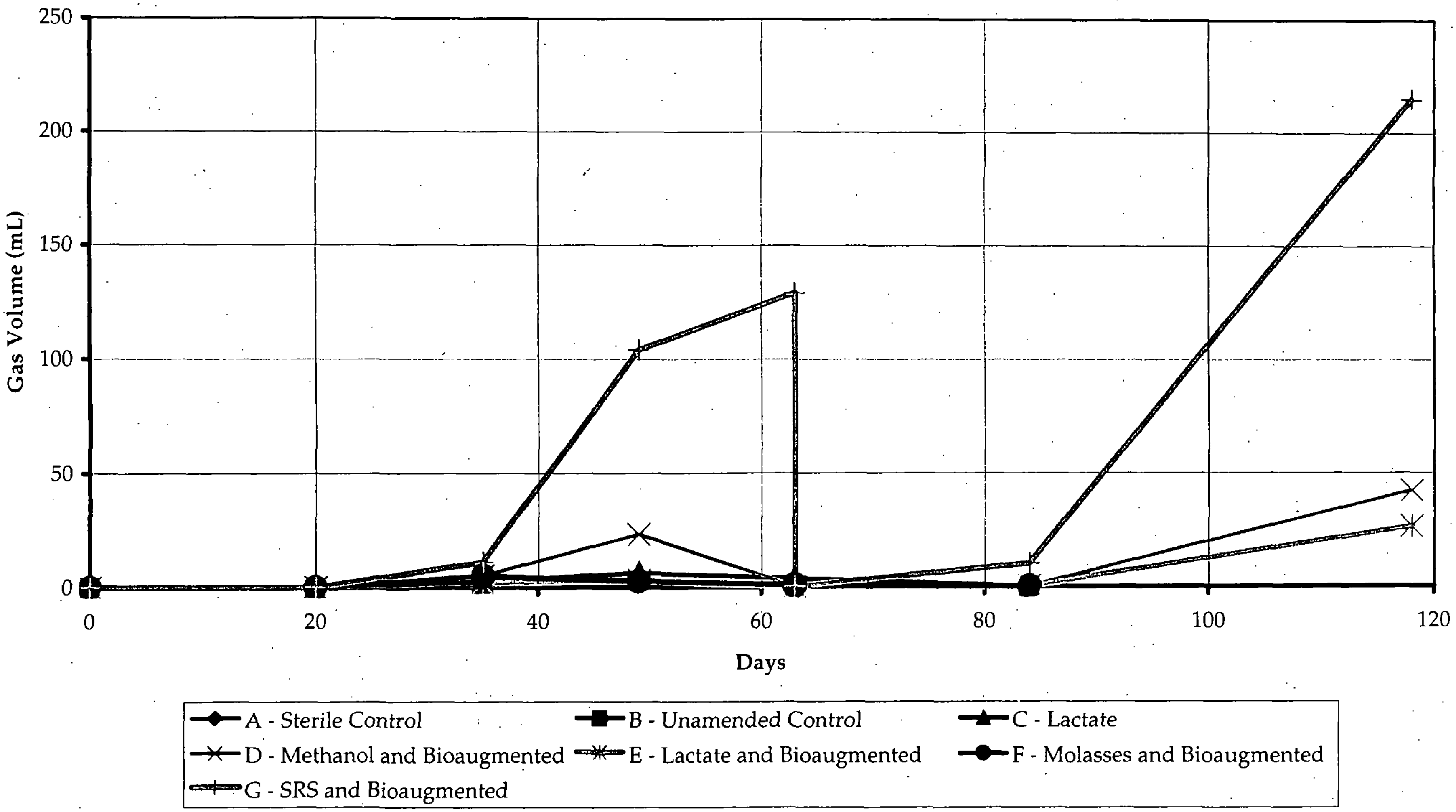

**Figure 4**
**Methane Concentrations - Microcosms Containing RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

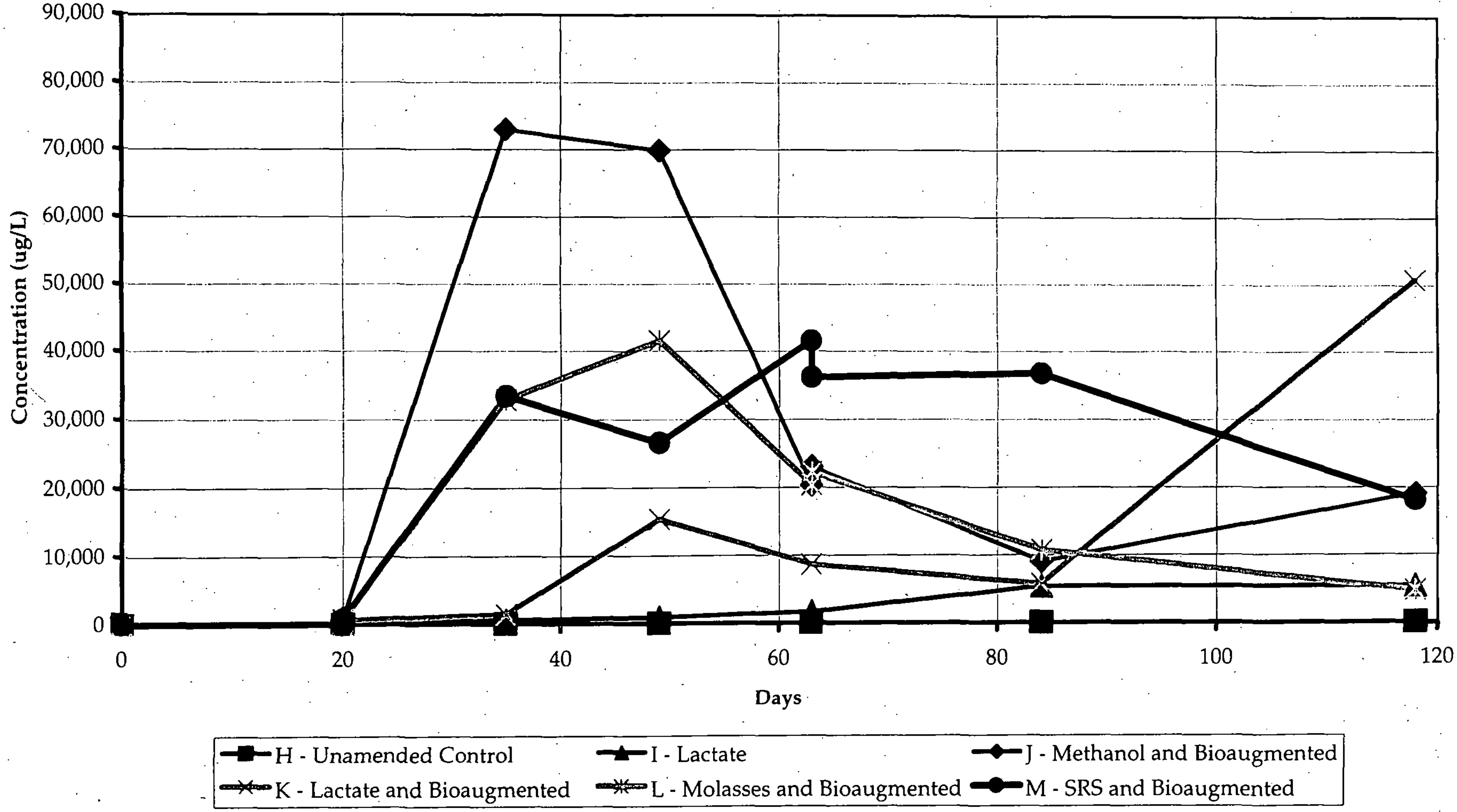

**Figure 5**
**Gas Production - Microcosms Containing RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

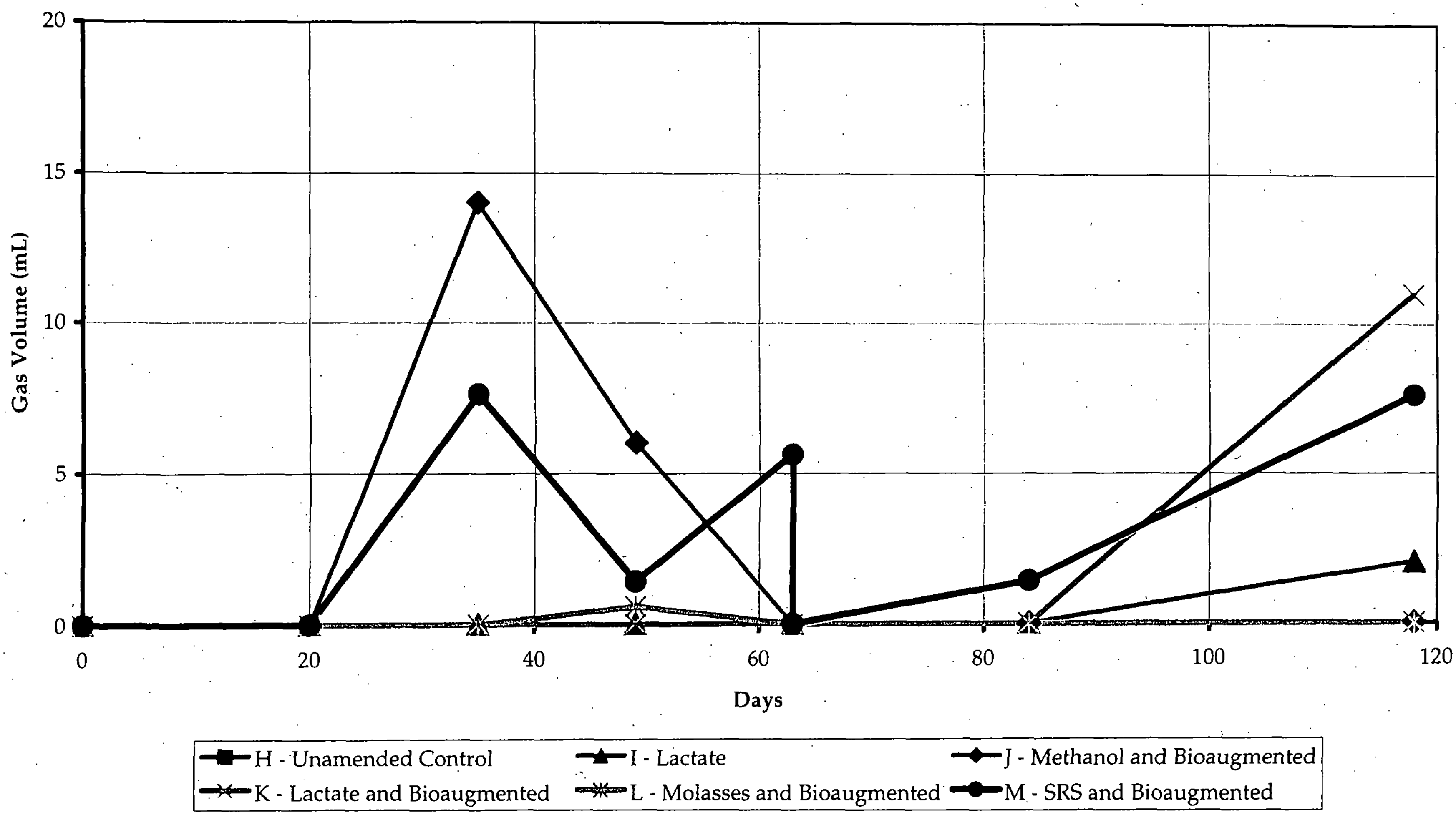

**Figure 6**
**Microcosm A Results - Sterile Control**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

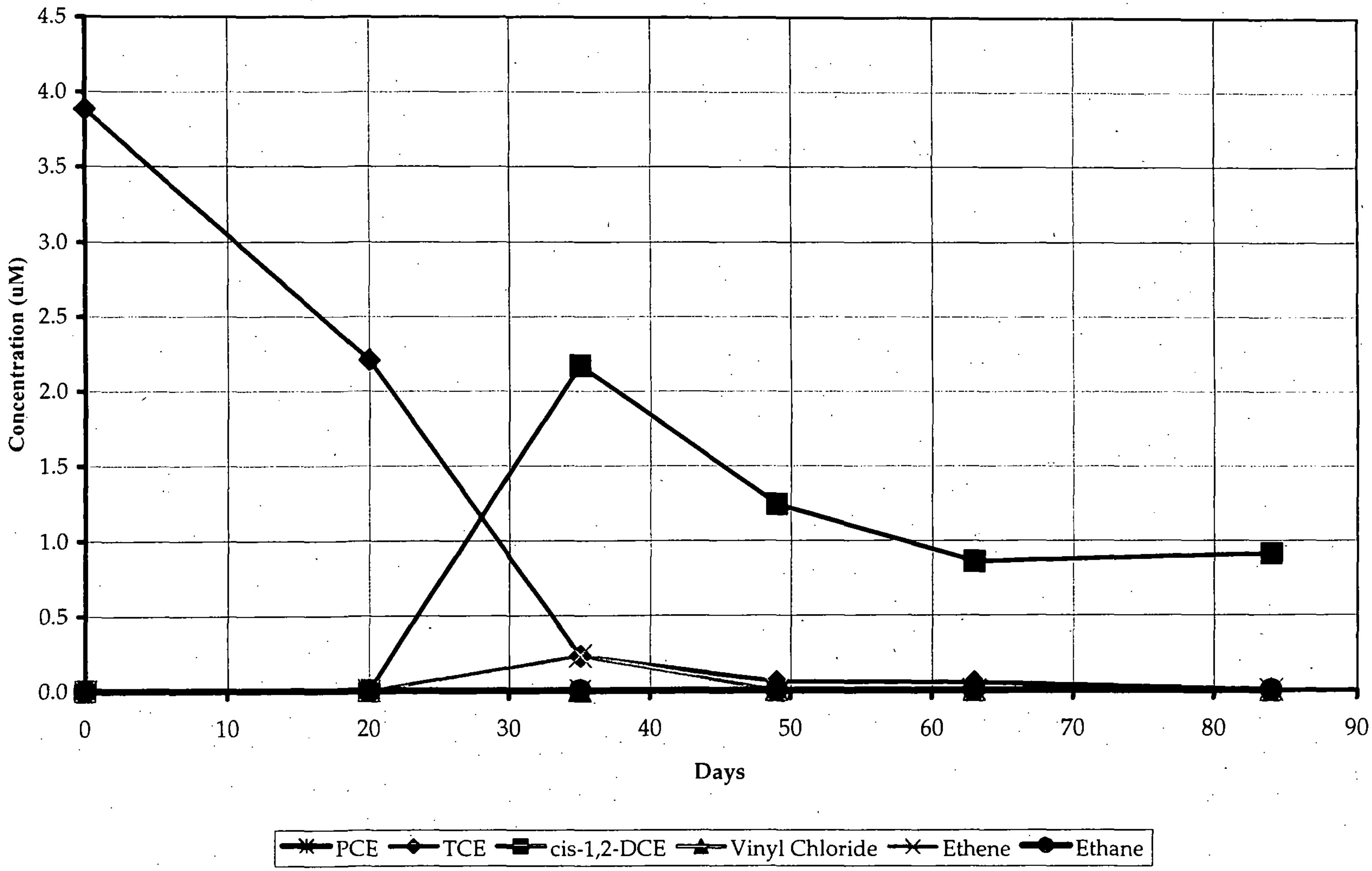


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**Figure 7**
**Microcosm B Results - Unamended Control - RI-23 Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

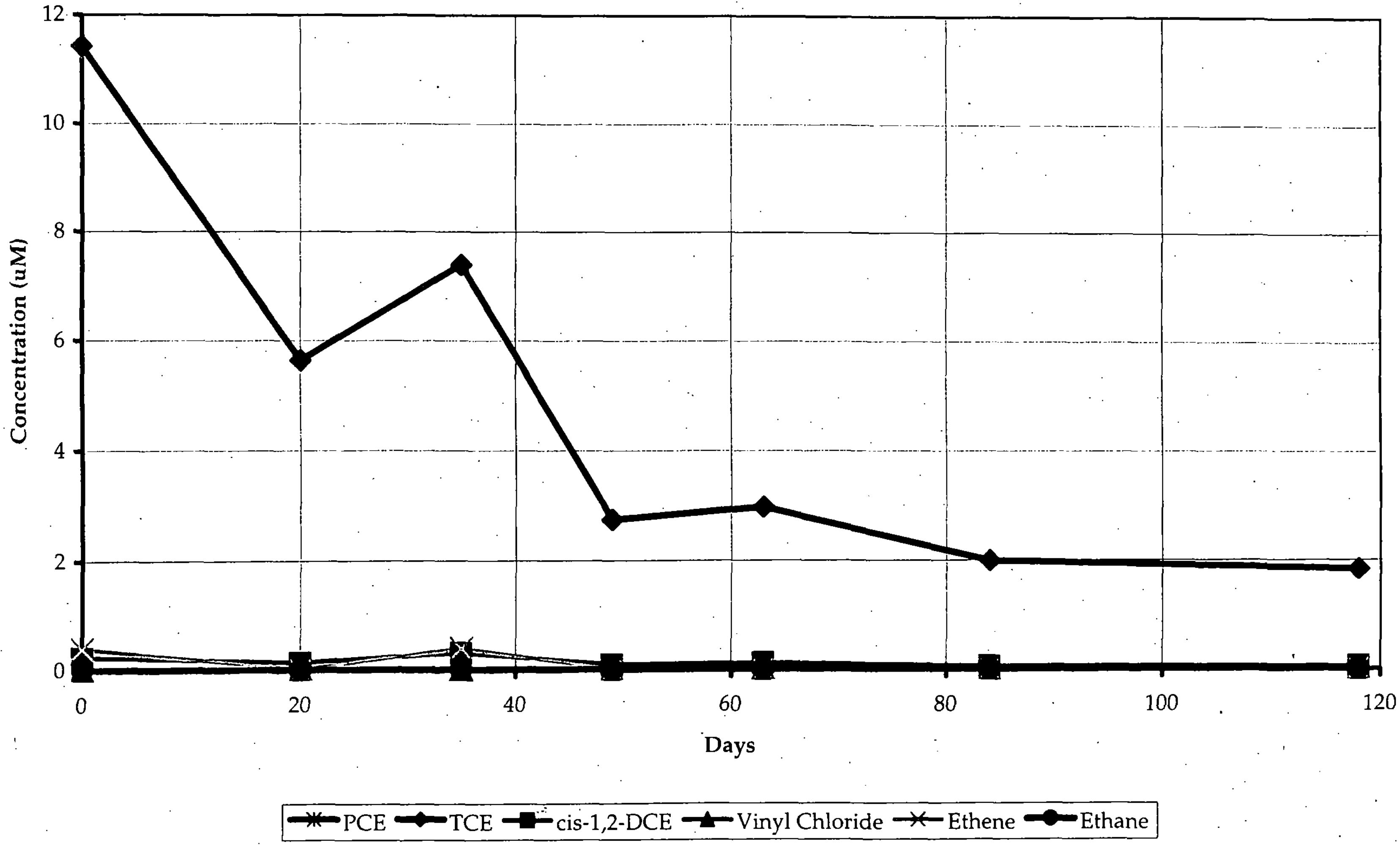


**Figure 8**
**Microcosm C Results - Lactate - RI-23 Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

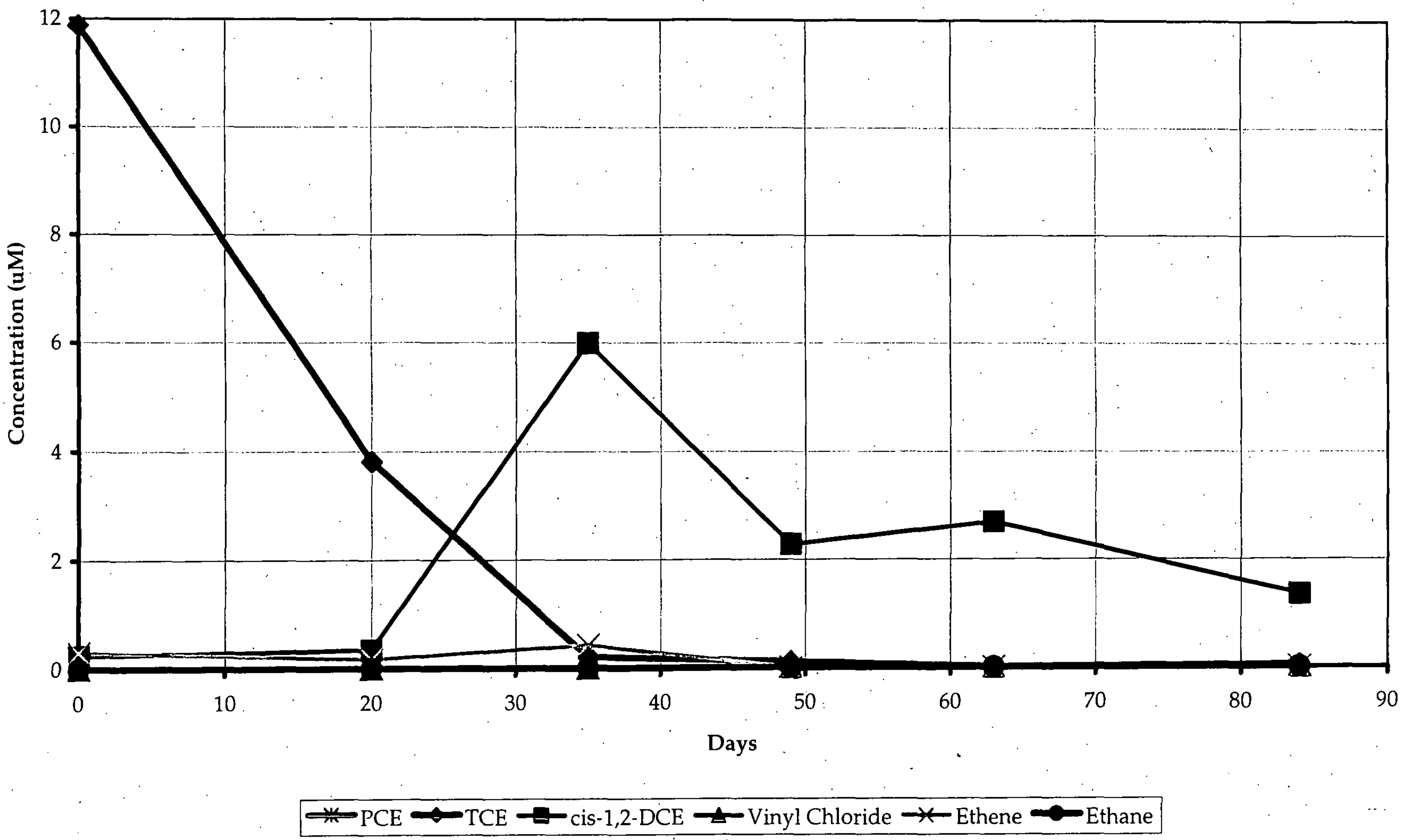


Figure 9
Microcosm D Results - Methanol and Bioaugmented - RI-23 Ground Water
Bioaugmentation Microcosm Study
North Penn Area 5 Site - Colmar, Pennsylvania

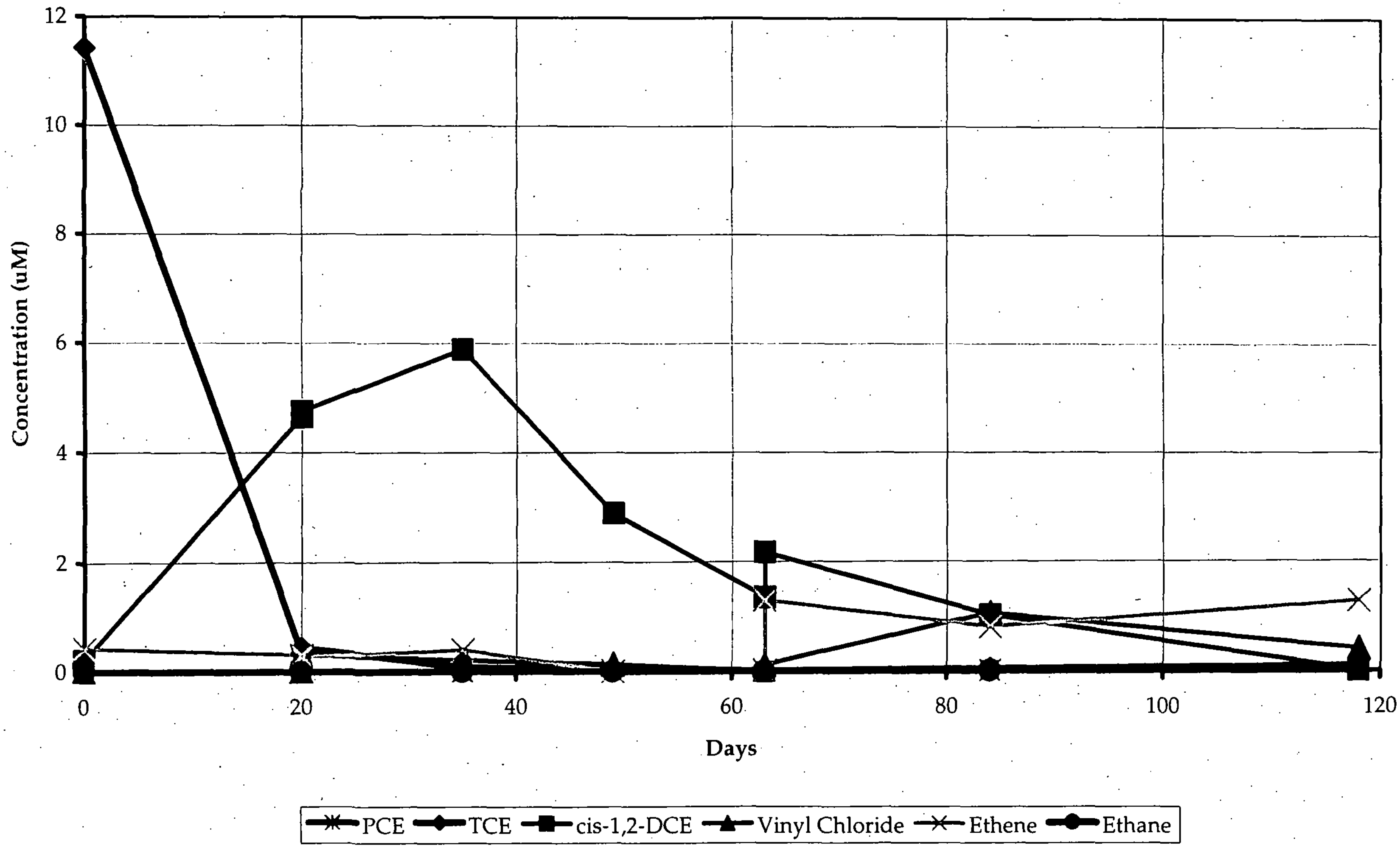


**Figure 10**
**Microcosm E Results - Lactate and Bioaugmented - RI-23 Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

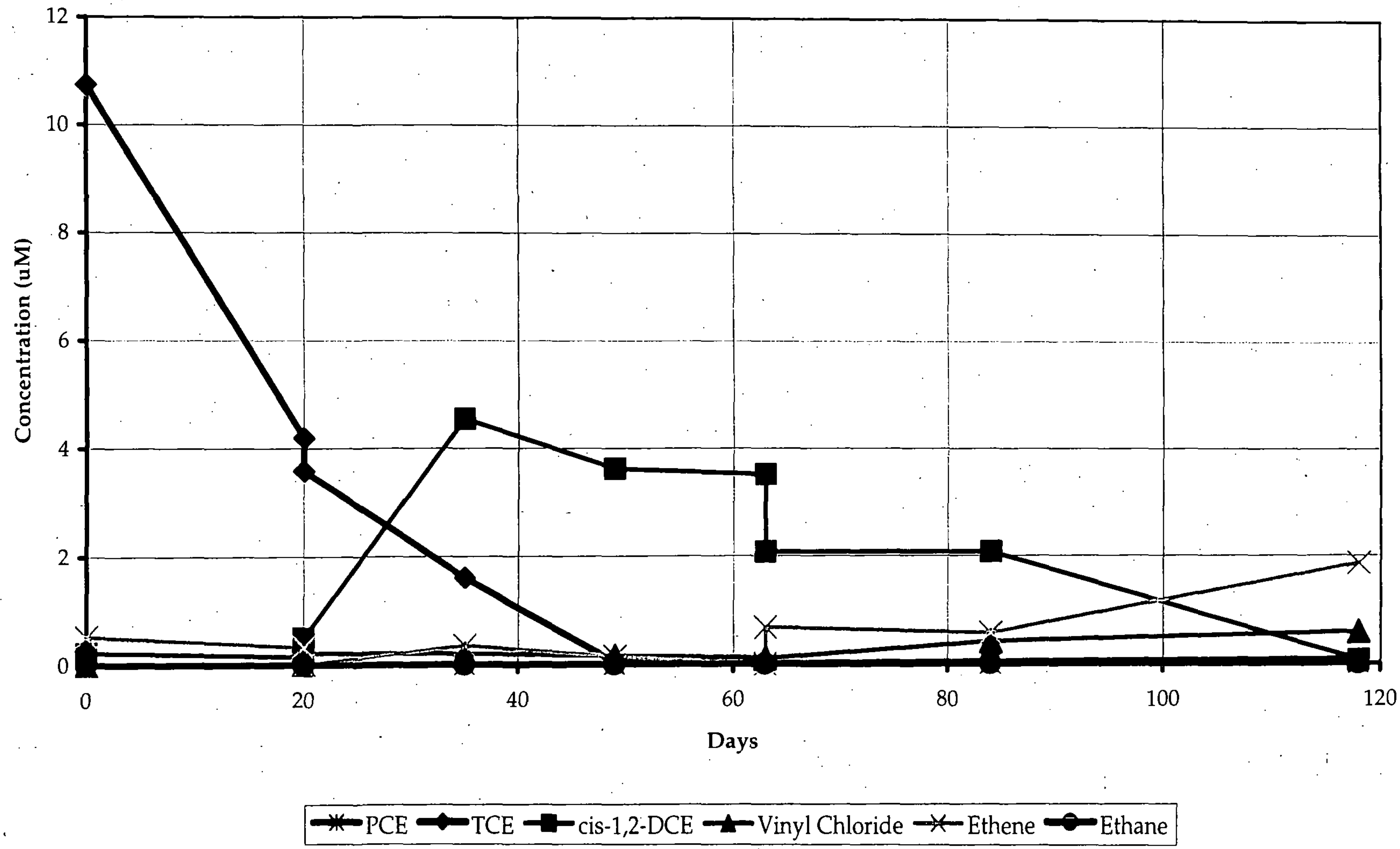


Figure 11
Microcosm F Results - Molasses and Bioaugmented - RI-23 Ground Water
Bioaugmentation Microcosm Study
North Penn Area 5 Site - Colmar, Pennsylvania

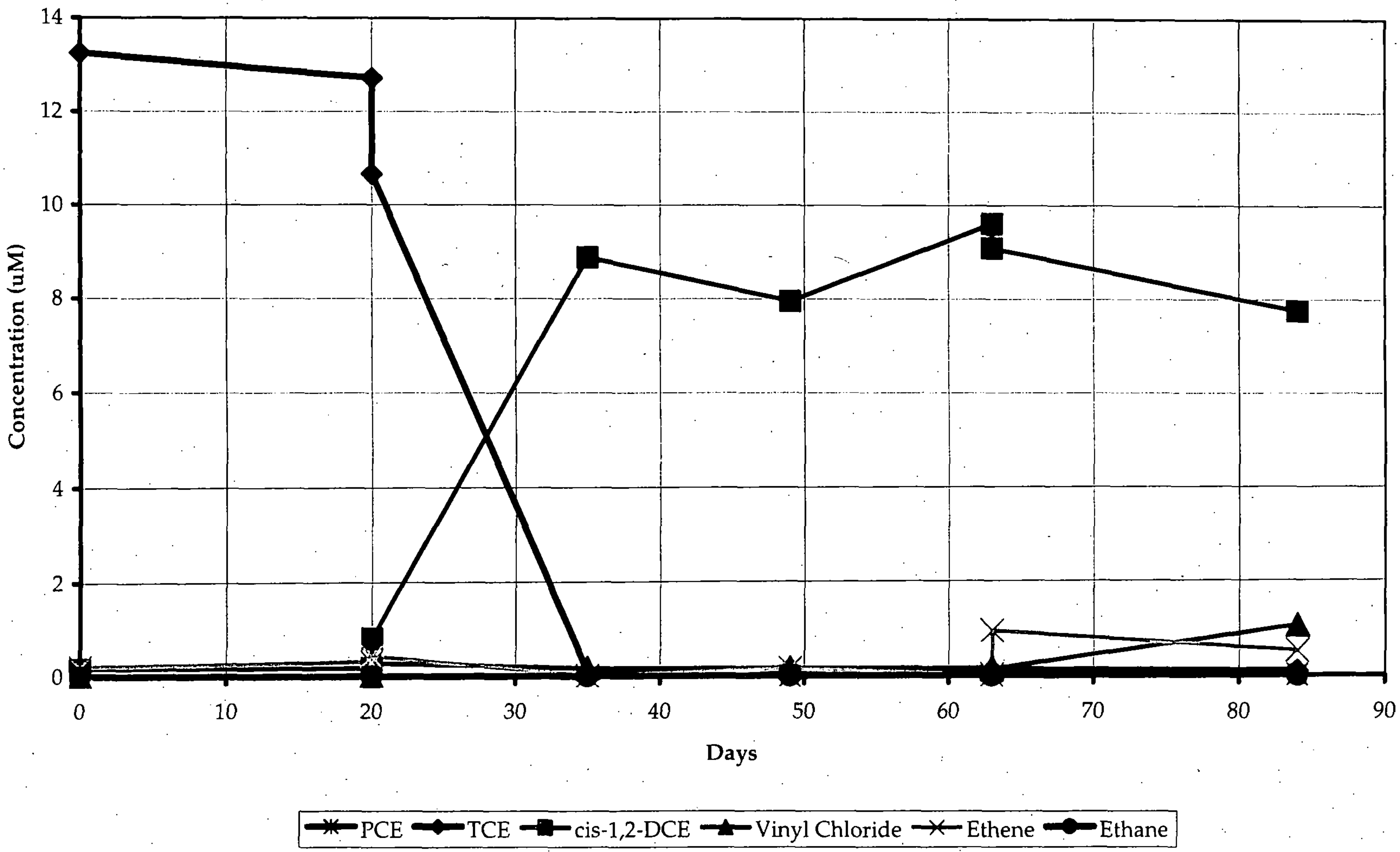
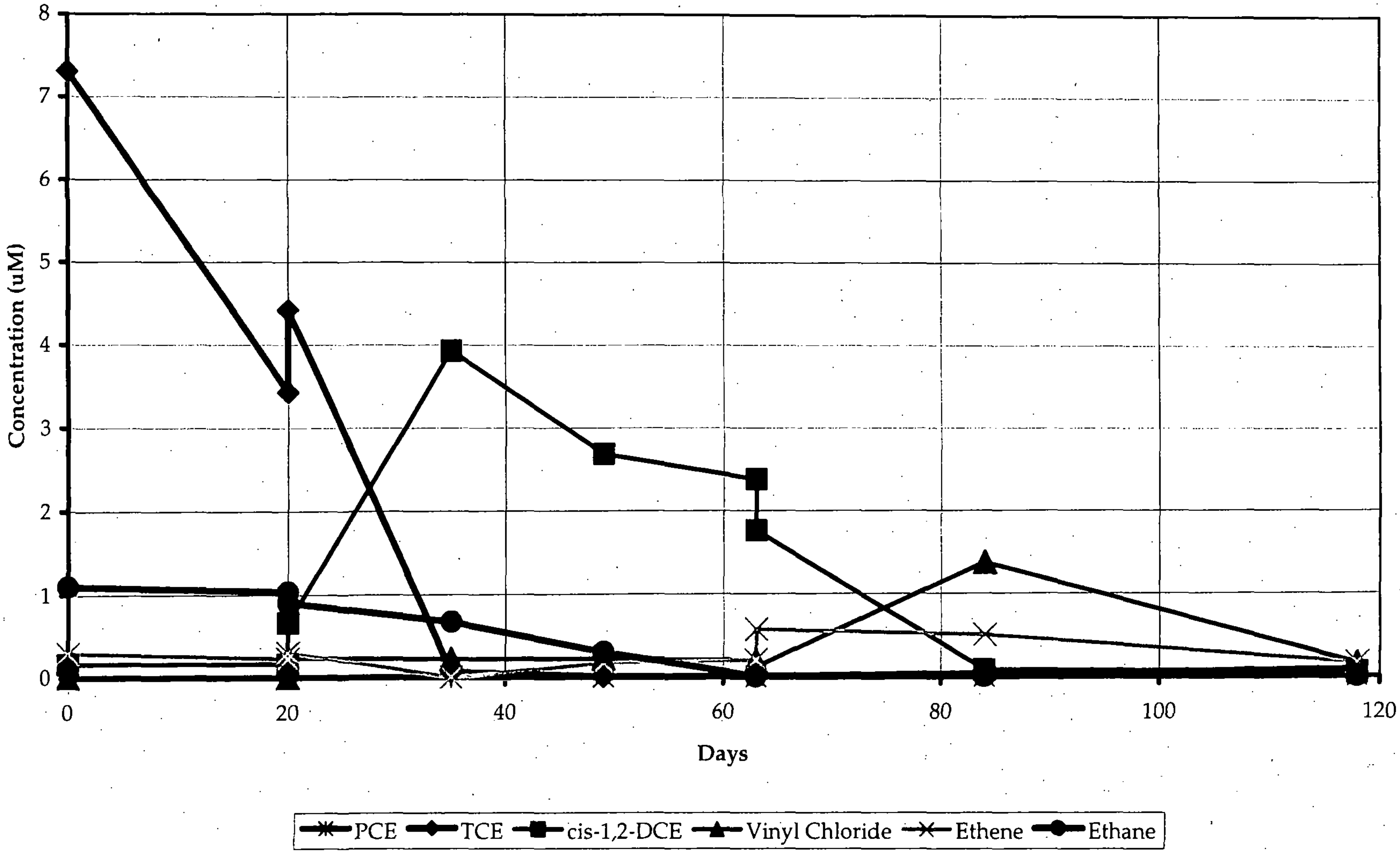


**Figure 12**
**Microcosm G Results - Slow Release Substrate and Bioaugmented - RI-23 Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**



## Figure 13
## Microcosm H Results - Unamended Control - RI-27S Ground Water
## Bioaugmentation Microcosm Study
## North Penn Area 5 Site - Colmar, Pennsylvania

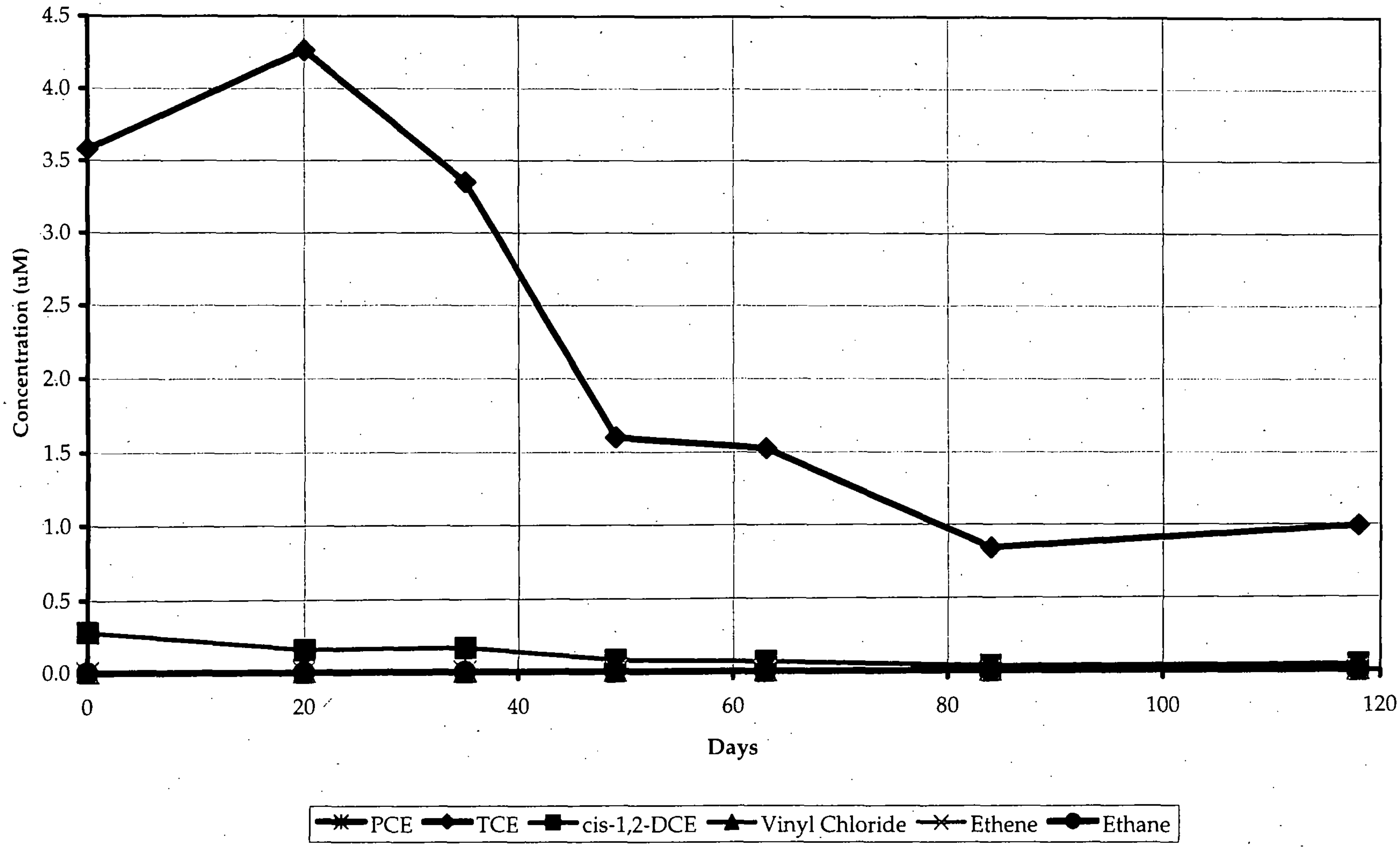


**Figure 14**
**Microcosm I Results - Lactate - RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

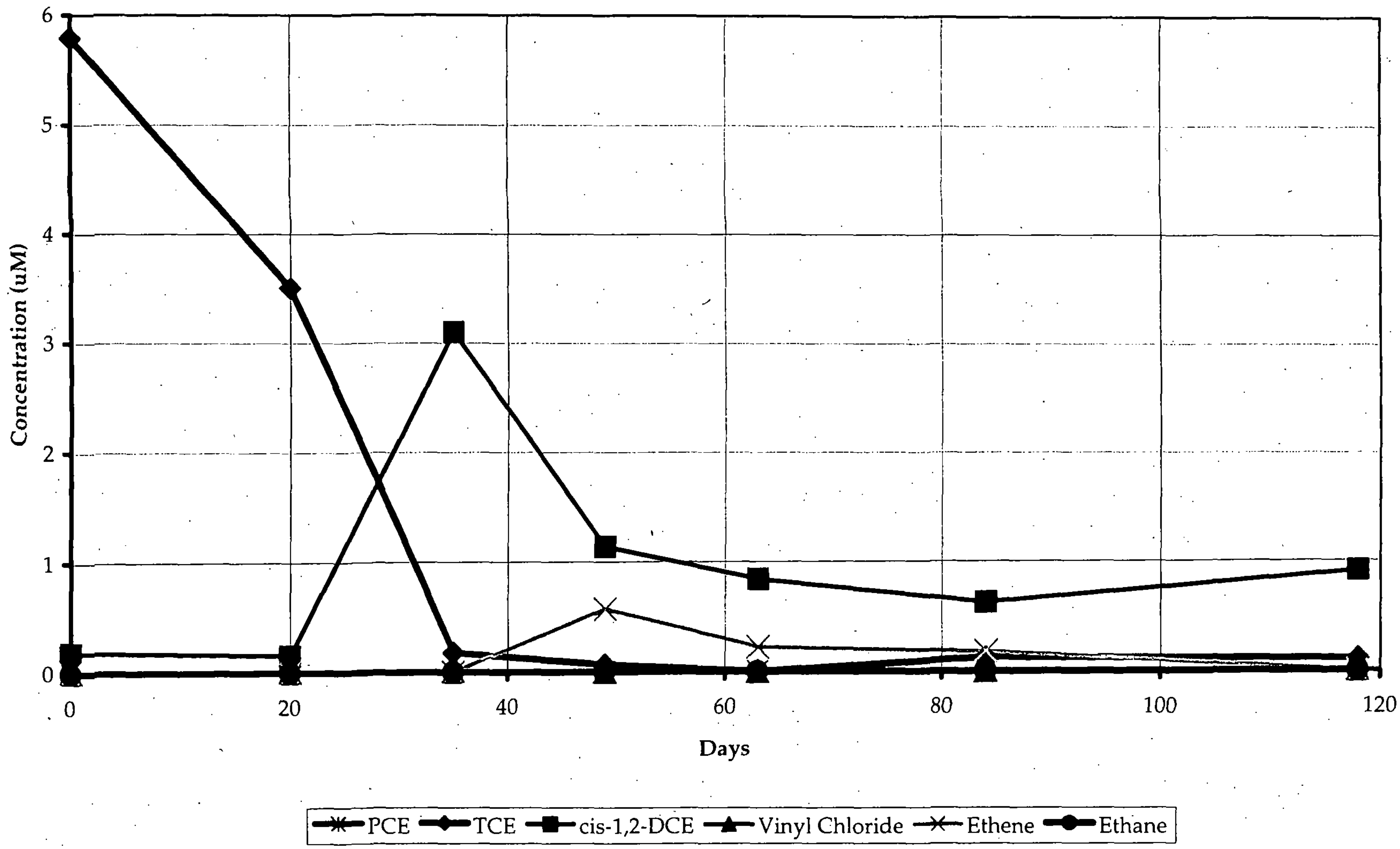


**Figure 15**
**Microcosm J Results - Methanol and Bioaugmented - RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

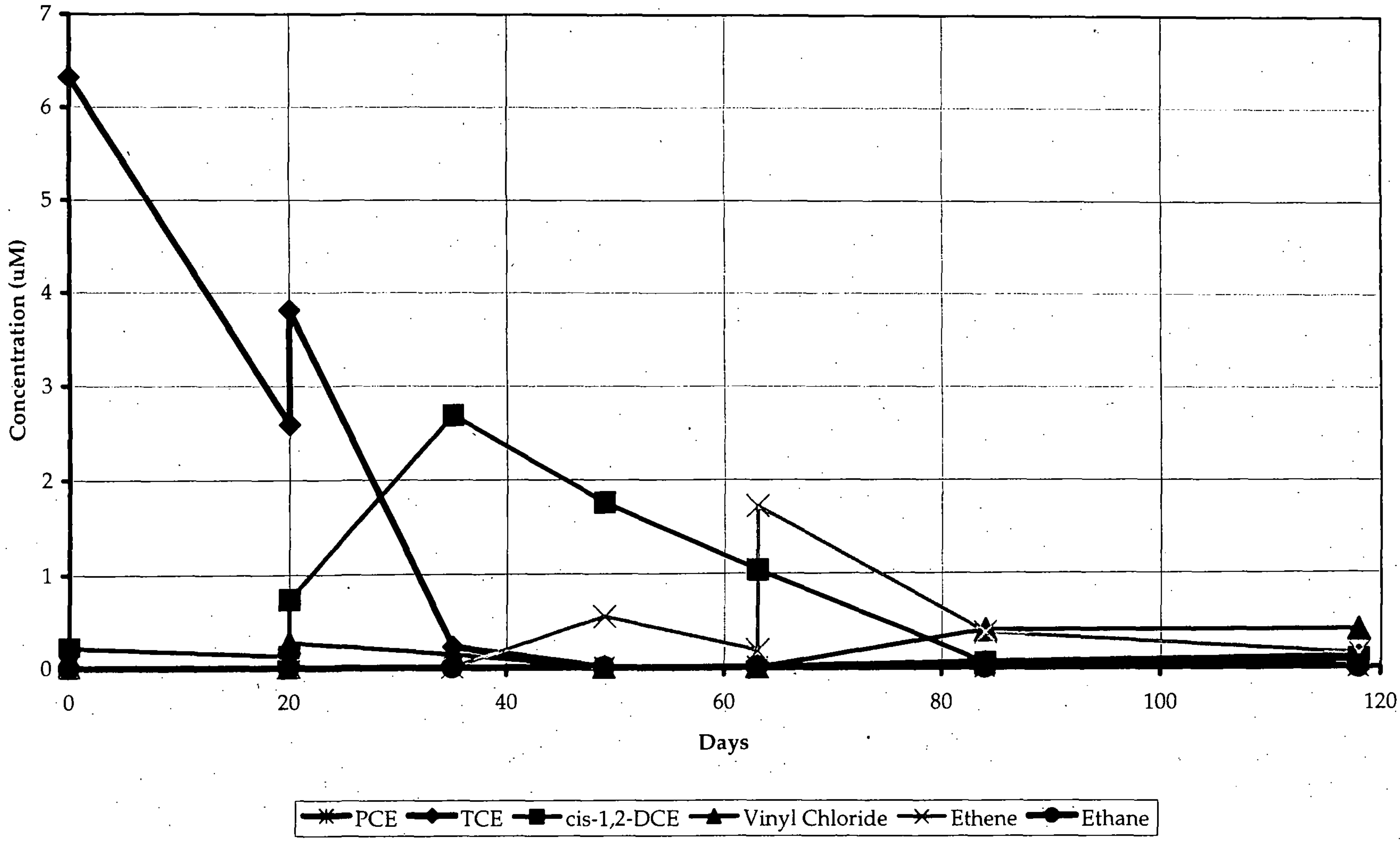


**Figure 16**
**Microcosm K Results - Lactate and Bioaugmented - RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

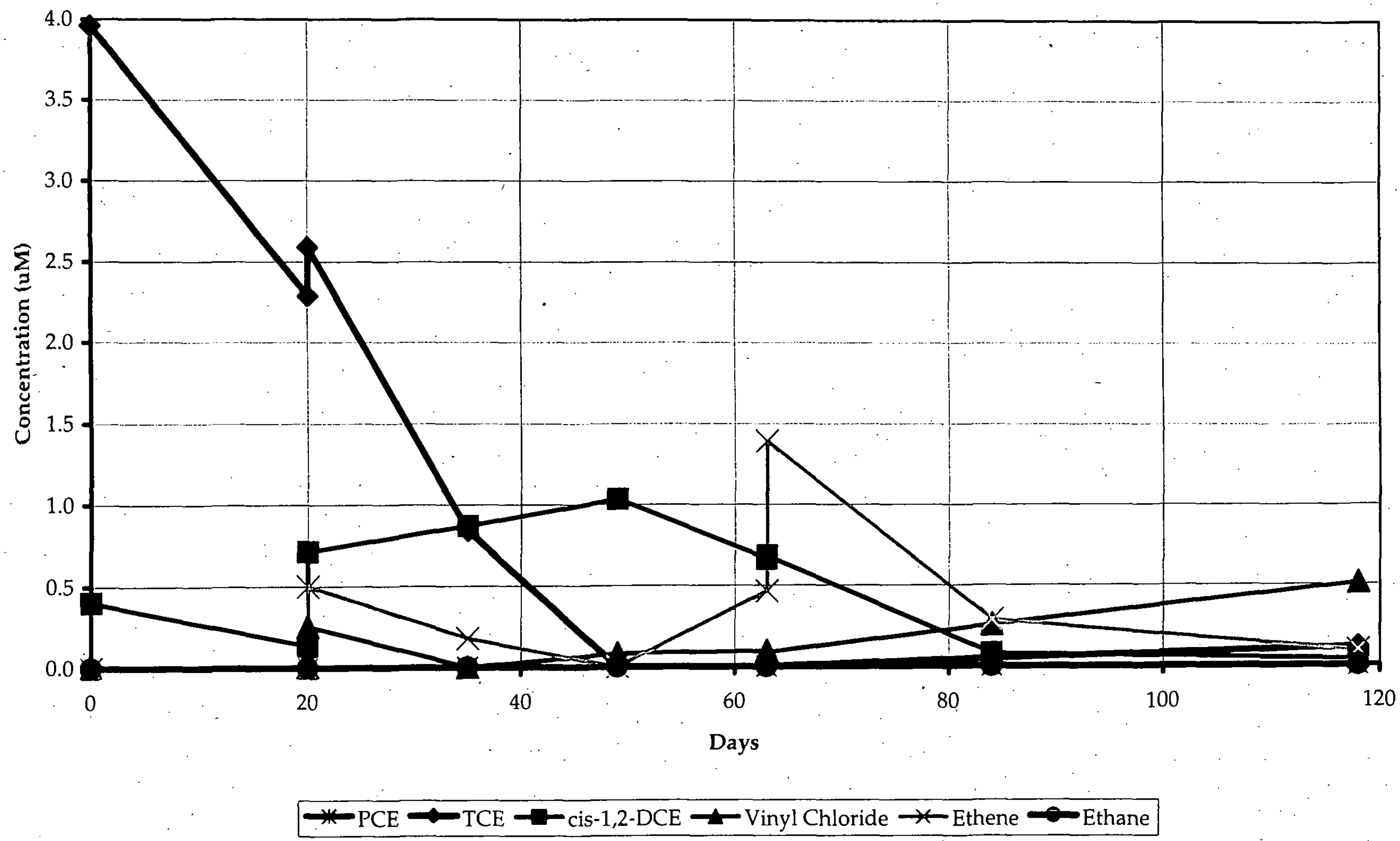
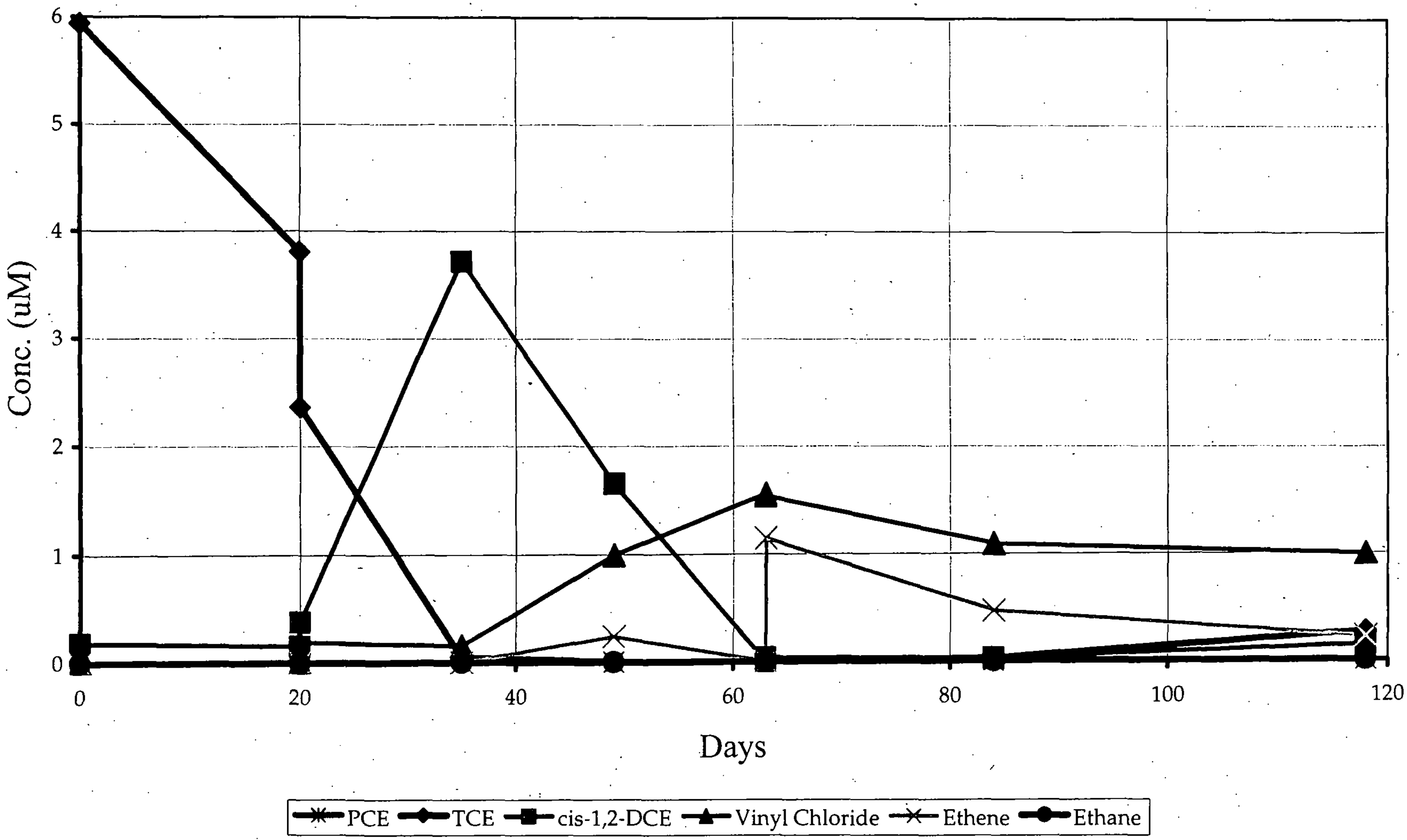


**Figure 17**
**Microcosm L Results - Molasses and Bioaugmented - RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**

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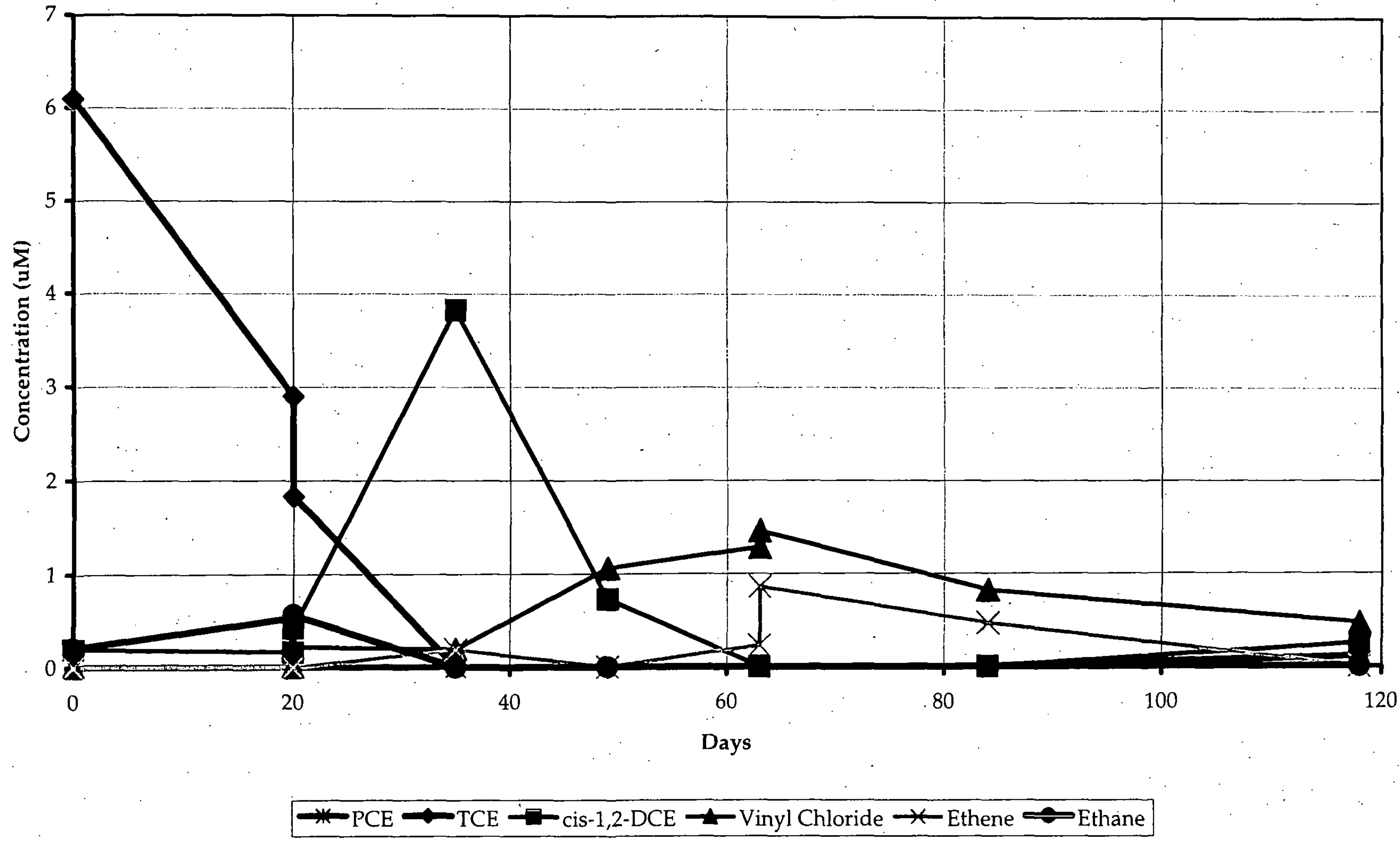
## Figure 18
**Microcosm M Results - Slow Release Substrate and Bioaugmented - RI-27S Ground Water**
**Bioaugmentation Microcosm Study**
**North Penn Area 5 Site - Colmar, Pennsylvania**



# *Tables*

*Tables*

*Table 1*
*Ground Water Analytical Results - VOCs and Natural Attenuation Parameters*
*Bioremediation Evaluation - July 2003 Sampling Event*
*North Penn Area 5 Site - Colmar, Pennsylvania*

| Parameters[1] | Analytical Method | Units | RI-18S | RI-18D | RI-23 | RI-24 | RI-25 | RI-27S | RI-27D | RI-28 | RI-82 (RI-28 Duplicate) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Volatile Organic Compounds*[2] | | | | | | | | | | | |
| cis-1,2-Dichloroethene | SOW OLM03.2 | ug/L | 2 J | ND (2) | 67 | ND (2) | 4 J | 27 | ND (2) | ND (2) | ND (2) |
| Trichloroethene | SOW OLM03.2 | ug/L | 92 | ND (1) | 900 D | ND (1) | 190 | 1,200 D | 1 J | 43 | 48 |
| | | | | | | | | | | | |
| *Dissolved Gases*[3] | | | | | | | | | | | |
| Ethane | AM20GAX | ng/L | 14 | 16 | 28 | ND (<5.0) | ND (<5.0) | 17 | 83 | ND (<5.0) | ND (<5.0) |
| Ethene | AM20GAX | ng/L | 25 | 18 | 27 | 6 | 16 | 31 | 10,000 | 18 | 11 |
| Hydrogen | AM20GAX | nM | 1.6 | 1.6 | 2.4 | 2.2 | 1 | 1.6 | 1.7 | 1.4 | 1.3 |
| Methane | AM20GAX | ug/L | 76 | 1.4 | 0.26 | ND (<0.02) | 0.05 | 0.28 | 4.4 | 0.05 | 0.06 |
| Carbon Dioxide | AM20GAX | mg/L | 140 | 60 | 110 | 66 | 140 | 14 | 5 | 68 | 65 |
| Nitrogen | AM20GAX | mg/L | 15 | 16 | 16 | 16 | 16 | 17 | 17 | 16 | 16 |
| Oxygen | AM20GAX | mg/L | 3 | 2.7 | 1.4 | 4.9 | 2 | 3.3 | 2.4 | 2.4 | 3.8 |
| *Natural Attenuation and Other Inorganic Parameters*[2] | | | | | | | | | | | |
| Alkalinity to pH 8.3 | EPA 310.1 | mg/L as $CaCO_3$ | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) |
| Alkalinity to pH 4.5 | EPA 310.1 | mg/L as $CaCO_3$ | 37.2 | 136 | 87.0 | 13.4 | 61.7 | 236 | 156 | 10.8 | 10.6 |
| Ammonia-Nitrogen | EPA 350.3 | mg/L | 0.099 J | 0.093 J | 0.081 J | 0.079 J | 0.084 J | 0.11 | 0.10 | 0.080 J | 0.086 J |
| Bicarbonate | SM-18 2320B | mg/L as $CaCO_3$ | 37.2 | 136 | 87.0 | 13.4 | 61.7 | 236 | 156 | 10.8 | 10.6 |
| Carbonate | SM-18 2320B | mg/L as $CaCO_3$ | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) | ND (0.41) |
| Chloride | EPA 300.0 | mg/L | 97.8 | 43.0 | 14.6 | 2.8 | 30.4 | 18.6 | 3.0 | 3.8 | 3.9 |
| Iron (total) | SOW ILM04.0 | mg/L | 0.951 | 2.37 | 0.0784 J | 0.112 | 0.0535 J | 0.832 | 0.266 | 0.0147 J | 0.0212 J |
| Iron (dissolved)[4] | SOW ILM04.0 | mg/L | 0.126 | 1.37 | ND (0.0253) | 0.0280 J | ND (0.0253) | 0.568 | 0.105 | ND (0.0014) | ND (0.0014) |
| Nitrate-Nitrogen | EPA 300.0 | mg/L | 2.9 | ND (0.40) | 0.83 | 1.0 | 1.5 | 2.2 | ND (0.40) | 0.58 | 0.59 |
| Nitrite-Nitrogen | EPA 300.0 | mg/L | ND (0.40) | ND (0.40) | ND (0.40) | ND (0.40) | ND (0.40) | ND (0.40) | ND (0.40) | ND (0.40) | ND (0.40) |
| Sulfate | EPA 300.0 | mg/L | 15.1 | 26.4 | 21.7 | 23.3 | 21.3 | 23.5 | 12.1 | 16.6 | 15.6 |
| Sulfide | EPA 376.2 (modified) | mg/L | ND (0.022) | ND (0.022) | ND (0.022) | ND (0.022) | 0.024 J | 0.059 J | 0.22 | ND (0.022) | ND (0.022) |
| Total Organic Carbon | EPA 415.1 | mg/L | 0.80 J | 0.71 J | 3.1 | 1.0 J | 1.0 J | 1.0 J | 0.91 J | 0.77 J | 0.60 J |
| *Field Parameters*[5] | | | | | | | | | | | |
| pH | Field | standard units | 5.97 | 7.34 | 6.31 | 5.32 | 6.3 | 8.09 | 8.85 | 5.34 | 5.34 |
| Temperature | Field | °C | 16.6 | 16.5 | 14.1 | 14 | 18.1 | 13.6 | 22.9 | 12.5 | 12.5 |
| Specific Conductance | Field | mS/cm | 463 | 474 | 298 | 0.107 | 306 | 591 | 324 | 0.081 | 0.081 |
| Dissolved Oxygen | Field | mg/L | 4.75 | 1.57 | 1.46 | 4.89 | 5.72 | 0.86 | 3.51 | 3.71 | 3.71 |
| Redox Potential | Field | mV | 141 | -10 | 185 | 276 | 216 | 197 | -138 | 303 | 303 |
| Turbidity | Field | NTU | 141 | 123 | 17.5 | 51.6 | 23.7 | 147 | 207 | 96.2 | 96.2 |
| *Dehalococcoides Ethenogenes*[6] | | | | | | | | | | | |
| Result | Quantitative Real Time PCR | 16S rRNA Gene Copies/mL | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) | ND ($5x10^2$) |

***Notes:***

(1) Ground water samples were collected by ERM 23-25 July 2003 using low-flow purging and sampling techniques. Bladder pump was used for all wells except RI-28.
A peristaltic pump was used for RI-28 due to it being a small diameter well (1-inch diameter).
(2) Samples analyzed by Lancaster Laboratories of Lancaster, PA.
(3) Samples analyzed by Microseeps of Pittsburgh, PA.
(4) Samples analyzed for dissolved parameters were field filtered using an in-line, 0.45 micron filter.
(5) Field parameters were measured using a flow-through cell equipped with a multi-parameter meter (Horiba Model No. N/A).
(6) Dehalococcoides ethenogenes (DHE) analyzed by Microbial Insights of Rockford, TN.
ND (Method Detection Limit) - Parameter not detected above its Method Detection Limit (MDL).
J - estimated value. The estimated concentration falls within the MDL and Limit of Quantitation (LOQ).
D - Compund quantitated on a diluted sample.

August 2003

*Table 2*
*Microcosm Setup Summary*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

| Microcosm | Ground Water (mL[1]) | Saturated Overburden Soil (g[2]) | Substrate | Substrate Dosage (mgC/L[4]) | Nitrogen, Phosphorus, & Yeast Extract (mg/L[5]) | Bicarbonate (mg/L) | Resazurin (mg/L) | Trichloroethene Saturated Water (mg/L) |
|---|---|---|---|---|---|---|---|---|
| A | 365 (RI-23) | 390 | Sterile | 0 | 0 | 500 | 1 | 1 |
| B | 365 (RI-23) | 390 | Unamended | 0 | 0 | 500 | 1 | 1 |
| C | 365 (RI-23) | 390 | Lactate | 500 | 50:5:50 | 500 | 1 | 1 |
| D | 365 (RI-23) | 390 | Methanol & DE[3] | 500 | 50:5:50 | 500 | 1 | 1 |
| E | 365 (RI-23) | 390 | Lactate & DE | 500 | 50:5:50 | 500 | 1 | 1 |
| F | 365 (RI-23) | 390 | Molasses & DE | 500 | 50:5:50 | 500 | 1 | 1 |
| G | 365 (RI-23) | 390 | SRS & DE | 2,000 | 50:5:50 | 500 | 1 | 1 |
| H | 280 (RI-27S) | 0 | Unamended | 0 | 0 | 500 | 1 | 0 |
| I | 280 (RI-27S) | 0 | Lactate | 500 | 50:5:50 | 500 | 1 | 0 |
| J | 280 (RI-27S) | 0 | Methanol & DE | 500 | 50:5:50 | 500 | 1 | 0 |
| K | 280 (RI-27S) | 0 | Lactate & DE | 500 | 50:5:50 | 500 | 1 | 0 |
| L | 280 (RI-27S) | 0 | Molasses & DE | 500 | 50:5:50 | 500 | 1 | 0 |
| M | 280 (RI-27S) | 0 | SRS & DE | 2,000 | 50:5:50 | 500 | 1 | 0 |

***Notes:***
(1) - mL (milliliter)
(2) - g (grams)
(3) - DE (dechlorinating enrichment culture)
(4) - mgC/L (milligrams carbon per liter)
(5) - mg/L (milligrams per liter)

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm A Results - Sterile Control**

| Compound | Unit | Concentrations | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 35 Days | 49 Days | 63 Days | 84 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 |
| Trichloroethene | ug/L | **510** | **290** | **30** | **7.4** | **6.8** | <2.2 |
| cis-1,2-dichloroethene | ug/L | <4.0 | <4.0 | **210** | **120** | **83** | **88** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 |
| Ethene | ug/L | trace | trace | **6.5** | <2.4 | <2.4 | <1.2 |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 |
| Methane | ug/L | <1.3 | <1.3 | **3.9** | <1.3 | <1.3 | **20** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 |
| Trichloroethene | uM | **3.9** | **2.2** | **0.23** | **0.056** | **0.052** | <0.017 |
| cis-1,2-dichloroethene | uM | <0.041 | <0.041 | **2.2** | **1.2** | **0.86** | **0.91** |
| Vinyl chloride | uM | <0.064 | <0.064 | <0.064 | <0.064 | <0.064 | <0.035 |
| Ethene | uM | <0.086 | <0.086 | **0.23** | <0.086 | <0.086 | <0.046 |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 |
| Total CVOCs | uM | **3.9** | **2.2** | **2.6** | **1.3** | **0.91** | **0.91** |

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm B Results - Unamended Control**

| Compound | Unit | Concentrations | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 35 Days | 49 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **1,500** | **740** | **970** | **360** | **390** | **260** | **240** |
| cis-1,2-dichloroethene | ug/L | **22** | **13** | **30** | **8.9** | **11** | **4.6** | **4.3** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Ethene | ug/L | **11** | trace | **11** | <2.4 | <2.4 | <1.2 | <1.2 |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | <1.3 | <1.3 | **6.7** | <1.3 | **56** | **3.4** | <0.7 |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **11.4** | **5.6** | **7.4** | **2.7** | **3.0** | **2.0** | **1.8** |
| cis-1,2-dichloroethene | uM | **0.23** | **0.13** | **0.31** | **0.092** | **0.11** | **0.0475** | **0.0444** |
| Vinyl chloride | uM | <0.064 | <0.064 | <0.064 | <0.064 | <0.064 | <0.035 | <0.035 |
| Ethene | uM | 0.39 | <0.086 | **0.39** | <0.086 | <0.086 | <0.046 | <0.046 |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **12.0** | **5.8** | **8.1** | **2.8** | **3.1** | **2.0** | **1.9** |

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm C Results - Lactate**

| Compound | Unit | Concentrations | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 35 Days | 49 Days | 63 Days | 84 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 |
| Trichloroethene | ug/L | **1,560** | **500** | **27** | **14** | trace | **4.7** |
| cis-1,2-dichloroethene | ug/L | **23** | **33** | **580** | **220** | **260** | **130** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 |
| Ethene | ug/L | **8.5** | **4.7** | **12** | <2.4 | trace | <1.2 |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 |
| Methane | ug/L | **23** | **1,290** | **21,000** | **33,500** | **26,300** | **21,100** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 |
| Trichloroethene | uM | **11.9** | **3.8** | **0.21** | **0.11** | <0.030 | **0.036** |
| cis-1,2-dichloroethene | uM | **0.24** | **0.34** | **6.0** | **2.3** | **2.7** | **1.3** |
| Vinyl chloride | uM | <0.064 | <0.064 | <0.064 | <0.064 | <0.064 | <0.035 |
| Ethene | uM | **0.30** | **0.17** | **0.43** | <0.086 | <0.086 | <0.046 |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 |
| Total CVOCs | uM | **12.4** | **4.3** | **6.6** | **2.4** | **2.7** | **1.38** |

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

Microcosm D Results - Methanol and Bioaugmented

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | 1,500 | 45 | 58 | 10 | 6.2 | trace | trace | 3.8 | 9.0 |
| cis-1,2-dichloroethene | ug/L | 21 | 450 | 460 | 570 | 280 | 130 | 210 | 97 | <2.2 |
| Vinyl chloride | ug/L | <4.0 | <4.0 | 19 | 13 | 8.0 | trace | 6.9 | 65 | 24 |
| Ethene | ug/L | 12 | 8.6 | 7.5 | 11 | <2.4 | <2.4 | 36 | 22 | 35 |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | 11 | 830 | 1830 | 36,700 | 53,800 | 18,700 | 18,500 | 11,000 | 40,400 |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | 11.4 | 0.34 | 0.44 | 0.076 | 0.047 | <0.030 | <0.030 | 0.029 | 0.068 |
| cis-1,2-dichloroethene | uM | 0.22 | 4.6 | 4.7 | 5.9 | 2.9 | 1.3 | 2.2 | 1.0 | <0.023 |
| Vinyl chloride | uM | <0.064 | <0.064 | 0.30 | 0.21 | 0.13 | <0.064 | 0.11 | 1.0 | 0.38 |
| Ethene | uM | 0.43 | 0.31 | 0.27 | 0.39 | <0.086 | <0.086 | 1.3 | 0.79 | 1.3 |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | 12.1 | 5.3 | 5.8 | 6.6 | 3.1 | 1.3 | 3.6 | 2.9 | 1.7 |

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm E Results - Lactate and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **1,410** | **550** | **470** | **210** | **5.4** | trace | trace | **3.6** | **8.5** |
| cis-1,2-dichloroethene | ug/L | **22** | **14** | **48** | **440** | **350** | **340** | **200** | **200** | **5.8** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **14** | **13** | **10** | **7.7** | **6.6** | **26** | **37** |
| Ethene | ug/L | **15** | **9.2** | trace | **10** | **4.3** | trace | **19** | **16** | **52** |
| Ethane | ug/L | <2.4 | trace | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | 16 | 93 | 770 | **25,200** | **36,700** | **25,600** | **14,700** | **10,700** | **30,600** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **10.7** | **4.2** | **3.6** | **1.6** | **0.041** | <0.030 | <0.030 | **0.027** | **0.065** |
| cis-1,2-dichloroethene | uM | **0.23** | **0.14** | **0.50** | **4.5** | **3.6** | **3.5** | **2.1** | **2.1** | **0.060** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.22** | **0.21** | **0.16** | **0.12** | **0.11** | **0.42** | **0.6** |
| Ethene | uM | **0.54** | **0.33** | <0.086 | **0.36** | **0.15** | <0.086 | **0.68** | **0.57** | **1.9** |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **11.5** | **4.7** | **4.3** | **6.7** | **4.0** | **3.6** | **2.8** | **3.1** | **2.6** |

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm F Results - Molasses and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 |
| Trichloroethene | ug/L | **1,740** | **1,670** | **1,400** | **11** | **18** | **9.1** | **14** | **9.8** |
| cis-1,2-dichloroethene | ug/L | **16** | **17** | **78** | **860** | **770** | **930** | **880** | **750** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **17** | **10** | **9.3** | **9.0** | **7.6** | **65** |
| Ethene | ug/L | **5.6** | **8.6** | **12** | trace | **4.2** | trace | **26** | **14** |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 |
| Methane | ug/L | **7.0** | **500** | **1,830** | **29,200** | **35,900** | **19,200** | **16,000** | **7,530** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 |
| Trichloroethene | uM | **13.2** | **12.7** | **10.7** | **0.084** | **0.14** | **0.069** | **0.11** | **0.075** |
| cis-1,2-dichloroethene | uM | **0.17** | **0.18** | **0.80** | **8.9** | **7.9** | **9.6** | **9.1** | **7.7** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.27** | **0.16** | **0.15** | **0.14** | **0.12** | **1.0** |
| Ethene | uM | **0.20** | **0.31** | **0.43** | <0.086 | **0.15** | <0.086 | **0.93** | **0.50** |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 |
| Total CVOCs | uM | **13.6** | **13.2** | **12.2** | **9.1** | **8.4** | **9.8** | **10.2** | **9.4** |

*Table 3*
*Microcosms A through G Results - RI-23 Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm G Results - Slow Release Substrate and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **960** | **450** | **580** | **8.0** | trace | trace | trace | **3.6** | **10** |
| cis-1,2-dichloroethene | ug/L | **16** | **16** | **64** | **380** | **260** | **230** | **170** | **7.2** | **4.3** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **15** | **14** | **14** | **12** | **7.1** | **86** | **10** |
| Ethene | ug/L | **8.3** | **6.5** | **8.5** | trace | **4.7** | **5.6** | **16** | **14** | **4.6** |
| Ethane | ug/L | **33** | **31** | **27** | **20** | **8.9** | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | **15** | **120** | **1,010** | **40,300** | **85,900** | **32,300** | **39,000** | **11,600** | **6,470** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **7.3** | **3.4** | **4.4** | **0.061** | <0.030 | <0.030 | <0.030 | **0.027** | **0.076** |
| cis-1,2-dichloroethene | uM | **0.17** | **0.17** | **0.66** | **3.9** | **2.7** | **2.4** | **1.8** | **0.074** | **0.044** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.24** | **0.22** | **0.22** | **0.19** | **0.11** | **1.4** | **0.16** |
| Ethene | uM | **0.30** | **0.23** | **0.30** | <0.086 | **0.17** | **0.20** | **0.57** | **0.50** | **0.16** |
| Ethane | uM | **1.1** | **1.0** | **0.90** | **0.67** | **0.30** | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | 8.9 | 4.9 | 6.5 | 4.9 | 3.4 | 2.8 | 2.4 | 2.0 | 0.4 |

*Table 4*
*Microcosms H through M Results - RI-27S Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm H Results - Unamended Control**

| Compound | Unit | Concentrations | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 35 Days | 49 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **470** | **560** | **440** | **210** | **200** | **110** | **130** |
| cis-1,2-dichloroethene | ug/L | **27** | **15** | **16** | **7.5** | **6.3** | **3.1** | **3.6** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Ethene | ug/L | <2.4 | trace | <2.4 | trace | trace | <1.2 | <1.2 |
| Ethane | ug/L | trace | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | <1.3 | <1.3 | **8.0** | **7.5** | **8.1** | **3.8** | <0.7 |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **3.6** | **4.3** | **3.3** | **1.6** | **1.5** | **0.84** | **0.99** |
| cis-1,2-dichloroethene | uM | **0.28** | **0.15** | **0.17** | **0.077** | **0.065** | **0.032** | **0.037** |
| Vinyl chloride | uM | <0.064 | <0.064 | <0.064 | <0.064 | <0.064 | <0.035 | <0.035 |
| Ethene | uM | <0.086 | <0.086 | <0.086 | <0.086 | <0.086 | <0.046 | <0.046 |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **3.9** | **4.4** | **3.5** | **1.7** | **1.6** | **0.87** | **1.0** |

*Table 4*
*Microcosms H through M Results - RI-27S Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm I Results - Lactate**

| Compound | Unit | Concentrations | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 35 Days | 49 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **760** | **460** | **23** | **8.3** | trace | **16** | **14** |
| cis-1,2-dichloroethene | ug/L | **18** | **15** | **300** | **110** | **81** | **60** | **88** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | **4.6** |
| Ethene | ug/L | trace | trace | trace | **16** | **6.2** | **5.0** | <1.2 |
| Ethane | ug/L | trace | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | <1.3 | **140** | **590** | **910** | **1,680** | **5,350** | **5,350** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **5.8** | **3.5** | **0.18** | **0.063** | <0.030 | **0.12** | **0.11** |
| cis-1,2-dichloroethene | uM | **0.19** | **0.15** | **3.1** | **1.1** | **0.84** | **0.62** | **0.91** |
| Vinyl chloride | uM | <0.064 | <0.064 | <0.064 | <0.064 | <0.064 | <0.035 | **0.074** |
| Ethene | uM | <0.086 | <0.086 | <0.086 | 0.57 | 0.22 | 0.18 | <0.043 |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **6.0** | **3.7** | **3.3** | **1.8** | **1.1** | **0.92** | **1.09** |

*Table 4*
*Microcosms H through M Results - RI-27S Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm J Results - Methanol and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **830** | **340** | **500** | **29** | trace | trace | trace | **5.9** | **13** |
| cis-1,2-dichloroethene | ug/L | **21** | **12** | **71** | **260** | **170** | **100** | **100** | **3.5** | **6.7** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **17** | **8.6** | trace | trace | trace | **24** | **24** |
| Ethene | ug/L | <2.4 | trace | trace | trace | **15** | **4.8** | **48** | **10.0** | **3.8** |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | **19** | <1.3 | **1,000** | **72,900** | **69,800** | **20,300** | **23,000** | **8,960** | **19,000** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **6.3** | **2.6** | **3.8** | **0.22** | <0.030 | <0.030 | <0.030 | **0.045** | **0.099** |
| cis-1,2-dichloroethene | uM | **0.22** | **0.12** | **0.73** | **2.7** | **1.8** | **1.0** | **1.0** | **0.036** | **0.069** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.27** | **0.14** | <0.064 | <0.064 | <0.064 | **0.38** | **0.38** |
| Ethene | uM | <0.086 | <0.086 | <0.086 | <0.086 | **0.54** | **0.17** | **1.7** | **0.36** | **0.14** |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **6.5** | **2.7** | **4.8** | **3.0** | **2.3** | **1.2** | **2.7** | **0.82** | **0.69** |

*Table 4*
*Microcosms H through M Results - RI-27S Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm K Results - Lactate and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **520** | **300** | **340** | **110** | trace | trace | trace | **6.4** | **15** |
| cis-1,2-dichloroethene | ug/L | **39** | **13** | **69** | **84** | **100** | **64** | **66** | **7.5** | **3.7** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **16** | trace | **5.2** | **6.0** | **5.5** | **16** | **32** |
| Ethene | ug/L | <2.4 | trace | **14** | **5.0** | <2.4 | **13** | **39** | **8.0** | **2.6** |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | <1.3 | **20** | **600** | **1,440** | **15,300** | **8,620** | **8,580** | **5,680** | **50,700** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **4.0** | **2.3** | **2.6** | **0.84** | <0.030 | <0.030 | <0.030 | **0.049** | **0.114** |
| cis-1,2-dichloroethene | uM | **0.40** | **0.13** | **0.71** | **0.87** | **1.0** | **0.66** | **0.68** | **0.077** | **0.038** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.26** | <0.064 | **0.083** | **0.096** | **0.088** | **0.26** | **0.51** |
| Ethene | uM | <0.086 | <0.086 | **0.50** | **0.18** | <0.086 | **0.46** | **1.4** | **0.29** | **0.09** |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **4.4** | **2.4** | **4.1** | **1.9** | **1.1** | **1.2** | **2.2** | **0.67** | **0.76** |

*Table 4*
*Microcosms H through M Results - RI-27S Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm L Results - Molasses and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **780** | **500** | **310** | **6.3** | trace | trace | trace | **3.1** | **35** |
| cis-1,2-dichloroethene | ug/L | **18** | **15** | **37** | **360** | **160** | trace | **3.4** | **2.4** | **14** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **12** | **9.7** | **62** | **97** | **96** | **68** | **62** |
| Ethene | ug/L | trace | trace | <2.4 | trace | **6.6** | trace | **32** | **13** | **6.1** |
| Ethane | ug/L | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | **8.5** | **18** | **780** | **32,800** | **41,500** | **20,300** | **22,200** | **10,700** | **4,700** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **5.9** | **3.8** | **2.4** | **0.048** | <0.030 | <0.030 | <0.030 | **0.024** | **0.27** |
| cis-1,2-dichloroethene | uM | **0.19** | **0.15** | **0.38** | **3.7** | **1.7** | <0.041 | **0.035** | **0.025** | **0.14** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.19** | **0.16** | **0.99** | **1.6** | **1.5** | **1.1** | **1.0** |
| Ethene | uM | <0.086 | <0.086 | <0.086 | <0.086 | **0.24** | <0.086 | **1.1** | **0.46** | **0.22** |
| Ethane | uM | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **6.1** | **4.0** | **2.9** | **3.9** | **2.9** | **1.6** | **2.7** | **1.6** | **1.6** |

*Table 4*
*Microcosms H through M Results - RI-27S Ground Water*
*Bioaugmentation Microcosm Study*
*North Penn Area 5 Site - Colmar, Pennsylvania*

**Microcosm M Results - Slow Release Substrate and Bioaugmented**

| Compound | Unit | Concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Days | 20 Days | 20 Days | 35 Days | 49 Days | 63 Days | 63 Days | 84 Days | 118 Days |
| Tetrachloroethene | ug/L | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <4.0 | <2.2 | <2.2 |
| Trichloroethene | ug/L | **800** | **380** | **240** | trace | trace | trace | trace | trace | **14** |
| cis-1,2-dichloroethene | ug/L | **19** | **16** | **41** | **370** | **70** | trace | trace | trace | **24** |
| Vinyl chloride | ug/L | <4.0 | <4.0 | **14** | **12** | **66** | **80** | **91** | **51** | **29** |
| Ethene | ug/L | trace | trace | trace | **5.3** | <2.4 | **6.5** | **24** | **13** | <1.2 |
| Ethane | ug/L | **6.2** | **16** | **17** | <2.4 | <2.4 | <2.4 | <2.4 | <1.2 | <1.2 |
| Methane | ug/L | **11** | **9.2** | **780** | **33,400** | **26,500** | **41,500** | **36,100** | **36,700** | **18,000** |
| Tetrachloroethene | uM | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.024 | <0.013 | <0.013 |
| Trichloroethene | uM | **6.1** | **2.9** | **1.8** | <0.030 | <0.030 | <0.030 | <0.030 | <0.017 | **0.11** |
| cis-1,2-dichloroethene | uM | **0.20** | **0.17** | **0.42** | **3.8** | **0.72** | <0.041 | <0.041 | <0.023 | **0.25** |
| Vinyl chloride | uM | <0.064 | <0.064 | **0.22** | **0.19** | **1.1** | **1.3** | **1.5** | **0.82** | **0.46** |
| Ethene | uM | <0.086 | <0.086 | <0.086 | **0.19** | <0.086 | **0.23** | **0.86** | **0.46** | <0.043 |
| Ethane | uM | **0.21** | **0.53** | **0.57** | <0.080 | <0.080 | <0.080 | <0.080 | <0.043 | <0.043 |
| Total CVOCs | uM | **6.5** | **3.6** | **3.0** | **4.2** | **1.8** | **1.5** | **2.3** | **1.3** | **0.8** |