

# FINAL REPORT

## Biologically Active Zone Enhancement (BAZE) for In Situ RDX Degradation in Ground Water

ESTCP Project ER-0110

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## List of Acronyms

µg	microgram
AOP	advanced oxidation process
ARDC	Agricultural Research and Development Center
ASTM	American Society for Testing and Materials
BAZE	Biologically Active Zone Enhancement
CHAAP	Cornhusker Army Ammunition Plant
DO	dissolved oxygen
DoD	Department of Defense
Eh	redox potential
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EW	extraction well
FUDS	Formerly Used Defense Sites
GAC	granular activated carbon
gal	gallons
gpm	gallons per minute
HA	health advisory
HASP	health and safety plan
HPLC	high pressure liquid chromatograph
IW	injection well
kgal	1,000 gallons
L	liter
LF	linear foot
mg	milligram
MW	monitoring well
NOP	Former Nebraska Ordinance Plant
O&M	operation & maintenance
ORP	oxidation-reduction potential
OSHA	Occupational Health and Safety Administration
PLFA	phospholipid fatty acid
pmole	pica mole
ppb	parts per billion
ppm	parts per million
QA	quality assurance
QC	quality control
RDX	Royal Demolition Explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
ROD	record of decision
SOP	standard operating procedure
TNB	trinitrobenzene
TNT	trinitrotoluene
TOC	Total organic carbon
UIC	Underground Injection Control
USEPA	U.S. Environmental Protection Agency

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## Executive Summary

In 2001, the U.S. Army Engineer Research and Development Center (ERDC) received funding from the Environmental Security Technology Certification Program (ESTCP) to conduct in situ studies validating sodium acetate injection as a means to enhance biological transformation of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) in groundwater. The field demonstration that evaluated the Biologically Active Zone Enhancement (BAZE) process was conducted at the former Nebraska Ordnance Plant (NOP), located near Mead, Nebraska. Runway deicer (sodium acetate) was earlier selected as the organic carbon source during bench-scale studies that used aquifer material collected at NOP. The results of the field demonstration indicated that RDX concentrations were reduced from an average of 256 µg/L to below the laboratory detection limit of 0.1 µg/L. The field demonstration data also quantified the capital and operation & maintenance (O&M) cost associated with the use of the BAZE process for in situ treatment of RDX contamination in groundwater. The estimated demonstration cost was \$74/kgal while the real world cost for a BAZE system was determined to be \$27/kgal (\$7.40/m<sup>3</sup>), which is comparable to the cost for a traditional pump-and-treat method.

Wells were installed for the field demonstration in September 2003 and pre-treatment groundwater samples were collected in December 2003. The first sodium acetate injection was performed January 2004 and acetate injections/sampling was completed in August 2005.

Fifteen rounds of sodium acetate solution were injected and circulated through the treatment system during the course of the study. During each injection event, approximately 200 gallons (757 L) of 13% sodium acetate solution were diluted with groundwater pumped from the extraction well into an in-line mixer resulting in a 0.3% sodium acetate solution. The sodium acetate solution was then equally distributed to both injection wells. Water samples from the BAZE injection/recirculation system were collected during this process and analyzed for total organic carbon (TOC) and acetate concentrations. After 5-6 hours of injection, the system was allowed to circulate for an additional 6 hours to assure mixing in the aquifer. The sodium acetate was transported downstream with the groundwater flow and was distributed along the contaminant plume.

Groundwater samples were collected from the monitoring wells and were analyzed for explosives, TOC, and nutrients (acetate, nitrate, nitrite, and sulfate). Representative samples were also analyzed for dissolved metals, biomass composition, and plant toxicity. RDX concentrations were reduced over time in all the affected wells (MW-02, -03, -04, -06, -07, and -10). Induction of RDX degradation occurred at different times at the affected wells depending on the well's distance from the injection site. Degradation was evidenced at 2-3 months at well MW-04, which was located 50 LF down gradient of the treatment system, and at 12 months at well MW-10 that was 200 LF down gradient. Residual sodium acetate concentrations in the groundwater increased during the study indicating sufficient levels were present to sustain treatment and support a microbial community. Biomass increased over the course of the demonstration indicating biological stimulation and oxidation-reduction potential (ORP) levels

decreased, indicating anaerobic conditions. Together, the slow degradation induction, the residual acetate concentrations, increased biomass, and anaerobic conditions confirm the development of an enhanced microbial community that was responsible for the RDX degradation.

# **1. Introduction**

## **1.1 Background**

Some active and formerly-used federal facilities exhibit expansive plumes of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) contamination that could impact the water supply of surrounding communities. The Department of Defense currently has 583 sites with confirmed explosives-contaminated groundwater and 88 additional sites are suspected of groundwater contamination with explosives and other organics (Defense Environmental Network and Information Exchange, [DENIX] 2003). Currently, there is no generally accepted in situ process for the remediation of RDX in groundwater. Available remediation alternatives are limited to long-term groundwater pumping and ex situ treatment followed by discharge or re-injection of treated water.

The U.S. Army Engineer Research and Development Center (ERDC) proposed using the biologically active zone enhancement (BAZE) process, an in situ technique, for the remediation of RDX contamination. The proposed technology uses a readily available carbon source (electron donor) to create conditions in the subsurface conducive to the growth of indigenous microorganisms that will metabolize explosives compounds. The BAZE process involves injecting 0.3% runway deicer solution (97% sodium acetate) into the groundwater and distributing the amendment downstream into the contaminated plume. Monitoring wells were used to verify chemical and biological effects caused by the injection of this carbon source. The ERDC had successfully tested the technology in laboratory-scale studies and had optimized some field parameters at that time.

The potential benefit of the BAZE process is a low cost and/or competitive alternative technology for in situ remediation of RDX contaminated groundwater.

## **1.2 Objectives of the Demonstration**

The objective of this field demonstration was to validate the ability of sodium acetate injections to enhance indigenous biological activity in order to cost effectively remediate RDX-contaminated groundwater. The study was designed to identify, collect, and verify the economic, operational, and performance data that will be used to transition this technology to potential users. The field demonstration was conducted at the former Nebraska Ordnance Plant (NOP) located in Mead, NE.

## **1.3 Regulatory Drivers**

The former NOP is currently under U.S. Environmental Protection Agency (USEPA) Record of Decision (ROD) USEPA/541/R-97/143 to contain/remediate explosives contaminated groundwater. This ROD states that the major components of the remediation system include hydraulically containing contaminated groundwater that exceeds the Final Target Groundwater Cleanup Goals of 2 µg/L. The BAZE process reduced the groundwater RDX concentration to below this target level.

#### **1.4 Stakeholder/End-User Issues**

The U.S. Army Corps of Engineer's Kansas City District is the project lead on the NOP site and requires that remedial technologies: (1) adhere to local, state and federal regulatory guidelines, (2) meet health advisory levels set forth in the ROD and by the USEPA, (3) have no detrimental effect on overall water quality, (4) have no detrimental effect to the hydrodynamic characteristics of the aquifer, (5) have small surface footprint, (6) are simple to operate, and (7) have a low cost to performance ratio. The BAZE system performed efficiently and the technology may be transitioned to the Kansas City District for implementation. The BAZE process does not produce any hazardous byproducts that need further disposal, as it is an extension of natural biodegradation. The system is small and transportable and does not require any specialized equipments or custom-built prototypes.

## 2. Technology Description

### 2.1 Technology Development and Application

Biodegradation of RDX and/or HMX has been studied since the 1970s. McCormick et al. (1981) reported RDX biodegradation with municipal anaerobic sludge and proposed a pathway based on the sequential reduction of RDX to hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), and hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX). The proposed pathway suggests that one or more nitro groups are reduced to the point where destabilization of the triazine ring occurs, and the ring is fragmented by hydrolytic cleavage. Fragments of the ring are further reduced resulting in a mixture of hydrazines, formaldehyde, and methanol (Beller and Tiemeier 2002; Morley et al. 2002; Hawari et al. 2000). Hawari et al. (2000) reported evidence of the formation of two-ring cleavage metabolites (methylenedinitramine and bis-hydroxymethylnitramine) during treatment of RDX with domestic anaerobic sludge. Both of these metabolites are reported to decompose in water to produce nitramine and formaldehyde, which in turn biotransform to nitrous oxide and carbon dioxide. Halasz et al. (2002) confirmed these findings; however, it is not certain whether methylenedinitramine was an initial enzymatic hydrolysis product or simply formed via the spontaneous hydrolysis of an unknown initial RDX enzymatic product.

Beller (2002) studied bacteria enriched from RDX-contaminated aquifer sediments consumed RDX in a defined, bicarbonate-buffered, anaerobic medium containing hydrogen as the sole electron donor and RDX as a potential electron acceptor and sole nitrogen source. RDX was not consumed in live controls that did not contain hydrogen. However  $^{14}\text{C}$ -labeled RDX suggested that mineralization to carbon dioxide was negligible (<2%). Several lines of evidence suggest that the RDX-transforming bacteria under study were homoacetogens, including correlations between RDX consumption and acetate production. Methanogens were unlikely to be responsible for RDX metabolism, as the presence of 2-bromoethanesulfonate, an inhibitor of methanogenesis, did not appear to affect RDX metabolism. The presence of nitrate reversibly halted RDX metabolism, whereas ammonium had no discernible effect, which implies that: (i) nitrate, which commonly occurs in RDX-contaminated groundwater, may inhibit in situ RDX metabolism, and (ii) although RDX may act as both a nitrogen source and cometabolic electron sink, the latter role predominates, as RDX reduction will proceed regardless of whether or not a more favorable nitrogen source is present.

Earlier studies also indicated that the anaerobic biodegradation of explosives could be stimulated by amending cultures with readily biodegradable carbon sources. Waisner et al. (2002) studied RDX biodegradation in soil slurries using different redox incubation conditions. Their results indicated a 20% mineralization rate under anaerobic conditions when an external carbon source (acetate) was added to the culture media. Experimental results suggested that biodegradation of RDX is a cometabolic process (Waisner et al. 2002). Spain et al. (2000) reported biodegradation of RDX under aerobic and anaerobic conditions. Pennington and Brannon (2002) reported mineralization of the initial

degradation products of RDX was nearly an order of magnitude greater under anaerobic conditions. Hawari (2002) reported that RDX can be degraded under nitrate and sulfate reducing and methanogenic conditions. Shull et al. (1999) reported that indigenous bacteria found in vadose zone beneath a Pantex Plant degraded RDX under anoxic or microaerobic conditions. They suggested that injecting either an inert gas or highly degradable organic substance would be required. They also suggested that supplemental nutrients (organic carbon and phosphorus) were not necessary for RDX degradation, but the addition of organic carbon increases the degradation rate significantly. Other researchers have studied multiple technologies in conjunction with in situ bioremediation. Scherer et al. (2000) studied permeable reactive barriers (PRB) for in situ groundwater clean up. Shrouf et al. (2005) showed that high RDX removal efficiency is achievable and sustainable using zero-valent iron (ZVI). They concluded that bioaugmentation could enhance the efficacy and start-up of ZVI-PRB.

As of 2008, additional laboratory studies of in situ bioremediation of RDX suggest a considerable improvement in the state of the art of this technology. Young et al. (2006) conducted laboratory study to examine the ability of two microbial cultures (anaerobic sludge and a facultative enrichment culture) to biodegrade single- and dual-contaminant mixtures of trichloroethene (TCE) and RDX under anaerobic conditions. The single component batch tests, both cultures degraded RDX and its nitroso metabolites to below detection limits in <7 days. The dual-contaminant batch tests, both acclimated cultures rapidly biodegraded mixtures of RDX and TCE. However, both cultures degraded RDX and RDX-nitroso compounds to below detection limits in <4 days. Sherburne et al. (2005) batch experiments confirm that the inhibitory effect of ammonium is postulated due to the repression of enzymes that initiate RDX degradation by reducing its nitro groups, based on the known fact that ammonia represses nitrate and nitrite reductases. Their observation suggests that the absence of easily assimilated nitrogen sources, such as ammonium, enhances RDX degradation. Although specific end products of RDX degradation were not determined, the production of nitrous oxide suggests that *A. paludosum* cleaved the triazine ring.

Schaefer et al. (2006) compared microcosm and column studies by using biological and abiotic approaches for treating co-mingled perchlorate, nitrate, and nitramine explosives in groundwater. They showed microscale and nanoscale ZVI, and nickel catalyzed the reduction of RDX, HMX, and nitrate concentrations to below detection within 2 hours. Szecsody et al. (2007) studied the effectiveness of abiotic/biotic mineralization of RDX, HMX, and TNT in aquifer sediments by combinations of biostimulation (carbon, trace nutrient additions) and chemical reduction of sediment to create a reducing environment. Their results concluded that dithionite reduction of sediment results in a mixture of ferrous iron phases and resulted in some microbial population death at high concentration (10x death at 0.1 mol/L dithionite), but the mineralization of RDX and HMX increases directly with the amount of dithionite treatment most likely due to the addition of formate mineralization, which is a coupled reaction requiring both ferrous iron surface phases and viable microbes.

Ahmad et al. (2007) conducted a treatability study using organic mulch as an electron donor for treating RDX and HMX contaminated groundwater. Their findings concluded: (1) columns packed with a 70 percent:30 percent (volume:volume) mulch:pea gravel mixture were effective at completely removing RDX and HMX from the 20-pore volume mark; (2) pseudo first-order rate constants for RDX removal at steady-state ranged from 0.20/h to 0.27/h; (3) RDX was not detected in the column; (4) accumulation of RDX intermediates in the steady-state column effluent was <2% of the influent RDX mass; and, (5) no RDX, HMX, or RDX reduction intermediates (i.e., MNX, DNX, TNX) were detected in column-bed samples.

Field projects are being implemented to demonstrate in situ bioremediation. An ESTCP project (Field Demonstration/Validation of Electrolytic Barriers for Energetic Compounds at Pueblo Chemical Depot - ER-0519) demonstrated the efficacy of an electrolytic reactive barrier (e-barrier) for treatment of energetic compounds in groundwater. Comfort (2003) demonstrated the in situ permanganate oxidation and biodegradation of RDX in a perched aquifer.

U.S. Patent No. 6936456 - Bioremediation of nitrogenous contaminants is a novel process for the remediation of RDX which can be used in situ on contaminated media. The process comprises the bioremediation by one or more microorganisms capable of metabolizing the energetic materials. Examples of such microorganisms include *Rhizobium rhizogenes*, *Burkholderia sp.*, and *Cladosporium cladosporioides* (ATCC 66669). Strains of these microorganisms have been deposited. The strain designated A1 has been deposited as *Rhizobium rhizogenes* BL (ATCC PTA-4110) and the strain designated C8 has been deposited as *Burkholderia sp.* (ATCC PTA-4111). Additionally, with the addition of a carbon source, such as a sugar, the process can totally degrade the energetic materials in two to three days.

Prior to this field demonstration, Wani and Davis (2006) used acetate as a carbon source in a treatment-column system designed to reduce RDX concentrations in aquifer material. Influent RDX concentrations were removed to below detection limits (20µg/L) in all active treatment columns, without evidence of nitroso-metabolites. The current study was based on the hypothesis that an acetate amendment would also enhance biological activity under in situ conditions. It was believed that an electron donor introduced into a contaminated plume would encourage indigenous bacteria to create a zone in the subsurface conducive to the anaerobic biological destruction of RDX contamination. Hence, enhancing a bioremediation process that biologically utilizes an organic carbon (as an electron donor) source to consume electron acceptors and create a biologically active zone in the saturated zone. Figure 1 shows a carton illustrating this treatment model.

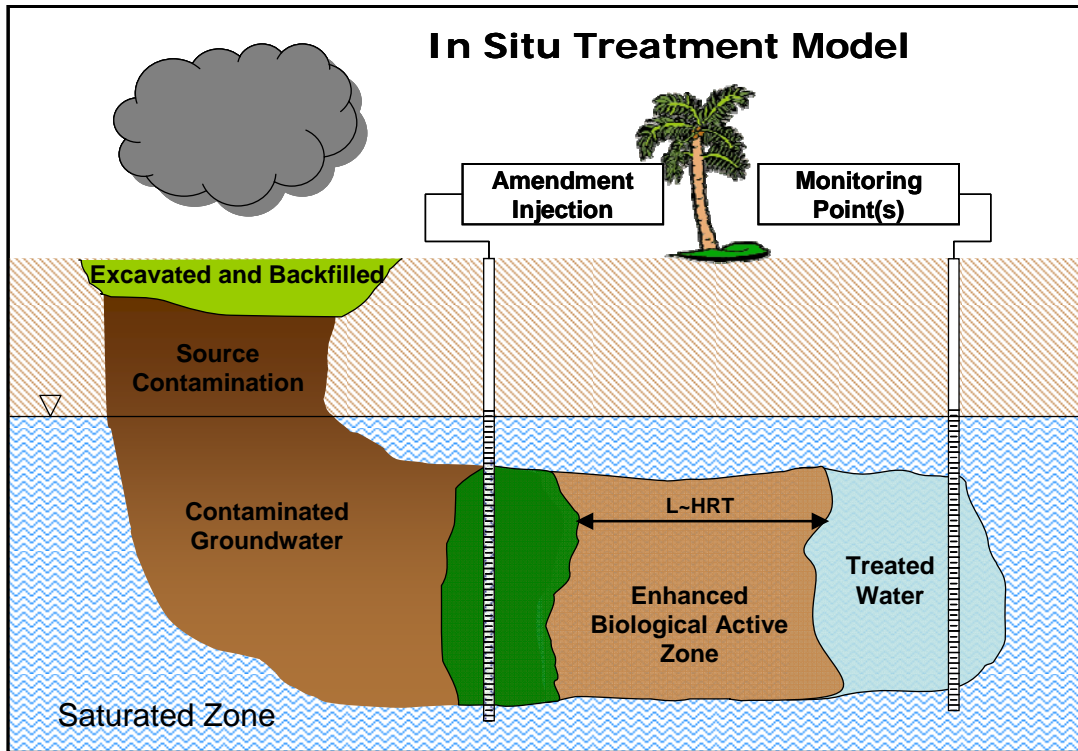


Figure 1. Conceptual model of bioremediation technology.

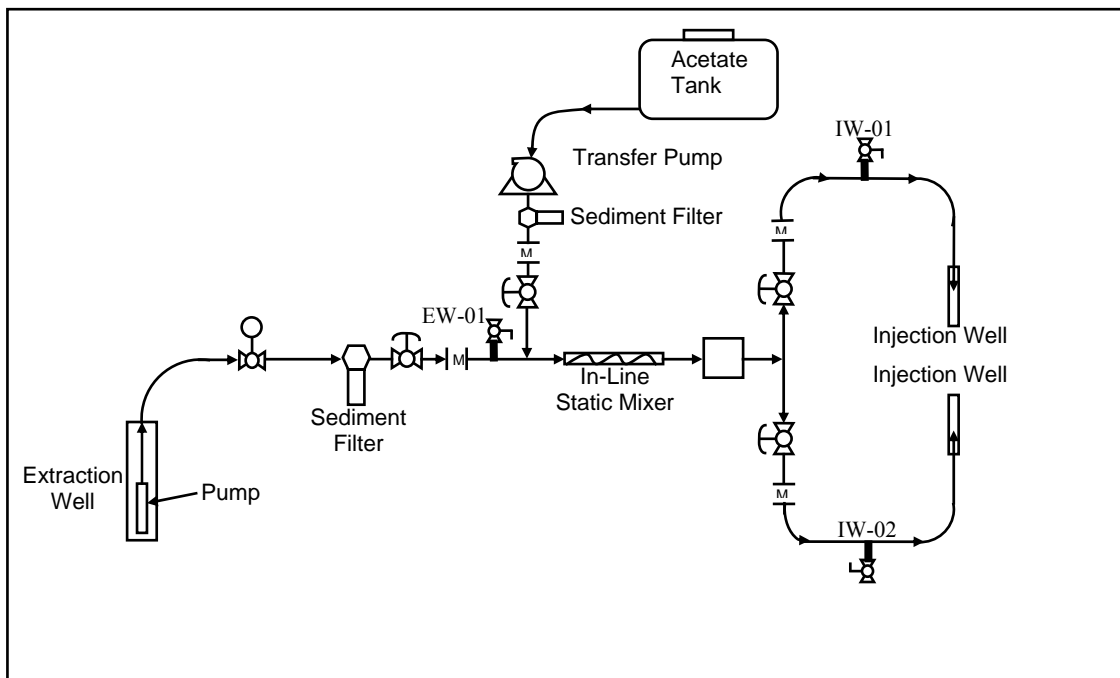


Figure 2. BAZE system schematic.



The BAZE system, illustrated in Figure 2, included: extraction and injection wells, a groundwater extraction pump, a transfer pump, an in-line static mixer, flow meters, and associated piping, tankage and appurtenance. A 3-in (7.6-cm) submersible pump (95 L/min) powered by a portable generator was used to extract groundwater from an extraction well (EW-01) via flexible tubing to the injection/recirculation system. The pump was suspended 60-LF (18.3 m) below ground surface (bgs) by a stainless steel cable attached to the well cap. The pump tubing was connected to the BAZE injection / recirculation system through a pressure gauge, a particle filter, ball valve, flow meter, and extraction well sampling port. The groundwater flowed through a “tee” that intersected the concentrated sodium acetate solution from the acetate feed tank. The acetate feed system included a 225 gallon (850 L) holding tank, a high pressure pump (0.5 gpm or 0.13 L/min), a filter, flow meter, backflow preventer, and ball valves. The mixture intersected at the main PVC pipe “tee” and flowed through an in-line static mixer to a flow-thru cell where groundwater quality parameters were recorded every 15 minutes. The in-line static mixer was used to ensure uniform mixing of the acetate feed solution into the groundwater. After the flow-thru cell, diversion pipes linked to each injection well were installed with a gate valve, where a flow meter regulated the acetate-amended groundwater flow evenly to the two injection wells.

The injection wells (labeled IW-01 for injection well #1 and IW-02 for injection well #2) were located 15-LF (4.6 m) from each side of the extraction well. After the sampling ports, the acetate solution was injected (5-6 hrs) into each injection well at a depth of 60-LF (18.3 m) bgs at approximately 12.5 gpm (47.3 L/min) each. The BAZE system was allowed to re-circulate groundwater for 5-6 additional hours to assure mixing in the aquifer. An average of 18,000 gallons (68.2 m<sup>3</sup>) of groundwater including acetate injection solution was re-circulated per event.

A concentrated acetate solution was prepared by mixing solid sodium acetate (runway deicer, 97% acetate) in two 110-gallon (415-L) tanks, each containing 100 gallons (380 L) of site groundwater from EW-01. About 165 lb (75 kg) of runway deicer (equivalent to 146 kg sodium acetate or 105 kg acetate) was added into each mixing tank and mixed for 15-20 minutes to allow complete dissolution. The solution was allowed to settle for 3-4 hours to separate the supernate from filler and/or insoluble materials in the runway deicer. The supernatant were transferred through a 20-micron filter to the holding tank and the solution was brought up to 200 gallons (757 L) by adding additional groundwater from the extraction well as needed. The acetate solution was again mixed in the holding tank, prior to collecting aliquots for acetate and TOC analyses. The solution in the holding tank was about 13% (as acetate) which was close to the theoretical maximum concentration of 13.1% (as acetate) calculated using estimates of 330 lb (150 kg) runway deicer (97% sodium acetate) with roughly 5% insoluble materials. Water samples were collected periodically from sample ports from the extraction and two injection wells until the completion of acetate injection, and then samples were collected hourly for six hours from the extraction well's sample port. Samples were analyzed for acetate and TOC concentrations.

## 2.2 Previous Testing of the Technology

This field demonstration was made to perform the first successful field demonstration of this technology at a DoD site. A site-specific treatability study (Appendix D) was performed as the first phase of a four-year field demonstration project (Wani et al. 2002). The treatability study determined the suitability of two formerly-used federal ordnance facilities for pilot-scale demonstration/ validation of in situ remediation of RDX contaminated groundwater. The column studies (Figure 3) examined the use of four amendments (acetate, ethanol, soluble starch, and acetate plus ammonium) as electron donors and developed the kinetic rate for RDX reductive biodegradation. All the amendments studied achieved the necessary reducing conditions for remediating the RDX inlet concentration from 100  $\mu\text{g/L}$  to less than 1  $\mu\text{g/L}$ . The addition of some amendments showed increased toxicity based on Microtox analysis. Ethanol addition itself did not result in increased toxicity but the biological activity in this system induced high toxicity to the test organism. The addition of soluble starch resulted in increased toxicity that was partially removed by biological activity in the columns. The addition of ammonium as a nitrogen source did not significantly increase the removal rate of RDX. Based on these observations, acetate was chosen for use in the field evaluation.

A supplemental study (Appendix E) was conducted to examine the effects of aquifer temperature on RDX biodegradation rates and to examine the fate (mineralization) of RDX (Wani et al., 2002). Figure 4 shows the columns setup for the temperature and mineralization studies. The results of this supplemental study demonstrated that aquifer temperature has a significant effect on the rate of RDX biodegradation. With a 5°C decrease in aquifer temperature (from 15 to 10°C); the RDX biodegradation rate coefficient was reduced by roughly 37%. At 5°C the rate coefficient was approximately 1/3 of the rate estimated at 15°C.



Figure 3. Experimental column setup.



Figure 4. Temperature/mineralization setups.

Results of a radiolabel study demonstrated that the fate of RDX is highly dependent on the redox conditions in the aquifer. In treatment columns amended with [ $^{14}\text{C}$ ]-carbon, 23-46% of the initial radiolabeled tracer was mineralized to  $^{14}\text{CO}_2$  under very low redox potential conditions as compared to <5% in control columns where redox potential was high. The dissolved fraction of the radiolabeled [ $^{14}\text{C}$ ]-carbon in the treatment columns varied between 46 and 64%. No nitroso-substituted transformation products were detected in the dissolved fraction, indicating transformation to non-nitroso-metabolites via ring cleavage. The results of this supplemental study demonstrated that RDX can be biotransformed under very low redox potential conditions.

### **2.3 Factors Affecting Cost and Performance**

Several factors that might affect the capital costs of the proposed BAZE technique are the depth of the contamination, the amount and accuracy of existing historical site data, and the condition and location of any existing wells or equipment. Capital costs would be appreciably higher if the location of the RDX plume needed characterizing prior to treatment or if additional injection or monitoring wells required installing. For example, capital costs for the demonstration project included expenses for thirteen geoprobe pushes, the installation and removal of six temporary piezometers, and the installation of fourteen monitoring wells.

The operation and maintenance (O&M) cost would be influenced by the extent of the contamination, the presence of any ubiquitous electron acceptors, and the presence of possible co-contaminants. Power, labor, and analytical costs would increase if the plume was large and heavily contaminated or the desired treatment levels were reduced, all of which would require additional treatment time. Additional acetate would also be needed, but this cost would be minimal. Analytical costs could be substantial if monthly sampling events were written into the scope of work. The presence of co-contaminants would also increase the operating costs because additional treatment time and acetate would be needed to remediate the groundwater. Ubiquitous electron acceptors, like nitrate and sulfate, in the aquifer material would have a minor effect on the operating costs. Their presence would only slightly increase the mass of acetate needed to achieve the reduced conditions necessary for reductive RDX biotransformation. Coexistence of other inhibitory chemicals, such as heavy metals, would not appreciably affect the performance of the proposed treatment system.

### **2.4 Advantages and Limitations of the Technology**

The proposed technology enhances the growth of indigenous microorganisms, which in turn facilitates anaerobic biological destruction of explosive compounds. In fact, the process has a high potential for regulatory acceptance because of its reliance on indigenous microorganisms, complete destruction of the energetic compound, and a substantial reduction in treatment time compared to other technologies, especially the pump-and-treat technology. The conventional pump-and-treat approach to groundwater cleanup is costly, seldom restores the groundwater to health-based levels within a

reasonable period, and merely brings contamination to the surface for treatment or disposal elsewhere.

The addition of sodium acetate did not produce toxic or hazardous byproducts; therefore, the proposed BAZE process may not require any special regulatory permits. Another advantage of acetate addition is that any chlorinated solvents or perchlorates present in the aquifer will undergo reductive biotransformation along with the explosives (Sewell et al., 2006; Shrouf and Parkin, 2006). In general, in situ bioremediation is an attractive technique for the destruction of energetic compounds because there are no disposal costs associated with spent materials and the surface footprint is reduced to a series of wells. Both of these factors help reduce the cost of the process.

The main limitation of this technology is that it can require longer treatment times than traditional remediation methods to achieve regulatory contaminant concentrations at sites with relatively high starting concentrations. Other potential limitations of the technology are: 1) the potential for biofouling; 2) difficulties in effective electron donor distribution, 3) potential impacts to secondary water quality parameters; 4) potential gas production (e.g., methane generation), 4) competition for electron donors for biological reduction of common cocontaminants such as chlorinated solvents, and 5) a transient increase in toxicity.

The addition of organic compounds to an aquifer could result in the growth of microorganisms and may result in the plugging of pore spaces and/or growth of organisms around injection and extraction wells (i.e., biofouling). This limitation may be overcome by managing the amount and rate of injection to ensure transport of the microorganisms and amendments away from the injection area. Carbon source distribution in the subsurface could be a major challenge especially in the aquifers with very low or very high hydraulic conductivity. In stagnant aquifers (low hydraulic conductivity), the natural flow of groundwater may not uniformly distribute the carbon source. Similarly, an aquifer with very high hydraulic conductivity might washout the electron donor prior to distribution within the entire aquifer. The aquifers with high levels of inhibitory compounds (heavy metals, extreme pH, etc.) for biological growth might create difficulties in stimulating the resident microorganisms and at times might lead to process failure. Other treatment technologies might be required in addition to BAZE process. Since the BAZE process does not alter the aquifer pH significantly, the mobilization of metals may not be a great concern. However, the reductive environment created because of carbon source injection might lead to mobilization of iron thereby affecting secondary water quality. In presence of high nitrate levels, the denitrification process might lead to increased nitrogen gas production. Also in case of methanogenesis, significant quantities of methane gas could be produced under reduced conditions. These gases could lead to blockage of pore space and groundwater flow restrictions, especially in the aquifers with a low hydraulic conductivity. These limitations were not an issue over a 20 month period during the field demonstration.

### 3. Demonstration Design

#### 3.1 Performance Objectives

The overall objective of this demonstration was to validate the ability of sodium acetate injection to enhance indigenous biological activity in order to cost effectively remediate RDX-contaminated groundwater. The performance objectives for the demonstration are outlined in Table 3-1. The demonstration was designed to identify and verify the economic, operational, and performance data needed in order to transfer the technology to potential users (Appendix F: Field Demonstration Plan). Through this technology demonstration, issues such as ease of implementation, cost-effectiveness, and treatment efficiency were studied. The field demonstration also provided site-specific information, which cannot be addressed in bench-scale treatability studies. The main issues addressed were the verification of the treatability study predictions and the validation that the BAZE process is an effective and economical remedial technology for RDX contaminated groundwater.

**Table 3-1. Performance Objectives.**

<b>Primary Performance Criteria</b>	<b>Expected performance</b>	<b>Actual performance</b>
% Reduction	98%	> 98%, achieved
Treated aquifer RDX conc.	2 µg/L	< 2 µg/L, achieved
Treated aquifer toxicity	Non toxic	Non toxic, achieved
Ease of Use	Operator acceptance	Achieved –personnel easily operated the system

#### 3.2 Selection of Test Site(s)

Site screening and selection process were described in depth in a previous Treatability Study (Wani et al., 2002). The primary factors used in the selection process were contamination, hydrogeology, geochemistry and infrastructure availability. Two sites selected for detailed evaluation: 1) the former Nebraska Ordnance Plant, Mead, NE and 2) Cornhusker Army Ammunition Plant, Grand Island, NE. The results of the treatability/feasibility study were used to determine the better site for the field demonstration. Although treatability study results for these two sites were similar, the Nebraska Ordnance Plant was selected for the field demonstration based on the availability of existing infrastructure and the possibility of implementation following the demonstration. However, NOP did provide a challenge. The existing plume map showed a well-defined RDX plume (Figure 5), but after several geoprobe pushes only one push met the criteria for a field demonstration.

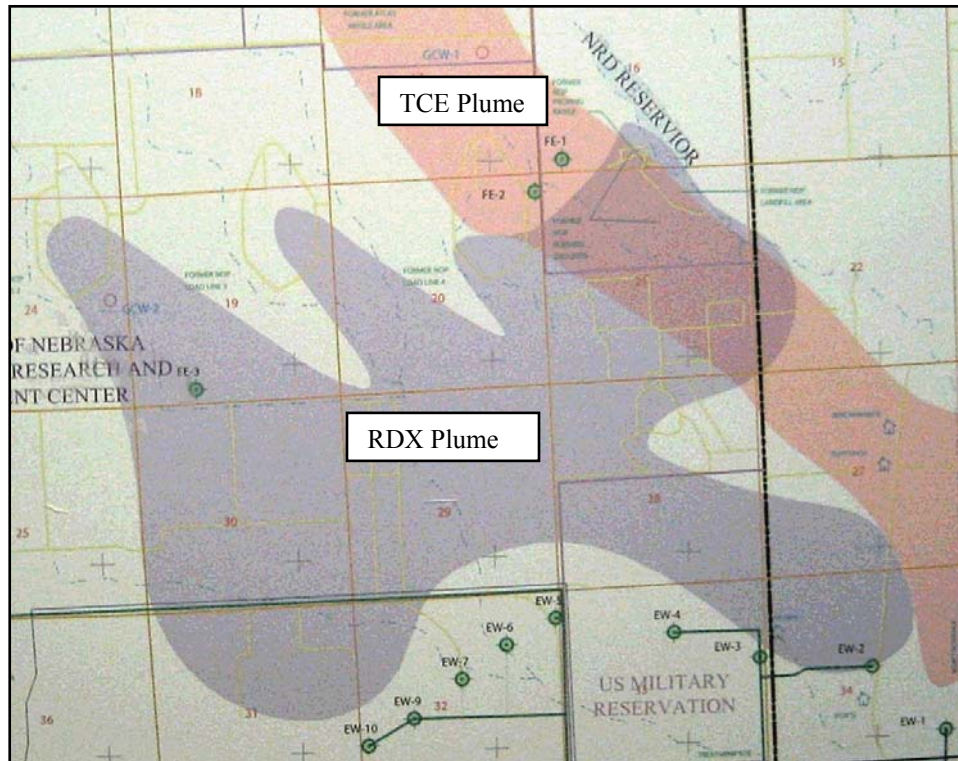


Figure 5. NOP RDX and TCE plumes location.

### 3.3 Test Site Description

The former NOP is located about 1.5 mile (2.4 km) mile south of Mead, which is 30 miles (48 km) west of Omaha and 35 miles (56 km) northeast of Lincoln, NE. The former NOP covers 17,258 acres (6,987 hectares) in Saunders County. Currently, the University of Nebraska, Agricultural Research and Development Center (ARDC), U.S. Army National Guard and Reserves, U.S. Department of Commerce and private interests, own the land.

The former NOP was a load, assemble, and pack facility, which produced bombs, boosters and shells (SIC#2892). Most of the raw materials used to manufacture the weapons at the former NOP were fabricated at other locations and shipped to NOP for assembly. However, ammonium nitrate was produced on site during the first months of operation in 1943. During World War II Nebraska Defense Corporation operated the production facilities. Production was terminated for the interim period 1945 through 1949. In 1950, the former NOP was reactivated in order to produce an assortment of munitions for use in the Korean conflict. NOP was placed on standby status in 1956, declared excess to Army needs in 1959, and closed in 1962.

The BAZE test area was located in the northeastern portion of the former NOP site (Todd Valley) and is illustrated in Figure 6. The elevation of the test area is between 1,070 LF

(326 m) and 1,080 LF (329 m) above mean sea level (MSL). The geological units underlying the test area were a 10-15 LF (3.0-4.6 m) deep layer of loess (buff to yellowish brown loamy deposit chiefly deposited by the wind) underlain by a 55-65 LF (17-20 m) deep layer of fine sand. Below the fine sand layer is a 30-50 LF (9-15 m) deep layer of sand and gravel. The water table varies between 45-55 LF (14-17 m) bgs at the test site. The bedrock beneath the test area consists of Cretaceous shales and sandstones of the Omandi Formation, which is underlain by Pennsylvanian shales and limestones. The Omandi Formation consists of an upper shale and lower sandstone lithofacies at the site. The sandstone lithofacies of the Omandi Formation are fine to medium grained with some gravel at the base. The sandstone varies in thickness from 20 LF (6 m) to 105 LF (32 m) bgs. The shale lithofacies is clayey nonclacareous shale with some interbedded thin silt and sand. The maximum thickness of shale is about 52 LF (16 m). The hydraulic conductivity of Todd Valley fine sand unit is estimated to be 0.034 LF/min (1.04 cm/min) and the Todd Valley sand and gravel unit is 0.08 LF/min (2.44 cm/min). The hydraulic conductivity of Omandi sandstone aquifer is estimated to be 0.044 LF/min (1.34 cm/min).

The RDX concentrations in the soil vary between 60 and 300  $\mu\text{g/L}$  at the test site. The results of a 1991-92 evaluation study by USACE indicated that explosive contamination in the soil was mostly limited to areas in and under drainage ditches and sumps in the load lines and the Bomb Booster area. It is believed that this contamination originated from the discharge of water used to wash away explosive dust and residue generated during the ordnance load, assemble, and pack processes. RDX, 2,4,6-trinitrotoluene (TNT), and 1,3,5-trinitrobenzene (TNB) were the explosive contaminants most often detected. RDX, TNT, and TCE plumes were identified in the groundwater samples.



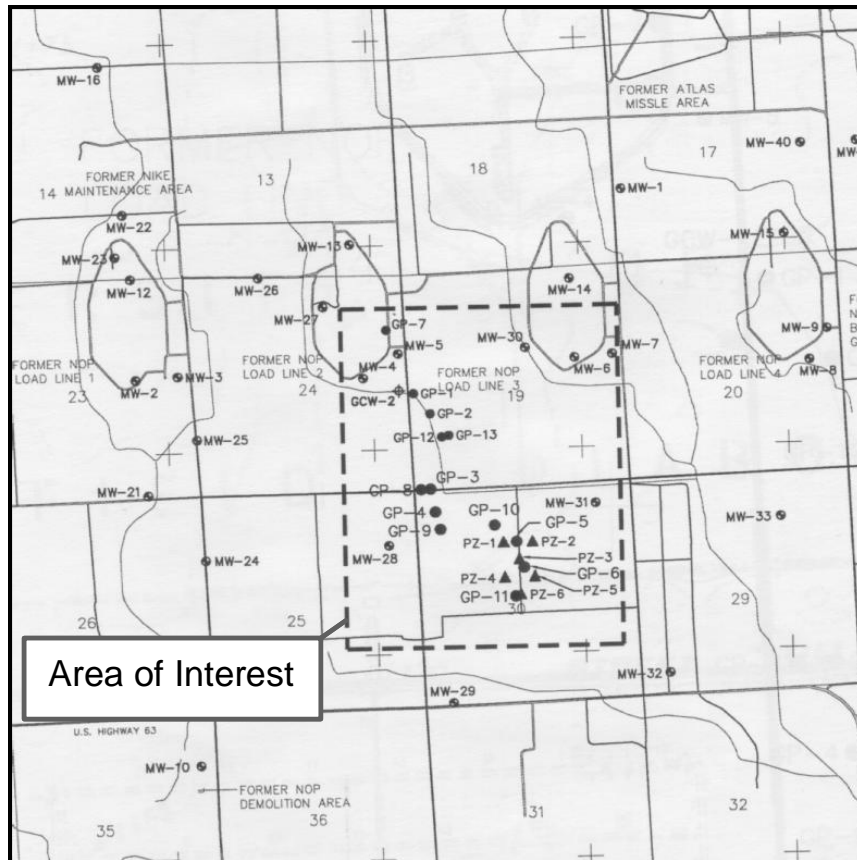


Figure 6. General site map showing BAZE area of interest.

### 3.4 Pre-Demonstration Testing and Analysis

URS GROUP, INC and its subcontractors for the U.S. Army Engineers District, Kansas City, assisted in the pre-demonstration field activities (Appendix G). The preliminary field investigations, conducted in September 2003, delineated an area of elevated RDX concentrations and determined the local groundwater flow characterization (flow direction, depth to water, well recharging capacity, etc.). In order to pinpoint an area with sufficient RDX concentration for the field demonstration, 13 borings (GP-1 through GP-13) were drilled into the subsurface groundwater using the Geoprobe method (Figure 7). This method consisted of drilling to the appropriate depth using 1-in (2.54 cm) ID, 5 LF (1.5 m) long cores. After removing the screen, the well casing was purged prior to collecting 1 L groundwater samples. The target RDX concentration in the groundwater was 100-500  $\mu\text{g/L}$  so that statistically significant contaminant reductions could be demonstrated. Groundwater samples were collected and analyzed for explosives using U.S. USEPA Method 8330 from discrete intervals ranging from 45-95 LF (13.7-29.0 m) bgs. Up to six groundwater samples were collected from each boring location. The explosive analysis of site samples showed RDX concentrations ranging from non-detect to 450  $\mu\text{g/L}$  at 54- to 58-LF (16.5-24.4 m) bgs. Based on the analytical data, the area near GP-5 was selected for the field demonstration (Table 3-2).





Figure 7. Geoprobe activities.

Once the site location for field demonstration was selected, six piezometers were installed in a zigzag pattern via the Geoprobe method. The network of 1-in (2.54 cm) temporary piezometers (PZ-1 thru PZ-6) was installed near GP-5 to aid in the evaluation of the local groundwater flow direction (Figure 8). The piezometers were screened at approximately 50-80 LF (15.2-24.4 m) bgs using 30 LF (9.1 m) of 0.010-inch (0.25 mm) slot screen with 20/40 filter pack for each piezometer. After the piezometers were installed and developed, three rounds of water level measurements were recorded. Water levels in existing monitoring wells near the selected demonstration area were also measured and recorded. A site-wide groundwater flow map was created using the temporary piezometers, existing monitoring wells, and area staff gauges (Figure 9). The temporary piezometers were abandoned within 30 days of installation to comply with State of Nebraska regulations.

**Table 3-2. Geoprobe Analytical Results and Coordinates.**

<b>Sample Location</b>	<b>Sample Date</b>	<b>Screen Depth LF</b>	<b>RDX Conc. µg/L</b>	
GP-1	9/29/2003	44'-48'	0.6	
		54'-58'	0.1	
		64'-68'	5	
		54'-58'	2	
		64'-68'	83	
GP-3	9/29/2003	44'-48'	Non Detect	
		64'-68'	Non Detect	
		74'-78'	47	
GP-4	9/30/2003	44'-48'	Non Detect	
	10/2/2003	54'-58'	Non Detect	
		74'-78'	4	
		84'-88'	Non Detect	
GP-5	9/30/2003	94'-98'	Non Detect	
		10/3/2003	44'-48'	No Sample
			54'-58'	450
	64'-68'		47	
	74'-78'		79	
GP-6	9/30/2003	84'-88'	1	
		94'-98'	Non Detect	
		44'-48'	44	
GP-7	9/30/2003	54'-58'	4	
		64'-68'	Non Detect	
		44'-48'	Non Detect	
GP-8	10/2/2003	54'-58'	0.4	
		64'-68'	Non Detect	
		44'-48'	Non Detect	
GP-9	9/29/2003	54'-58'	Non Detect	
		64'-68'	Non Detect	
		74'-78'	Non Detect	
		84'-88'	11	
		94'-98'	Non Detect	
GP-10	9/29/2003	54'-58'	Non Detect	
		64'-68'	1.1	
		74'-78'	Non Detect	
		84-88	0.32	
		94-98	Non Detect	
GP-11	9/29/2003	54'-58'	Non Detect	
		64'-68'	1.1	
		74'-78'	Non Detect	
		84-88	1.2	
GP-12	9/29/2003	94-98	Non Detect	
		64'-68'	Non Detect	
		74'-78'	Non Detect	
		84-88	Non Detect	
GP-13	9/29/2003	94-98	Non Detect	
		64'-68'	Non Detect	
		74'-78'	Non Detect	
		84-88	Non Detect	

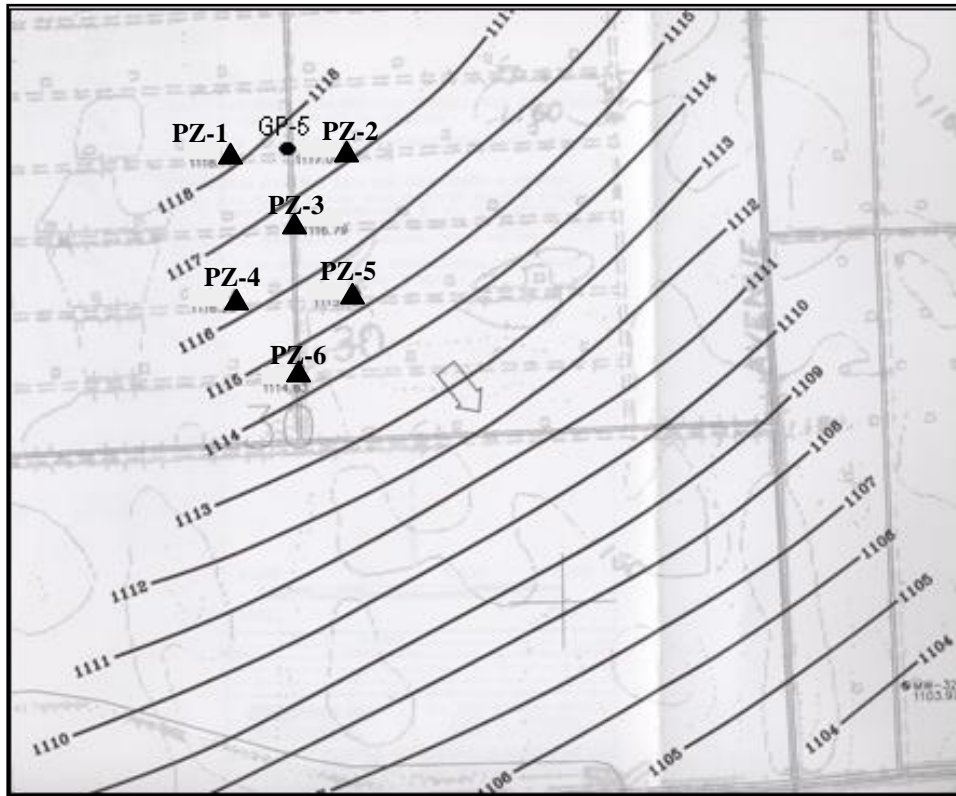


Figure 8. Groundwater flow map.

A groundwater flow model, MODFLOW, was used to evaluate multiple pumping and injection rates and to estimate the capture- and recharge-zones of the BAZE extraction and injection wells. The model was also used to determine the down gradient zone of influence under steady-state conditions for a 2-year period (duration of the BAZE demonstration). After calibrating the model with water levels measured using the piezometers and existing monitoring wells, the model was used to simulate extraction flows for 10-, 20-, and 30-gpm (38-, 76-, and 114-Lpm). The extraction well capture zone and injection well recharge zone were determined to be 100-, 175-, and 250-LF (31-, 53-, and 76-m) wide at 10-, 20-, and 30-gpm (38-, 76-, and 114-Lpm) extraction rates, respectively. The MODPATH model, which tracks particle travel time, was used to calculate the capture and recharge zones. The model also predicted a recharge zone of influence of 1,450 LF (442 m) over a 2 year period (Figure 9), which corresponds to an interstitial velocity of approximately 1.87 LF/d (58 cm/d).

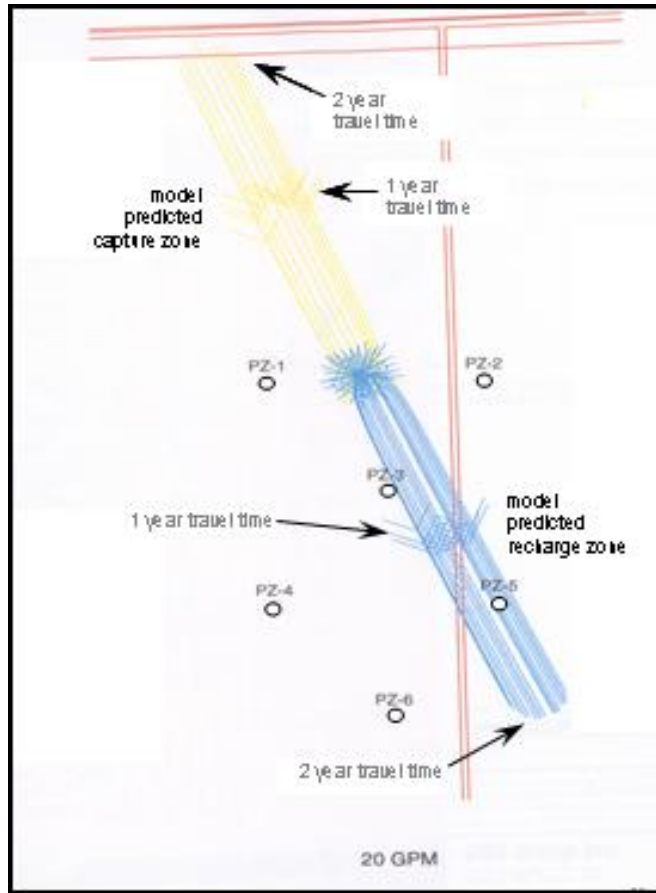


Figure 9. Model prediction for capture and recharge zone for extraction using an injection rate of 20 gpm.

The extraction well, two injection wells, and eleven monitoring wells were installed to monitor the performance of the BAZE process. General information concerning the wells is listed in Table 3-3. The extraction and injection wells were installed using rotary drilling and the monitoring wells were installed using a truck-mounted hollow-stem drilling rig equipped with nominal 8-in (21 cm) augers.

The monitoring wells were constructed of 2 in (5 cm) diameter Schedule 40 PVC pipe. Because the topography of the demonstration area was uneven, the second and third clusters of monitoring wells were approximately 4 LF (1.2 m) deeper than the other wells used during this study. The well pads were covered with a 2 LF (0.6 m) square concrete pad and a flush mount cover was placed in the concrete over each well. The well installation and maps of the sampling area are illustrated in Figures 10 and 11. The monitoring wells were screened in the zone exhibiting the highest RDX concentrations, between 55 and 75 LF (16.8 to 22.9 m) bgs. One monitoring well (MW-01) boring was sampled for particle size distribution analysis and biological parameters in five foot intervals between 50- and 70-LF bgs (15.2- and 21.3-m) bgs. Results of the particle size distribution analysis for that well are illustrated in Figure 12. Upon completion of well

installation and development, groundwater samples were collected and analyzed for initial water quality and contaminant concentration parameters.

**Table 3-3. Descriptions of wells used during field demonstration.**

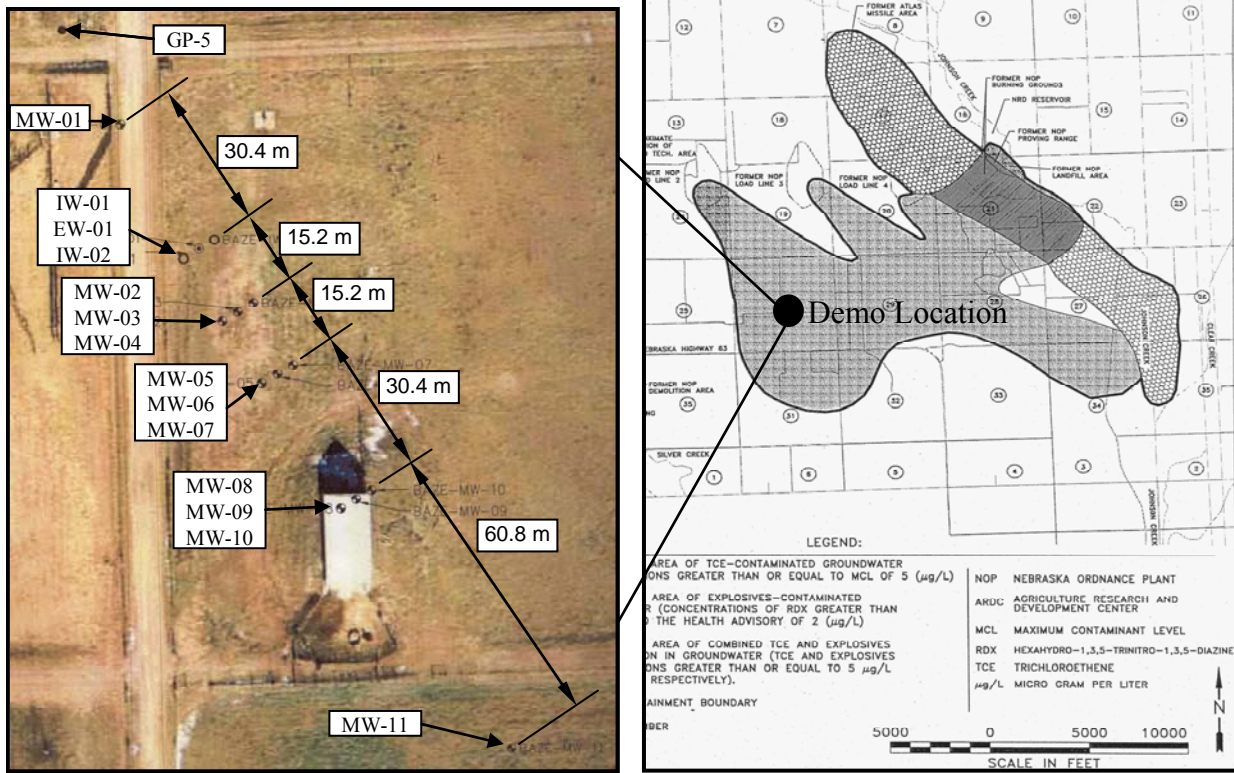
Well ID	Well description	Well size (in/cm)	Well depth (LF/m)	Distance from MW-01 (LF/m)
MW-01	Upstream monitoring well-used as treatment control	2/5.1	73/22.3	0
*EW-01	Extraction well	6/15.2	73/22.3	100/30.4
*IW-01, IW-02	Injection wells	4/10.2	73/22.3	100/30.4
MW- 02, 03, 04	First cluster of monitoring wells	2/5.1	72/21.9 to 73/22.3	150/45.7
MW-05, 06, 07	Second cluster of monitoring wells	2/5.1	78/23.8 to 79/24.1	200/60.8
MW-08, 09, 10	Third cluster of monitoring wells	2/5.1	78/23.8	300/91.4
MW-11	Furthest monitoring well	2/5.1	74/22.6	500/152.4

\* - Extraction and injection wells are clusters (see Figure 11).



Figure 10. Installation of wells (above) and final product (below).





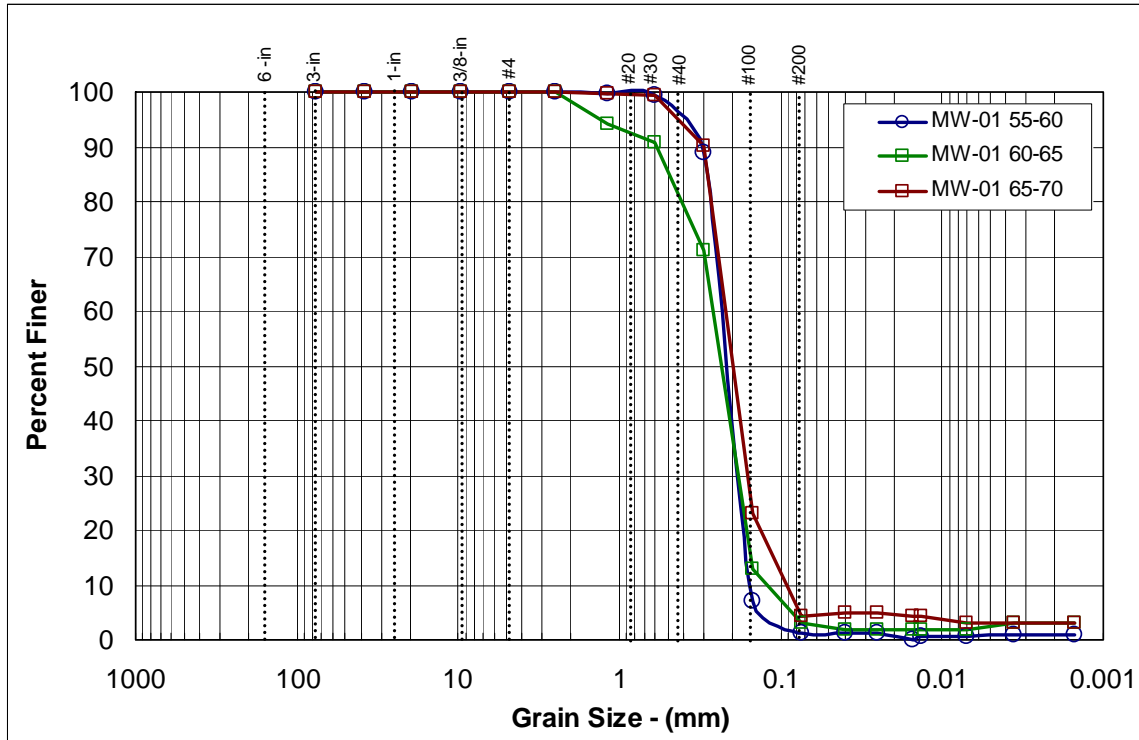


Figure 12. Particle size distribution curves for MW-01.

### 3.5 Testing and Evaluation Plan

Appendix H is an interim report that provides details of the field demonstration and data acquisition.

#### 3.5.1 Demonstration Installation and Start-Up

Based on the Geoprobe activities (Table 3-2) and the groundwater modeling results, the demonstration site was located southwest of GP-5 (Figure 11). The demonstration setup consisted of eleven monitoring wells, an extraction well, two injection wells, and a portable system of pipes and fittings. A stainless steel 1.5-in (3.8 cm) low-flow submersible pump and 0.5-in. (1.3 cm) ID x 10-LF long (3 m) stainless steel tubes were used to extract the groundwater samples. Each monitoring well (MW-01 thru MW-11) was sampled monthly, except MW-11, beginning in December 2003 and sampling was completed in August 2005. The sampling plan is described briefly below and in detail in the demonstration plan found in Appendix E.

Prior to sampling, depth to the water table and total well depth were measured and recorded in order to monitor changes in the groundwater plume as well as to detect early signs of biofouling. Water quality parameters such as pH, conductivity, ORP, DO, and temperature were also assessed at this time using an YSI multi-probe multi-meter (Model 556 MPS, YSI Corporation, Yellow Springs, OH) equipped with a

flow-through cell, which allowed samples to be measured without exposure to the atmosphere. Three well volumes of groundwater were then purged from each monitoring well to complete the pre-sampling procedures.

After purging, dual-level sampling was employed at each monitoring well to track any vertical changes in RDX concentration. Groundwater samples were collected at 70-LF (21.3 m) and at 60-LF (18.3 m) bgs from the extraction well, both injection wells, and some monitoring wells (MW-01 thru MW-04, and MW-11). Groundwater samples were collected at 74-LF (22.6 m) and 64-LF (19.5 m) bgs from the remaining monitoring wells (MW-05 thru MW-10). The difference in sampling elevations was an attempt to collect samples at the same depth in the water table across the well field.

Twenty-one rounds of groundwater samples were collected from the monitoring wells and were analyzed for acetate, nitrate, nitrite, sulfate, TOC, and explosives. Three sets of these samples were analyzed for metals, biomass composition, and toxicity over the period of the demonstration. Injection and re-circulation samples were collected from 3 sampling ports on the injection/re-circulation system during each injection event and analyzed for TOC and acetate. Figure 13 shows a photograph of the injection system.

### **3.5.2 Period of Operation**

The field demonstration involved collecting groundwater samples, injecting sodium acetate, and re-circulating the treated groundwater. The sampling schedule and protocol were described above and in Appendix E. The monthly injection and re-circulation of sodium acetate began in January 2004 and ended in June 2005, for a total of 15 injection and re-circulation events. The system usually operated for approximately 12 hours per treatment. Two 24-hr injection and re-circulation events were conducted, one in February 2004 and one in March 2004, to determine if the sodium acetate solution was uniformly distributed across the 60-LF (18.3 m) injection zone. The calculated recirculation volume for each event is illustrated in Figure 14.



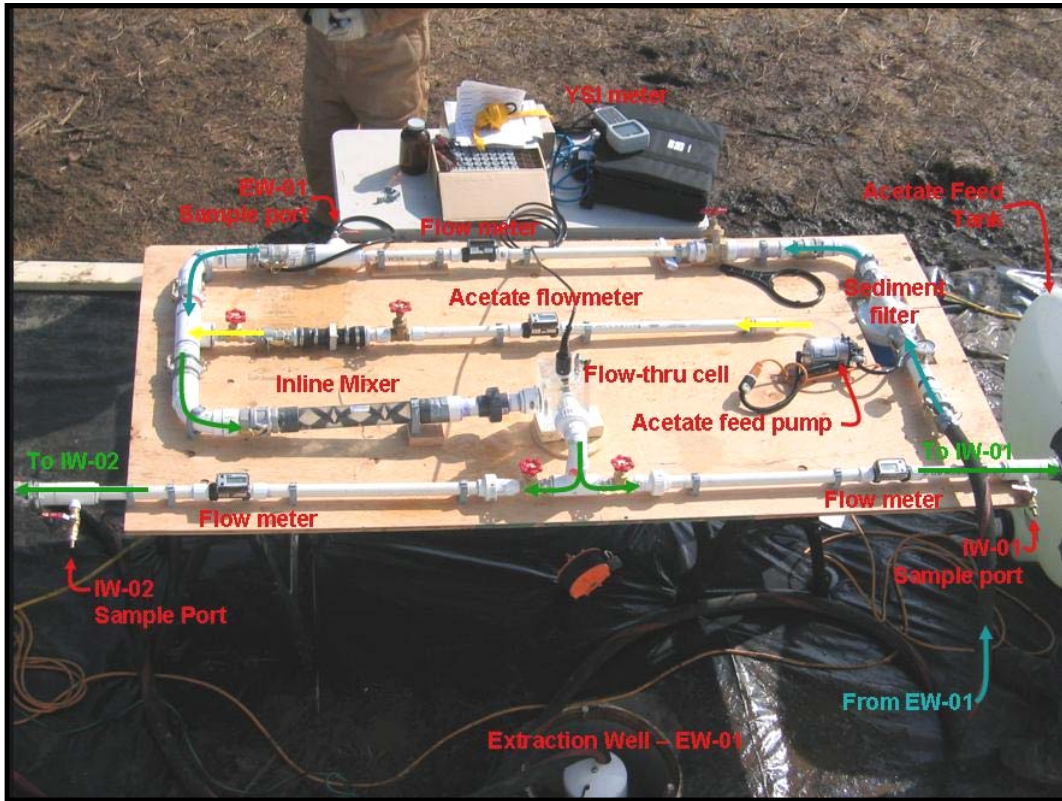


Figure 13. Injection system, sodium acetate, and flow meter.

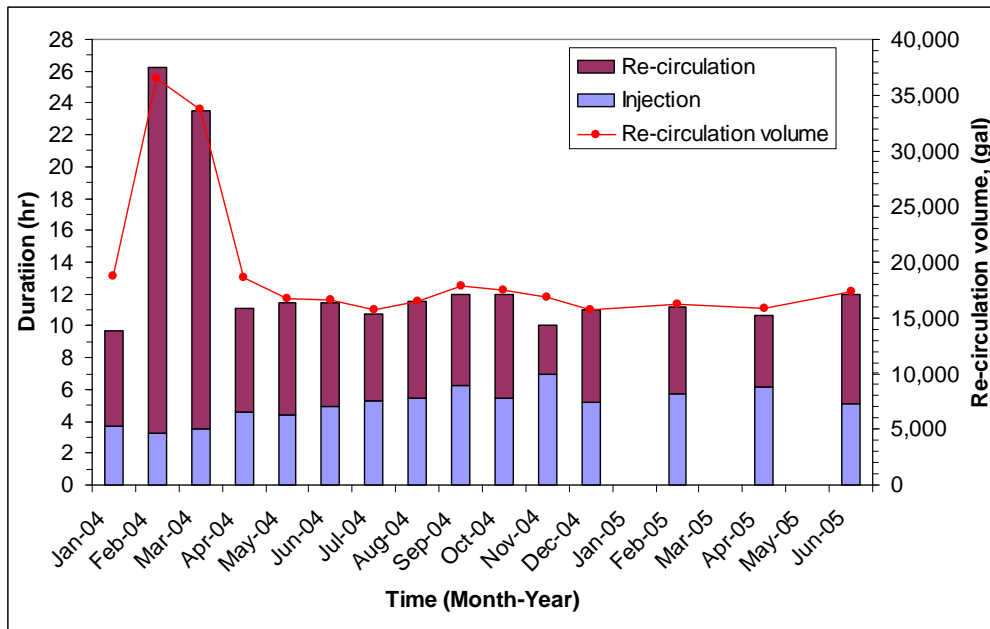


Figure 14. Calculated recirculation volume for each treatment event.

### **3.5.3 Amount/Treatment Rate of Contaminant**

The estimated volume of RDX-contaminated water treated during this demonstration was 9,565 kgal (36,207 m<sup>3</sup>). This estimate was calculated by using a 20-LF (6.1 m) well screen height in the aquifer, the treatment's zone of influence [60-LF (18.3 m) wide], the project's duration (576 days), and a groundwater flow of 1.85-LF/d (56 cm/d). Based on the average background RDX concentration (256 µg/L) and the final RDX concentration for the affective wells, the mass of RDX destroyed over the duration of the demonstration was 20 lbs (9.07 kg). A total of 4,955 lbs (2,250 kg) runway deicer (97% sodium acetate) was used over the course of the BAZE demonstration. The water solubility of runway deicer is approximately 95% and sodium acetate is 72% acetate by weight. Using these data, it was calculated that 3,289 lb (1,493 kg) acetate was injected into the subsurface. Therefore, it was estimated that 164g acetate was added to the system in order to destroy 1g RDX.

### **3.5.4 Residuals Handling**

Because the BAZE system is an in situ treatment, residual handling and offsite disposal were not issues for this demonstration.

### **3.5.5 Operating Parameters for the Technology**

The injection system was operated monthly for 12 months (until December 2004) and thereafter every other month until the end of the field demonstration (August 2005). Monthly injection events were halted in December 2004 because acetate concentrations remained sufficient for treatment in the affected monitoring wells after 30 days. Optimal injection/recirculation times were calculated using data from the 24-hour injection event conducted in March 2004 (Figure 15). The results indicated that 8-10 hrs was sufficient to mix the acetate solution, with no added benefit realized when longer recirculation times were used. Operating parameters measured during injection/recirculation (pH, temperature, conductivity, DO, and ORP) were determined every 15 minutes (Figure 16). The system pumped groundwater from the extraction well at 24 gpm (91 Lpm) and the sodium acetate feed pump operated at approximately 0.5 gpm (1.9 Lpm). Roughly 12.2 gpm (46 Lpm) of treated groundwater was directed to each injection well, which allowed for replacement of at least one pore volume in the injection zone over a 12 hour period.

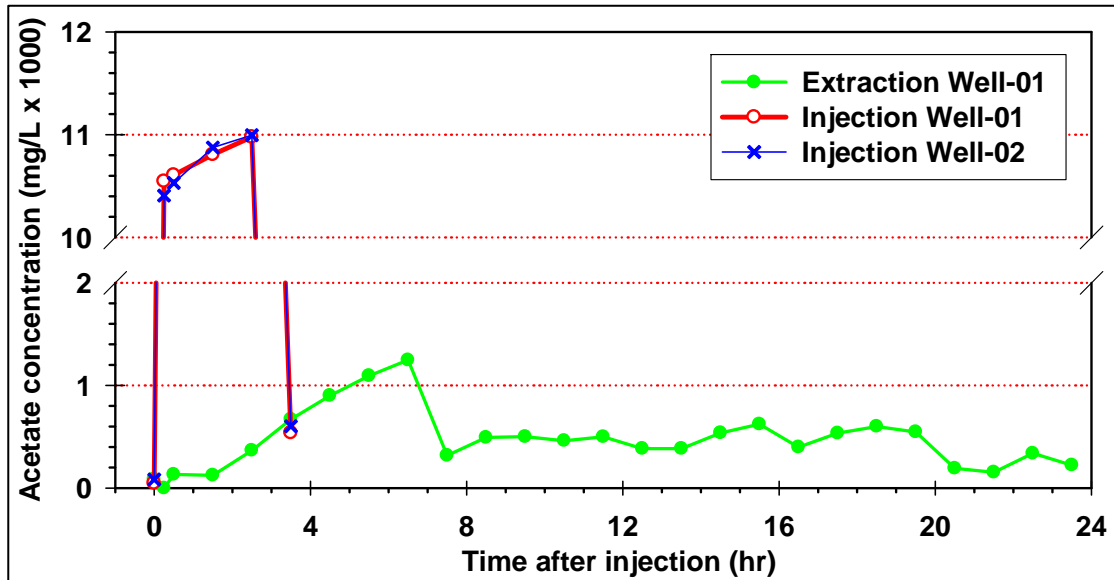


Figure 15. Acetate concentration in operating system during March 2004 injection event.

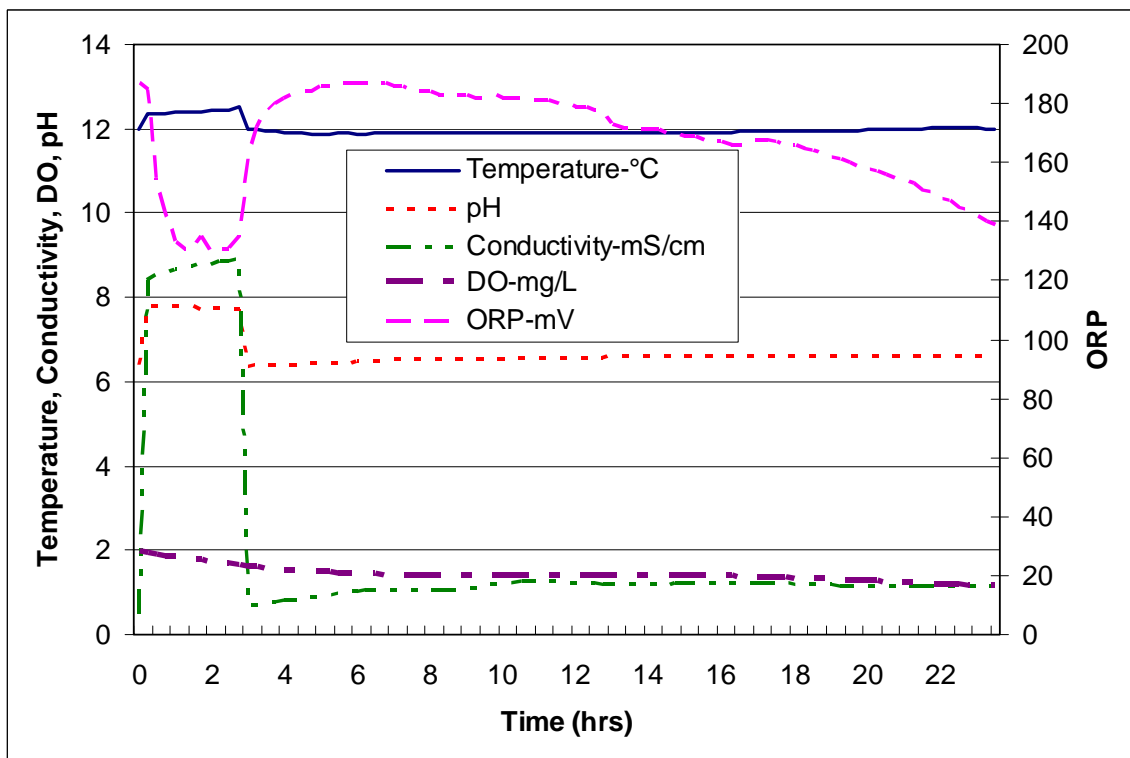


Figure 16. Injection and re-circulation YSI reading for March 2004.

### 3.5.6 Experimental Design

The overall experimental design was to inject a sodium acetate solution and re-circulate the mixture to ensure the widest distribution to the aquifer. Two tracer tests

were employed to evaluate the mixing efficiency of the injection/recirculation system and to determine the actual groundwater flow at the demonstration site. Bromide was used as a non-reactive tracer for both tests. To test the injection/recirculation system mixing efficiency, a concentrated bromide solution was injected into both injection wells at the beginning of the amendment injection to evaluate the mixing efficiency of the BAZE injection/re-circulation system. Samples were collected from both injection wells and the extraction well for 12 hours to monitor the mixing across the injection and extraction zone. Bromide analysis results demonstrated uniform distribution throughout the injection and recirculation zone (Figure 17). The second bromide test was conducted to determine the local groundwater flow. Figure 18 shows the result of the bromide tracer test for MW-04 which is 50-LF (15.2 m) from the injection point. From the curvature of the tracer breakthrough curve, the travel time for a parcel of liquid to travel from the injection point to MW-04 is the time corresponding to the bromide concentration equal to half of the maximum bromide concentration. From the estimated travel time of 27 days, the groundwater flow was estimated to be 1.85 LF/d (56.4 cm/d), which is comparable to the previous estimate of 1.67 LF/d (50.9 cm/d) (URS Greiner Woodward Clyde, 2000) and the model prediction of 1.87 LF/d (58 cm/d). The other parameter that varied during the demonstration period was the sodium acetate feed rate. After the third injection event, the sodium acetate feed rate was reduced from 1 gpm (3.79 Lpm) to about 0.5 gpm (1.89 Lpm). The goal was to gradually introduce the amendment to the aquifer in order to avoid abrupt changes to the biological system. After a year, injection events were conducted every other month, because adequate residual acetate concentrations were evidenced in the monitoring wells after 30 days (Figure 19). This provided 60 days of treatment between injections. Table 3-4 lists and describes the type of experiments conducted over the duration of the demonstration.

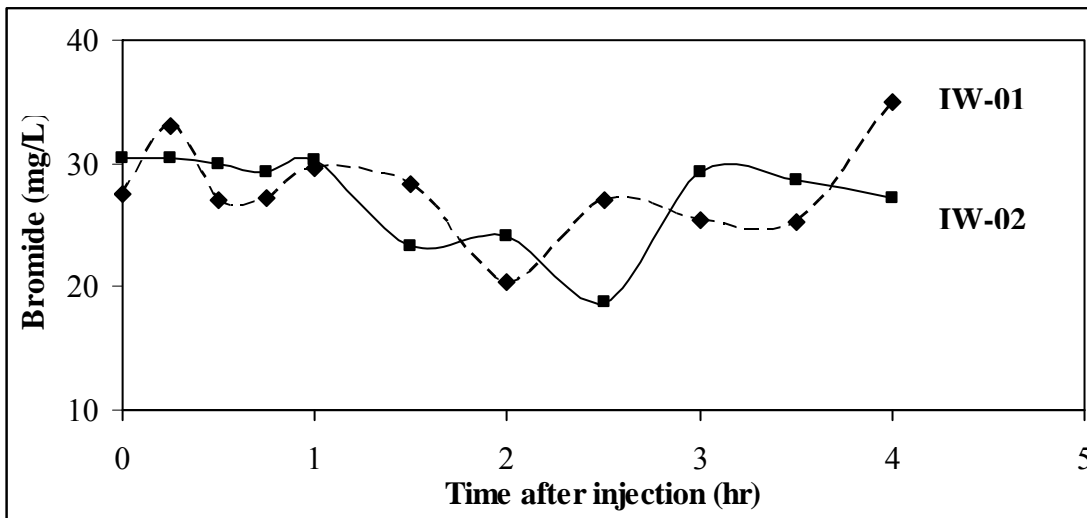


Figure 17. Bromide tracer test to assure adequate mixing.

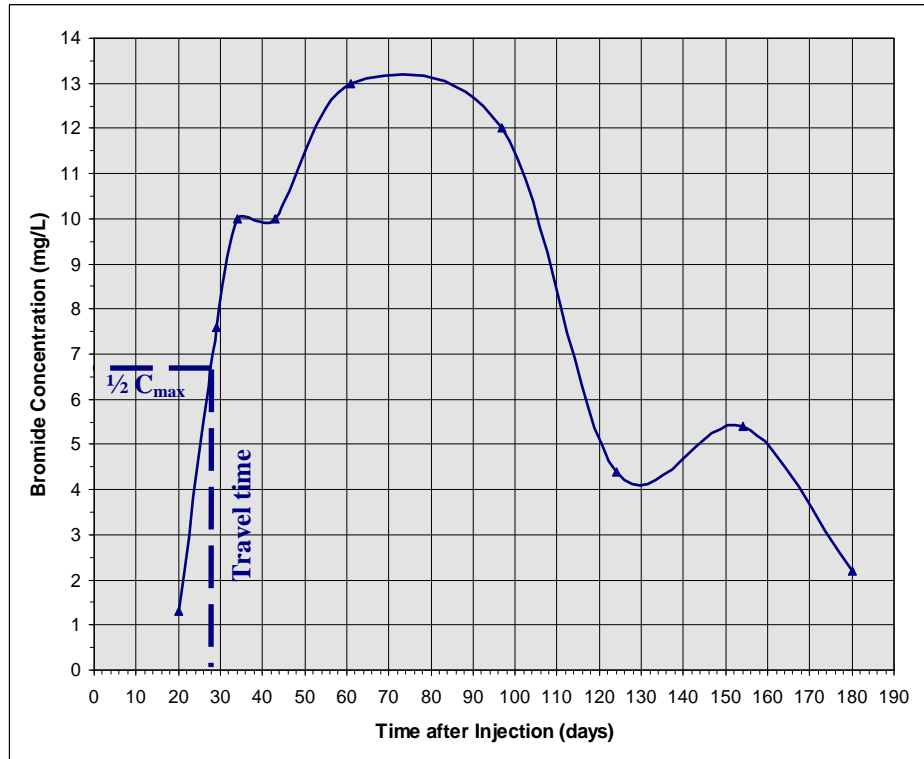


Figure 18. Bromide tracer test to determine groundwater flow at MW-04.

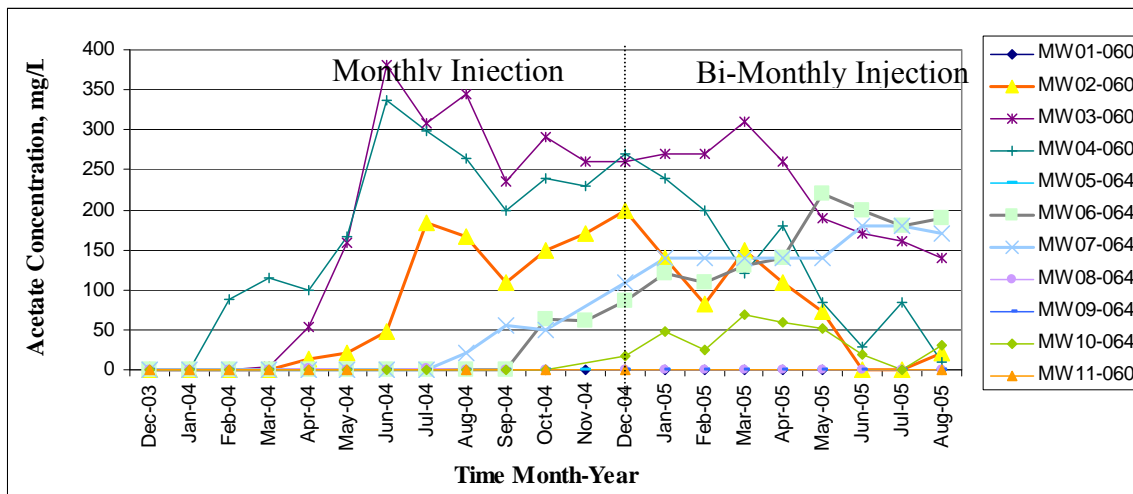


Figure 19. Acetate concentration in monitoring wells over project duration.

**Table 3-4. List of Supplemental Experiments.**

<b>Performance Monitoring Test and Parameters</b>	<b>Description</b>	<b>Usefulness / Results</b>
Re-circulation duration	To determine how long to re-circulate after injecting	After 2 – 24hr tests, 5-6 hrs was determined to be sufficient
Bromide tracer	a) To assure adequate mixing across the injection and extraction  b) To determine groundwater flow rate	a) Check system efficiency – Adequate mixing was evident.  b) Assisted in determining which wells would be affected by the second sodium acetate injection.
Acetate feed rate	Determine residual acetate concentration	To reduce possible microorganism shock
pH	Monitoring chemical change	Monitor possible mobilization of metals caused by lowered pH levels. pH levels remained constant.
ORP	Monitoring redox potential to assure anaerobic conditions	Negative ORP values indicated anaerobic conditions.
Temperature	Monitoring change in temperature	Negligible change in temperature
Dissolved oxygen	Assure anaerobic conditions	Low DO concentration indicated anaerobic conditions
Conductivity	Monitoring the effect of ion concentration of sodium acetate with groundwater while injecting	Increased conductivity levels during injection confirmed acetate was present at the injection points.
Well and water depths	To evaluate biofouling	No biofouling was evident.

### 3.5.7 Sampling Plan

Groundwater samples were collected monthly by the ERDC PI and/or University of Nebraska under the direct supervision of the ERDC PI or Co-PI over the period of the demonstration. Groundwater samples were obtained prior to sodium acetate injection to prevent perturbation to the groundwater aquifer. Samples were analyzed for ordnance related compounds (ORC), nutrients, and physical parameters.

Groundwater samples were also collected for metals, biological community, and toxicity analyses beginning in December 2003 and every sixth month until the end of the demonstration (Table 3-5). Samples were collected from the screened portion of the wells at two depths (10 and 20 LF) (3.0 and 6.1 m) below the groundwater level. Figure 20 shows the average depth to water in relation to the ground elevation.

Groundwater samples were collected using a 1.5-in (3.81 cm) diameter stainless steel low-flow pump, ½-in diameter x 10-LF (1.27 cm ID x 3 m) stainless steel tubing equipped with an in-line flow-through cell (Figures 21 and 22). Sampling equipment was decontaminated prior to sampling the next well.

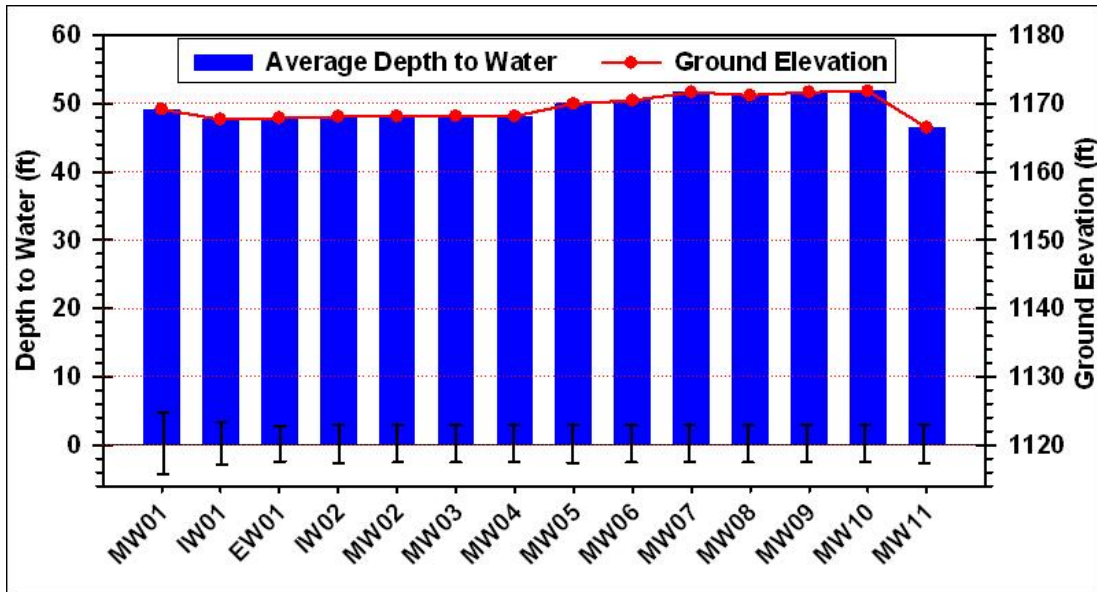


Figure 20. Average depth to water in monitoring, injection, and extraction well compared to ground elevation at each well.



Figure 21. Sampling extraction well and sampling equipment.





Figure 22. University of Nebraska sampling MW-08.

Samples used for organics analysis were collected from two depths per well to assure a homogenous water column in the screen. During each sampling event for ORC and nutrients; (two) 1-L samples were collected at one depth while (three) 1-L samples were collected at the other depth which included a QA/QC sample. Subsequence QA/QC samples were collected at the other depth during the next sampling event. Two additional randomly selected samples were collected as blind ORC samples, which were used to evaluate the analytical laboratory. ORC and nutrients samples did not require preservatives because the analytes are stable in water. There was no evidence that the RDX concentration changed vertically in the wells, as the correlation coefficient between the two depths was 0.99.

The biological, toxicity, and metal samples were collected at one depth. One liter samples were collected for toxicity and metals while a 1-gallon (3.79 L) sample was collected for biological analysis. The samples used for metal analysis were filtered through an in-line 0.45 $\mu$ m filter and preserved with nitric acid. Physical conditions (ORP, pH, conductivity, DO, and temperature) were recorded before and after sampling via an in-line flow-through cell and a multiprobe meter. Well depth and depth to water levels were also recorded.

Ground water samples were stored at 4°C to restrict biological activity and were tightly sealed to avoid cross contamination during storage/shipment. A sample identification system ensured tracking of sample from collection, through analysis, data validation, and data reduction activity. A typical sample label included nomenclature as follows: MW represents monitoring well, EW denotes extraction



well, and IW denotes injection well. The well number followed the well type (e.g., 01-11 for MW, 01 for EW, and 01-02 for IW). A monitoring well upstream of the injection wells was used as the experimental control for baseline data and was designated as MW01.

After sampling the wells, the injection system was prepared for operation. Samples were collected from the sodium acetate feed tank and from the injection system. Samples from the injection system were collected initially every 15, 30, and 60 minutes. After injection was complete; a 40-ml sample was collected from the extraction well every hour thereafter until completion of the recirculation. These samples were filtered through 0.45 $\mu$ m filters to remove active biomass in order to preserve the acetate levels for anion and TOC analysis. Samples were wrapped and padded to prevent breakage and shipped for analysis in rigid, insulated coolers. A chain of custody (CoC), which listed sampling information and requested laboratory analyses, was prepared for each sampling event. The CoC also documented the release of the samples at the site by authorized persons through acceptance of the samples at the laboratory by authorized persons. Samples were sent to the ERDC – EL laboratory, Vicksburg, MS via overnight delivery and/or delivered to the ERDC-Omaha analytical laboratory, depending on the required analysis. Analytical methods and sampling frequency are described in Table 3-5.

**Sample Analysis.** Groundwater samples collected from monitoring and injection wells were analyzed for chemical, microbiological, and toxicological parameters. The frequency of analysis was the same as the frequency of sampling (Table 3-5). The chemical analysis methods were standard methods approved by the USEPA and/or ASTM. The microbiological and toxicological methods were also standard methods used widely in environmental analysis.

Lipid biomarker technology, using the phospholipid fatty acid (PLFA) analysis, quantified the in situ microbial biomass and community structure. The lipid biomarker approach provided data pertaining to the physiological state of the microbial community, onset of environmental stress, and exposures to xenobiotics (White et al., 1996). The results are reported as pmole (pica mole) of PLFA per mL of groundwater.

The toxicological assessment used a MicroTox/MutaTox analysis over a 5 and 15 min time period. The bacterial bioluminescence is measured after each time interval using a MicroTox M500 Analyzer. The results are reported as EC<sub>50</sub> values, the effective concentration where 50% of the exposed fluorescence from the test microorganism is inhibited. The higher the EC<sub>50</sub> value, the lower the acute toxicity.

**Table 3–5: Summary of Periodic Analyses.**

<b>Contaminant/Parameter</b>	<b>Analytical Method</b>	<b>Analytical Frequency</b>
Explosives	SW846-8330 Modified	monthly
Nitrate	USEPA Method 300.0	monthly
Nitrite	USEPA Method 300.0	monthly
Sulfate	USEPA Method 300.0	monthly
Bromide	USEPA Method 300.0	monthly
Total Organic Carbon	SW846-9060	monthly
Dissolved Metals	USEPA Method 200.15	biannually
Microbial Community	PLFA (White et al., 1996)	biannually
Toxicological Profile	Micro/MutaTox (Azur Environmental 1998)	biannually
Water Level	Direct Measurement	monthly
Water Temperature	Direct Measurement	monthly
Eh	Electrode	monthly
DO	Electrode	monthly
Conductivity	Electrode	monthly
pH	Electrode	monthly

**Experimental Controls.** The experimental control in this BAZE demonstration project was a monitoring well (MW01) up gradient of the injection wells. It was sampled at the beginning of the study and at every sampling interval to develop the baseline contaminant concentrations in the groundwater plume used in assessing the performance of the BAZE process. The samples from this control monitoring well underwent the same analytical protocol as the samples from other monitoring wells downstream from the injection wells.

**Data Quality Parameters.** Prior to sampling, each well was purged (three well volumes) to remove any stagnant groundwater. Ten percent of the field samples were used for QA/QC for data completeness as well as accuracy. Results from the monitoring well samples were analyzed to assess the effective zone of the BAZE process and were compared with the control monitoring well data for establishing the BAZE process performance.

**Data Quality Indicators.** ERDC-Omaha analyzed all samples for nutrient and explosives concentrations. Duplicate samples were sent to ERDC-Vicksburg at every sampling event for explosive analyses as a data quality check.

**Calibration Procedures, Quality Control Checks, and Corrective Action.** The principal analytical laboratory (ERDC-Omaha) utilized sample recovery, checked standards, and spiked samples to validate its data. Samples were randomly selected for duplicate analysis to evaluate the analytical variation. Blind samples were collected from randomly selected wells and analyzed to validate the precision and accuracy of the analytical data. Check standards were analyzed after every 10 samples to validate the reproducibility of the instrument. Duplicate samples were

collected on site and analyzed for explosives by ERDC-Vicksburg. Analytical results show an average correlation of 98% between the ERDC-Omaha and ERDC-Vicksburg laboratories over the duration of the demonstration. The instruments used for chemical, microbiological and toxicological analysis were calibrated using standards prepared from stock solutions of known concentrations. The on-site multiprobe instrument used for measuring ORP, pH, DO, conductivity, and temperature was calibrated prior to sampling per manufacture's instruction for instrument reliability and repeatability.

### **3.5.8 Demobilization**

Since the BAZE demonstration was an in situ process, no residual materials were generated. The demonstration site required no decontamination or restoration. All aboveground structures were placed in a mobile trailer and transported back to ERDC-Vicksburg after the demonstration. The subsurface structures were left undisturbed after the demonstration with permission from the site owners, as the monitoring wells were State of Nebraska-approved and could be used for future monitoring of the aquifer.

### **3.6 Selection of Analytical/Testing Method**

The analytical/testing methods used in evaluating the performance of this demonstration study were Standard Methods approved by ASTM or USEPA and are summarized in Table 3.5.1.

### **3.7 Selection of Analytical/Testing Laboratory**

#### **Chemical analyses of the samples taken during the BAZE demonstration were performed by:**

Environmental Chemistry Branch  
US Army Engineer Research and Development Center  
420 South 18<sup>th</sup> Street  
Omaha, NE 68102

and

Environmental Engineering Branch (EP-E)  
U.S. Army Engineer Research and Development Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180

**The laboratories have the facilities, personnel, expertise, and resources to perform explosives, and inorganic analysis in soil and water.**

**Microbiological analysis of the collected groundwater samples from the demonstration site was performed by:**

Environmental Processes and Effects Branch  
U.S. Army Engineer Research and Development Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180

**and the toxicological analysis on these groundwater samples was performed by:**

Environmental Risk Assessment Branch  
U.S. Army Engineer Research and Development Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180

**Both of these laboratories have the facilities, personnel, and expertise to perform microbiological and toxicological analysis on soil and water samples.**

## 4. Performance Assessment

### 4.1 Performance Data

The BAZE process performance was assessed by the criteria tabulated in Table 4-1 below. The overall conclusion is that the system performed as expected: The RDX concentrations were reduced (Figure 23), negligible mobility of metals or other organic constituents was observed, and the system was easily operated. However, wells within the clusters performance were marginal. Therefore wells within a cluster were not utilized as planned due to their placement. Our observation based on field parameters (i.e., ORP, DO, and conductivity data), biomass buildup, residual acetate (Figure 19), difference in initial RDX concentrations for MW-01 and the three well clusters, and little to no reduction in RDX concentration for most westerly wells (Figure 23) is that the RDX plume flow path was more easterly. Initially, each row of well cluster (i.e., MW-02, -03, and -04) was to be averaged to determine the performance of the NOP demonstration at different cluster distances. An explanation would be the placement of the wells at or near the edge of the RDX plume. Based on the analytical data from multiple samples in water column, field data, and no detection of acetate concentration, no other observation could be given except that acetate injection was not the cause. Figure 24 shows the model predicted flow path and the observed flow path of the RDX plume.

A statistical analysis was conducted to accept or reject wells within a cluster for evaluation. The result of that statistical analysis rejected the use of each well per cluster except for Cluster 1, MW-06 and MW-07 in Cluster 2, and MW-10 in Cluster 3. Therefore, two possible scenarios will be addressed for RDX concentration reduction. Scenario 1 is to evaluate the most easterly wells (MW-04, -07, and -10) and scenario 2 is to evaluate each well from Cluster 1, two wells from Cluster 2, and one well from Cluster 3. The performance criteria for both scenarios are in Table 4-1. Table 4-1.1 includes a more detail evaluation of the process performance. Scenario 1 results for the mostly easterly wells show a reduction in RDX concentration ranging from 74 to 98%. Scenario 2 results for Clusters 1-3 show a reduction in RDX concentration ranging from 74 to 96%.

**Table 4-1. BAZE Process Performance Criteria in NOP Demonstration.**

<b>Performance Criteria</b>	<b>Description</b>	<b>Primary or Secondary Criteria</b>
Contaminant Reduction	RDX concentration was reduced by 98% in scenario 1 and 96% in scenario 2. The lowest RDX concentration was $\leq 2 \mu\text{g/L}$ .	Primary
Contaminant Mobility	Dissolved metals were not mobilized based on 3 rounds of data. Nitrate, nitrite, and sulfate constituents did not accumulate over the duration of the project.	Secondary
Microbial Activity	Microbial composition and buildup of biomass were monitored by PLFA analysis. Biomass buildup was observed during the operation of the BAZE demonstration and some biomass enrichment was observed.	Primary
Hazardous Materials	No hazardous material was introduced in the aquifer. Toxicity results showed no increase in toxicity to selected plants, thereby indicating no accumulation of harmful transformation products in the aquifer.	Secondary
Process Waste	No process waste was produced.	Secondary
Factors Affecting Technology Performance	Operating conditions such as pH, temperature, conductivity, acetate feed rate, and depth to water table were generally constant over a 1.5 year effort. High DO levels hindered RDX reduction. Once anaerobic conditions were achieved, microbial biomass increased, ORP levels decreased, and residual sodium acetate levels existed. The westerly (MW-05 & -08) and centerly wells (MW-09, & -11) were not effective because the plume flow path varied from the model's prediction and potentially wells were located near outer edge of RDX plume.	Primary or Secondary
Ease of Use	The system was easy to operate. One operator with moderate experience and a helper is recommended, but a third person would expedite the sampling and injecting process.	Primary
Versatility	The BAZE technology can be used at most sites with explosives contaminated groundwater plume. Amendment feed can be adjusted according to the contaminant concentration and the flow rate. Hydrogeology could be a controlling factor, however.	Secondary
Maintenance	The BAZE system was low maintenance except during periods of extreme cold which caused the pipes to freeze. An enclosed structure or portable building would help alleviate this problem.	Secondary
Scale-up Constraints	There are no scale-up constraints. However, the plume should be well defined.	Secondary

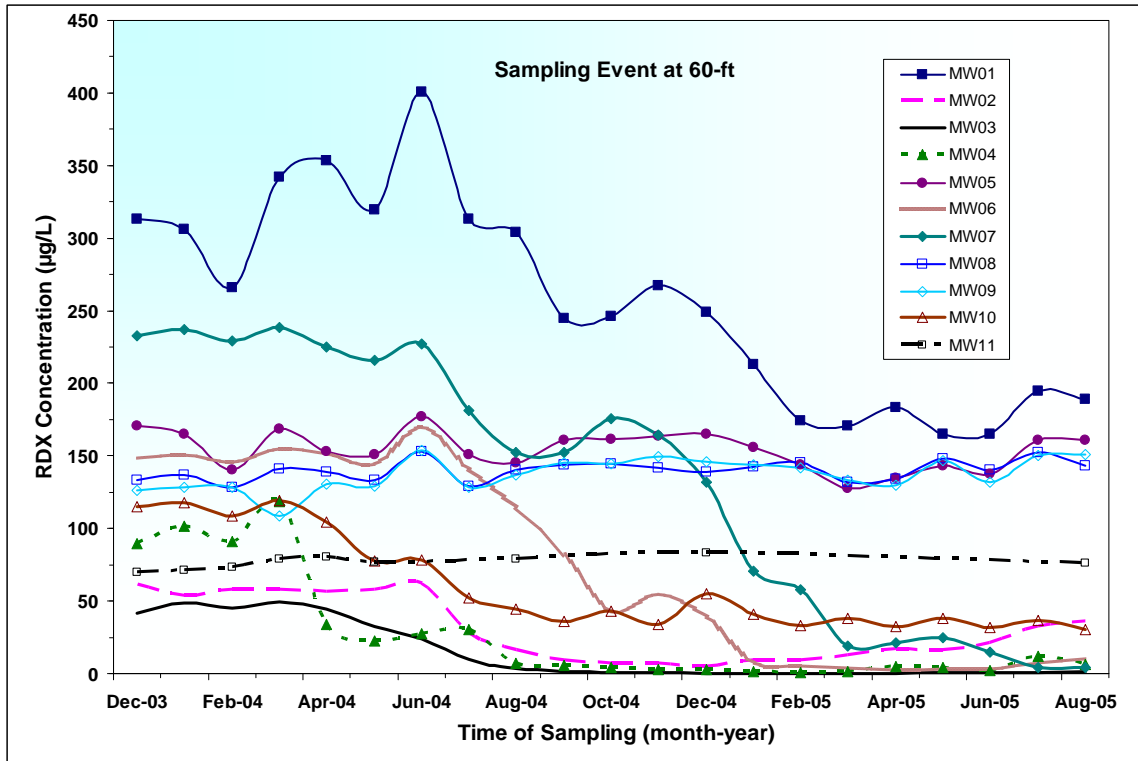


Figure 23. RDX concentrations over duration of demonstration.

**Table 4-1.1: BAZE Process Performance.**

Wells	Dist. from Injection, LF (m)	Induction Time, Month	RDX Concentration, µg/L		% Loss
			<sup>1</sup> Start	<sup>2</sup> End	
MW-1	-100 (-30.4)	---	313	189	40
MW-4	50 (15.2)	2-3	89.9	6.42	93
MW-7	100 (30.4)	4-5	233	4.28	98
MW-10	200 (60.8)	4-5	115	30.2	74
MW-11	400 (121.6)	---	70	75.9	---
<sup>3</sup> Cluster 1 (MW-2, 3, 4)	50 (15.2)	2-3	<sup>4</sup> <b><i>66</i></b>	<b><i>14.6</i></b>	78
<sup>3</sup> Cluster 2 (MW-6, 7)	100 (30.4)	4-5	<b><i>191</i></b>	<b><i>7.1</i></b>	96
<sup>3</sup> Cluster 3 (MW-10)	200 (60.8)	4-5	115	30.2	74
Notes:					
1 – Start represents initial RDX concentrations (Dec 2003).					
2 – End represents RDX concentrations at end of field demonstration (August 2005).					
3 – Distances between wells per cluster are 15 LF (4.6 m).					
4 – Bold and italicize values are effective cluster averages.					



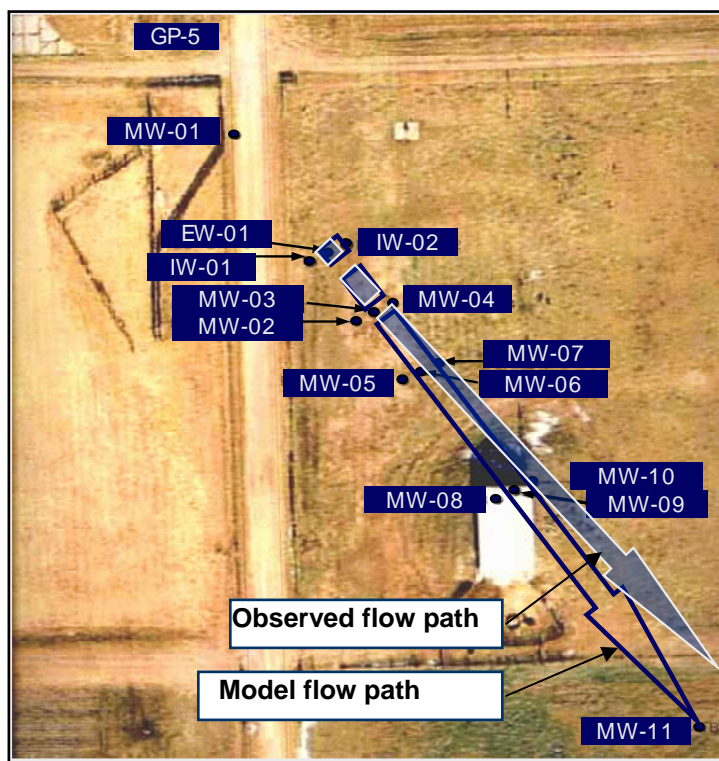


Figure 24. Model and Observed RDX Plume flow path.

#### 4.2 Performance Confirmation Methods

Monthly sampling of wells, monitoring during injection events, and semi-annual sampling for microbial populations confirmed the BAZE process performance. As discussed in section 3, split samples were collected by experienced personnel and independently analyzed by two laboratories. Figure 25 shows the correlation between the analytical results of ECB-Omaha and EP-E, Vicksburg. Overall, the results from the two laboratories were comparable. A correlation existed between the reduction in RDX concentration and development of a microbial community, as evidenced by the PLFA data (Figure 26). Physiochemical data was collected monthly and compared to previous values, yielding reliable field measurements. The Quality Assurance Project Plan ([QAPP]: Appendix B) was executed as described in the Field Demonstration Plan (Appendix F) and the expected performance and performance confirmation methods are presented in Table 4-2 below.

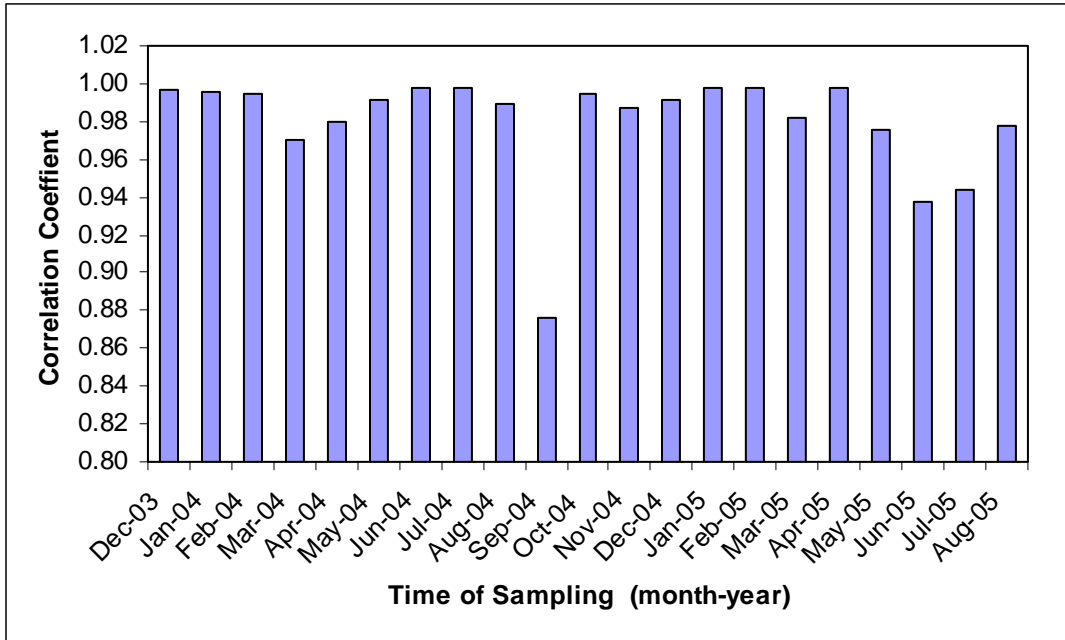


Figure 25. Correlation of RDX concentrations between two laboratories.

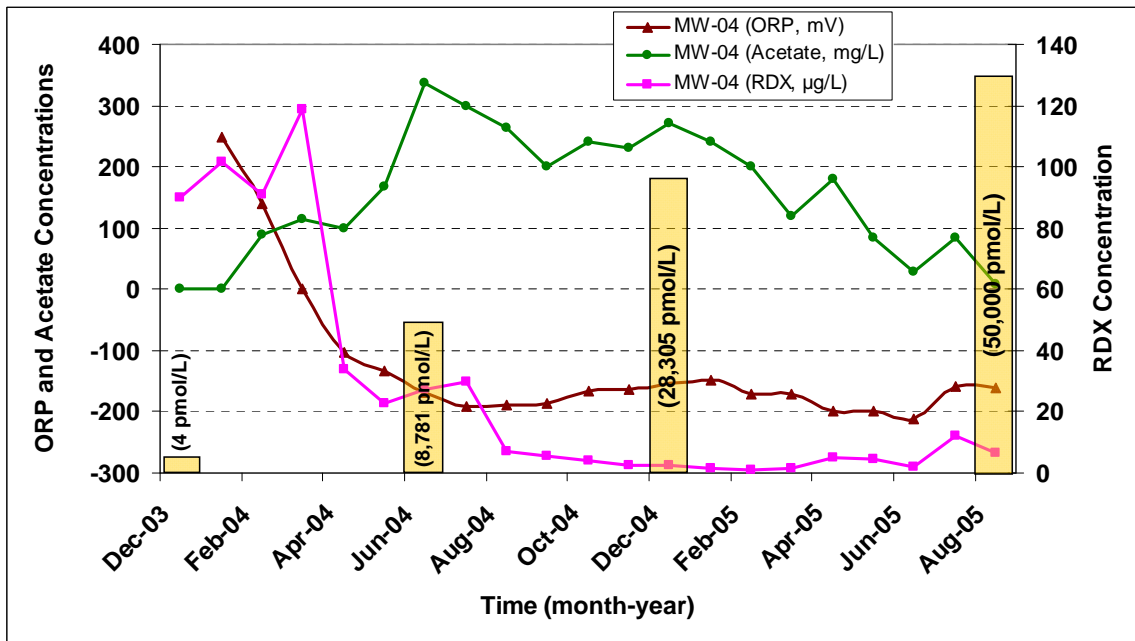


Figure 26. Correlation between RDX concentrations and microbial community biomass.

**Table 4-2. BAZE Demonstration Project Expected Performance and Confirmation Methods**

<b>Performance Criteria</b>	<b>Expected Performance Metric</b>	<b>Performance Confirmation Method*</b>	<b>Actual Performance Metric</b>
<b>PRIMARY CRITERIA (Performance Objectives) (Qualitative)</b>			
<b>Contaminant mobility</b>	Reduce RDX concentration near the injection point	Analysis of samples from 11 monitoring wells (MW01-MW11) for explosives using USEPA's SW846-8330 method	Based on initial and final RDX concentrations at impacted wells, RDX concentrations were reduced by up to 98%.
<b>Faster remediation</b>	Endpoint attained faster	Analysis of samples from 11 monitoring wells (MW01-MW11) for explosives using USEPA's SW846-8330 method	Once the microbial community was established; BAZE process reduced RDX concentrations to near the regulatory level of 2 µg/L.
<b>Ease of Use</b>	Minimal operator training required.	Experience from the operation of the demonstration unit will confirm or reject it.	The ease of operating the BAZE system was confirmed by college students.
<b>PRIMARY CRITERIA (Performance Objectives) (Quantitative)</b>			
<b>Feed Stream</b>			
- Flow rate	Model estimated 1.87 LF/day	Tracer test	1.85 LF/day
- Contaminant concentration	Pre-demo RDX was 450 µg/L.	USEPA Method 8330	Actual RDX levels ranged from 42 to 233 µg/L
<b>Target Contaminant</b>			
- % Reduction	Reduce RDX by 98%	Analysis of samples from monitoring wells (MW01-MW11) using USEPA Method 8330	RDX reduced by up to 98%
- Regulatory standard	Achieve US USEPA's health advisory level of 2 µg/L		Lowest levels achieved were < 0.1 µg/L.
<b>Hazardous Materials</b>			
- Generated	No hazardous material was expected to be generated.	Analysis for toxic degradation by plants and RDX and its intermediates	No hazardous material was generated by injecting sodium acetate into the aquifer.
<b>Process Waste</b>			
- generated	No process waste was expected except for purged groundwater	Observation in the field and purged groundwater was handled on site.	Chemical analysis
<b>Factors Affecting Performance</b>			
- Throughput	Not a concern, as most of the time throughput was fixed.	Flow rates monitored at each sampling interval.	Acetate injection averaged 0.50 gpm and recirculation rate averaged 24.5 gpm.
- Media size	NOP aquifer material is sandy.	Permeability test on site-specific aquifer material in the treatability study.	Confirmed as sandy material
- Media constituents	Media constituents will not affect BAZE process as the amendment is soluble in water and has no affinity for sorption.	Analysis of acetate concentration from monitoring well samples across the plume length using USEPA Method 300.0	Acetate distribution was uniform throughout the plume.
<b>SECONDARY PERFORMANCE CRITERIA (Qualitative)</b>			
<b>Plume size</b>	Wide	Cluster of monitoring wells	Not as defined per historical data

<b>Reliability</b>	Minor breakdowns	Operation of injection system	As expected with freezing
<b>Performance Criteria</b>	<b>Expected Performance Metric</b>	<b>Performance Confirmation Method*</b>	<b>Actual Performance Metric</b>
<b>Safety</b> - Hazards  - Protective clothing	Weather related  Class D	No hazardous chemicals will be used or produced. Other hazards will be assessed from demonstration operation.	No hazards other than weather related.
<b>Versatility</b> - Intermittent operation  - other applications	The BAZE system is versatile.  BAZE process could be applied to most explosives-contaminated aquifer with slight modifications on quantity and frequency of amendment addition.	Demonstration operation results  BAZE demonstration results will confirm it	The system operated as a batch system. Acetate feed and injection flowrates are adjustable.  BAZE reduced HMX concentration while nitrate levels did not increase.
<b>Maintenance</b>  - Required  - Eliminated	Filters replacement and potential mechanical equipment breakdown.	Experience from demonstration operation	Injection pump, PVC pipe, and flow meter may require maintenance because of freezing weather. An enclosed structure would eliminate this issue.
<b>Scale-Up Constraints</b>  - Engineering  - Flow rate  - Contaminant concentration	Minimal engineering scale-up such as pump sizing, preparing a larger batch of acetate solution, and operating space.  Actual flow rate will dictate the quantity of amendment needed.  Not a concern as far as resident microorganisms is concerned. However, will affect the quantity and frequency of amendment addition.	Monitor during demonstration operation.  Experience from the demonstration operation.  Experience from the demonstration process	Since the RDX plume was more easterly than expected via groundwater model, additional monitoring wells would have helped.  Acetate feedrate was reduced to meet the biological needs.  As the RDX concentration decreased, less acetate injection was required.

### 4.3 Data Analysis, Interpretation and Evaluation

The data obtained from the BAZE demonstration project were presented as RDX removal as a function of time, length of plume, amendment concentration (sodium acetate), and groundwater ORP, DO, and pH. This allowed the development of correlations between RDX removal and these operating parameters. The groundwater pH, conductivity, well depth, and temperature values remained relatively constant over the duration of the project (Figures 20, 27-29). After assessing the physical and chemical data, correlations were developed between ORP levels, acetate concentrations, DO readings, and RDX reduction. Negative ORP values and low DO content indicated anoxic conditions, which

are suitable for anaerobic microbial activity, and a constant acetate concentration indicated an abundant carbon source was available. These physical conditions would be conducive for sustaining an anaerobic microbial community, whose development was confirmed using PLFA analysis. These results would indicate that the RDX degradation was caused by microbial activity. Figures 23, 30, and 31 illustrate the reduction of RDX concentrations in down-gradient wells as compared to the baseline well (MW-01).

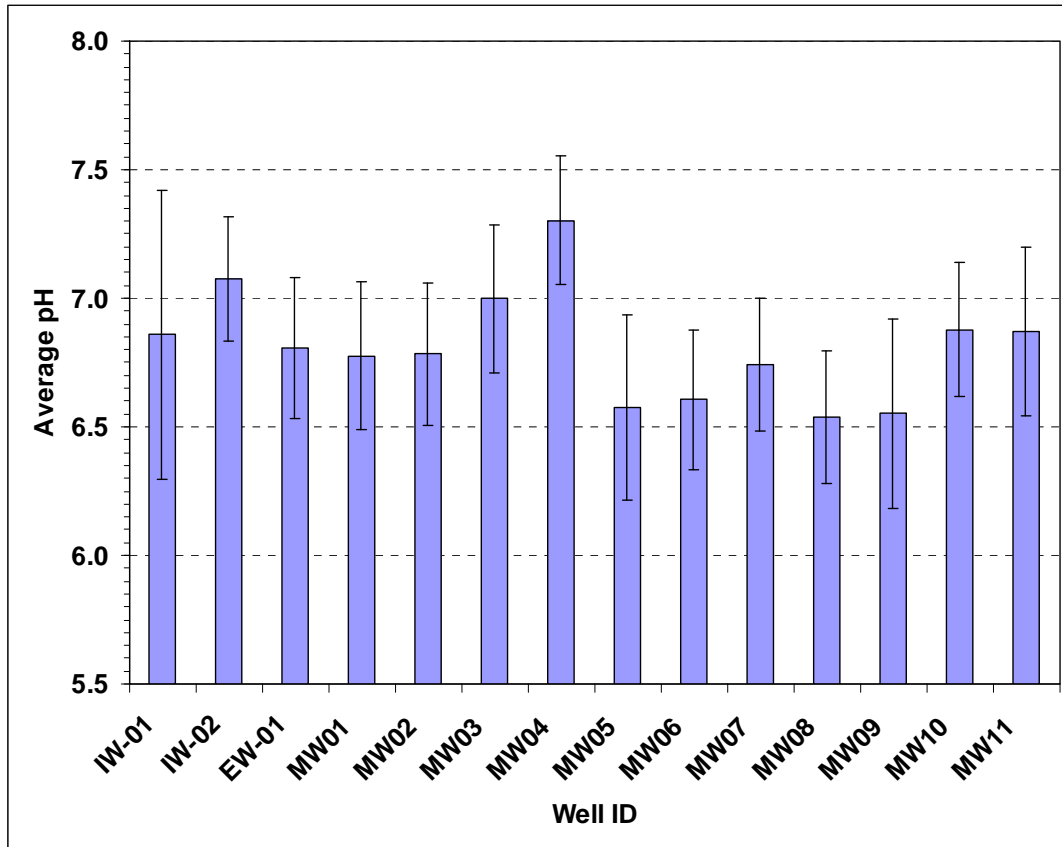


Figure 27. Average pH levels over the period of the demonstration.

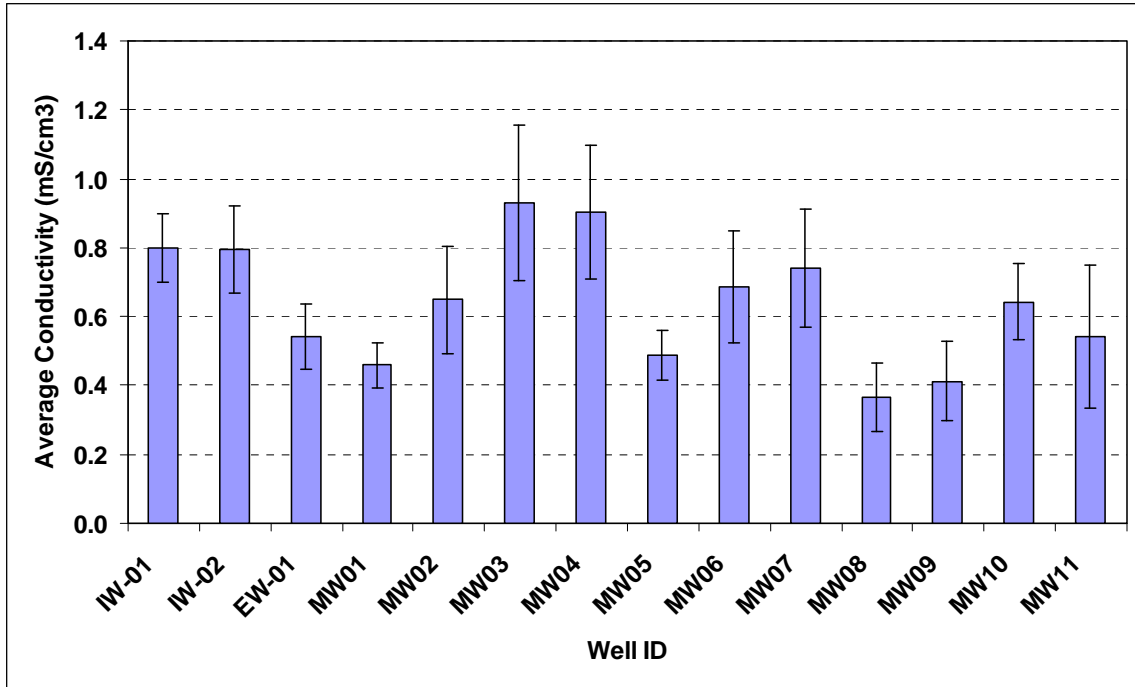


Figure 28. Average conductivity values over the period of the demonstration.

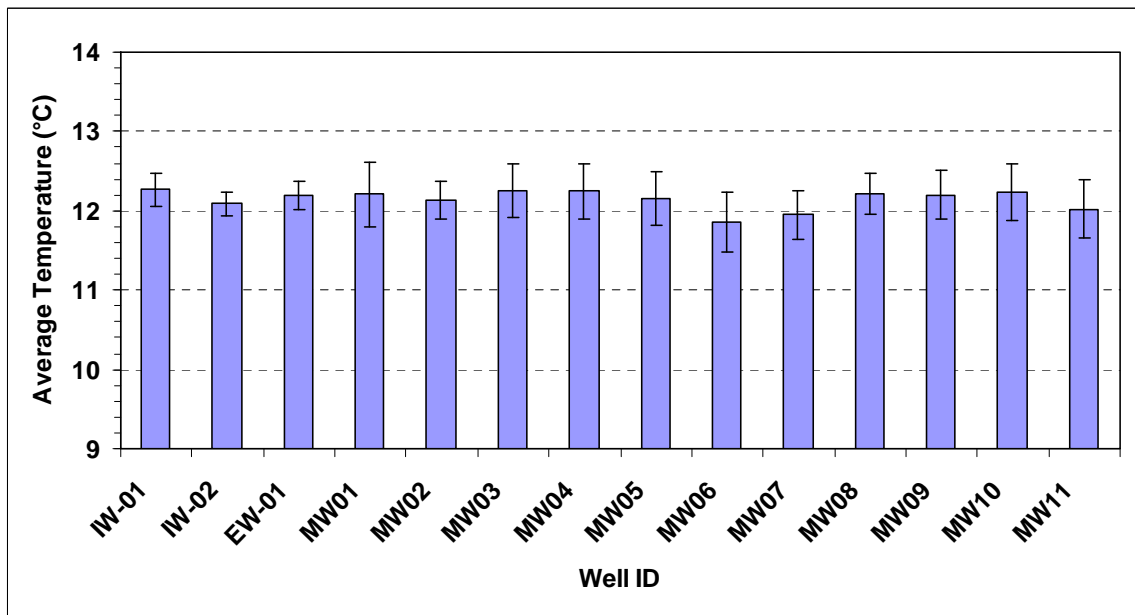


Figure 29. Average temperatures over the period of the demonstration.

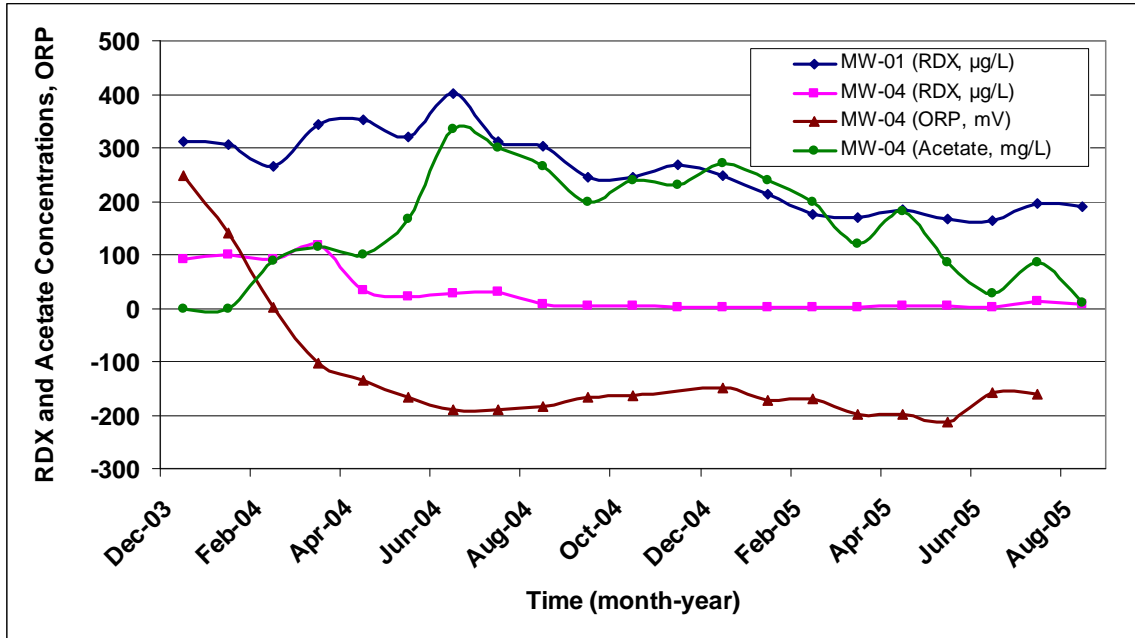


Figure 30. Comparison of RDX and acetate concentrations and ORP levels. Well MW-01 was the upgradient well and Well MW-04 was within the treatment zone.

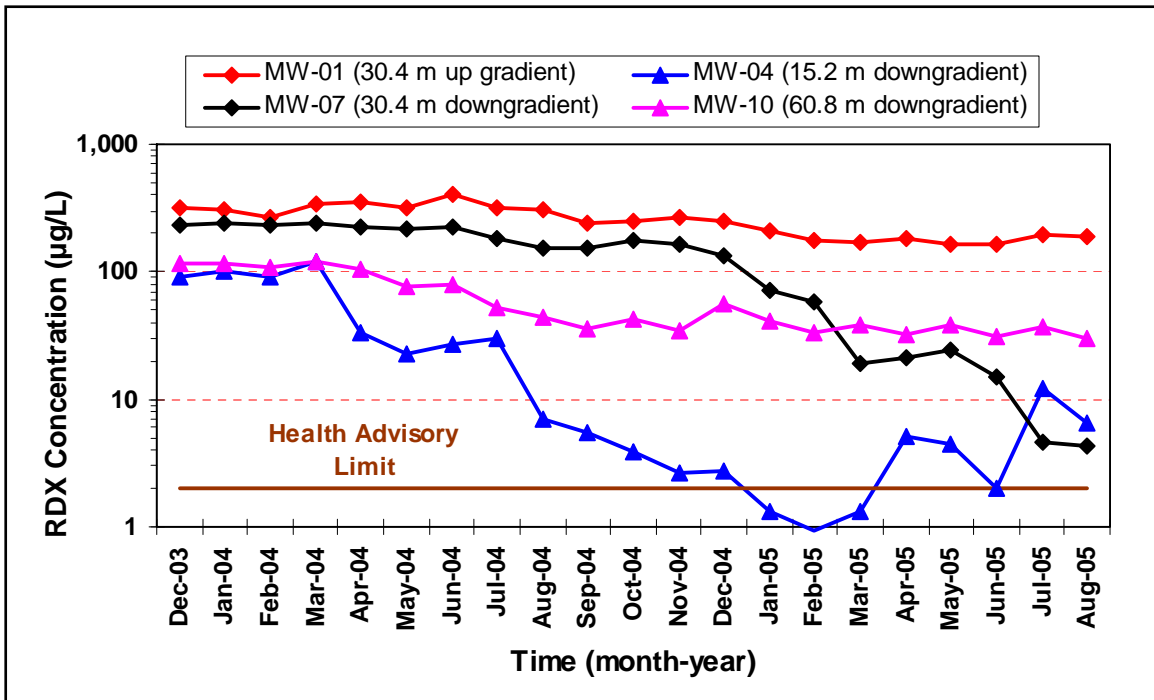


Figure 31. Comparison of RDX concentrations with the upgradient well and most easterly downgradient wells within the treatment zone.

## 5. Cost Assessment

### 5.1 Cost Reporting

The cost report for the BAZE at the NOP site was prepared based on guidelines provided by the Federal Remediation Technologies Roundtables (FRTR) *Guide to Documenting and Managing Cost and Performance Information for Remediation Projects* (FRTR, 1998). This cost reporting format distinguishes between capital, O&M, and other technology specific costs (amounted treated and/or destroyed).

The actual cost of demonstrating BAZE at the NOP site was \$683,000 (Table 5-1). The majority of the cost was contributed to validation and analytical analyses, wells installation, and labor. Some costs often associated with demonstration plans, such as building structures, closing installed wells, or offsite disposal costs, were not necessary for this evaluation. A detailed cost assessment is presented in the Cost and Performance report.

**Table 5-1. BAZE Cost Tracking.**

COST CATEGORY	SUB CATEGORY	COSTS(\$)
<b>FIXED COSTS</b>		
1. CAPITAL COSTS	Mobilization/demobilization	2,500
	Planning/preparation	58,500
	Site work	68,000
	Equipment cost	
	- Structures	0
	- Process equipment	20,052
	Start-up and testing	63,675
Other	- Engineering and local support	25,000
	- Management support	10,000
	<b>Sub-Total (\$)</b>	<b>\$247,727</b>
<b>VARIABLE COSTS</b>		
2. O&M	Labor	82,650
	Materials and consumables	10,772
	Utilities and fuel	225
	Equipment cost	1,500
	Performance testing/analysis	339,750
<b>Sub-Total (\$)</b>		<b>\$434,897</b>
<b>TOTAL DEMONSTRATION COST (\$)</b>		<b>\$682,624</b>

Based on the demonstration cost and site conditions as outlined in Tables 5-1 and 5-1.1, the demonstration cost was \$19/m<sup>3</sup> for contaminated groundwater treated or \$74/g of RDX destroyed. For simplicity, the average background RDX concentration from MW-01 (256 µg/L) was used as the basis for estimating the mass of RDX treated. The amount of acetate per RDX treated was 161 g acetate/g RDX.



**Table 5-1.1: BAZE Site Conditions.**

Parameter	Value
Porosity of aquifer	0.30
Groundwater flow	1.85 LF/day (56 cm/d)
Number of injection wells	2
Average RDX background concentration (MW-01)	256 µg/L
Treatment flow rate	0.5 gpm (1.9 Lpm)
Radius of recirculation per injection well	15 LF (4.6 m)
Recirculation zone subsurface depth	20 LF (6.1 m)
Recirculation zone subsurface width	60 LF (18.3 m)
Project duration	576 days
Volume of groundwater treated	9,565 kgal (36,203 kL or 36,203 m <sup>3</sup> )
Shape of area each side of extraction well (assumption)	Oval
Shape of area at injection wells (assumption)	Circle
Percent of runway deicer as sodium acetate	97%
Fraction of sodium acetate as acetate by weight	0.72
Solubility of runway deicer	95%
Mass of runway deicer	4,955 lb (2,250 kg)
Mass of runway deicer injected (expressed as acetate)	3,289 lb (1,493 kg)
Acetate feed concentration	130,000 mg/L
Acetate feed volume/injection	200 gallon (756 L)
Acetate concentration after recirculation	400 mg/L
Percent of insoluble runway deicer	5%
Extraction well pump capacity	25 gpm (94.6 Lpm)
Injection rate per well	12.5 gpm (47.3 Lpm)
Injection/recirculation duration time	12 hrs
Quantity Treated [gal, (m <sup>3</sup> )]	9,565,826 (36,203)
Unit Cost [\$/kgal (\$/m <sup>3</sup> ) of water treated]	71 (19)
Unit Cost (\$/gram of RDX destroyed)	74

## 5.2 Cost Analysis

The primary cost drivers were site investigation, well placement (capital costs), labor, and sampling and analysis (O&M) costs. The site investigation cost was more than expected due to the lack of adequate RDX plume location. Previous site investigation showed a well defined RDX plume and location. Multiple borings were required to location a RDX plume and adequate RDX concentration for this demonstration. The site investigation cost should be miniature for a well-defined site. The installation of 3 monitoring well clusters, background, and off-site wells was required for validation; however, well clusters are not required for a full-scale BAZE system. Labor cost was significant because of multiple partners (see Section 8) and their travel, mainly ERDC and University of Nebraska personnel. The University of Nebraska professor, graduate students, and/or contractors and ERDC traveled monthly to NOP for sampling and injection. The major costs were chemical analyses for validation of the BAZE system. However, this cost should reduce significantly.

Operating BAZE to meet a lower RDX concentration should not increase the cost significantly, because the field demonstration used 161 g acetate per g of RDX destroyed per 30 days. From our observation, if optimized, the injection rate could be reduced to 120 g acetate per g of RDX destroyed per 45 days (Figure 19). If implemented, a full scale BAZE system cost is expected to be much lower.

- *Real World Cost.* The real world cost of implementing the BAZE system will assist in determining the transition from demonstration scale to full-scale. The BAZE demonstration system is a full-scale system with the exception of requiring constant power and a potable water source, and acetate feed tanks with in-tank mixers. The same basic design and control mechanism can be used to build a larger or multiple systems including an air conditioned building. An example of a site conditions is given below. For the real world cost assessment, the assumptions are as follows:
  - o Site Location – NOP – RDX plume located near the north end of quadrant 14.
  - o RDX plume surface area – 80,000 ft<sup>2</sup>
  - o Plume width – 45 LF
  - o Plume depth – 20 LF
  - o Groundwater velocity – 1.85 LF/day
  - o Injection time – once monthly
  - o Acetate injection rate – 0.5 gpm
  - o Extraction rate – 25 gpm
  - o Injection rate – 12 gpm
  - o RDX concentration – 100 µg/L
  - o Treatment rate – 161 g of acetate/g of RDX destroyed

**Table 5-2: Real World Cost Assumptions and Estimations.**

Category	Sub-Category	Cost
<b>Capital Cost</b>		
Planning/preparation:		93,500
Engineering design and modeling	58,500	
Regulatory interaction	5,000	
Written plans (work, health and safety, sampling plans)	30,000	
Site Work (wells installation, survey, and hydrogeology, )		34,000
Equipment Cost:		65,000
Temporary heat/cool structure (20'x30') and utilities	45,000	
Process Equipment	20,000	
<b>Total Capital Cost</b>		<b>\$192,500</b>
<b>O&amp;M Cost</b>		
Labor:		\$3,100
Maintenance of technology and equipment	3,100	
Sampling, Injection, and Analysis		\$161,300
Sampling/analysis of 3 monitoring wells over 3 year period	61,150	
Monthly injection/analysis	100,150	
Material and consumables	13,150	\$13,150

Utilities		4,650
Electricity: (primarily for pumps)	3,100	
Water	1,550	
Total Annual O&M Cost		<b>182,200</b>
<b>Total Annual O&amp;M Cost, Present Value</b>		<b>174,820</b>
<b>Total Real World Cost, Present Value</b>		<b>367,320</b>

Note:

- 1) Cost based on installation of two injections and one extraction well.
- 2) Costs based on assumption of monthly sampling/analysis of 3 monitoring wells for Year 1 and quarterly for Year 2-3 and cost \$1,000 per well per sampling and analysis event including inflation.
- 3) Inflation rate assumed 3% annual, discount rate assumed 5%.
- 4) Remediation period for BAZE is estimated to be 3 years.

Under the above conditions, Table 5-2 summarizes the anticipated capital and O&M costs. The estimated capital cost is \$192,500, which includes a HVAC building. The estimated present value of the O&M costs is \$174,820 over 3 year period. The total present value of a real world cost is \$367,320 or \$27/kgal.

*Cost Comparison.* The most commonly used technology for remediating RDX in groundwater is pump-and-treat with GAC adsorption (ex situ). Based on an ESTCP cost and performance report, conventional GAC unit cost for treating explosives is \$100/kgal (\$26.4/m<sup>3</sup>) (ESTCP, 2003). The annual cost is \$106,800 with a 30 year life-cycle. The present value of GAC is estimated at \$1,641,730. The BAZE life-cycle depends on the size of the plume and the number of BAZE systems imploded. However, for the above real world example, the BAZE life-cycle is 3 years. The total present value of BAZE is \$367,320.

*Cost Basis.* The basis for comparison was cost per 1,000 gallon (kgal) or m<sup>3</sup> of contaminated groundwater treated and mass of RDX destroyed. Although it is easy to calculate the number of gallons treated in a pump-and-treat system, the volumetric treatment rate for BAZE and other in situ methods must be estimated.

Over the period of demonstration, the average background RDX concentration was 256 µg/L, which was reduced to below the U.S. USEPA's health advisory level of 2 µg/L in the most effective monitoring well (MW-04) for some of the test duration. The estimated volume of groundwater treated in this demonstration was 9,565 kgal (36,203 m<sup>3</sup>). This estimate was based on the treatment zone of influence [20-LF (6.1 m) deep and 60-LF (18.3 m) wide], a project duration of 576 days, and the groundwater flow [1.85-LF/d (0.56 m/d)]. Using the average background and final RDX concentrations and the volume of groundwater treated, approximately 20 lbs (9.07 kg) was degraded over the period of demonstration. With the total demonstration cost of \$683,000, the unit cost for demonstrating the BAZE system was \$71/kgal (\$18.87/m<sup>3</sup>) contaminated groundwater treated or \$74/g of RDX destroyed.

A total of 2250 kg runway deicer (97% sodium acetate) was used for 15 rounds of injection throughout the BAZE demonstration. With approximately 95% solubility of runway deicer (consisting of 72% acetate), 1,493 kg acetate was injected into the groundwater over the period of demonstration. This mass of acetate divided by the mass of RDX destroyed, translates to a stoichiometric consumption of approximately 161 g acetate/g RDX.

*Cost Drivers.* The primary cost drivers for the demonstration were site investigation, site construction, principally well placement (capital costs), and sampling and analysis (O&M) costs. The primary cost drivers for a real world remediation is the cost of sodium acetate, labor, and chemical analysis.

*Life Cycle Costs.* The major capital cost for the BAZE system was the installation of injection, extraction, and monitoring wells. Minimal equipment costs included the purchase of pumps and real-time instruments for recording physical parameters. As such, no significant depreciation costs over the project life cycle are required. Additional costs for the treatment system will include O&M, since experience with in situ biotreatment indicates that some costs will increase from monitoring and prevention of biofouling.

## **6. Implementation Issues**

### **6.1 Environmental Checklist**

The BAZE system did not involve the use of any toxic or hazardous chemicals or foreign microorganisms. The only chemical amendment was sodium acetate which is not regulated for addition to groundwater. Construction of monitoring and injection wells was performed by a direct push system that did not excavate any soil from the site. However, the installation of these wells required a permit from the State of Nebraska. There was no atmospheric emission from the BAZE system from well construction to final demobilization. In this context, no regulatory permits were required for executing this demonstration project on the NOP site.

### **6.2 Other Regulatory Issues**

The BAZE process itself does not present any regulatory issues. It exploits the natural microorganisms present in the groundwater and aquifer material and the amendments do not produce any known toxic or hazardous byproducts. Potential regulatory concerns could arise if this treatment system is transitioned to the site following demonstration. The primary concern is the requirement for an Underground Injection Control (UIC) permit. Interstate Technology and Regulatory Council reviewed state policies on enhanced anaerobic bioremediation. They reported that UIC permits for injection of food-grade or common commercial substrates are generally waived or implemented with minimal paperwork (Parsons, 2004). A permit was not required for this evaluation because of the research nature of the project.

### **6.3 End-User Issues**

After the completion of the BAZE demonstration, the technology will be transferred to regulatory agencies such as the USEPA, Army Environmental Center, and other agencies for information dissemination and future application of BAZE process on full-scale levels. The primary end-users for this innovative in situ technology will be the formerly and/or currently used federal ordnance sites with explosives contaminated groundwater plumes. Currently there are 583 sites with confirmed explosives-contaminated groundwater at 82 installations nationwide. At 22 other installations, 88 additional sites are suspected of groundwater contamination with explosives and organics (DENIX 2003).

The BAZE process is the extension of natural biodegradation and has limited issues for the end-user. Unlike pump-and-treat with GAC adsorption, the BAZE process does not produce any hazardous byproducts that need further disposal.

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## 8. Points of Contact

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Roy Wade	Engineering Research Development Center-WES-EL Attn: CEERD-EP-E 3909 Halls Ferry Rd Vicksburg, MS 39180	601-634-4019 601-634-3518 wader@wes.army.mil	Co-PI
Betty Floyd	Engineering Research Development Center-WES-EL Attn: CEERD-EV-A 3909 Halls Ferry Rd Vicksburg, MS 39180	601-634-2448 601-634-4838 floyd@wes.army.mil	Financial POC
Vicki Murt	CENWK-EC-EC 601 East 12th Street, Room 610 Kansas City, MO 64106	816-983-3889 816-983-5550 Vicki.L.Murt@ nwk02.usace.army.mil	Site Manager
Daniel Duncan	University of Nebraska- Agricultural Research and Development Center 1071 County Road G Ithaca, NE 68033-2234	402-624-8011 402-624-8010 dduncan1@unl.edu	Site Contact
Matthew Morley	Dept. of Civil Engineering University of Nebraska-Lincoln W348 Nebraska Hall Lincoln, NE 68588-0531	402-472-2057 402-472-8934 mmorley2@unl.edu	Site Support
Jeff Breckenridge	USACE Center of Expertise 12565 West Center Rd Omaha, NE 68144	402-697-2577 402-697-2639 Jeff.L.Breckinridge@ nwd02.usace.army.mil	Expert

## **APPENDICES**

## **Appendix A**

### **Analytical Methods Supporting the Sampling Plan**

Explosives (RDX and its transformation products)	: SW846-8330
Inorganic Anions (acetate, nitrate, nitrite, and sulfate)	: EPA Method 300.0
Total Organic Carbon	: SW846-9060
Microbial Community – Phospholipid Fatty Acid Analysis	: White et al. 1996
Toxicological Profile – Micro/MutaTox	: Azur Environmental

## **Appendix B : Quality Assurance Project Plan (QAPP)**

### ***B.1 Purpose and Scope of the Plan***

The purpose of this QAPP is to clearly delineate BAZE QA policy, management structure, and procedures, which will be used to implement the QA requirements necessary to document the reliability and validity of environmental data. The QAPP is reviewed to help ensure that data generated for the purposes described above are scientifically valid. This process will ensure that data collected under this QAPP has been collected and managed in a way that guarantees its reliability and therefore can be used in assessment of the BAZE process.

### ***B.2 Quality Assurance Responsibilities***

Organization and responsibilities for implementing safe hazardous waste site investigation procedures, and specifically for the requirements of this “Quality Assurance Project Plan” are described below.

ERDC personnel relevant to this QAPP are:

Project Manager (PM)	Ed Louis	816-983-3563
Remedial Investigations (RI)	Vicki Murt	816-983-3889
Quality Assurance Officer (QAO)	Richard Karn	601-634-3863
Health and Safety Officer (HSO)	Roy Wade	601-634-4019
Site Safety Officer (SSO)	Roy Wade	601-634-4019
Principal Investigator (PI)	Jeffrey Davis	601-634-2125
Co-PI	Roy Wade	601-634-4019

### **PROJECT MANAGER**

The responsibilities of the Project Manager are:

- To see that the project is performed in a manner consistent with ERDC procedures,
- To have an approved QAAP and HASP prepared and properly implemented for this project,
- To provide the QAAP and HASP with project information relevant to quality assurance, and health and safety matters,
- To implement the QAAP and HASP,
- To ensure compliance with the QAAP and HASP by all field personnel,
- To coordinate with the Quality Assurance Officer on QA/QC, and
- To coordinate with the Health and Safety Officer on health and safety matters.

The Project Manager has the authority to take the following actions:

- To determine matters relating to schedule, cost, QA/QC, and personnel assignments on hazardous waste management projects,
- To appropriately delegate day-to-day authority and responsibilities to the Site Manager,
- To temporarily suspend field activities, if health and safety of personnel are endangered, pending further consideration by the Health and Safety Officer or a Corporate Health and Safety Officer, and
- To temporarily suspend an individual from activities for infractions of the plan, pending further consideration by the Health and Safety Officer.

### **HEALTH AND SAFETY OFFICER (HSO)**

The HSO has the following responsibilities:

- To interface with the Project/Site Managers as may be required in matters of health and safety,
- To develop a HASP for the project and to submit it to the ERDC Health and Safety Administrator for approval,
- To appoint or approve a SSO to assist in implementing the HASP,
- To monitor compliance with the approved HASP,
- To assist the Project/Site Manager in seeing that proper health and safety equipment is available for the project, and
- To approve personnel for -work on this Site with regard to medical examinations and health and safety training.

The HSO has the authority to take the following actions:

- To suspend work or otherwise limit exposures to personnel, if the HASP appears to be unsuitable or inadequate,
- To direct personnel to change work practices, if they are deemed to be hazardous to health and safety of personnel, and
- To remove personnel from the project if their actions or conditions endanger their health and safety or the health and safety of co-workers.

### **QUALITY ASSURANCE OFFICER (QAO)**

An ERDC employee will serve as QAO for the duration of the field activities. The QAO has the following responsibilities:

- To implement quality assurance plan on-site as primary work function,
- To direct quality assurance plan in data generation, analysis and interpretation,

- To assist the Project/Site Manager in all aspects of implementing the QAPP,
- To maintain documentation of quality assurance measures taken at the site,
- To distribution of QAPP and Compliance Agreements,

The SSO has the authority to take the following actions:

- To temporarily suspend field activities, if the activities are not inline with the QAPP,

### **SITE SAFETY OFFICER (SSO)**

An ERDC employee will serve as SSO for the duration of the field activities. The SSO has the following responsibilities:

- To direct health and safety activities on-site as primary work function,
- To report safety-related incidents or accidents to the Project Manager and HSO,
- To assist the Project/Site Manager in all aspects of implementing the HASP,
- To maintain health and safety equipment on-site as specified in the plan,
- To perform health and safety activities on-site as specified in the HASP, and report results to the Project/Site Manager and the HSO,
- To maintain documentation of health and safety measures taken at the site including:
  - Distribution of HASP and Compliance Agreements,
  - Levels of personal protection,
  - Environmental monitoring results, and
  - Incident reporting.

The SSO has the authority to take the following actions:

- To temporarily suspend field activities, if the health and safety of personnel are endangered, pending further consideration by the HSO, and
- To temporarily suspend an individual from field activities for infractions of the HASP, pending further consideration by the HSO.

### ***B.3 Data Quality Parameters***

To ensure the representativeness of the samples collected from each monitoring and injection well, each well will be purged prior to sampling. Samples will be collected after purging three well volumes from each well to remove the stagnant water and to collect the real-time representative samples. This sampling protocol will be used throughout the study. Samples will be collected over a period of 18 to 24 months for the completeness of the performance data with sufficient reliability. Samples will be collected monthly, which will provide 18 data points for evaluation and interpretation of the demonstration performance. 10% of the total field samples

will be used for QA/QC for data completeness and accuracy. The results from the monitoring well samples will be compared to assess the effective zone of BAZE process. Finally these monitoring well results will be compared with the control monitoring well results for estimating the BAZE performance process.

#### ***B.4 Calibration Procedures, Quality Control Checks, and Corrective Action***

The instruments used for chemical, microbiological and toxicological analysis will be calibrated daily from standards prepared from stock solutions. Check standards will be run after every 10 samples to validate the repeatability of the instrument. Some of the samples will be randomly selected for duplicate analysis to evaluate the analysis variation, if any.

Similarly the on-site real-time instruments like ORP electrodes, pH meters, DO meters, and electronic depth meters will be calibrated prior to sampling at each sampling interval for instrument reliability and repeatability.

Data collected from the field demonstration will be analyzed and interpreted in terms of performance of BAZE process in removing RDX from groundwater, e.g., RDX removal efficiency represented over the well field. This will also help in evaluating the zone of influence of BAZE process. Data reduction and reporting will also include the estimation of capital and operating costs from this field demonstration.

#### ***B.5 Demonstration Procedures***

Technology demonstration will start with the emplacement of injection and monitoring wells, and the construction of injection system. After determining the local groundwater flow a system of wells will be constructed. The well field will consist of three injection/ recirculation and thirteen monitoring wells. Wells will be drilled to 80 feet and screened over a thirty-foot interval (50-80 ft bgs). All wells will be developed to ensure no foreign material is introduced into the aquifer and to ensure flow into or from the wells is unobstructed. Following development of the wells samples will be taken to obtain the initial concentration of RDX and other geochemical data in the demonstration area. Injection will not commence until one month has elapsed since well installation. An injection/recirculation system will draw aquifer water from the center and feed it back to the aquifer through the outer wells. A flow through cell will be placed inline to examine the electrochemical properties (Eh and pH) of the injected/recirculated fluids real-time. BAZE process is a no or low maintenance alternative to pump and treat system. However, well maintenance will be carefully monitored so that no foreign material gets into the wells that might obstruct the flow.

#### ***B.6 Calculation of Data Quality Indicators***

The principal indicators of data quality for the purpose of this QAPP will be precision, bias, accuracy, representativeness, comparability, completeness, and sensitivity.

Precision, a measure of agreement among repeated measurements of a particular parameter under identical or substantially similar conditions will be presented as 'standard deviation'. Some



samples will be randomly selected for duplicate analysis on a same analytical instrument using the same measurement method. Data bias (systematic or persistent distortion of a measurement process) and accuracy (a measure of the overall agreement of a measurement to a know value including random error –precision, and systematic error-bias) will be performed by using a reference material of know concentration like check standards or spiked samples. The results will be expressed as percent recovery or percent bias.

Data representativeness, comparability, and completeness are described above in Section E.3. Analytical instrument and measurement method sensitivities are addressed in Appendix D.

### ***B.7 Data Format***

The logs of the direct real-time readings like Eh, pH, DO, and water depth for each individual well on each sampling interval will be kept in the field log book. The amount of acetate added into the injection well on each sampling interval will also be noted in the field log book. Any maintenance issues or unanticipated responses encountered in the field will be clearly marked in the field log book.

Logs of the samples collected from each well will be kept in the field log book. Samples logs will include the name, number, and date of collection of the sample as shown in Sample Label. Log of analytical results from each sample will be kept in the offsite log book at ERDC, Vicksburg, MS.

### ***B.8 Data Storage and Archiving Procedures***

Demonstration results data will be stored in both paper files as well as electronic files. In case of electronic files spreadsheets will be used for data reduction and presentation. Database files will be used for initial storage and archiving of the field and analytical data. All the data regarding operational parameters recorded real-time as well as the analytical data will be stored offsite at ERDC Vicksburg. Copies of direct real-time data recorded onsite will also be kept in the field log book.

## **Appendix C : Health and Safety Plan (HASP)**

**Health and Safety Plan**  
**for**  
**Former Nebraska Ordnance Plant**

Submitted to:

**Department of the Army**  
**Kansas City District, Corps of Engineers**  
**700 Federal Building**  
**Kansas City, Missouri 64106**

June 16, 2003

## NOTICE

In the event of future revisions to the Health and Safety Plan (HASP), a log sheet describing the revisions to the plan will be issued to persons receiving the plan. The log sheet should be inserted into the plan at this location in the document.

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## ADMINISTRATIVE INFORMATION

Project Name:	Biologically Active Zone Enhancement (BAZE) for In Situ RDX Degradation in Groundwater
Project Number:	ESTCP #0110
Site Location:	Saunders County, Nebraska
Project Manager (PM):	Ed Louis
Investigations Leader:	Vicki Murt
Site Safety Officer (SSO):	Roy wade
Health and Safety Officer (HSO):	Roy Wade
ERDC-Lead Principal Investigator (PI)	Jeffrey Davis
ERDC-Co-PI	Roy Wade
Effective Dates:	March 2003 through December 2004 (subject to time extensions by review and amendments)

# **INTRODUCTION AND SITE INFORMATION**

## **INTRODUCTION**

This Health and Safety Plan (HASP) describes health and safety requirements for fieldwork and research efforts at the former Nebraska Ordnance Plant (NOP) site. This HASP is consistent with requirements of the Occupational Safety and Health Administration (OSHA) Hazardous Waste Site Regulations; 29 CFR 1910.120 and 29 CFR 1926.65; and the U.S. Army Corps of Engineers Safety and Health Requirement Manual (EM385-1-1). This HASP is applicable to all personnel who enter work areas described in this HASP and who are under the supervision of US Army Engineer Research and Development Center-Waterways Experiment Station (ERDC-WES) or WES contractors. The HASP describes the procedures to be followed and the protective equipment to be used by WES employees and its subcontractors working at the site.

The primary objective of the HASP is to establish, before field activities begin, work safety requirements and protection procedures to minimize the potential for exposure of field personnel to physical and chemical hazards at the site. All personnel will be required to abide by its provisions. The health and safety requirements presented in this HASP are based on information available at this time and are subject to revision upon subsequent discoveries regarding potential hazards at the site.

The compliance agreement presented in Attachment 1 must be signed by all personnel directly involved in field activities prior to commencement of work on the Site.

All on-site fieldwork performed in exclusion zones and decontamination stations will be performed in accordance with OSHA regulations. This HASP shall not be used for work other than that described in Section 4 nor shall it be modified or used after the expiration date without written approval of the ERDC-PI and ERDC Safety Officer.

ERDC contractors/subcontractors may use their own HASP if such a provision is contained in a written agreement with the contractors. HASP requirements in plans prepared by ERDC contractors must be as stringent as those contained in this HASP.

## **SITE INFORMATION**

The former NOP is located about one-half mile south of Mead, NE, which is 30 miles west of Omaha and 35 miles northeast of Lincoln, NE. NOP covers 17,258 acres in Saunders County. Currently, the land is owned by the University of Nebraska, Agricultural Research and Development Center (ARDC), U.S. Army National Guard and Reserves, U.S. Department of Commerce, and private interests. The NOP was a load, assemble, and pack facility, which produced bombs, boosters and shells. Most of the raw materials used to manufacture the weapons at the former NOP were fabricated at other locations and shipped to the former NOP for assembly. However, ammonium nitrate was produced on site for the first months of operation in 1943. The plant was operated intermittently for about 20 years until 1962. During World War II the production facilities were operated by Nebraska Defense Corporation. Production was terminated for the interim period 1945 through 1949. In 1950 the former NOP was reactivated in order to produce an assortment of weapons for use in the Korean conflict. NOP was placed on standby status in 1956 and declared excess to Army needs in 1959.

Bedrock beneath the northeastern portion of site (in Todd Valley) consists of Cretaceous shales and sandstones of the Omandi Formation. The Omandi Formation is underlain by Pennsylvanian shales and limestones. The Omandi Formation has been divided into an upper shale and lower sandstone lithofacies at the site. The sandstone lithofacies of the Omandi Formation are fine to medium grained with some gravel at the base. The sandstone varies in thickness from 20 to 105 feet below ground surface (bgs). The shale lithofacies is clayey nonclacareous shale with some interbedded thin silt and sand. The maximum thickness of the shale is about 52 feet. The southeast portion of the site (in Platte River Valley) consists of a sand and sandy gravel layer of 39-49 feet thickness. Overbank silts and clays, 10-17 feet thick, overlie the Platte River alluvial sand. The transmissivity of the Platte River alluvial aquifer, estimated through slug testing, is  $1.5 \times 10^4$  gallons per day per foot. The hydraulic conductivity of Todd Valley fine sand unit is estimated at  $0.034 \text{ ft min}^{-1}$ , and the Todd Valley sand and gravel unit is  $0.08 \text{ ft min}^{-1}$ . The hydraulic conductivity of Omandi sandstone aquifer is estimated at  $0.044 \text{ ft min}^{-1}$  (URSGWC, 2000).

The results of a 1991-92 evaluation study by USACE indicated that explosive contamination is mostly limited to soils in and under drainage ditches and sumps in the load lines and the Bomb Booster area. It is believed that this contamination originated from the discharge of water used to wash away explosive dust and residue which resulted from the ordnance load, assemblies, and packs process. RDX, TNT, and 1,3,5-trinitrobenzene (TNB) were the soil explosive contaminants most often detected. RDX, TNT and TCE were identified in the groundwater samples.



## **FIELD ACTIVITIES**

The anticipated field activities of future investigations at the former NOP are described briefly in the following sections. These activities are expected to include site management, non-intrusive, and intrusive activities. It is noted that not all activities described in this section will be conducted at each sub-site or during each phase of fieldwork. Detailed descriptions of fieldwork to be conducted at each sub-site or during a phase of work will be summarized in future sampling plans as the investigations are scheduled.

### **SITE MANAGEMENT**

This activity covers general management of activities and personnel during field events and includes general activities at the field office such as receipt of deliveries, shipment of samples, radio and telephone communications, documentation of field activities, maintaining field supplies, etc. Transport of project personnel and visitors to various site locations is also included in this activity.

### **SITE RECONNAISSANCE**

A site reconnaissance of individual sub-sites of the former NOP may be conducted during the planning of fieldwork and/or at the commencement of field activities. This activity may include walk-through, to familiarize the field team with site conditions, building surveys, utility clearance for intrusive work, and air quality surveys. An area reconnaissance and air quality survey will be conducted in landfill areas prior to initiating other field activities.

### **SURVEYING**

Surveying is a non-intrusive activity that will occur throughout the field activities for investigation and remedial design. Monitoring wells, sampling locations, and important site features will be surveyed for vertical and horizontal control to provide accurate location data and produce multipurpose maps.

### **GEOPHYSICAL SURVEYS**

Surface geophysical surveys will be conducted at selected locations on the former NOP prior to initiating intrusive activities. The purpose of the geophysical surveys will be to identify subsurface anomalies, such as buried debris, munitions, or drums in order to avoid drilling through them.

### **GEOTECHNICAL TESTING**

Selected samples from subsurface soil and monitoring well borings may be subjected to physical property testing. Testing may be carried out at the former NOP in a geotechnical laboratory at the field office. All tests would be performed in a vented and hooded area to reduce the potential for dust exposure. Tests involving grain size/hydrometer and Atterberg limits would pose the greatest potential hazard to personnel due to dust and frequency of handling.

## **MONITORING WELL INSTALLATION AND DEVELOPMENT**

Monitoring wells will be installed at various locations on the former NOP to investigate groundwater contamination. The monitoring well borings will be drilled using auger or rotary drilling techniques. At selected well clusters, the deepest monitoring well boring typically will be continuously sampled. At other monitoring well borings, soil samples typically may be collected at 5-foot intervals.

As part of the logging of monitoring well borings, down hole geophysical surveys of individual borings may be conducted to better define the stratigraphy of the site and assist with the interpretation of subsurface materials at individual boring locations.

Following monitoring well installation, each well will be developed to remove any materials introduced into the formation during drilling operations. Development activities will consist of surging, pumping, bailing, or other well development methods.

## **MONITORING WELL MEASUREMENTS AND SAMPLING**

Water level measurements, aquifer testing, and groundwater sampling will be conducted at existing or future monitoring wells. Aquifer testing may include installation of data loggers, and aquifer pump tests. Monitoring well samples typically will be collected using submersible pumps and non-dedicated, stainless steel or Teflon bailers. Each well will be purged prior to sampling. In addition, private water supply wells may be sampled at the well head or from a separate tap.

# HAZARD ASSESSMENT

## INTRODUCTION

Previous field investigations performed at the former NOP indicate the presence of organics, metals, explosives, physical and biological hazards in soil, groundwater, and surface water samples collected from various locations on the property. Although all routes of exposure may present potential risk to field personnel, it is anticipated that dermal contact with contaminated particulates and liquids, and inhalation of contaminated particulates and vapors pose the greatest hazard. Every effort should be made by field personnel to avoid skin contact with contaminated water and soil, and breathing vapors. Ingestion of contaminated particulates is a secondary route of exposure. Personal protective clothing and air monitoring have been specified in this HASP to reduce the risk of potential exposure through these routes. The hazards described below were identified from previous reports and documentation on the former NOP (Donohue, 1991; Law Environmental, 1990; TCT -St. Louis, 1991).

## CHEMICAL HAZARDS

Relevant information for the chemical contaminants of concern is detailed below. Table 2 provides a summary of the contaminants and concentrations detected to date. These data are based on information collected during previous investigations at the former NOP.

**Table 1. Maximum Concentration Detected in Various Media at Former NOP Sites**

Explosives	Soils		Groundwater		Surface Water	
	Conc. (mg/kg)	Location	Conc. (µg/kg)	Location	Conc. (µg/kg)	Location
TNT	175,929	LL2	48.8	-	48.8	----
DNT	118	LL2	----	----	----	----
RDX	23,270	LL2	130	Irrigation	898	LL2
HMX	2,431	LL2	----	----	60	LL2
DNB	1	LL2	----	----	----	----
TNB	338	LL1	742	ARDC	742	LL4
Tetryl	1,159	BBA	----	----	----	----

LL = Load Line; BBA = Bomb Booster Assembly

### *Trinitrotoluene (TNT)*

2,4,6-Trinitrotoluene is a colorless to pale yellow solid that is odorless. Exposure to TNT targets the blood, liver, kidneys, eyes, skin, cardiovascular system, and central nervous system. Exposure is predominantly through dermal contact. Symptoms of exposure include sneezing, cough and sore throat, jaundice, muscular pain, dermatitis, and kidney and liver damage. Acute and chronic exposure to TNT causes a reduction of red blood cell count and hemoglobin content; leukocytosis (change in white blood cell count) may occur. Cataracts may be associated with chronic exposure to TNT. Nose bleeds and hemorrhages caused by capillary fragility can be

attributed to TNT exposure. Systemic effects of TNT exposure take the form of toxic hepatitis leading to yellow atrophy of the liver or hypoplasia of the bone marrow resulting in aplastic anemia.

### ***Dinitrotoluene (DNT)***

2,4- and 2,6-Dinitrotoluene are both orange-yellow solid with a characteristic odor. DNT targets the blood, liver, and cardiovascular system. Exposure routes are primarily -inhalation and dermal contact. Chief symptoms of DNT exposure may include unpleasant metallic taste, weakness, dizziness, headache, loss of appetite, nausea, vomiting, difficulty in sleeping, and pain, numbness, and tingling in the extremities. Other symptoms are jaundice, anemia, anoxia, and cyanosis (a bluish discoloration of the skin). Dinitrotoluene is mutagenic in some testing animals, and NIOSH considers it a potential human carcinogen.

### ***Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)***

RDX, also known as cyclotrimethylene trinitramine, is a white crystalline compound. The primary exposure route is via inhalation of dust. Ingestion of RDX can also occur. RDX targets the central nervous system. Acute symptoms are present within a few hours after exposure and follow a general sequence of: restlessness and hyperirritability, weakness, headache, dizziness, severe nausea and vomiting, epileptic-like seizures which often are repeated, unconsciousness between or after convulsions, muscle twitching and soreness, stupor, delirium, and confusion. Recovery is gradual and is often accompanied by amnesia. Irritation to skin and mucous membranes can also occur as symptoms of RDX exposure. RDX is a potential carcinogen.

### ***Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)***

HMX is a potential carcinogen. It is present as a major component of some forms of munitions (Octol). HMX is a compound unique to the explosive industry and is present as an impurity to RDX. Symptoms from HMX exposure appear to be similar to RDX although less severe. Exposure is through inhalation of dust particles. Skin irritation can occur following dermal contact.

### ***Dinitrobenzene (DNB)***

Dinitrobenzene is a pale yellow solid. Exposure occurs through inhalation, ingestion and dermal contact. Dinitrobenzene targets the central nervous system, blood, liver, eyes, and cardiovascular system. Symptoms of exposure include bad taste, burning mouth, dry throat, thirst, yellowing of hair, eyes, and skin, visual disturbances, and a bluish skin discoloration that occurs because of insufficient oxygen to body tissues.

### ***Trinitrobenzene (TNB)***

Trinitrobenzene is slightly yellowish crystalline solids. Like DNB, exposure occurs through inhalation, ingestion and dermal contact. Exposure to TNB causes rapid heart rate, rapid breathing, abnormally low blood pressure, and respiratory depression. TNB is a possible animal teratogen. TNB exposure may also cause brown discoloration of the vessels of the mucus

membrane that lines the inner surface of eyelid. Other symptoms of TNB exposure include headache, dizziness, and lethargy.

### ***Tetryl***

Tetryl, also known as 2,4,6-trinitrophenylmethylnitramine, is a colorless to yellow solid that is odorless. Target organs of tetryl exposure include the eyes, skin, respiratory system, and central nervous system. Exposure to tetryl can occur via inhalation of dusts, ingestion, and dermal contact. Symptoms of tetryl exposure include dermatitis, itching and redness of the skin, irritability, fatigue, malaise, insomnia, headaches, lassitude, nausea and vomiting, sneezing, coughing, coryza (respiratory disease), nosebleeds, keratitis (an eye inflammation), edema on nasal folds, cheeks and neck, and anemia.

Table 3 provides a summary of the important safety information for the chemical parameters of concern. Material Safety Data Sheets (MSDS) are included in Attachment 2. In the following paragraphs, reference is made to several terms that may not be familiar to all readers. A brief definition of important terms is provided below:

- **Threshold Limit Value (TLV)** -Airborne concentrations of substances and represent “conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without health adverse”. TLVs are guidelines for occupational exposures established by the American Conference of Governmental Industrial Hygienists (ACGIH).
- **Recommended Exposure Limit (REL)** -The 8-hour time weighted average exposure recommended by the National Institute of Occupational Safety and Health (NIOSH).
- **Immediately Dangerous to Life or Health (IDLH)** –The concentration, which “poses an immediate threat to life or produces irreversible, immediate debilitating effects on health” (American National Standards Institute). NIOSH defines IDLH as, “air concentrations, which represent the maximum concentration from which, in the event of respirator failure, one could escape within 30 minutes without a respirator and without experiencing any escape impairing or irreversible health effects.
- **Permissible Exposure Limit (PEL)** -The 8-hour time-weighted average (TWA), short-term exposure limit (STEL) or ceiling concentration above which workers cannot be exposed. Enforceable standards by OSHA. (Note: PEL values reported in Table 2 are based on the 8-hour time-weighted average).

### **PHYSICAL HAZARDS**

Several physical hazards have been identified with the former NOP. In many instances, the physical hazards associated with a project or field activity are the most dangerous. Each of these hazards is discussed in the following paragraphs.

Known underground facilities, structures, and utilities will be located from available record information prior to initiating intrusive work. The locations must be considered as approximate. Be aware and always suspect the existence of underground utilities such as electrical, power, gas, petroleum, telephone, sewer, and water.

**Table 2. Contaminant Health and Safety Information**

<b>Explosives</b>	<b>PEL/TLV mg/m<sup>3</sup></b>	<b>IDLH mg/m<sup>3</sup></b>	<b>IP eV</b>	<b>LEL %</b>	<b>UEL %</b>	<b>Vapor Pressure mmHg</b>
TNT	0.5	NE	11.78	NA	NA	0.5
DNT	1.5	Ca/200	NA	NA	NA	1
RDX	1.5	NA	NA	NA	NA	NA
HMX	NA	NA	NA	NA	NA	NA
DNB	1/0.15 ppm	200	10.43-10.71	NA	NA	NA
TNB	NE	NE	NE	NE	NE	NE
Tetryl	0.1/1.5	NE	NA	NA	NA	Low

Ca = Carcinogen; NA = Not Available; NE = None Established

IP = Ionization Potential; LEL = Lower Explosive Limit; UEL = Upper Explosive Limit

### ***Radioactive Waste***

Low-level radioactive waste has been disposed off in landfill areas at the former NOP. These waste materials are associated with cancer research conducted by the University of Nebraska and are expected to be alpha and beta emitters only. The materials were landfilled with other medical and research wastes in trenches at Load Lines 1 and 2 and in the landfill near the former NOP sewage treatment plant. Intrusive activities are not planned in landfill areas at the Load Lines or sewage treatment plant. However, groundwater monitoring wells will be drilled and installed in the vicinity of the landfill trenches. Contact with low-level radioactive materials is unlikely and since the waste materials are likely alpha and beta emitters, potential exposure by field personnel is minimal.

### ***Slips, Trips and Falls***

Personnel should be aware that the protective equipment worn may limit manual dexterity, hearing, visibility, and may increase the difficulty of performing some tasks. This may result in greater physical hazards, such as slip, trip, and fall incidences, while wearing protective equipment. Personal protective equipment places an additional strain on the wearer when performing work that requires physical activity. Heat exhaustion or heat stroke is possible, especially during warm weather.

### ***Climate-Heat Stress***

- **Heat Exhaustion:** nausea, headache, weakness, dizziness, , pale, cool, moist skin, or extreme perspiration.
- **Heat stroke:** a sudden lack of perspiration; dry, pale to red skin; and strong rapid pulse. This condition requires immediate medical attention.

All field personnel shall be monitored for heat stress when air temperatures become excessive by following the procedures in Attachment 3. Equipment for monitoring heat stress, such as thermometers and scales, will be maintained by the SSO at the field office and other support areas. Note that USACE guidance requires that 8°C be subtracted from ACGIH heat stress TLVs when personnel are wearing Tyvek coveralls, and 10°C subtracted for polyethylene Tyvek

coveralls. These correction factors shall supersede those listed in Attachment 3 for all work performed at the former NOP.

- All personnel should be aware of the physical condition of themselves and their fellow workers. One or more of the following control measures may be implemented:
- **Acclimatization:** Personnel not accustomed to working in hot environments will be eased into a full work schedule over several days.
- **Adequate Liquids:** Provide sufficient cool (not cold) liquids to replace lost body fluids. Employees must replace water and electrolytes lost from sweating. Employees will be encouraged to drink more than the amount required to satisfy thirst since thirst satisfaction is not an accurate indicator of adequate fluid replacement. Replacement fluids can be commercial mixes such as Gatorade or Quick Kick, fruit juices or water.
- **Work/Rest Regimens:** Implementation of a work-rest regimen that will provide adequate break periods for cooling down. This may require additional shifts of workers or suspending work during the hottest parts of the day.
- **Breaks:** All breaks are to be taken in a cool and shaded rest area. Impermeable protective garments are to be removed during rest periods. Employees shall not be assigned other tasks during rest periods.

### *Climate-Cold Stress*

Exposure to cold or wet and cold environments can result in cold stress (hypothermia) or cold injury (frostbite). In the event field activities are conducted during cold weather, ACGIH cold stress TLVs will be followed. Appropriate first-aid treatment for cold stress will be provided until medical care is available.

Special precaution must be taken when operating machinery (i.e., drill rigs) in the vicinity of overhead electrical power lines. Contact with electricity can shock, burn, and result in death. All overhead electrical power lines are to be considered energized and dangerous. Walk completely around the machine and look up before beginning work at a site in the vicinity of power lines. Determine what the minimum distance from any point on the machine to the nearest power line will be when operating. Do not raise a mast or boom, or operate the machine if this distance is less than 20 feet. Standard procedures for drilling safety are included in Attachment 4.

Working around heavy machinery can pose a noise hazard for site personnel. Hearing protection is required for personnel working where a noise-producing source (i.e., drill rig, steam cleaner) forces a person to raise their voice to communicate with someone 3 feet away.

Personnel should be aware of wind directions and attempt to coordinate field activities and gasoline powered equipment so that exhaust fumes and chemical vapors are located downwind from work areas.

### **UNEXPLODED ORDNANCE**

Due to the history of activities at the former NOP, the potential exists for unexploded ordnance (UXO) to be encountered. This is of particular concern during trenching, excavation, and waste

pile sampling activities. If suspected or known UXO is encountered the field crew will immediately stop work and leave the exclusion zone area. The UXO will not be probed, touched, or handled by personnel and subcontractors under any circumstance. Specific emergency response procedures for UXO encounters are included in Section 7.1.5.

**BIOLOGICAL HAZARDS**

Medical wastes were landfilled with other debris in trenches at Load Lines 1 and 2 and the sewage treatment plant. This waste is associated with animal and cancer research conducted by the University of Nebraska. Medical waste materials pose a biological hazard to personnel who come in contact with the material. Intrusive activities planned for each of these areas do not include drilling or sampling through the land filled waste material. Therefore, the likelihood of exposure to the medical waste is minimal. Personnel should be alert to any change in material under investigation. Contact with suspect material is important in minimizing any potential exposure.

Assume that all animals are potentially dangerous. A person who is bitten by an animal may become infected by tetanus or rabies. Warm-blooded animals, such as dogs, cats, rats, and prairie dogs can transmit rabies. Rabies can be transmitted when the saliva from an infected animal contacts an open wound (even a scratch) or any normal body opening such as the mouth or eye.

Poisonous snakes and insects may also pose a hazard to field personnel. Extra precaution will be taken in suspect environments to avoid exposure. Insects (fleas and ticks) may also be carriers of infectious disease. Cases of Lyme disease have been reported in southeast Nebraska. A mild winter is likely to result in a heavy flea and tick season. Personnel sensitive or allergic to insect bites e.g., bees and wasps also should be cautious and alert to their working environment.

**HAZARD EVALUATION**

The hazards associated with fieldwork at the former NOP include dermal contact with contaminated liquids and particulates, inhalation and ingestion of contaminated particulates, vapors, and liquids, working around heavy machinery, and heat and cold stress from conducting physically taxing activities such as drilling and sampling during extreme weather. The overall hazard evaluation for each activity is summarized in Table 4.

**Table 3. Hazard Assessment Summary**

Activity	Hazards		Overall Hazard Rating
	Chemical	Physical	
Site Reconnaissance	Low	Low	Low
Surveying	Low	Low	Low
Geophysical Surveys	Low	Low	Low
Geotechnical Testing	Moderately Low	Low	Low
Field Screening	Medium	Medium	Medium
Monitoring Well Installation	Low	Low	Low
Monitoring Well Sampling	Low	Low	Low
Decontamination	Low	Low	Low



# **GENERAL HEALTH AND SAFETY REQUIREMENTS**

## **TRAINING**

All appropriate personnel and subcontractors will be required to have formal 40-hour HAZWOPER training and 3 days of supervised field experience as specified in the Occupational Safety and Health Administration's "Hazardous Waste Operations and Emergency Response; Final Rule" (29 CFR Part 1910.120, March 6, 1989). This training will include chemical and physical hazards, protective equipment, emergency procedures, decontamination, work zones, and the proper operation and care of environmental monitoring equipment and respirators. On-site supervisors shall have completed an additional 8 hours of specialized training. This training may include, but is not limited to, the following topics:

- Safety management;
- Employer responsibilities under OSHA;
- Protective equipment selection;
- Health and hazard monitoring;
- Health and safety logistics; and
- Liability control.

The Site Safety Officer is required to be certified in basic first-aid. In addition, site-specific health and safety training will be provided for unusual site conditions, work activities, and staff needs. Site-specific training, if required, will be conducted during the safety briefing or when site conditions warrant. The training will be conducted by the SSO, Health and Safety Officer, or designated professional and documented for the project files. Training records of each personnel are kept on file by the HSO. Copies of training records may also be kept on-site.

## **MEDICAL MONITORING**

All personnel conducting work on the Site governed by this HASP will be required to comply with the provisions of the Employee Medical Surveillance Program, EMSP, or an equivalent program fulfilling OSHA requirements [29 CFR 1910.120(t)]. Personnel not completing a baseline physical examination will be required to complete the equivalent of such an examination prior to working on the Site. All personnel who have met the baseline examination requirement must have completed an annual physical within the past 12 months to work in the exclusion zone and contamination reduction area. Medical monitoring records for each personnel are kept by the HSO. Copies of compliance with the medical monitoring program may be kept on-site.

Additional medical monitoring for site-specific hazards is not required at this time. Temporary support personnel are exempt from the medical monitoring requirements. Their duties are limited to office and administrative tasks in support areas only.

## **COMPLIANCE AGREEMENT AND SAFETY MEETINGS**

All field personnel will receive a copy of this HASP and read the plan prior to commencement of fieldwork on the Site governed by this HASP. The Compliance Agreement contained in Attachment 1 will be signed by field personnel after reading the plan and prior to initiating fieldwork on the Site. This agreement will be retained as part of the project files. In addition, a project-specific safety briefing will be conducted by the SSO or his/her designee prior to work on the Site. During the briefing session an overview of the objectives of the project and the HASP will be discussed, including:

- Scheduled field activities and personnel responsibilities
- Standard operating procedures
- Site control procedures
- Contaminants and hazards identification and precautions
- Exposure risk
- Warning symptoms from exposure to contaminants
- Protective equipment usage
- Decontamination facility and procedures
- Monitoring instruments usage
- Prohibitions
- Emergency response.

Briefings will be repeated to new personnel as they arrive at the Site. In addition, on-site safety meetings will be conducted periodically by the SSO on an as-needed basis, to review safety requirements or to discuss modifications to the HASP.

## **DOCUMENTATION**

The SSO will document implementation of this HASP. The SSO will set up a file to maintain health and safety related records and activity reports. This file will contain the following:

- Visitor and site personnel registers
- Signed copies of the Compliance Agreement
- Copies of safety equipment operation manuals
- Records of usage and calibration of environmental monitoring equipment
- Employee injury/exposure incident reports
- Records of safety violations and remedial actions taken.

A separate health and safety field logbook may be maintained on-site and should contain information such as: weather conditions, employees on-site, level of personal protection worn, monitoring instrumentation readings (average, peak, and background), subjects discussed during site health and safety briefings, and safety violations.

Field safety audits will also be conducted during the fieldwork to monitor compliance with the HASP. These audits are often conducted unannounced by the HSO. Violations to the HASP, if any, are discussed with the SSO and Site Manager upon completion of the audit. Recommendations for corrective action are discussed and initiated. A final audit report is completed, with copies sent to the Project Manager.

## **INCIDENT REPORTING**

In the event of an accident or incident, the SSO shall immediately notify the HSO and the Project Manager. The ERDC HSO will be notified by the Project Manager or his/her designee. Injuries, exposures, illnesses, safety infractions, and other incidents must be reported within 24 hours of occurrence. Within 2 working days of any reportable accident or incident, the SSO or HSO shall complete and submit to the USACE Contracting Officer an Accident Report on ENG Form 3394. Further detail on reporting and filing an accident or incident is given in Attachment 5.

## **GENERAL SAFETY PROVISIONS**

The following general provisions will be in effect during all site activities on the Site governed by this HASP:

- There will be no activities conducted on-site without sufficient backup personnel. At a minimum, two persons (“buddy system”) must be present at the site during all site activities.
- No employee may be allowed on-site without the prior knowledge and consent of the SSO.
- No loose jewelry, clothing, or long hair shall be permitted on or near equipment with moving parts.
- Employees shall avoid unnecessary contamination by walking around pools of liquids, discolored areas, or any area that shows obvious evidence of contamination.
- Personnel shall not enter a contaminated area unless it is necessary.
- Field personnel must observe each other for signs of toxic exposures, (changes in skin color, coordination, pupil size, etc.) and inform each other of non-visual effects (headaches, nausea, dizziness, etc.).
- Drilling operations will be suspended during high winds and electrical storms.
- Field activities will be suspended during severe weather such as thunderstorms, tornado warnings, and winter storm warnings.
- Damaged personal protective equipment or clothing will be immediately repaired or replaced, as appropriate.
- Smoking, eating, drinking, or any other activity involving hand-to-mouth contact while in the exclusion and contamination-reduction zones are prohibited.
- Personnel must thoroughly wash their hands and face before eating, smoking, or drinking.
- Facial hair that could interfere with proper respirator fit is not allowed for activities that may require respiratory protection.

- Personnel shall not wear contact lenses while in the exclusion and contamination-reduction zones.
- Unauthorized removal of materials from the Site is prohibited.
- Possession of controlled substances and items while working on-site is prohibited.

### **VISITOR CLEARANCE**

All visitors will require clearance by the SSO and/or HSO. Visitors will only be allowed in support zone areas and roads unless compliance with this HASP is acknowledged in conformance with Sections 5 and 6.3. Clearance to enter the exclusion zone is not required for government agency personnel operating under a separate safety plan. These visitors will be given a safety briefing upon entering the Site.

### **ILLUMINATION**

Most project operations will occur during daylight hours, between sunrise and sunset, as determined locally. Where sufficient illumination is not naturally occurring supplementary lighting will be provided in compliance with OSHA regulations.

### **SANITATION**

The Project Manager will ensure that adequate sanitation facilities are provided for field personnel in compliance with OSHA regulations. The SSO shall ensure that all on-site personnel have ready access to soap and clean water or equivalent for washing before exiting any contaminated areas and proceeding to support facilities. Potable water shall be maintained for drinking purposes, and common drinking cups shall not be used. These facilities shall be maintained in the Support Zone, not in areas known or suspected to be contaminated.

## **SITE-SPECIFIC HEALTH AND SAFETY REQUIREMENTS**

### **SITE ACCESS**

Access to the exclusion zone and decontamination areas will be limited to personnel working on-site, project management, and approved visitors as discussed in Section 5.7. Due to the size of the candidate areas of investigation and the inclusion of private property, the entire former NOP cannot be designated as the exclusion zone. Therefore, exclusion zones and decontamination areas will be established at, or near specific work locations.

### **WORK ZONES**

An exclusion zone boundary will be established approximately 20 feet around all intrusive activities and marked by survey flags, traffic cones, or stakes and hazard tape. The exclusion zone may be expanded at the discretion of the Project Manager, Site Manager, or SSO to protect the health and safety of other personnel and visitors working on the Site.

Decontamination will occur at the edge of the exclusion zone or in a separate contamination reduction area as described in Section 6.4. Personnel entering the exclusion zone and decontamination areas must wear the required protective equipment as described in Section 6.3.

Temporary support facilities will be established outside the exclusion and decontamination zones. These facilities will provide rest areas and supplies (i.e., drinks, first-aid kit, etc.) for personnel working in a specific exclusion zone. Permanent support facilities and offices will be established on the Site. The actual location(s) will be dependent upon current site activities. These facilities will be the staging area for site activities and will include a telephone and radio base station for communication with field crews and emergency response personnel.

## PERSONAL PROTECTIVE LEVELS AND EQUIPMENT

Personal Protective Equipment (PPE) is described below for each type of work activity to be conducted on the former NOP. PPE for each specific activity is summarized in Table 5. Further review is being conducted on PPE for agent compounds.

**Table 4. Personal Protection Equipment and Air Monitoring Summary**

Activity	Levels of Protection		Air Monitoring		Action Levels		Special Precautions
	Standard	Upgrade	HNu/O VA	Detector Tubes	Upgrade ppm	Stop Work* ppm	
Management	D	None	None	None	None	None	
Site Reconnaissance	D	None	None	None	None	None	
Surveying	D	Mod. D	Varies	None	None	None	
Geophysical Surveys	D	Mod. D	None	None	None	None	
Geotechnical Testing	D	Mod. D/C	None	None	Dust	NA	Dust
Field Screening	Mod. D	C	Varies	None	3	500/100 0	
Monitoring Well Installation <sup>1</sup>	D/Mod. D	Mod. D/C	YES	Benzene	3 <sup>2</sup>	500/100 0	Splash, Drilling
Monitoring Well Sampling	Mod. D	C	YES	None	3	500/100 0	Splash
Decontamination <sup>1</sup>	D/Mod. D	Mod. D/C	YES	None	3	500/100 0	Splash

\* Action Level – Full-face/half-face respirator. Action level for Benzene is 50/10 ppm for full-face/half-face respirators.

<sup>1</sup> These intrusive activities can be performed in Level D protection at off-site background locations.

<sup>2</sup> Upgrade from Level D to Modified D will be based on visible contamination, odors, or air monitoring results

### *Non-Intrusive Activities*

Non-intrusive activities include site reconnaissance (utilities survey, building surveys, site walk-throughs), surveying, surfacial geophysical surveys, air quality surveys, and coordination of field activities. These activities will generally be performed in Level D protective equipment as listed below.

### **LEVEL D PROTECTION**

- Coveralls (cotton or Tyvek) or work clothes

- Boots (steel toe, as appropriate) or work shoes
- Safety glasses or goggles (as required by OSHA)
- Hard hat (as required by OSHA).

Some activities, such as private water well sampling, sample container handling, and geotechnical laboratory testing, will be performed in Level D protection with the addition of chemical resistant gloves. The level of protection for performing geotechnical testing may upgrade to Modified Level D or Level C, depending upon the location of sample collection and available data on potential contamination.

### ***Intrusive Activities***

Modified level D protection will be worn as a minimum by site personnel when performing intrusive activities and when present in an exclusion zone and decontamination area. Intrusive activities include subsurface soil sampling; sediment and surface water sampling; monitoring well installation, development, and sampling; soil gas surveys and field screening techniques; and equipment decontamination.

Intrusive activities at off-site, background locations can be performed in Level D protection with the approval of the SSO or HSO. Personnel will upgrade to modified Level D protection when discolored materials or odors are detected and as dictated by air monitoring results.

The personal protective equipment to be used for on-site intrusive activities is as follows.

### ***MODIFIED LEVEL D PROTECTION***

- Tyvek coveralls (Poly-coated Tyvek for splash hazards),
- Chemical-resistant boots (PVC, Neoprene, Rubber) or work boots with covers ( steel-toed as appropriate),
- Inner gloves (latex or vinyl),
- Outer, chemical-resistant gloves (nitrile, PVC, Neoprene),
- Safety glasses or goggles,
- Hard hat (as required by OSHA), and
- Splash shield (optional).

Poly-coated Tyvek and a splash shield will be utilized during activities, which pose a splash or spray hazard to personnel. In particular, monitoring well development, ground-water sampling, and equipment decontamination will require coated Tyvek coveralls.

A splash shield will be worn during equipment decontamination utilizing a high-pressure sprayer. Ankles and wrist will be taped for modified Level D protection.

## **DECONTAMINATION PROCEDURES**

### ***General***

Decontamination of equipment and personnel will be performed to limit the migration of contaminants off-site and between work zones at the Site. Decontamination at the main station will generally be limited to the initial and final-decontamination of drilling and sampling equipment, decontamination of geotechnical laboratory equipment, and decontamination of well construction materials. As a general rule, decontamination of drilling, sampling, and excavation equipment will be accomplished at the edge of individual exclusion zones of the borings, monitoring wells etc. Additional, centrally-located decontamination stations may be established as project activities and needs warrant. Heavy equipment will be decontaminated with a high-pressure steam cleaner.

Equipment and other tools will be cleaned prior to the site entry to remove grease, oil, encrusted dirt, or other materials. The SSO or site manager will inspect all equipment prior to use on-site.

Reusable sampling equipment and any other tools used for intrusive work will be decontaminated between sampling locations. Cleaning will consist of scraping and scrubbing to remove encrusted materials followed by an Alconox soap and water wash, if necessary, and potable water rinse. Following decontamination, clean equipment will be stored on plastic sheeting and air dried, wrapped in plastic, or wrapped in aluminum foil if not immediately reused. At the conclusion of work at the Site, all equipment will be thoroughly cleaned using the methods previously described. The SSO will inspect all equipment leaving the Site for adequacy of decontamination.

### ***Personnel Decontamination Procedures***

Personnel decontamination will be conducted at a decontamination area set up at the edge of each exclusion zone or a central decontamination station. Decontamination will consist primarily of soap and water washing and water rinse of exterior protective gear followed by doffing of the gear.

The general decontamination sequence for activities conducted at modified Level D is as follows:

- Wash outer gloves and boots,
- Rinse outer gloves and boots,
- Remove tape at wrists and boot interface,
- Remove outer gloves and boot covers,
- Remove coveralls,
- Remove and rinse goggles and hard hat, and
- Remove inner gloves.

Decontamination equipment and supplies consist of, but are not limited to, the following:

- Potable water,

- Washtubs,
- Alconox, prepared according to mixing instructions,
- Brushes and hand sprayers,
- Plastic sheeting,
- 5-gallon buckets with lids, and
- Garbage bags.

### ***Equipment Decontamination Procedures***

Large equipment decontamination will be conducted at the exclusion zone or an established decontamination station. The general decontamination for large equipment is usually conducted with a high-pressure sprayer following the sequence below:

- Lay down plastic ground cloth (if appropriate),
- Rinse with potable water to remove soils,
- Wash with potable water and Alconox (or equivalent) solution, and
- Rinse with potable water.

Decontamination of small sampling equipment will be conducted at the exclusion zone or an established decontamination station. The general decontamination sequence is as follows:

- Lay down plastic ground cloth (if appropriate),
- Wash and scrub with potable water,
- Wash and scrub with Alconox and potable water,
- Rinse with potable water,
- Rinse with distilled water, and
- Air dry.

### ***Sample Handling***

The outer surface of all sample containers collected during the site characterization that are to be submitted to a laboratory for analysis will be decontaminated prior to packaging for shipment. Procedures for sample container decontamination will be as follows:

- Place clear plastic tape over label to protect the sample label,
- Rinse or spray the containers with distilled water. Containers with encrusted soil shall be cleaned by scrubbing with soap and water followed by a distilled water rinse,
- Dry sample containers, and
- Prepare for shipment.



In order to protect laboratory personnel from potentially contaminated samples and broken containers, the following precautions will be taken:

- The shipping cooler will be lined with bubble wrap or foam packaging material to protect containers from breakage,
- All samples will be placed in a plastic bag lining the cooler,
- Individual sample containers may be wrapped in foam or bubble wrap to prevent breakage,
- The plastic trash bag will be tied or sealed with packaging tape, and
- The drain hole on the cooler will be taped shut.

# EMERGENCY RESPONSE

## SITE EMERGENCIES

In the event that an emergency situation, such as an injury, illness, or fire arises the appropriate immediate response must be taken by the first person to recognize the situation. The field crew will immediately notify the site management of the incident, and the appropriate emergency organization will be contacted. A list of emergency contacts is provided in Section 7.2. A copy of the emergency telephone numbers, directions, and route map to the nearest hospital will be clearly posted at the work area and in vehicles (Quick Reference Chart - Section 7.2). The route to the hospital will be rehearsed by field personnel.

The Project Manager and HSO will be notified of any accident, injury, or illness. The ERDC Health and Safety Coordinator will be notified by the Project Manager or his/her designee. Documentation of the incident will follow the procedures in Section 5.5. Document the incident in the field logbook as the situation allows.

In the case of injury or illness, the proper emergency first-aid care will be rendered by a trained person. First-aid equipment and emergency eyewash stations will be available at the area of fieldwork. Personnel will be notified as to the locations of first-aid stations during the initial safety briefing session.

If the injury or illness is from exposure to a hazardous substance, rapid identification of that substance should be attempted. This information must be provided to the medical personnel. MSDS are provided in Attachment 2 for the compounds of concern.

Decisions to cease all field activities and evacuate the site will be made by the Site Manager and SSO. Field personnel will report to the field office to sign-out. Local authorities (civil defense, sheriff, fire department) will decide if an emergency requires evacuation of the surrounding community. Responsibility for community evacuations will be with the local authority in charge of the emergency.

The following emergency equipment will be kept at the field office and/or with each field crew:

- First aid kit,
- Emergency eye/body wash or bottles of clean water marked for emergency purposes,
- Radio communication equipment,
- Fire extinguisher,
- Telephone, and
- Drinking water/cups.

### *Personal Injury*

The following procedures will be implemented in the event of a personal injury:

- Administer first-aid and radio the field office (Site Manager and SSO) to arrange for emergency care (ambulance and paramedics), as appropriate.

- When the situation has been stabilized, decontaminate the injured person. Do not perform decontamination if it interferes with emergency treatment, such as in a life-threatening situation.
- Move the person to the support area if there is no risk of further injury.
- Wait for emergency care, document the event in the logbook, and maintain -radio contact with the Site Manager or SSO.
- In the case of a minor injury requiring medical treatment, transport the injured person to the hospital.

### ***Chemical Exposure***

In the event of a chemical exposure, the following procedures shall be followed:

- **Skin Contact:** Flush with water. Remove clothing, flush skin. Obtain medical attention.
- **Inhalation:** Remove the person from the area. Administer first-aid/CPR, as needed. Obtain medical attention.
- **Ingestion:** Contact the Poison Control Center for immediate treatment, and then obtain medical attention. Follow the instructions from the MSDS and/or Poison Control Center if the chemical is known. Inducing vomiting may cause further injury to the victim; do not induce vomiting unless instructed to do so. Treat victim for shock.
- **Eye Contact:** Flush eyes immediately with water for a minimum of 15 minutes. Obtain medical attention.

### ***Fire or Explosion***

In the event of a fire or explosion at the site, the following actions shall be implemented:

- Evacuate all personnel to a safe location upwind or crosswind of the incident. Contact the Site Manager and SSO.
- Use available fire extinguishers to control the fire, if appropriate (based up the nature, size, and intensity of the fire).
- Concurrently with the above, contact the local fire and police/sheriff departments, as appropriate.
- Alert the local hospital of the possibility of fire victims, as appropriate.

Document the incident in the field logbook and follow the procedures for incident reporting in Section 5.5.

### ***Severe Weather***

Personnel should also be aware of the possibility for the occurrence of severe weather such as tornado, thunderstorms, hail, or high winds. Necessary precautions or response, directed by the SSO, will be taken in the event of severe weather. For example, drilling and sampling operations will be suspended when the potential for lightning occurs.

In the event of a tornado, field personnel will seek shelter in a permanent structure. No attempts will be made to outrun a tornado in a vehicle. Personnel caught in the open will lie flat in a ditch or low area and cover their head. Personnel will seek cover (building or vehicle) immediately should hail develop during thunderstorms. Local weather broadcasts will be monitored by the Site Manager, SSO, or designee when the likelihood for severe weather exists.

### ***Unexploded Ordnance***

In the event a known or suspected ordnance is encountered, the following procedures will be implemented:

- Evacuate all personnel to a safe location upwind of the ordnance. Contact the Site Manager and SSO,
- Secure area against trespassers,
- The Site Manager or his/her designee will notify the USACE and appropriate emergency personnel. The field crew will take further instructions from the Site Manager and SSO, and
- The work area will remain evacuated until clearance has been received from the USACE that it is safe to proceed.

## **HOSPITAL INFORMATION AND EMERGENCY CONTACTS**

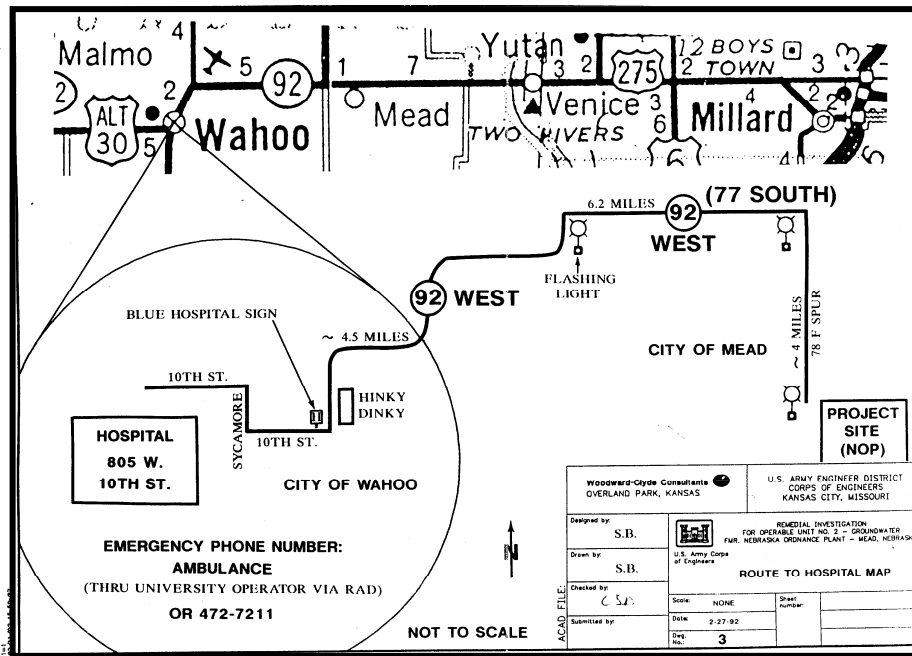
### **Hospital:**

Wahoo Hospital  
805 West 10<sup>th</sup> Street  
Wahoo, Nebraska

### **Route to Hospital from site:**

- Proceed north on 78F? Spur approximately 4 miles to intersection of Highway 92 west.
- Turn left (west) onto Highway 92 and proceed for 6.2 miles to the flashing light.
- Turn left (south) and continue on Highway 92 west approximately 4.5 miles to Wahoo.
- The hospital is on the right at the intersection on Highway 92 and 10th Street in Wahoo.

Distance to Hospital: Approximately 14.7 miles. The route to the hospital is depicted in Figure 1.



Name/Organization	Telephone Number
Ambulance-University of Nebraska operator	402/472-7211
Fire Department -Mead	402/624-2495

Figure 1. Quick Reference Chart

## PROJECT PERSONNEL AND RESPONSIBILITIES

Organization and responsibilities for implementing safe hazardous waste site investigation procedures, and specifically for the requirements contained in this plan, are described below.

The objective of this HASP is to establish and ensure safe implementation of procedures and practices for the Site investigations. Safety responsibilities are incorporated into the site management roles to ensure the protection of all those involved. Additionally, all persons participating in such investigations must be aware of the dangers and assume appropriate responsibility to protect themselves-and others.

USACE personnel relevant to this HASP are:

Project Manager (PM)	Ed Louis	816-983-3563
Remedial Investigations (RI)	Vicki Murt	816-983-3889
Principal Investigator (PI)	Jeffrey Davis	601-634-2125
Co-PI	Roy Wade	601-634-4019

### PROJECT MANAGER

For this project, the Project Manager has the following responsibilities:

- To see that the project is performed in a manner consistent with ERDC procedures,
- To have an approved HASP prepared and properly implemented for this project,
- To provide the HASP with project information related to health and safety matters,
- To implement the HASP,
- To ensure compliance with the HASP by all field personnel, and
- To coordinate with the Health and Safety Officer on health and safety matters.

The Project Manager has the authority to take the following actions:

- To determine matters relating to schedule, cost, and personnel assignments on hazardous waste management projects,
- To appropriately delegate day-to-day authority and responsibilities to -the Site Manager,
- To temporarily suspend field activities, if health and safety of personnel are endangered, pending further consideration by the Health and Safety Officer or a Corporate Health and Safety Officer, and
- To temporarily suspend an individual from activities for infractions of the plan, pending further consideration by the Health and Safety Officer.

### HEALTH AND SAFETY OFFICER (HSO)

The HSO has the following responsibilities:

- To interface with the Project/Site Managers as may be required in matters of health and safety,

- To develop a HASP for the project and to submit it to the ERDC Health and Safety Administrator for approval,
- To appoint or approve a SSO to assist in implementing the HASP,
- To monitor compliance with the approved HASP,
- To assist the Project/Site Manager in seeing that proper health and safety equipment is available for the project, and
- To approve personnel for -work on this Site with regard to medical examinations and health and safety training.

The HSO has the authority to take the following actions:

- To suspend work or otherwise limit exposures to personnel, if the HASP appears to be unsuitable or inadequate,
- To direct personnel to change work practices, if they are deemed to be hazardous to health and safety of personnel, and
- To remove personnel from the project if their actions or conditions endanger their health and safety or the health and safety of co-workers.

#### **SITE SAFETY OFFICER (SSO)**

An ERDC employee will serve as SSO for the duration of the field activities. The SSO has the following responsibilities:

- To direct health and safety activities on-site as primary work function,
- To report safety-related incidents or accidents to the Project Manager and HSO,
- To assist the Project/Site Manager in all aspects of implementing the HASP,
- To maintain health and safety equipment on-site as specified in the plan,
- To perform health and safety activities on-site as specified in the HASP, and report results to the Project/Site Manager and the HSO,
- To maintain documentation of health and safety measures taken at the site including:
  - Distribution of HASP and Compliance Agreements,
  - Levels of personal protection,
  - Environmental monitoring results, and
  - Incident reporting.

The SSO has the authority to take the following actions:

- To temporarily suspend field activities, if the health and safety of personnel are endangered, pending further consideration by the HSO, and
- To temporarily suspend an individual from field activities for infractions of the HASP, pending further consideration by the HSO.

## REFERENCES

- American Conference of Governmental Industrial Hygienists. 1991. Guid to Occupational Exposure Values -1991. ACGIH. Cincinnati, Ohio.
- Donohue. 1992. Draft Health and Safety Plan. Continuation of RI/FS. Former Nebraska Ordnance Plant Operable Unit 1. Mead, Nebraska. Prepared for Department of the Army, U.S. Army Engineer District, Kansas City Corps of Engineers. Kansas City, Missouri. February 1992.
- Donohue. 1991. Continuation of RI/FS Former Nebraska Ordnance Plant Operable Unit 1. Mead, Nebraska. Prepared for Department of the Army, U.S. Army Engineer District, Kansas City Corps of Engineers. Kansas City, Missouri. October 1991.
- Law Environmental. 1990. Soil Gas Survey Report for Nebraska Ordnance Plant. Saunders County, Nebraska. Prepared for U.S. Army Engineering District. Kansas City. February 1990.
- National Institute for Occupational Safety and Health. 1990. NIOSH Pocket Guide to Chemical Hazards. U.S. Department of Health and Human Services, NIOSH. Cincinnati, Ohio.
- TCT -St. Louis. 1991. Final Engineering Report, Preliminary Assessment of Ordnance Contamination at the Former Nebraska Ordnance Plant. Mead, Nebraska. Prepared for U.S. Army Corps of Engineers, Huntsville Division. Huntsville, Alabama. April 1991.
- USACE, 1991. Former Nebraska Ordnance Plant. Mead, Nebraska. Remedial Investigation, Operable Unit 1, Draft Report with Appendices A through D. U.S. Army Corps of Engineers, Kansas City District. Kansas City, Missouri. May 1991.
- Woodward-Clyde Consultants. 1989. Health and Safety Plan, Remediation of Other Contamination Services, Rocky Mountain Arsenal, Commerce City, Colorado. Prepared for U.S. Army Material Command, Rocky Mountain Arsenal, Commerce City, Colorado. March 1989.



**ATTACHMENT 1**  
**COMPLIANCE AGREEMENT**

Project Name : \_\_\_\_\_

Project Number: \_\_\_\_\_

I, \_\_\_\_\_, have read the Health and Safety Plan and hereby agree to abide by its provisions and to aid the Site Safety Officer in its implementation. I understand that it is in the best interest of me and my co-workers to ensure that site operations are conducted in the safest manner possible. Therefore, I will be alert to site health and safety conditions at all times.

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

## **ATTACHMENT 2**

### **MATERIAL SAFETY DATA SHEETS**

- 2,4,6-Trinitrotoluene (TNT)
- 2,4-Dinitrotoluene (2,4-DNT)
- 2,6-Dinitrotoluene (2,6-DNT)
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX or Cyclonite)
- Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX or Octogen)
- Dinitrobenzene
- Trinitrobenzene
- 2,4,6-Trinitrophenylmethylnitramine (Tetryl)

**Pages 33-40 are the Chemical MSDS**

# **ATTACHMENT 3**

## **HEAT STRESS**

The purpose of this document is to provide general information on heat stress and the methods that can be utilized to prevent or minimize the occurrence of heat stress.

Adverse climatic conditions are important considerations in planning and conducting site operations. Ambient temperature effects can include physical discomfort, reduced efficiency, personal injury, and increased accident probability. Heat stress is of particular concern while wearing impermeable protective garments, since these garments inhibit evaporative body cooling.

### **REQUIREMENT**

The NIOSH criteria document for heat stress recommends that environmental monitoring and other preventive measures be adopted in hot work environments. However, the provisions are not directly applicable to employees who are required to wear impermeable protective clothing. The reason for this exception is that impermeable clothing prevents the evaporation of sweat, which is one of the most important cooling mechanisms of the body. There is no recognized health standard protection for workers wearing impermeable protective clothing and respirators in hot environments.

### **ADDITIONAL HAZARD**

The use of Personal Protective Equipment of the types commonly used for hazardous waste work can place stress on the body. One common problem with the use of personal protective equipment, especially in hot environments, is heat stress. Protective clothing can cause excessive sweating and can prevent the body from properly regulating body temperature.

### **TYPES OF HEAT STRESS**

Heat stress is the aggregate of environmental and physical work factors that constitute the total heat load imposed on the body. The environmental factors of heat stress are the air temperature, radiant heat exchange, air movement, and water vapor pressure. Physical work contributes to the total heat stress of the job by producing metabolic heat in the body in proportion to the intensity of the work. The amount and type of clothing also affect the heat stress.

Heat strain is the series of physiological responses to heat stress. When the strain is excessive for the exposed individual, a feeling of discomfort or distress may result, and, finally, a heat disorder may ensue. The severity of strain will depend not only on the magnitude of the prevailing stress, but also on the age, physical fitness, degree of acclimatization, and dehydration of the worker.

Heat disorder is a general term used to describe one or more of the following heat-related disabilities or illnesses:

**Heat Cramps** -painful intermittent spasms of the voluntary muscles following hard physical work in a hot environment. Cramps usually occur after heavy sweating, and often begin at the end of a work shift,

**Heat Exhaustion** -profuse sweating, weakness, rapid pulse, dizziness, nausea, and headache. The skin is cool and sometimes pale and clammy with sweat. Body temperature is normal or subnormal. Nausea, vomiting, and unconsciousness may occur,

**Heat Stroke** -sweating is diminished or absent. The skin is hot, dry, and flushed. Increased body temperature, which, if uncontrolled, may lead to delirium, convulsions, coma, and even death. Medical care is urgently needed.

## **METHODS OF CONTROLLING HEAT STRESS**

As many of the following control measures as are appropriate to site conditions should be utilized to aid in controlling heat stress:

- Provide for adequate liquids to replace lost body fluids and replace water and salt lost from sweating. Encourage personnel to drink more than required to satisfy thirst. Thirst satisfaction is not an accurate indicator of adequate salt and fluid,
- Replace fluids with water, commercial mixes such as Gatorade or Quick Kick, or a combination of these,
- Establish a work regimen that will provide adequate rest periods for cooling down. This may require additional shifts of workers,
- Wear cooling devices such as vortex tubes or cooling -vests beneath protective garments,
- Take all breaks in a cool rest area (77°F is best),
- Remove impermeable protective garments during resting periods,
- Do not assign other tasks to personnel during rest periods,
- Inform personnel of the importance of adequate rest, acclimation, and proper diet in the prevention of heat stress.

## **MONITORING**

The heat stress of an area can be monitored by the Wet-Bulb Globe Temperature Index (WBGT) technique. Where heat stress is a possibility, a heat stress-monitoring device can be utilized.

The WBGT shall be compared to the Threshold Limit Values (TLV) outlined by the ACGIH TLV guides, and a work-rest regiment can be established in accordance with the WBGT. Note that 5 degrees C must be subtracted from the TLVs for heat stress listed to compensate for the wearing of impermeable protective clothing.

## **MEDICAL**

In addition to the provisions of the medical surveillance program, on-site medical monitoring of personnel should be performed by qualified medical personnel for projects where heat stress is a

major concern. Blood pressure, pulse, body temperature (oral) , and body weight loss should be taken and recorded.

**Heart Rate:** Count the radial pulse during a 30-second period as early as possible in the rest period. If the heart rate exceeds 110 beats per minute at the beginning of the rest period, shorten the next work cycle by one-third and keep the same. If the heart rate still exceeds 110 beats per minute at the next rest cycle, shorten the following work cycle by one-third.

**Oral Temperature:** Use a clinical thermometer or similar device to measure the oral temperature at the end of the work period (before drinking liquids). If the oral temperature exceeds 99.6°F (37.6°C), shorten the next work cycle by one-third without changing the rest period. If the oral temperature still exceeds 99.6°F (37.6°C) at the beginning of the next rest period, shorten the following work cycle by one-third. Do not permit a worker to wear a semi permeable or impermeable garment if his/her oral temperature exceeds 100.6°F (38.1°C).

**Body Water Loss:** Measure body weight on a scale accurate to ±0.25 pounds at the beginning and end of each work day (also lunch break, if possible) to see if enough fluids are being taken to prevent dehydration. Weights should be taken while the employee wears similar clothing. The body water loss should not exceed 1.5 percent total body weigh loss in a work day. Potable water and Gatorade or other electrolyte replacement fluid should be available. Workers should be encouraged to drink fluids during rest periods .

**Physiological Monitoring:** Initially, the frequency of physiological monitoring depends on the air temperature adjusted for solar radiation and the level of physical work. The length of the work cycle will be governed by the frequency of the required physiological monitoring.

**Table 5. Frequency of Physiological Monitoring for Fit and Acclimatized Workers<sup>1</sup>**

Adjusted Temperature <sup>2</sup>	Normal Work Ensemble <sup>3</sup>	Impermeable Ensemble
90°F	After each 45 minute of work	After each 15 minute of work
87.5°-90°F	After each 60 minute of work	After each 30 minute of work
82.5°-87.5°F	After each 90 minute of work	After each 60 minute of work
77.5°-82.5°F	After each 120 minute of work	After each 90 minute of work
72.5°-77.5°F	After each 150 minute of work	After each 120 minute of work

<sup>1</sup>For work levels of 250 kilocalories/hour.

<sup>2</sup>Calculate the adjusted air temperature ( $T_{adj}$ ) by using this equation:  $T_{adj} \text{ } ^\circ\text{F} = T \text{ } ^\circ\text{F} + (13 \times \% \text{ sunshine})$ . Measure air temperature (T) with a standard mercury-in-glass thermometer, with the bulb shielded from radiant heat. Estimate percent sunshine by judging what percent time the sun is not covered by clouds that are thick enough to produce a shadow. (100 percent sunshine = no cloud cover and a sharp, distinct shadow; 0 percent sunshine = no shadows).

<sup>3</sup>A normal work ensemble consists of cotton coveralls or other cotton clothing with long sleeves and pants.

Note: Reprinted from Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities (1985).

## **REFERENCES**

American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Chemical Substances in the Work Environment, 1984- 1985.

Olishifski, J.B., Fundamentals of Industrial Hygiene, National Safety Council, 1983.

National Institute for occupational Safety and Health, The Industrial Environment, Its Evaluation and Control, 1973.

# **ATTACHMENT 4**

## **SAFETY GUIDELINES FOR DRILLING INTO SOIL AND ROCKS**

The purpose of this operating procedure is to provide guidelines for safe conduct of drilling operations with truck-mounted and other engine-powered, drill rigs. The procedure addresses off-road movement of drill rigs, overhead and buried utilities, use of augers, rotary and core drilling, and other drilling operations and activities.

### **APPLICATION**

The guidelines shall be applied in all projects in which truck-mounted or other engine-powered drill rigs are used. The guidelines are applicable to each appropriate employee and contractor's rigs. For drill rigs operated by contractors, drill rig safety is the responsibility of the contractor.

### **RESPONSIBILITY AND AUTHORITY**

Drill rig safety and maintenance is the responsibility of the drill rig operator.

### **SAFETY GUIDELINES**

Before moving a rig, the operator must do the following:

- To the extent practical, walk the planned route of travel and inspect it for depressions, gullies, ruts, and other obstacles,
- Check the brakes of the truck/carrier, especially if the terrain along the route of travel is rough or sloped,
- Discharge all passengers before moving on rough or steep terrain,
- Engage the front axle (on 4x4, 6x6, etc. vehicles) before traversing rough or steep terrain.

Driving drill rigs along the sides of hills or embankments should be avoided; however, if side-hill travel becomes necessary, the operator must conservatively evaluate the ability of the rig to remain upright while on the hill or embankment. The possibility that the presence of drilling tools on the rig may reduce the ability of the rig to remain upright by raising the center of mass of the rig must be considered.

- Logs, ditches, road curbs, and other long and horizontal obstacles should be normally approached and driven over squarely, not at an angle
- When close lateral or overhead clearance is encountered, another person should guide the driver of the rig on the ground
- Loads on the drill rig and truck must be properly stored while the truck is moving, and the mast must be in the fully -lowered position
- After the rig has been positioned to begin drilling, all brakes and/or locks must be set before drilling begins. If the rig is positioned on a steep grade and leveling of the ground is



impossible or impractical, the wheel of the transport vehicle should be blocked and other means of preventing the rig from moving or tipping over employed.

### **BURIED AND OVERHEAD UTILITIES**

The location of overhead and buried utility lines must be determined before drilling begins, and their locations should be noted on boring plans or assignment sheets.

When overhead power lines are close by, the drill rig mast should not be raised unless the distance between the rig and the nearest power line is at least 20 feet or other distance as required by local ordinances, whichever is greater. The drill rig operator or assistant should walk completely around the rig to make sure that proper distance exists.

When the drill rig is positioned near an overhead line, the rig operator should be aware that hoist lines and power lines can be moved towards each other by wind. When necessary and approved by the PM and the utility, power lines may be shielded, shut down, or moved by the appropriate personnel.

### **CLEARING THE WORK AREA**

Before a drill rig is positioned to drill, the area on which the rig is to be positioned should be cleared of removable obstacles and the rig should be leveled if sloped. The cleared/leveled area should be large enough to accommodate the rig and supplies.

### **SAFE USE OF AUGERS**

Never place hands or fingers under the bottom of an auger flight or drill rods when hoisting the augers or rods over the top of another auger or rod in the ground or other hard surfaces, such as the drill rig platform. Never allow feet to get under the auger or drill rod while they are being hoisted.

When drill is rotating, stay clear of the drill string and other rotating components of the drill rig. Never reach behind or around a rotating auger for any reason.

Move auger cuttings away from the auger with a long- handled shovel or spade; never use hands or feet.

Never clean an auger attached to the drill rig unless the transmission is in neutral or the engine is off, and the auger has stopped rotating.

### **SAFE USE OF HAND TOOLS**

OSHA regulations regarding hand tools, in addition to the guidelines provided below should be observed:

- Each tool should be used only to perform tasks for which it was originally designed,
- Damaged tools should be repaired before use or discarded,
- Safety goggles or glasses should be worn when using a hammer or chisel. Nearby co-workers and by-standers should be required to wear safety goggles or glasses also or to move away,

- Tools should be kept cleaned and stored in an orderly manner when not in use.

### **SAFE USE OF WIRE LINE HOISTS, WIRE ROPE, AND HOISTING HARD WARE**

Safety rules described in 29 CFR 1926.552 and guidelines contained in the Wire RPE User's Manual published by the American Iron and Steel Institute shall be used whenever wire line hoists, wire rope, or hoisting hardware are used.

### **PROTECTIVE GEAR**

Items listed below should be worn by all members of the drilling team while engaged in drilling activities.

- Hard Hat,
- Safety Shoes (shoes or boots with steel toes and shanks), and
- Gloves.

### **Other Gear**

Items listed below should be worn when conditions warrant their use. Some of the conditions are listed after each item.

Safety Goggles or Glasses: Use when: (1) driving pins in and out of drive chains, (2) replacing keys in tongs, (3) handling hazardous chemicals, (4) renewing or tightening gauge glasses, (5) breaking concrete, brick, or cast iron, (6) cleaning material with chemical solutions, (7) hammering or sledging on chisels, cold cuts, or bars, (8) cutting wire lines, (9) grinding on abrasive wheels, (10) handling materials in powered or semi-powered form, (11) scraping metal surfaces, (12) sledging rock bits or core heads to tighten or loosen them, (13) hammering fittings and connections, and (14) driving and holding rivets.

Safety Belts and Lifelines: Safety belts and lifelines should be worn by all persons working on top of an elevated derrick beam. The lifeline should be secured at a position that will allow a person to fall no more than eight feet.

Life Vests: Use for work over water.

### **TRAFFIC SAFETY**

Drilling in streets, parking lots or other areas of vehicular traffic requires definition of the work zones with cones, warning tape, etc. and compliance with local police requirements.

### **FIRE SAFETY**

Fire extinguishers shall be kept on or near drill rigs for fighting small fires,

If methane is suspected in the area, a combustible gas instrument (CGI) shall be used to monitor the air near the borehole with all work to stop at 25 percent of the Lower Explosive Limit,

Work shall stop during lightning storms.

# **ATTACHMENT 5**

## **INCIDENT REPORT**

All health and safety incidents that occur during field and laboratory activities associated with investigations and remediation of sites containing hazardous materials must be reported to management.

### **DEFINITIONS**

A health and safety incident is any event listed below:

- Illness resulting from chemical exposure or unknown causes,
- Physical injury, including those that do not require medical attention,
- Fire, explosions, and flashes resulting from activities performed by main contractor and its subcontractors,
- Property damage resulting from activities performed by main contractor and its subcontractors,
- Vehicular accidents occurring on-site or while traveling to and from sites,
- Infractions of safety rules and requirements,
- Unexpected chemical exposures (indicated by irritation of eyes, nose, throat, or skin).

### **REPORTING PROCEDURES**

**Reporting Format:** Incident reports shall be prepared using proper paper work supplied by the contractor.

**Responsible Party:** Reports of incidents occurring in the field shall be prepared by the site safety officer or, in the absence of the site safety officer, the supervising field engineer, witness, or injured/exposed individual.

### **FILING**

A report must be submitted to the health and safety officer of the business unit to which the project manager belongs within 24 hours of each incident involving medical treatment. In turn, the health and safety officer must distribute copies of the report to the corporate health and safety administrator and the corporate health and safety officer. When an injury or illness is reported, the business unit health and safety officer must deliver a copy of the report to the individual in charge of personnel affairs so that a Worker's Compensation Insurance Report can be filed, if necessary. Reports must be received by personnel within 48 hours of each qualifying incident.

## **Appendix D**

# **Environmental Security Technology Certification Program**

## **Treatability Study for Biologically Active Zone Enhancement (BAZE) for In-situ RDX Degradation in Ground Water (ESTCP #0110)**

**Supplemental Report:  
Mass Balance of RDX Biotransformation, and Influence of  
Aquifer Temperature on RDX Biodegradation in Groundwater**



Altaf Wani, Deborah Felt, and Jeffrey Davis  
July 2003

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## Abstract

A series of column studies with site-specific aquifer material from the former Nebraska Ordinance Plant were performed to evaluate the influence of aquifer temperature on in situ RDX biodegradation, and to assess the ultimate fate of RDX in groundwater under biologically induced reductive conditions. In treatment columns RDX-contaminated water was amended with acetate as readily available carbon source, and in control columns no electron donor was used. The results of the temperature study demonstrated clear indications of adverse effects of lower aquifer temperature on biological activity of RDX-degraders. As the aquifer temperature decreased from 15 to 10 and eventually to 5 °C, the concentration of nitroso-substituted metabolites and untreated RDX increased in the effluent stream. The estimated first-order biodegradation rate coefficient  $k$  for RDX at 15 °C was 0.155 1/hr ( $\pm 0.019$ ,  $n = 3$ ). This rate coefficient decreased by about 37 percent to 0.098 1/hr ( $\pm 0.017$ ,  $n = 3$ ) at 10 °C, and by another 38 percent to 0.061 1/hr ( $\pm 0.016$ ,  $n = 3$ ) at 5 °C. An activation energy of 63.54 kJ/mol RDX was estimated from these reaction rate coefficients at three different aquifer temperatures. Results of the radiolabel study demonstrated that the ultimate fate of RDX under in situ reductive conditions is highly dependent on redox conditions in the aquifer. In treatment columns (redox change,  $\Delta E_h = -550$  to  $-700$  mV), 23-46 percent of initial radiocarbon was mineralized to  $^{14}\text{CO}_2$  as compared to <5 percent in control columns, where  $\Delta E_h$  ranged between 70 to  $-70$  mV. The dissolved fraction of initial radiocarbon in treatment columns estimated between 46 and 64 percent. No or very low levels of nitroso-substituted RDX transformation products were identified in dissolved fraction from treatment columns. In control columns dissolved fraction accounted for about 86 percent of initial  $^{14}\text{C}$  and was composed of mainly untreated RDX.

## Introduction

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A large number of active and formerly used military installations are contaminated with explosive polynitroorganics. The most common munition-derived pollutants encountered at these sites are nitroaromatics like 2,4,6-trinitrotoluene (TNT), and nitramines such as hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and octahydro-1,3,5,7-tetranitro-tetrazocine (HMX). These explosive compounds have entered the environment from sites where they were manufactured, stored, disposed, or used in military training. Currently, there are 583 sites with confirmed explosives-contaminated groundwater at 82 installations nationwide; and at 22 other installations, 88 additional sites are suspected of groundwater contamination with explosives and organics (Defense Environmental Network and Information Exchange (DENIX) 2002).

RDX, a cyclic nitramine explosive, has contaminated groundwater, soil, and surface water at many military installations, promoting concerns about potential toxic effects. In a previous treatability study (Wani et al. 2002), it has been shown that in situ bioremediation of RDX can be achieved by inducing a reductive environment using a benign carbon source (electron donor) in the aquifer. Among different electron sources tested, acetate as a carbon amendment resulted in the necessary reduced conditions for RDX biotransformation without the generation of toxic byproducts. The prior treatability study was conducted at room temperature ( $22 \pm 1$  °C), and the influence of lower aquifer temperatures (8-10 °C) on RDX biotransformation kinetics was not evaluated. In addition, the treatability study indicated no formation of nitroso-substituted products and complete RDX ( $\sim 100$  µg/L) removal from the groundwater. It was hypothesized that the ultimate fate of RDX under such in situ conditions appears to be nonvolatile non-nitroso transformation products. To back up this hypothesis and to evaluate the ultimate fate of RDX under reductive biotransformation, a radiolabel RDX study was performed. The prior study resulted in two unresolved issues: (a) the influence of aquifer temperature on RDX biotransformation kinetics and (b) the ultimate fate of RDX under in situ bioremediation. Because of these two unresolved issues, a supplemental study was conducted to (a) evaluate the influence of aquifer temperature on in situ RDX biodegradation and (b) assess the ultimate fate of RDX in groundwater under biologically induced reductive conditions.

## Literature Review

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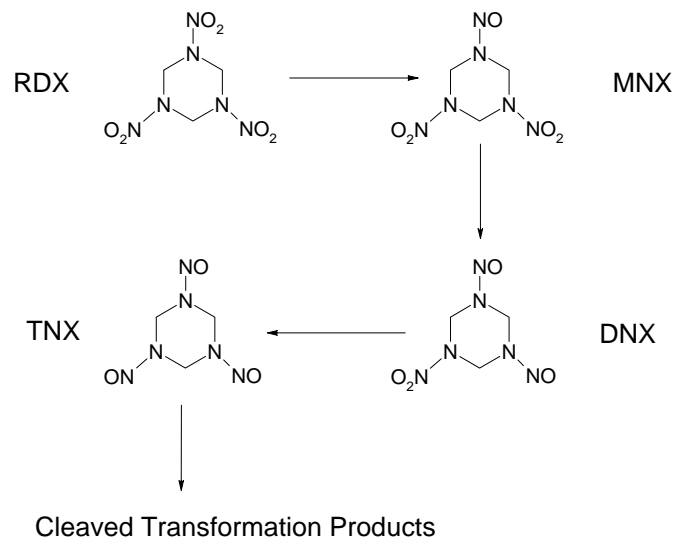
TNT, RDX and HMX, the most commonly encountered energetic contaminants in soil and groundwater, pose a significant cleanup challenge at many active and formerly used military sites in the United States and across the world. In the United States the contamination of soil and groundwater is attributed to World War II and the Korean conflict (Pennington 1999).

RDX, which is in the nitramine class of explosives, is widely used in munitions because of its explosive power, around 1.5 to 2 times that of TNT, and rapid detonating velocity, about 1.3 times that of TNT (U.S. Army 1984). RDX is of particular environmental concern because laboratory studies have established that it is generally resistant to microbial transformation in aerobic soils (McCormick et al. 1981) and it is not extensively sorbed on soils (sorption coefficient  $K_d$  of 0.83 to 0.95 L kg<sup>-1</sup>) (Singh et al. 1998, Sheremata et al. 2001). Remediating soil and water contaminated with RDX is of vital importance because ingestion of RDX can adversely affect the central nervous system, gastrointestinal tract, and kidneys. Common symptoms of RDX intoxication include nausea, vomiting, hyperirritability, headaches, and unconsciousness (Eitner 1989). RDX has also been associated with systemic poisoning usually affecting bone marrow and the liver (Agency for Toxic Substances and Disease Registry (ATSDR) 1996). The U.S. Environmental Protection Agency (EPA) has established drinking water health advisory of 2 µg/L for exposure to RDX (U.S. EPA 2002).

The fate and transport of RDX in the environment are influenced by many factors including photolysis by sunlight, hydrolysis, and biologically mediated degradation. Biodegradation of RDX is often attributed to cometabolism in the presence of a primary carbon source under various electron acceptor conditions. RDX can be biodegraded under anaerobic or anoxic conditions by facultative or anaerobic microorganisms (McCormick et al. 1981; Kitts et al. 1994; Freedman and Sutherland, 1998; Hawari et al. 2000a; Halasz et al. 2002; Beller 2002). Under aerobic conditions, RDX can be used as a sole source of nitrogen by aerobic microorganisms (Binks et al. 1995; Coleman et al. 1998; Brenner et al. 2000), or by fungus (Bayman et al. 1995; Fernando and Aust 1991; Sheremata and Hawari 2000).

Various laboratory studies have established that anaerobic RDX metabolism occurs more readily than aerobic metabolism, and that hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), and hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX) are the transient biotransformation intermediates (Figure 1) under anaerobic conditions (Hawari et al. 2000a, 2000b; McCormick et al. 1981; Kitts et al. 1994; Morley et al. 2002; Young et al. 1997; Beller 2002; Freedman and Sutherland 1998; Beller and Tiemeier 2002). Recent studies have tentatively identified methylenedinitramine (MDNA) as the ring cleavage metabolites during the bioremediation of RDX with anaerobic sludge. These studies suggest different views of the stability of MDNA; it can occur as a transient metabolite (Halasz et al. 2002) or as a persistent transformation product that appears at substantial concentrations relative to RDX (Oh et al. 2001). Nonetheless, Beller and Tiemeier (2002) reported that under in situ conditions MDNA was not detected in any of the samples from the RDX-contaminated aquifer at Iowa Army Ammunition Plant (IAAP), although relatively high concentrations of

MNX, DNX, and TNX were present. Although many researchers have established that RDX can be biodegraded through biological processes, successful application of these techniques to in situ treatment of contaminated soils and waters has yet to be proven in the field. The influence of such environmental conditions as aquifer temperature on RDX biodegradation has not been considered in previous research work. Moreover a better understanding of in situ biotransformation of RDX and the generation of transformation products requires the assessment of the ultimate fate of RDX.



**Figure 2. Anaerobic pathway**

## Site Description and Sampling

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The former Nebraska Ordnance Plant (NOP) is located about 1 km (half a mile) south of Mead, NE, which is 48 km (30 miles) west of Omaha and 56 km (35 miles) northeast of Lincoln, NE. The NOP covers 69.9 square km (17,258 acres) in Saunders County. Currently, the land is owned by the University of Nebraska, Agricultural Research and Development Center, U.S. Army National Guard and Reserves, U.S. Department of Commerce, and private interests. The past operational history, and geological and hydrological characteristics of the NOP site are discussed in Wani et al. (2002).

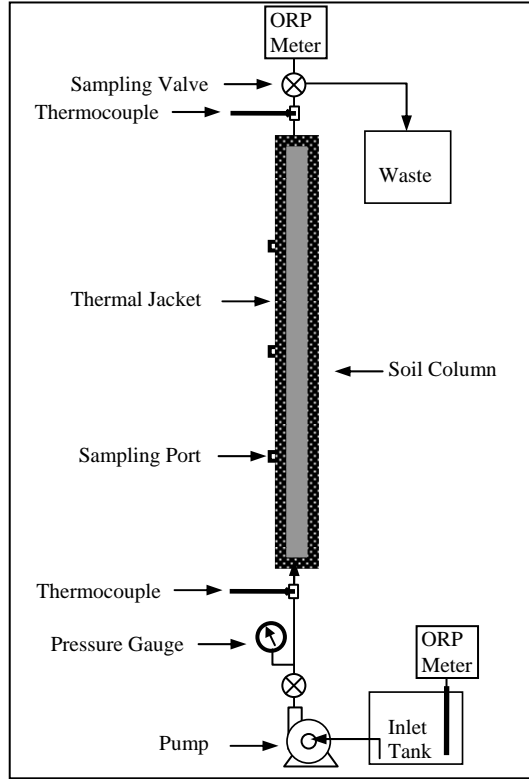
Aquifer material at the former NOP site was collected from Area 1, near monitoring well MW-5B, from a depth of 11 to 12 m (36 to 40 ft) below ground surface. Soil columns were collected in 5-cm (2-in) diameter acetate liners by the direct-push method using a track-mounted mobile sampling device. Further details on aquifer material sampling are presented in the biologically active zone enhancement (BAZE) treatability study report (Wani et al. 2002). The soil columns were thoroughly sealed at both ends to prevent loss of water from the aquifer material during storage and shipping. Samples of aquifer material were transported to the Environmental Laboratory, Vicksburg, MS, U.S. Army Engineer Research and Development Center, via a refrigerated truck.

## Materials and Methods

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### Experimental Setup

Two sets of triplicate columns were used to evaluate the effects of aquifer temperature on RDX biotransformation. In the first triplicate set, acetate was added as the carbon source (electron donor) while the second triplicate set served as amendment (carbon source) control. The polyvinyl chloride (PVC) columns were 104 cm (3.4 ft) long with an inside diameter of 3.8 cm (1.5 in.). Both ends of the columns were closed with PVC caps screened with porous (100  $\mu\text{m}$ ) PVC. Additional sampling ports, at 26 cm (10.2 in.), were placed along the entire column length resulting in three intermediate sampling ports in addition to the inlet and outlet ports for the development of the contaminant bed profile. Each column was individually wrapped with a thermal jacket composed of a cold water circulation unit covered with a 12-mm (0.5-in.) thick thermal insulation to prevent heat transfer from the environment. The difference in influent and effluent temperature was  $\pm 1$  °C. The detailed design of the column system with groundwater flow and other instrumentation is shown in Figure 3. Teflon-coated T-type thermocouples (Omega Engineering, Stamford, CT) equipped with digital panel monitors were installed at the inlet and outlet of each column, via flow-through cell, to record the temperature of influent and effluent groundwater streams. Pressure gauges were installed at the inlet to each individual column to examine the effects of microbial growth (biofouling) on groundwater flow, back pressure, and the hydrodynamic properties of the aquifer material. The outlet of each column was equipped with an oxidation-reduction potential (ORP) electrode via a flow-through cell to compare the reduced conditions along the column length with that of the inlet tank. Details on packing of these columns with site-specific aquifer material were presented in the initial BAZE treatability study (Wani et al. 2002). RDX-contaminated water was pumped through the columns using variable-control positive displacement pumps. Variable control on pump speed allowed the metering of desired water flow through each column.



**Figure 3. Experimental column setup for temperature study**

To assess the ultimate fate of RDX in groundwater under a biologically induced reductive environment, two separate sets of triplicate columns, as shown in Figure 4, were used. Similar to the temperature study, one set was used for amendment (carbon source) addition and the other set served as amendment (acetate) control. These PVC columns were of the same dimensions as described for the temperature study. These columns also had additional sampling ports at 26 cm (10.2 in.) for bed profile analysis. The schematics of this column system with RDX-contaminated water flow and other instrumentation are illustrated in Figure 4. Pressure gauges were installed at the inlet to each individual column to examine the changes in back pressure. The outlet of each column was equipped with an ORP electrode via a flow-through cell to compare the reduced conditions along the length of the column system with that of the inlet tank. These columns were packed with site-specific aquifer material (Wani et al. 2002). RDX-contaminated water was pumped through each column using variable-control positive displacement pumps. The column system along with pumps and inlet water reservoirs was securely installed in a cabinet to prevent release of any radioactivity.

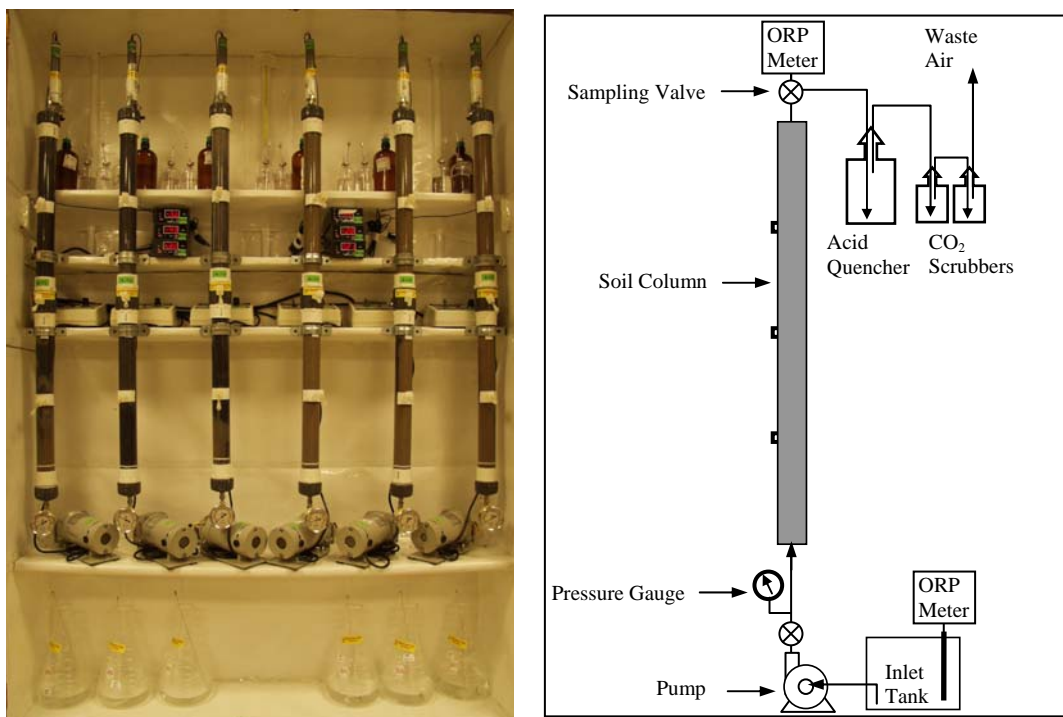


Figure 4. Experimental column setup for radiolabel RDX study

## Operation

RDX-contaminated water was prepared by spiking autoclaved organic-free reagent grade water with RDX stock solution. RDX-contaminated water with a concentration of about  $1.03 \pm 0.05$  mg/L was used in this study. The selection of acetate as the carbon source (electron donor) in this research work is based on other research that suggests that acetate is an excellent electron donor to stimulate in situ microbial reductive conditions (He et al. 2002; Wani et al. 2002). Acetate concentration of 500 mg/L (as carbon) was used in both temperature- and radiolabeled-studies to ensure that organic carbon is not the limiting factor. RDX-contaminated water flow through each column was initiated at  $\sim 0.2$  mL/min and maintained at this rate throughout the study. This water flow resulted in a velocity of about 0.85 m/d (2.7 ft/d), which is comparable with the NOP site groundwater velocity of approximately 0.61 m/d (2 ft/d).

Temperature-study columns were operated at three different temperatures (15, 10, and 5 °C) to evaluate the influence of aquifer temperature on RDX biotransformation kinetics. Each temperature test lasted for a month. Liquid samples were collected from inlet and outlet sampling ports every fifth day. After the columns reached the steady state, samples from intermediate ports along the column height were collected on the 23<sup>rd</sup> and 30<sup>th</sup> day for each temperature test. Water samples were stored at 4 °C until explosives and amendment analysis. The operating conditions are summarized in Table 7.



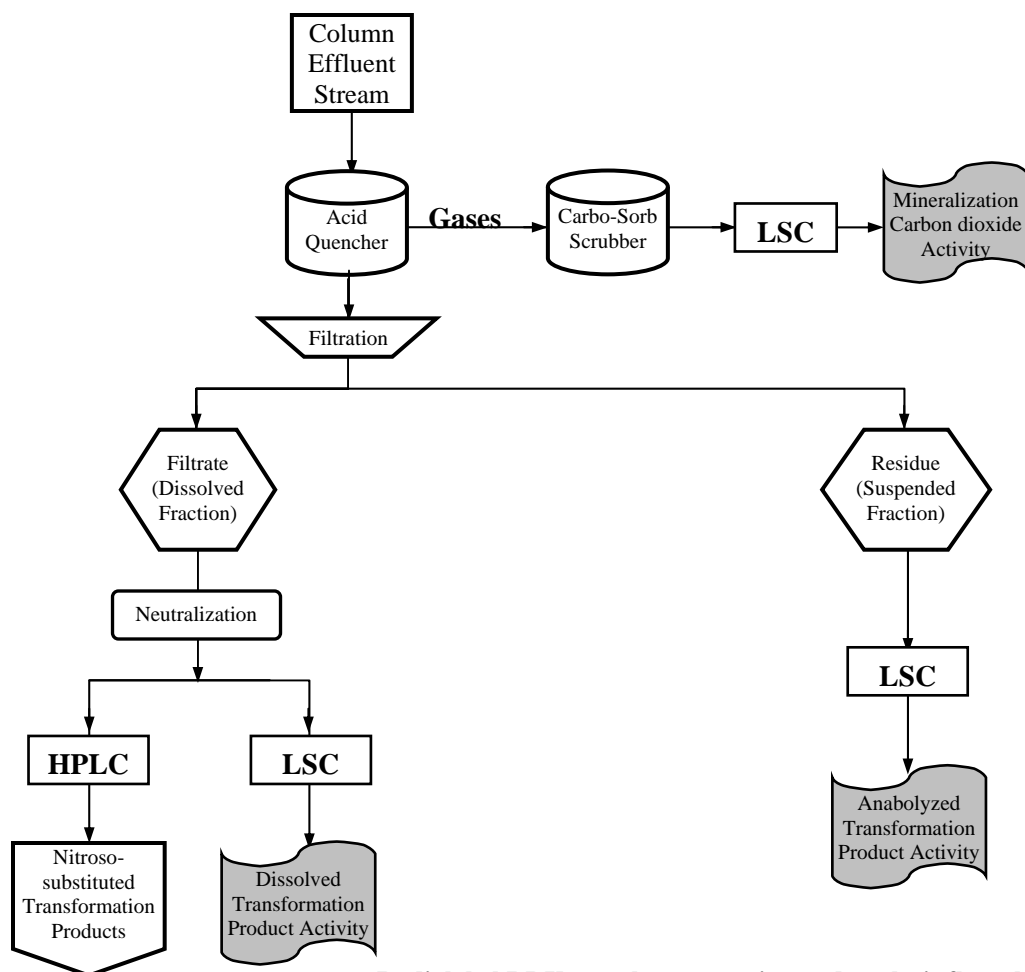
**Table 6. Column Operating Conditions**

<b>Column</b>	<b>Groundwater Flow rate mL/min</b>	<b>RDX Concentration mg/L</b>	<b>Acetate Concentration mg/L C</b>	<b>[<sup>14</sup>C]RDX Initial Activity dpm</b>
<b>Temperature Columns</b>				
T-T1	0.20	~1.0	~500	None
T-T2	0.20	~1.0	~500	None
T-T3	0.20	~1.0	~500	None
T-C1	0.20	~1.0	0	None
T-C2	0.20	~1.0	0	None
T-C3	0.20	~1.0	0	None
<b>Radiolabel RDX Columns</b>				
R-T1	0.20	~1.0	~500	~1,700,000
R-T2	0.20	~1.0	~500	~1,700,000
R-T3	0.20	~1.0	~500	~1,700,000
R-C1	0.20	~1.0	0	~1,700,000
R-C2	0.20	~1.0	0	~1,700,000
R-C3	0.20	~1.0	0	~1,700,000

Amendment concentrations are nominal.

dpm = disintegrations per minute ( $\mu\text{Ci} = 2.2$  million dpm)

Radiolabeled-study columns were fed with RDX-contaminated ( $1.05 \pm 0.06$  mg/L) groundwater for 2 months to reach steady state. Once the columns reached steady state conditions with steady RDX removal from feed water, a slug of [<sup>14</sup>C]RDX ( $\sim 0.76$   $\mu\text{Ci}$ ) was introduced into the inlet tank to each individual column. The effluent water stream, including any carbon dioxide evolved as a result of mineralization, was collected in a 500-mL glass sampler under an hydrochloric acid quenching solution (25 mL, 1N HCl) to release any dissolved carbon dioxide. The effluent gases from the acid quencher were passed through carbon dioxide scrubbers containing 100 mL Carbo-Sorb<sup>®</sup> (Packard Biosciences, Meriden, CT) to scrub out carbon dioxide from the gas stream. In another test it was found that Carbo-Sorb is a very efficient carbon dioxide scrubbing solution with a 99.99 percent recovery. At the end of the sampling, the sampling train (acid quencher-Carbo-Sorb scrubbers) was flushed with nitrogen gas to remove all the carbon dioxide from the acid quencher into the Carbo-Sorb scrubbers (Figure 5).



**Figure 5. Radiolabel RDX sample preparation and analysis flow chart**

The contents of the acid quencher (including the column effluent) were filtered (0.45  $\mu\text{m}$ ) to separate the suspended, mostly biomass (residue) and the dissolved (filtrate) fractions of RDX and its transformation products. The filtrate was neutralized with 1N NaOH. Liquid scintillation counting (LSC) was performed on aliquots from both the neutralized filtrate (dissolved fraction) and the residue (suspended fraction) to estimate the portion of [ $^{14}\text{C}$ ]RDX and its transformation products in the suspended and dissolved phases. A 4-mL aliquot of neutralized filtrate was mixed with 15 mL Ultima Gold<sup>®</sup> (Packard Biosciences) scintillation cocktail for radioactivity counting. The filter paper along with the residue was immersed in 15-mL Ultima Gold<sup>®</sup> scintillation cocktail for radioactivity counting. The contents of the Carbo-Sorb scrubbers were subjected to LSC to evaluate the fraction of [ $^{14}\text{C}$ ]RDX mineralized to [ $^{14}\text{C}$ ]CO<sub>2</sub>. A 10-mL aliquot from Carbo-Sorb scrubber was mixed with 10-mL Permafluor<sup>®</sup> scintillation cocktail (Packard Biosciences) for radioactivity counting. The total radioactivity from gaseous (mineralization CO<sub>2</sub>), suspended (nitroso- and non-nitroso-substituted nonvolatile metabolites), and dissolved (nitroso- and non-nitroso-substituted nonvolatile metabolites) phases was summed up and compared with the initial radioactivity introduced as [ $^{14}\text{C}$ ]RDX. An aliquot from

neutralized filtrate was analyzed for untreated RDX and nitroso-substituted (MNX, DNX, and TNX) nonvolatile metabolites using high-performance liquid chromatography (HPLC).

### Analytical Techniques

Acetate, sulfate, nitrate, and nitrite in liquid samples were analyzed on a DIONEX Ion Chromatograph. Chemical separation and detection were achieved using an Ionpac AS11 analytical column (4 by 250 mm) and a Dionex conductivity detector (1.25  $\mu$ L internal volume). The mobile phase consisted of NaOH at a flow rate of 1.5 mL/min. The sample volume was 25  $\mu$ L of filtered (0.45  $\mu$ m) sample. The instrument was calibrated daily from standards prepared from stock solutions. Check standards were run after every 10 samples.

The analysis of RDX and its nitroso-substituted transformation products was performed using a DIONEX HPLC system comprising of a P580 fluid pump, ASI-100 autosampler, and UVD340U absorbance detector. The injection volume was 25  $\mu$ L. Chemical separation was achieved using a Supelco CN reverse-phase HPLC column (25 cm by 4.6 mm) with a Novapak C-18 precolumn for the primary column. The mobile phase comprised of 1:3 (volume per volume) methanol/organic-free reagent water at a flow rate of 1 mL/min. Explosives absorbance was monitored at 245 nm. For EPA Method 8330 analytes (U.S. EPA 1994), a seven-point calibration curve was used. The instrument was calibrated daily from standards prepared from stock solutions. Check standards were run after every 10 samples.

Sample radioactive concentration via liquid scintillation counting was done on 2500 TR Packard Scintillation Counter (Packard Biosciences). The counter was equipped with a barium external source to enable correction for machine efficiency. The liquid scintillation protocol collected data up to 156 meqV, which is the maximum energy for [ $^{14}$ C]. Each sample was counted twice for 2 minutes.

Oxidation-reduction potential ( $E_h$ ) and pH were measured with electrodes that were calibrated weekly. Both ORP and pH were measured with Oakton WD-35100-00 model pH/ORP Controllers (Cole-Parmer, Vernon Hills, IL) with a measuring range of 0 to 14 for pH and -1250 to 1250 mV ORP. ORP was measured using a Cole-Parmer combination redox electrode with platinum sensing surface and Ag/AgCl reference electrode. The value  $E_h$  was obtained by adding standard potential of the reference electrode  $E_R$  to the measured potential  $E$ . For this ORP electrode  $E_R$  at 25  $^{\circ}$ C (room temperature) is 202 mV. pH was determined with a Cole-Parmer combination electrode.

### Biotransformation Kinetics

The rate of RDX biotransformation was determined by sampling at the intermediate ports in the column system. A contaminant profile was developed and an advection-dispersion model (Equation 1) for contaminant transport with decay was fitted to the results:

$$\frac{\partial C}{\partial t} = a v \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} - kC \quad (1)$$

where  $C$  = RDX concentration (mg/L),  $t$  = time elapsed (hr),  $\alpha$  = dispersivity (cm),  $v$  = interstitial velocity (cm/hr),  $x$  = distance from column inlet (cm),  $k$  = RDX first-order biodegradation rate coefficient (1/hr).

With the boundary conditions  $C(0,t) = C_0$  and  $\partial C/\partial x(\infty,t) = 0$ , at steady state, Equation 1 can be solved to Equation 2 as follows:

$$C = C_0 \exp\left(-\frac{\alpha x}{2\alpha v} \left(v - \sqrt{v^2 + 4ka v}\right)\right) \quad (2)$$

The bed-profile sampling for each temperature test was done twice on the 23<sup>rd</sup> and 30<sup>th</sup> days when the operating conditions were steady and columns had reached equilibrium conditions with steady RDX removal.

The rates of RDX biotransformation, estimated by fitting Equation 2 to the contaminant profile, at three different temperatures (15, 10, and 5 °C) were used to evaluate the influence of aquifer temperature on RDX biodegradation rate using the Arrhenius equation:

$$k = A \exp\left(-\frac{E_a}{RT}\right) \quad (3)$$

where

$A$  = Arrhenius constant,  $E_a$  = activation energy (J/mol),  $R$  = universal gas constant (J/mol-K),  $T$  = temperature (°K)

# Results

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## Temperature Study

### *Column hydrodynamics*

RDX-contaminated water flow during the entire 13-week study was approximately 0.2 mL/min in both triplicate column sets (Figure 6). This water flow resulted in an hydraulic residence time of  $24 \pm 1$  hr in individual columns. Figure 6 summarizes the groundwater temperature in each column. These temperature readings are the average of influent and effluent groundwater temperatures. The thermal jacket wrapped over the individual column was very efficient in maintaining the aquifer material and groundwater temperature in each column. The influent and effluent temperatures varied by 1 °C.

Reduced conditions were established in each column as shown in Figure 6. In treatment columns change in redox ( $\Delta E_h$ ) was between -600 and -850 mV. Anaerobic conditions were established in treatment columns by providing carbon source to indigenous microorganisms, which then used the oxygen, creating a reduced environment. The  $\Delta E_h$  in the control columns was very small (between 100 and -150 mV) compared with that of the treatment columns.

The influent stream pH varied between 6.5 and 7.5 for the treatment column set where RDX-contaminated water was amended with acetate (Figure 7). In the control column set the influent water pH was slightly higher (7.5 to 8). The effluent stream from the treatment column set showed a slight increase in pH (7.5 to 8). There was no measurable change in the effluent stream pH in the control columns (Figure 7).

There was no significant back pressure buildup due to biofouling in any of the columns, and head loss remained almost the same during the entire 13-week study, except in treatment column T-T2 (Figure 7). This steady increase in back pressure in Column T-T2 could be the result of a higher biomass yield that caused RDX biodegradation without the detection of any nitroso-metabolites (Figure 8). Occasional hikes in the back pressure were due mainly to plugging of the porous PVC screen at the column inlets due to extracellular secretions from biomass. After the porous PVC screens were cleaned or replaced, this flow resistance was removed and pressure loss across the columns dropped to initial levels.

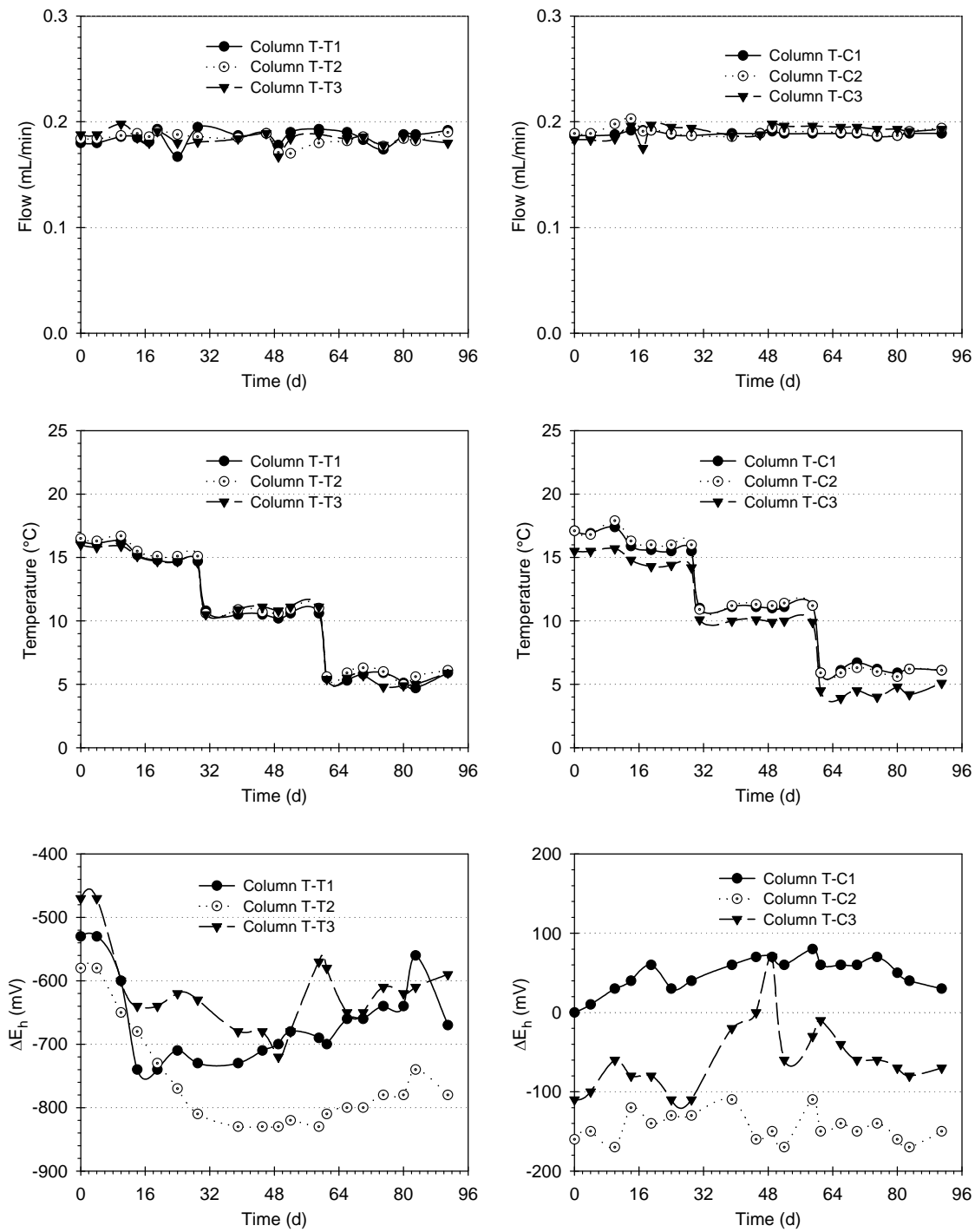


Figure 6. RDX-contaminated water flow, temperature, and change in redox potential for each column

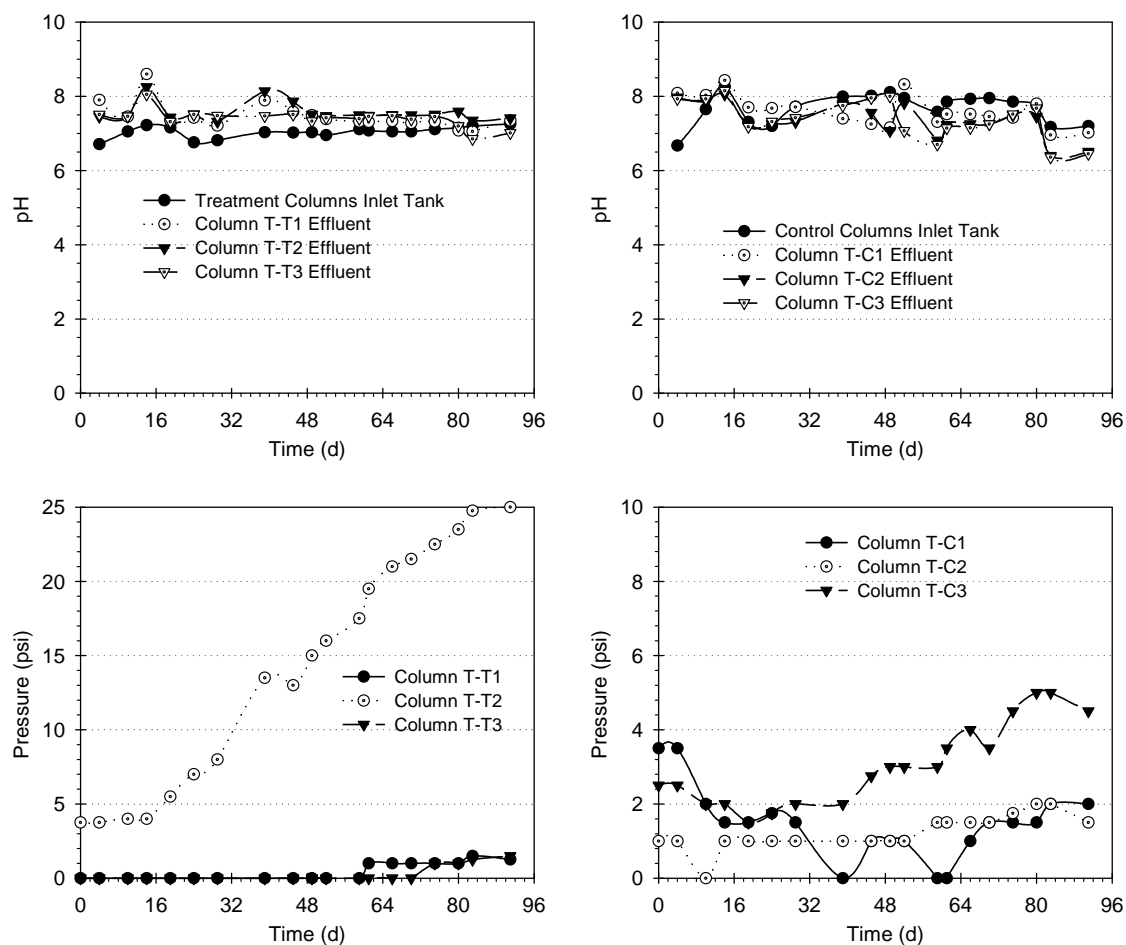


Figure 7. Feed water pH and flow resistance (back pressure) for each column

### *RDX biotransformation*

RDX concentrations in the influent groundwater, ranging between 1 and 1.2 mg/L, were reduced to below detection limits of 0.02 mg/L, at 15 °C, in all treatment columns. At lower temperatures (10 and 5 °C) low concentrations of RDX were observed in the effluent streams from Columns T-T1 and T-T3. However, these lower temperatures did not have any effect on the removal efficiency of RDX in Column T-T2. In Column T-T2 influent RDX was removed without the presence of any nitroso-substituted RDX metabolites at all three temperatures tested. In the other two treatment columns (T-T1 and T-T3) low levels (~ 0.2 mg/L) of the nitroso-substituted transformation products (MNX, DNX, and TNX) were observed in the effluent stream throughout the study (Figure 8). The other noticeable difference in Column T-T2 compared with Columns T-T1 and T-T3 was the steady back pressure development during the 13-week study. One plausible reason behind these two manifest observations in Column T-

T2 could be a higher biomass yield that caused RDX biodegradation without the detection of any transformation products and at the same time created a higher flow resistance resulting in higher

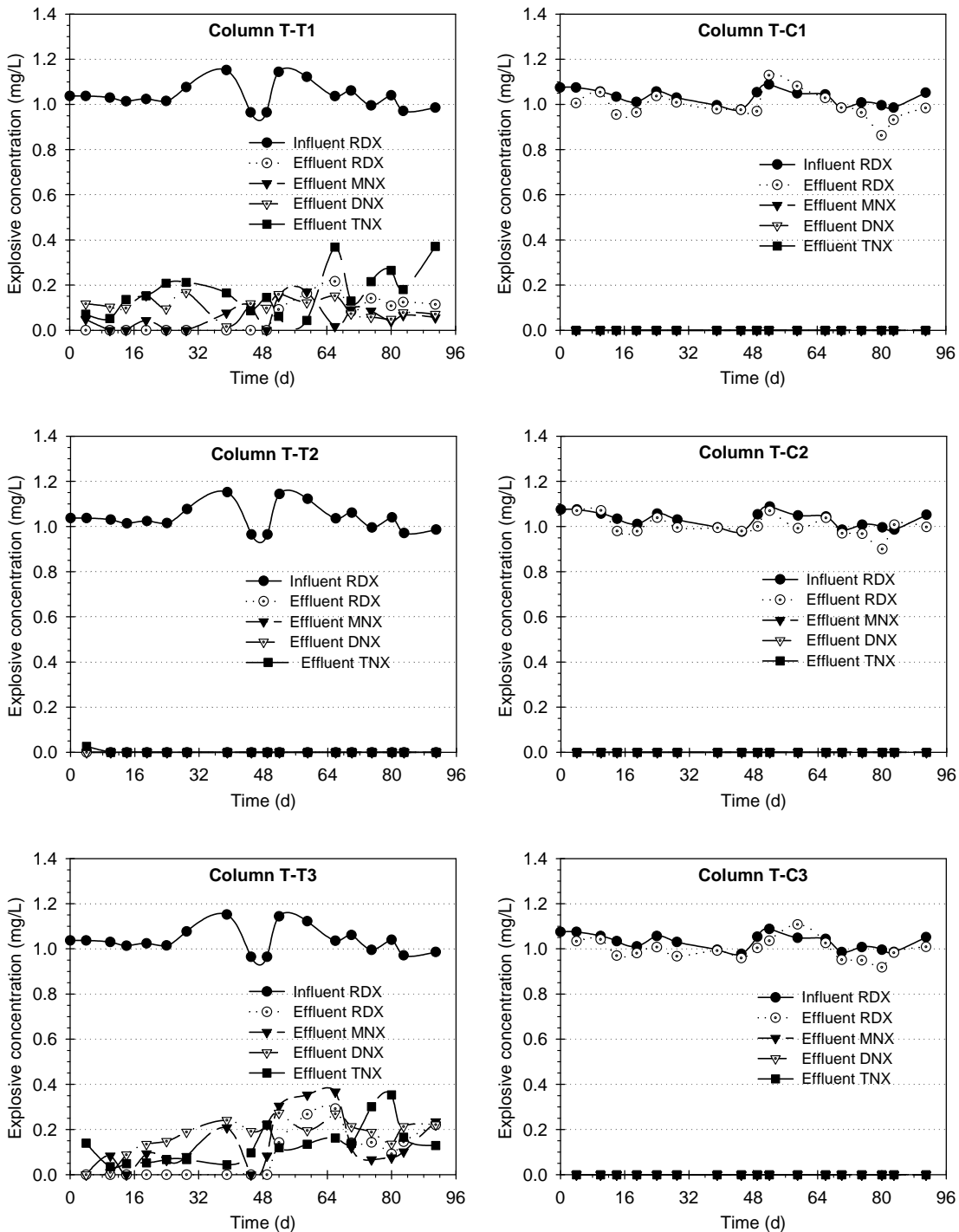


Figure 8. RDX and nitroso-RDX intermediates concentration in influent and effluent streams



back pressure along the column length. The assumption of high biomass yield is also substantiated by the lowest redox potential in Column T-T2 as a result of higher biological activity. The cumulative presence of nitroso-substituted transformation products in Column T-T1 and Column T-T3 accounted for about one-third of the influent RDX concentration on a molar basis. That leaves about 70 percent of the inlet RDX unaccounted for in terms of nitroso-substituted RDX intermediates, which might include other non-nitroso-transformation products as proposed by other researchers (Hawari et al. 2000a; McCormick et al. 1981).

In control columns no biodegradation of RDX was observed throughout the course of the study (Figure 8). During the entire study redox potential in control columns, where no electron donor was used, was very high compared with that of treatment columns (Figure 6). These results identify the need for low redox environment for reductive biotransformation of RDX in groundwater.

During the 13-week study, RDX was removed from the groundwater with the presence of low levels of all the three nitroso-substituted transformation products in treatment Columns T-T1 and T-T3; however, in treatment Column T-T2 effluent no MNX, DNX, or TNX was observed. This sequential reductive biotransformation has been reported for various RDX-metabolizing cultures that used organic electron donors (Freedman and Sutherland 1998; Hawari et al. 2000a, 2000b; Beller and Tiemeier 2002; McCormick et al. 1981). In all three control columns RDX was not biodegraded at all. In these control columns  $\Delta E_h$  between influent and effluent was between 100 and  $-150$  mV. From these results, it seems the ultimate fate of RDX appears to be dependent on redox conditions. In treatment column systems, with  $\Delta E_h$  between influent and effluent between  $-600$  and  $-850$  mV, RDX was transformed into nitroso- and non-nitroso-substituted metabolites. In Column T-T2 where  $\Delta E_h$  between influent and effluent was the lowest ( $-850$  mV) none of the nitroso-substituted transformation products was observed in the effluent stream. This might be because these nitroso-substituted intermediates are unstable at low redox and further undergo ring cleavage as postulated by other researchers (Hawari et al. 2000a, 2000b; McCormick et al. 1981). Oh et al. (2001) have tentatively identified a soluble intermediate MDNA as a result of ring cleavage. However, the formation and stability of MDNA as a biotransformation product of RDX under anaerobic conditions is not yet clear; it can occur as a transient intermediate (Halasz et al. 2002), or a stable transformation product (Oh et al. 2001).

In all three treatment columns, very little ( $\sim 1$  percent) of the inlet acetate concentration (500 mg/L as carbon) was used in the biological activity (Figure 9). Low (30-50 mg/L) levels of carbonate were observed in the effluent streams from these treatment columns.

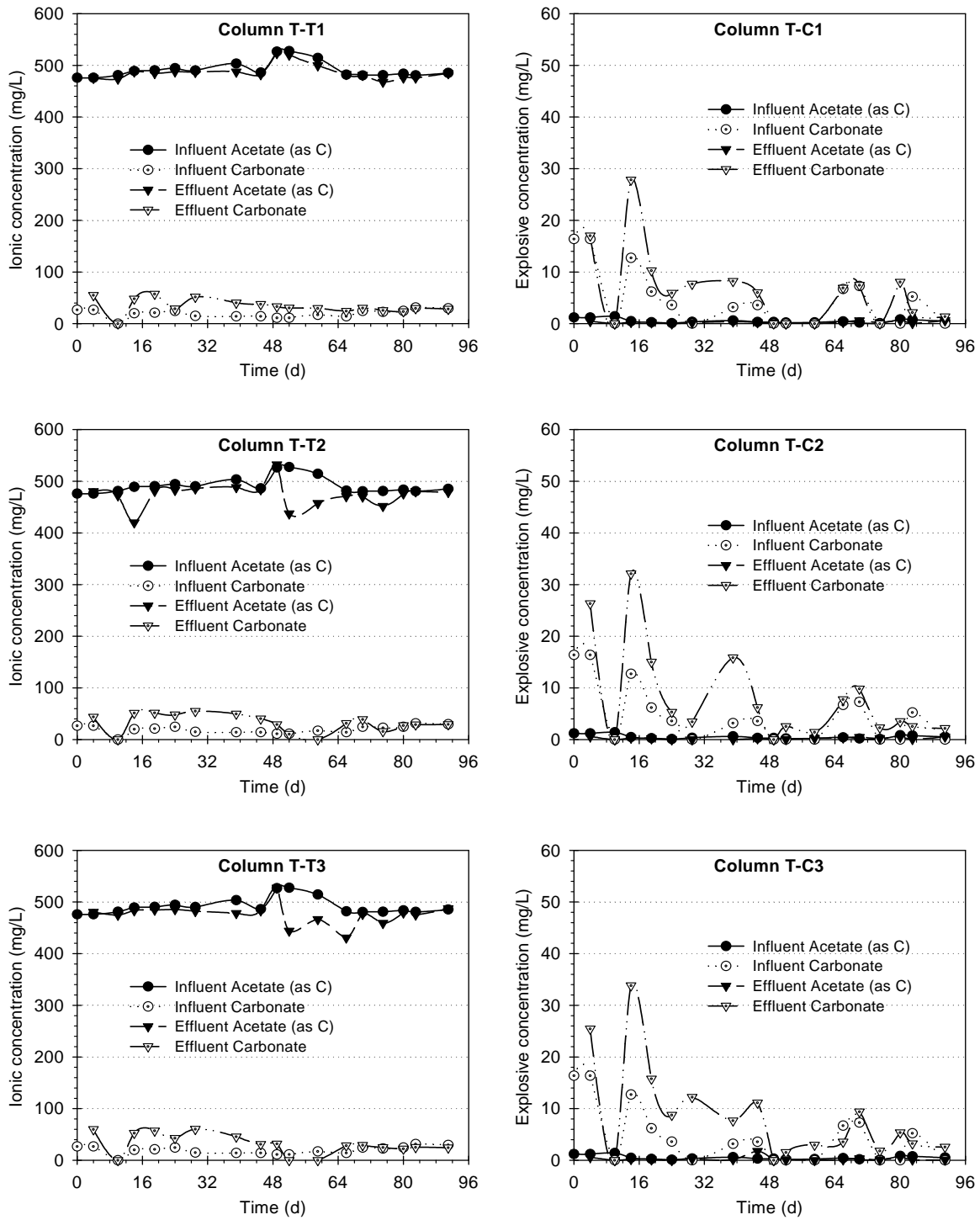


Figure 9. Amendment concentration in influent and effluent streams

### ***RDX biodegradation kinetics***

The rate of transformation of RDX in individual columns, under each temperature condition, was evaluated by fitting the advection-dispersion transport model with the contaminant decay model (Equation 2) to the axial RDX concentration profile along the column length. Two bed profile samplings were carried out at three different temperatures (15, 10, and 5 °C) to determine the average rate of RDX biotransformation with time of operation. Each temperature test lasted for 30 days, and bed profile samples were collected from intermediate ports along the column length at days 23 and 30.

Overtime, the two concentration profiles did not vary for the individual columns; however, Column T-T2 behaved differently from the other two treatment columns. The presence of acetate as a carbon source (electron donor) resulted in the transformation of RDX into different nitroso-substituted products in the treatment columns. In the control columns (where no acetate was added) no biotransformation of RDX was observed throughout the column length. In all the bed profile tests performed at various operating temperatures, the predominant transformation product identified at intermediate ports in Column T-T2 was MNX, but in Columns T-T1 and T-T3 a sequential biotransformation of RDX into MNX, DNX, and TNX was observed. This pattern of transformation products may be a result of presence of different microbial consortia because Column T-T2 was more reduced than Columns T-T1 and T-T3, which might have changed the microbial dynamics. Kitts, et al. (1994) observed the similar variable microbial ability to transform RDX. The researchers reported that two species (*Morganella morganii* and *Providencia rettgeri*) completely transformed RDX and subsequent nitroso-substituted intermediates, and a third one (*Citrobacter freundii*) partially transformed RDX and generated high concentrations of nitroso-substituted intermediates. Bed profile analysis at individual operating temperature is described in detail in the following paragraphs.

Axial RDX and its nitroso-transformation product concentration profiles during two bed profile tests carried out at 15 °C are shown in Figures 9 and 10. There was no significant difference between the two bed profile analyses for the individual columns. In Columns T-T1 and T-T3 the three nitroso-substituted metabolites were observed in a typical sequential manner with MNX followed by DNX and then TNX. However, in both the bed profile tests very low levels of MNX, and seldom DNX and TNX were observed in Column T-T2. Furthermore these transformation products were very short lived because of the very reduced conditions

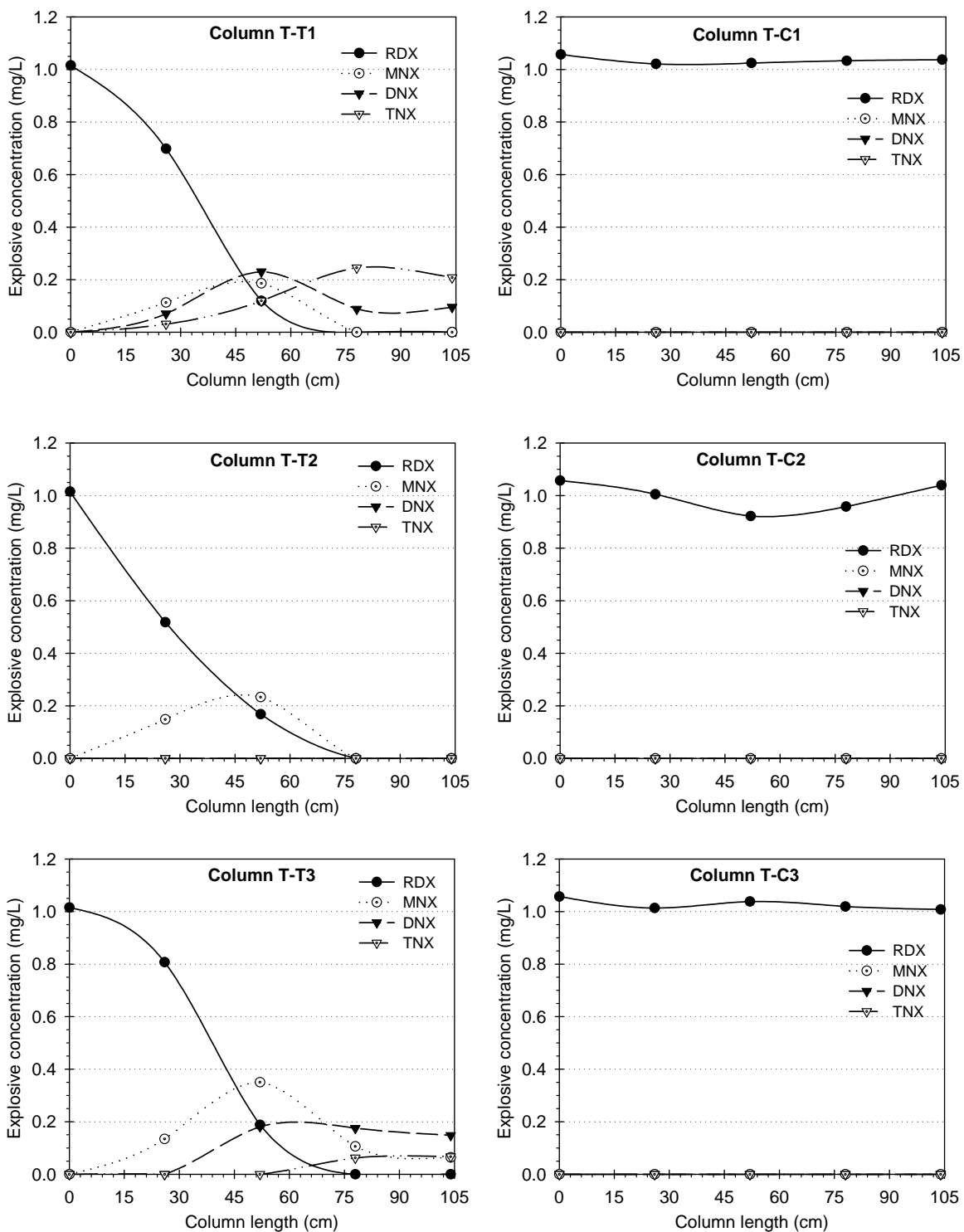


Figure 10. Axial concentration profile of RDX and its nitroso-substituted metabolites at 15°C (Test 1)

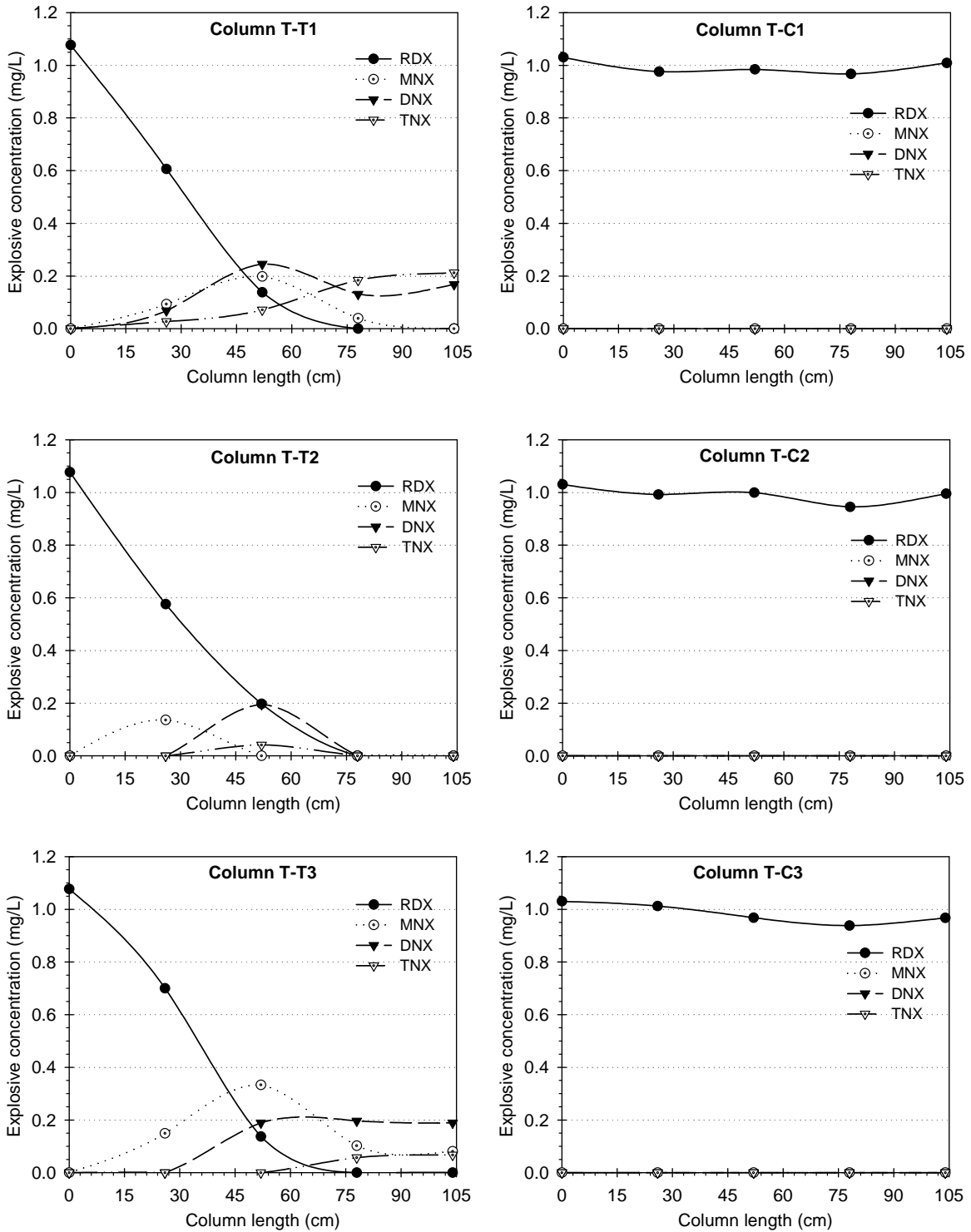


Figure 11. Axial concentration profile of RDX and its nitroso-substituted metabolites at 15°C (Test 2)

( $\Delta E_h = -850$  mV) in Column T-T2. In the control columns, no biotransformation of RDX was observed along the column length because of the lack of a reduced environment. In both bed profile tests, less than 1 percent of influent acetate concentration (about 500 mg/L as carbon) was used by the biological activity in the treatment columns (Figure 12). Very low ( $\sim 50$  mg/L) levels of carbonate were observed at intermediate ports in treatment columns.

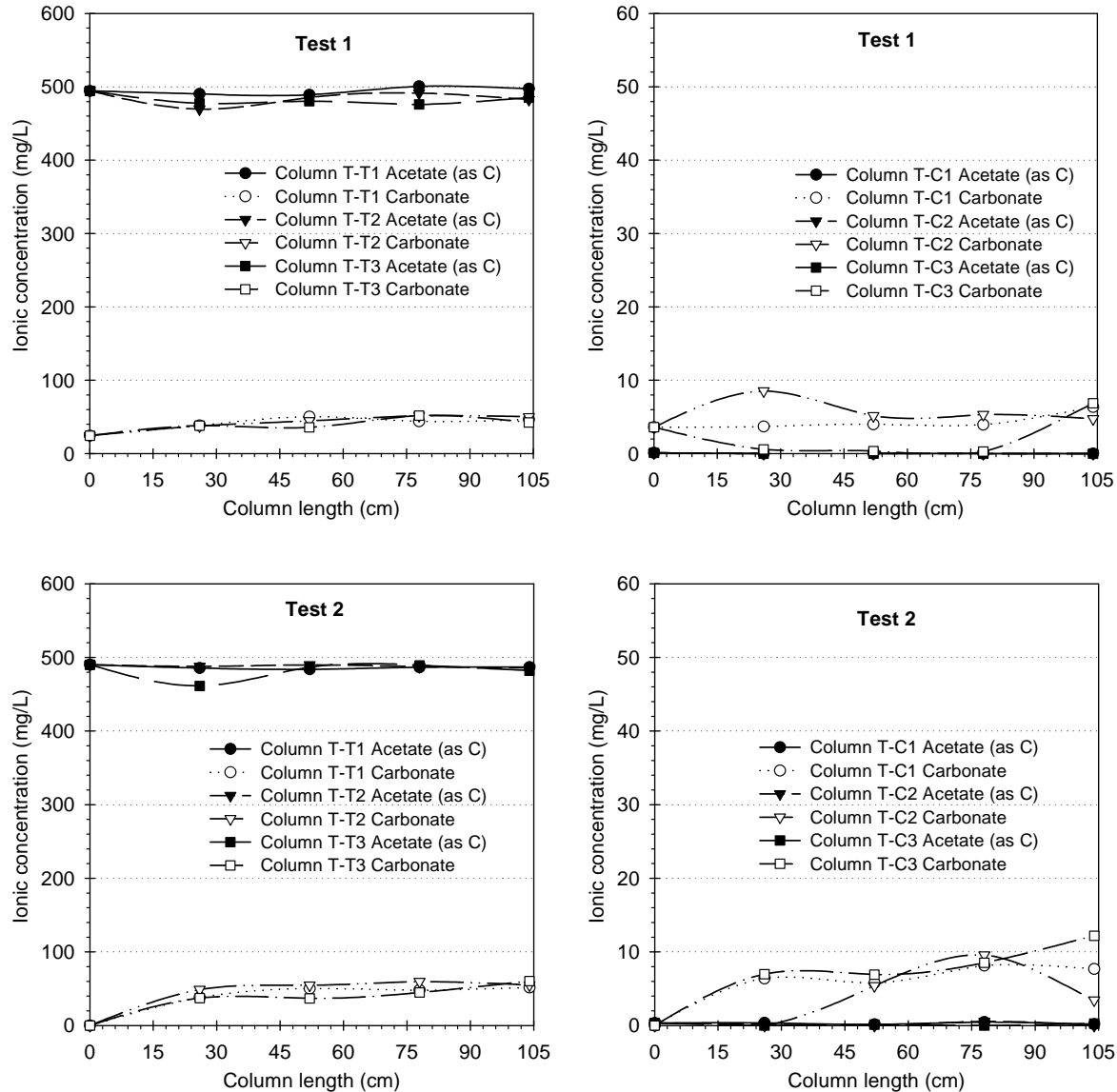


Figure 12. Axial concentration profile of acetate and carbonate at 15°C (Tests 1 and 2)

Figure 13 illustrates the RDX biodegradation kinetic data for treatment columns at 15 °C. The advection-dispersion transport model with contaminant decay given in Equation 2 fitted very well to RDX concentration data from both bed profile tests. The first-order degradation rate

coefficient  $k$  for RDX varied between 0.1297 and 0.1864 1/hr for the three treatment columns, with an average  $k$  value of 0.155 1/hr (standard deviation of 0.019). At this average  $k$  value the time needed for 50 percent removal of RDX is approximately 4.5 hr. RDX biodegradation kinetic parameters for individual columns are summarized in Table 8.

**Table 7. RDX Biodegradation Rate Kinetics at Three Different Temperatures**

Column	First –order biodegradation rate coefficient, $k$ (1/hr)					
	Temperature 15 °C		Temperature 10 °C		Temperature 5 °C	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
T-T1	0.1455	0.1864	0.1242	0.1022	0.0604	0.0775
T-T2	0.1632	0.1548	0.0995	0.1017	0.0679	0.0769
T-T3	0.1297	0.1511	0.0896	0.0721	0.0422	0.0424
Average	0.155 ( $\pm 0.019$ )		0.098 ( $\pm 0.017$ )		0.061 ( $\pm 0.016$ )	

Average represents the mean of two tests for all the three treatment columns at a particulate temperature. Values in parenthesis are the standard deviation ( $n = 6$ ).

Bed profile tests conducted at 10 °C are shown in Figures 13 and 14. There was no noticeable difference in the axial concentration of RDX and its nitroso-substituted transformation products in treatment columns. Similar to 15 °C tests, in Columns T-T1 and T-T3 a typical sequential transformation of RDX into MNX, DNX, and TNX was observed. Contrary to 15 °C test, measurable levels of RDX were also observed in the effluent stream of these two columns. Furthermore, in both the bed profile tests the levels of these nitroso-substituted transformation products were higher than those found at 15 °C. In Column T-T2, although no RDX or nitroso-substituted metabolites were observed in the effluent stream, RDX degradation was considerably delayed along the column height. These results indicate the adverse effect of lower temperature on biological activity responsible for RDX biotransformation. No biotransformation of RDX was observed in either of the control columns because of lack of reduced conditions. In both bed profile tests, very little influent acetate (~500 mg/L as carbon) was utilized by the biological activity in the treatment columns (Figure 16). Significantly low (~50 mg/L) levels of carbonate were observed at intermediate ports in treatment columns.

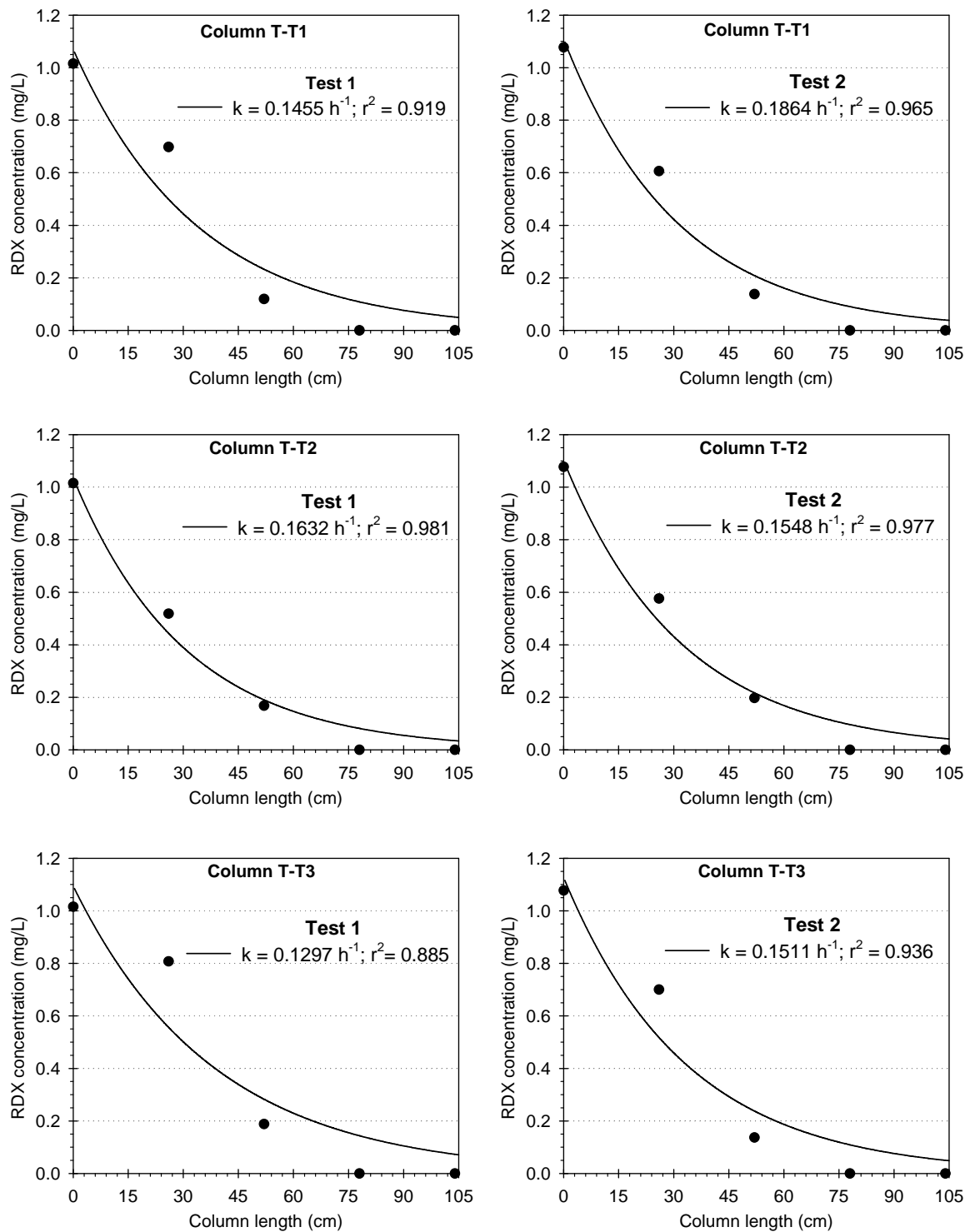


Figure 13. RDX biodegradation kinetic analysis in treatment columns at 15 °C (Tests 1 and 2)



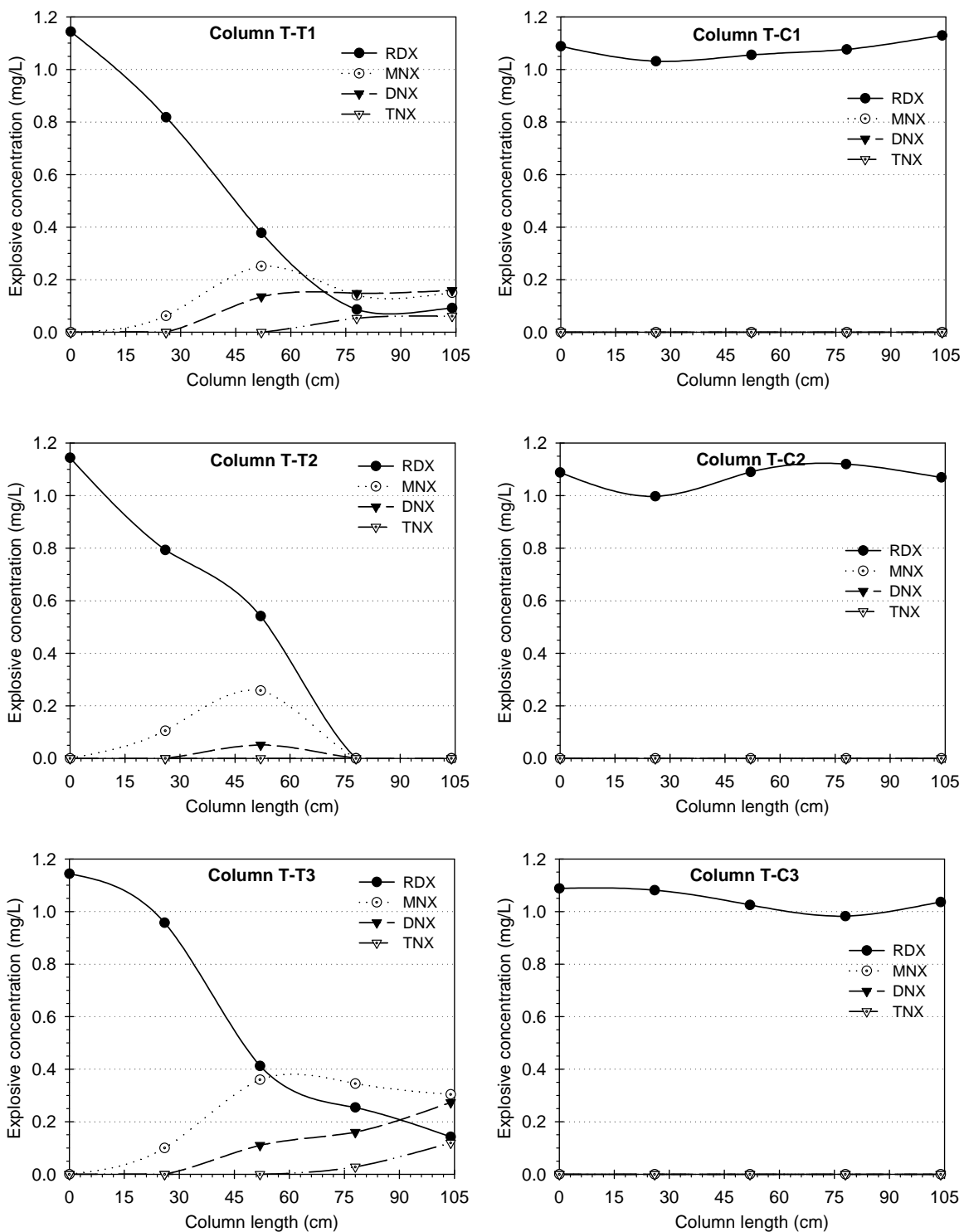


Figure 14. Axial concentration profile of RDX and its nitroso-substituted metabolites at 10°C (Test 1)

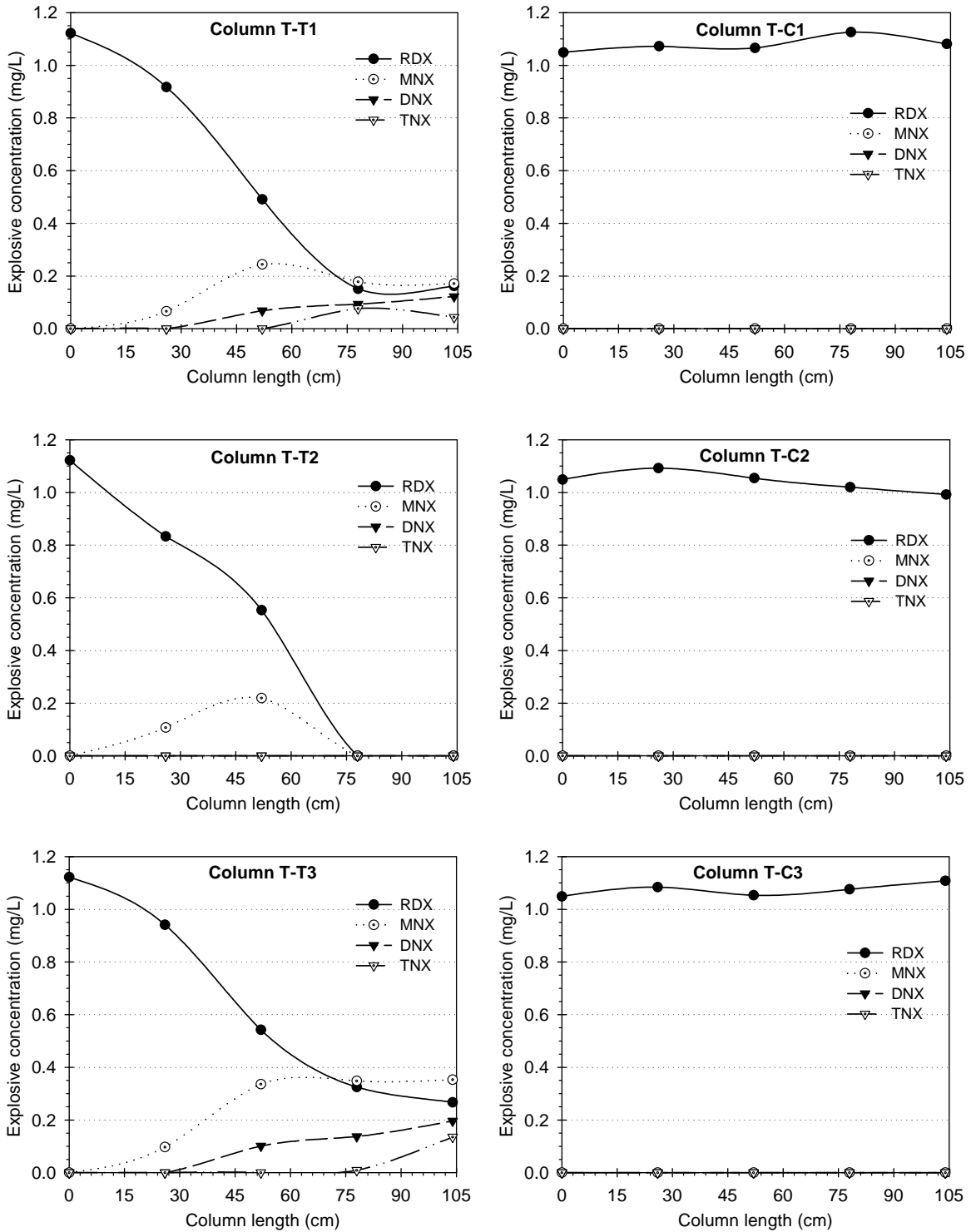
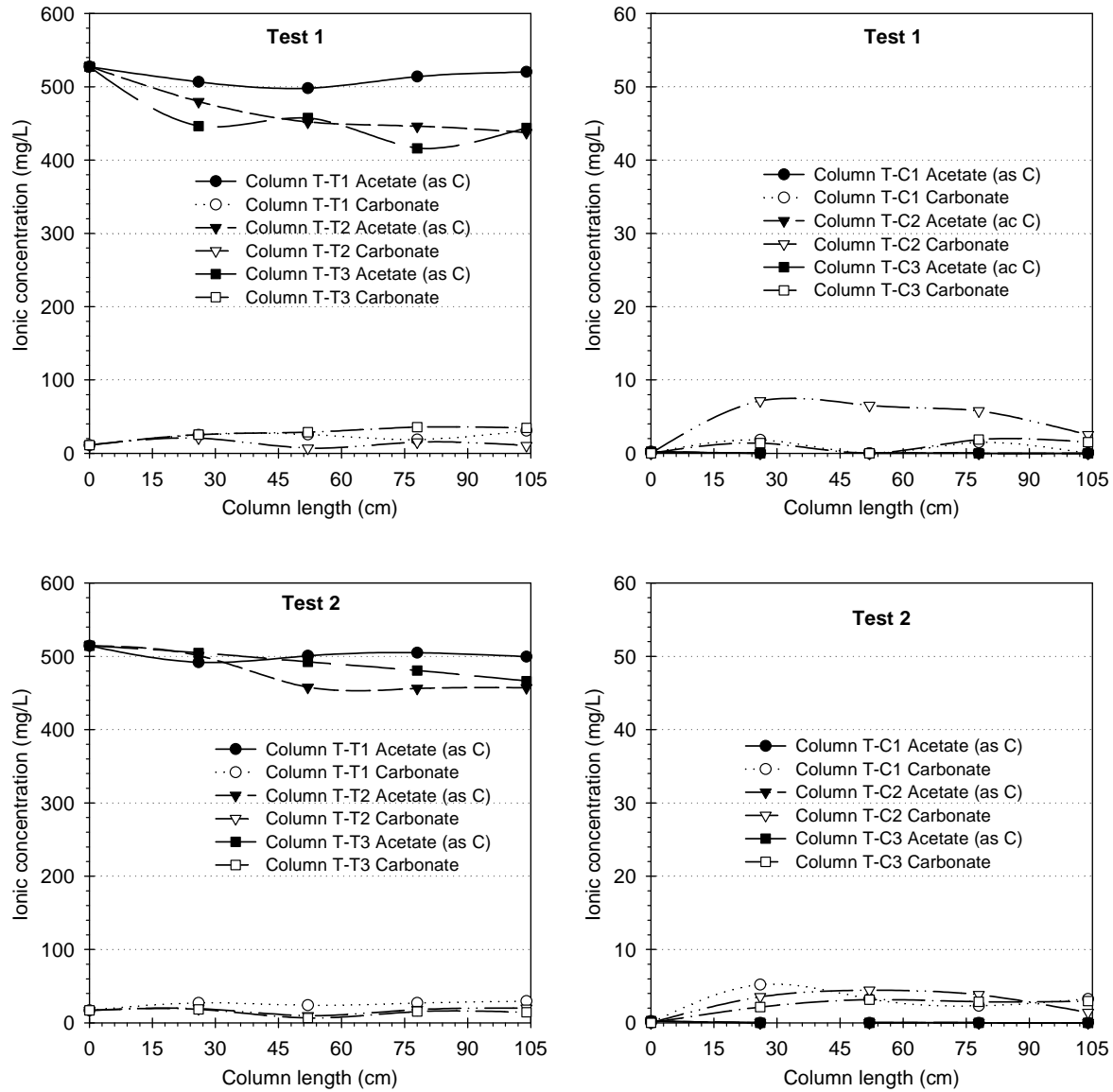


Figure 15. Axial concentration profile of RDX and its nitroso-substituted metabolites at 10°C (Test 2)



**Figure 16. Axial concentration profile of acetate and carbonate at 10°C (Tests 1 and 2)**

RDX biodegradation kinetic data for treatment columns at 10 °C are shown in Figure 17. Equation 2 fitted very well to the axial RDX concentrations from both the bed profile tests for all the three treatment columns. The first-order biodegradation rate coefficient  $k$  values for RDX were significantly lower than those for 15 °C, and varied between 0.0721 and 0.1242 1/hr for the three treatment columns (Table 8). At the average  $k$  value of 0.098 1/hr (standard deviation of 0.017), time needed for the removal of half of influent RDX concentration is approximately 7 hr, roughly 50 percent longer

than the time needed for the same percent removal at 15 °C. These results quantitatively demonstrate the adverse effects of lower aquifer temperature on biological activity and eventual RDX biotransformation rate. At 5 °C two bed profile tests were performed. The results of axial concentrations of RDX, MNX, DNX, and TNX in treatment and control columns are shown in Figures 17 and 18.

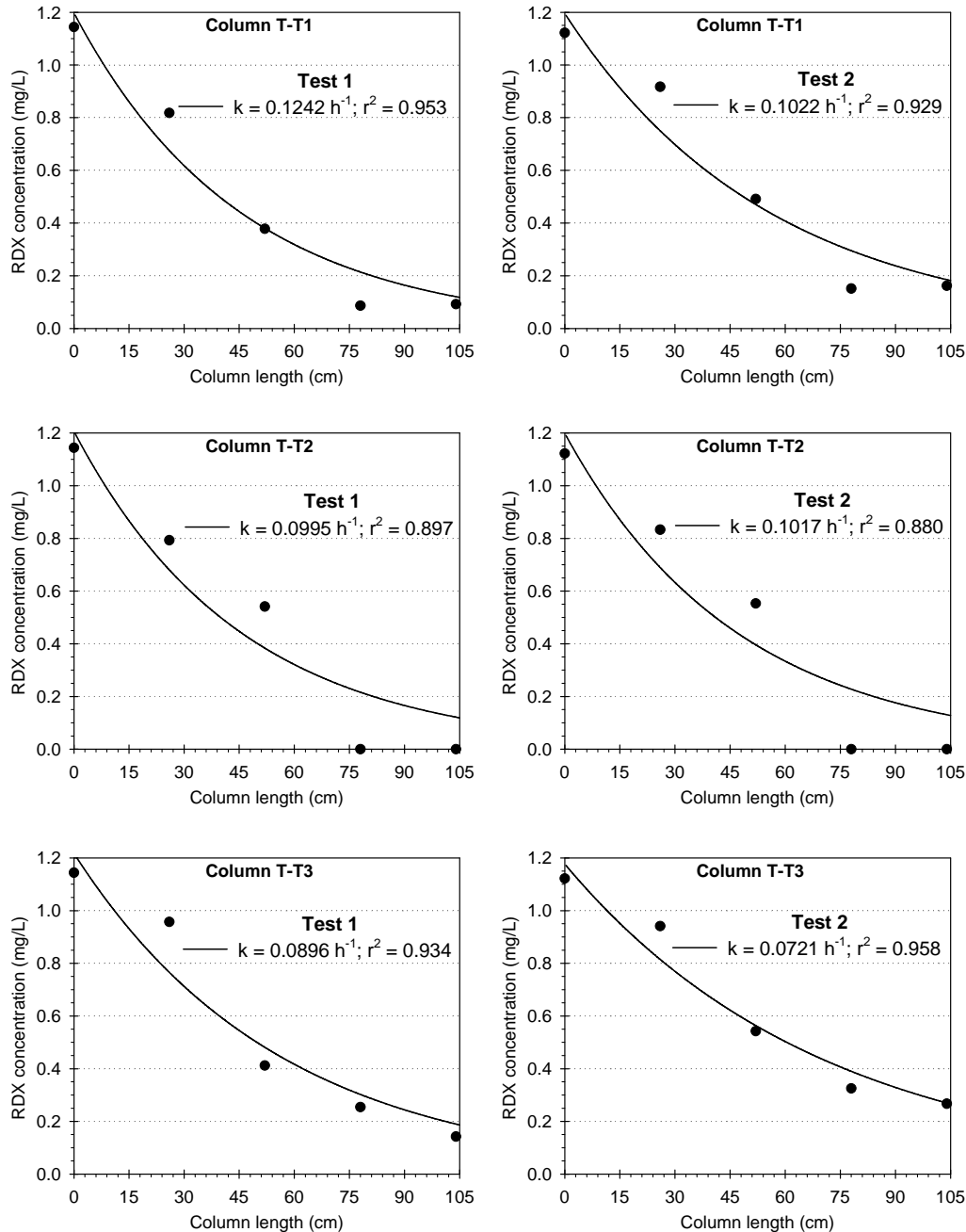


Figure 17. RDX biodegradation kinetic analysis in treatment columns at 10 °C (Tests 1 and 2)

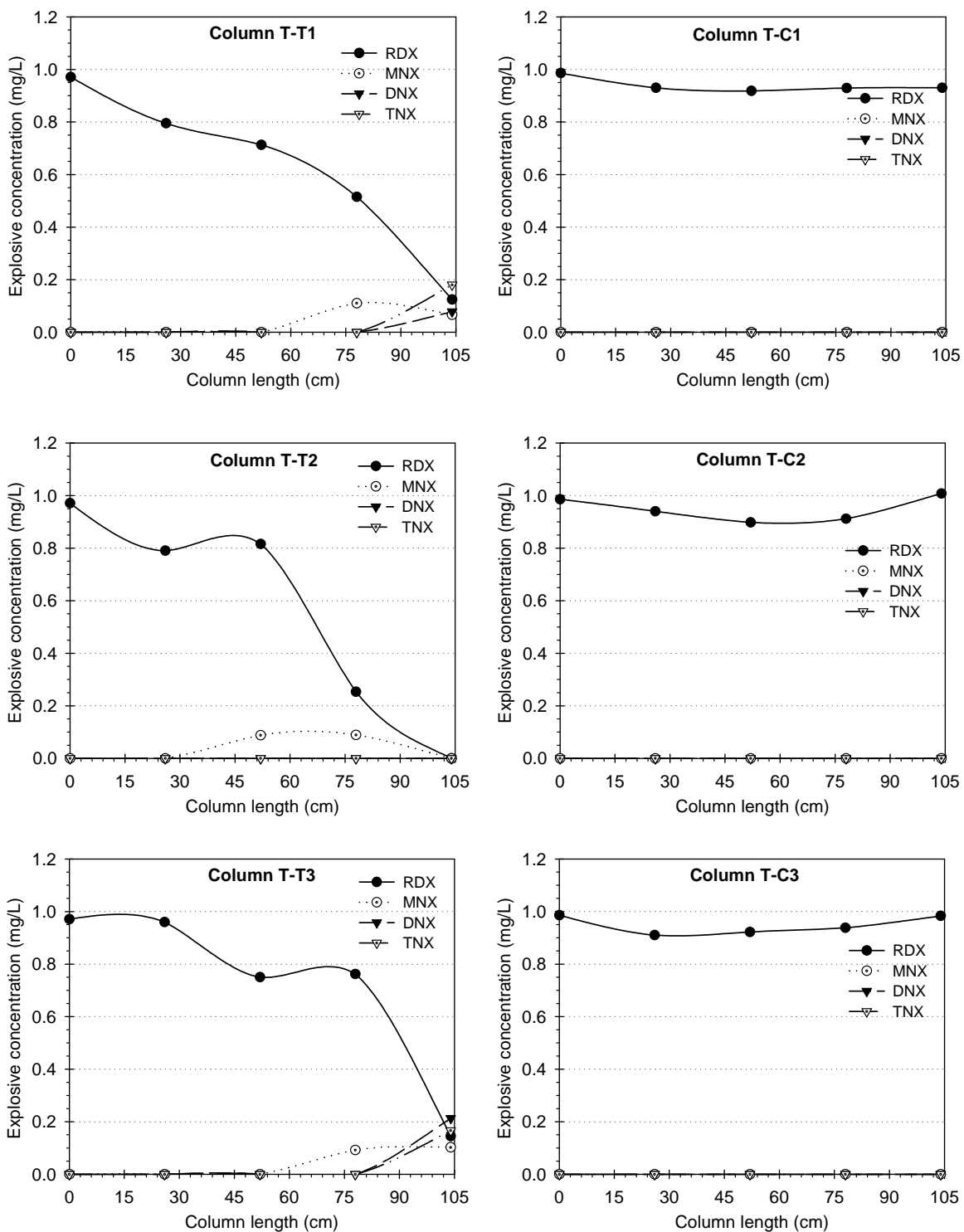


Figure 18. Axial concentration profile of RDX and its nitroso-substituted metabolites at 5°C (Test 1)

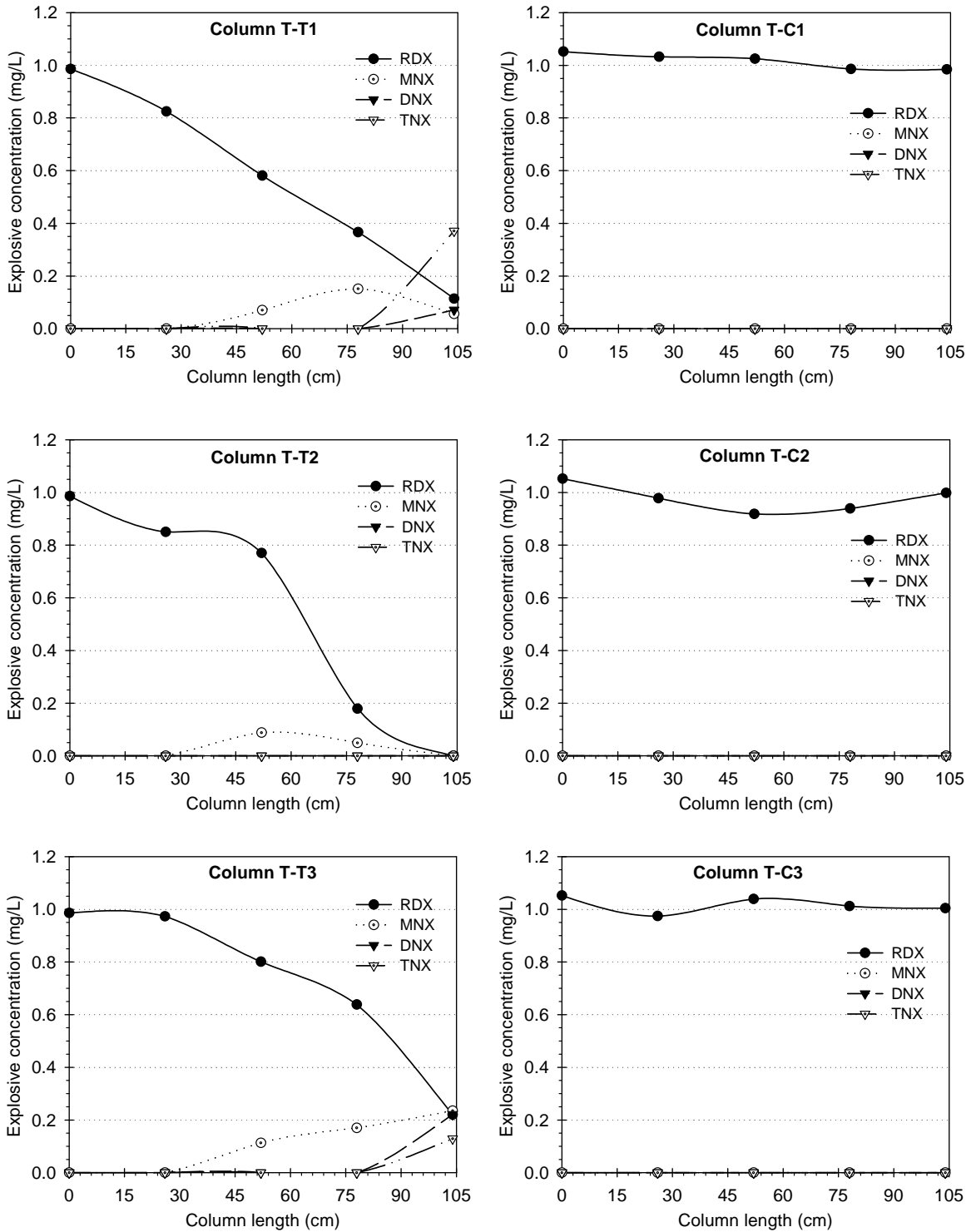


Figure 19. Axial concentration profile of RDX and its nitroso-substituted metabolites at 5°C (Test 2)

Explosives concentration profiles did not show any noticeable differences between the two bed profile analyses. Unlike the previous two tests conducted at 15 and 10 °C, low concentrations of RDX and MNX were observed in the effluent stream of each column during the 5 °C test. Concentrations were generally lower in Column T-T2. Additionally, in Columns T-T1 and T-T3 measurable concentrations of DNX and TNX were found in the effluent stream. No DNX or TNX was observed in Column T-T2, and the transient concentrations of MNX at intermediate sampling ports were not present in the column effluent. As discussed previously, the different behavior of Column T-T2 resulted primarily from the very reduced conditions ( $\Delta Eh = -850$  mV) in this column compared with Columns T-T1 and T-T3. In the control columns, no biotransformation of RDX was observed along the entire column length because of lack of reduced conditions. In both bed profile tests, little of the influent acetate (~500 mg/L as carbon) was utilized by the biological activity in the treatment columns (Figure 20). Very low (~30 mg/L) levels of carbonate were observed at intermediate ports in treatment columns. Figure 21 illustrates the RDX biodegradation kinetic analysis at 5 °C. The first-order degradation rate coefficient  $k$  for RDX varied between 0.0422 and 0.0775 1/hr (Table 8) for the three treatment columns, with an average  $k$  value of 0.061 1/hr (standard deviation of 0.016). These  $k$  values are significantly lower than the  $k$  values obtained at 15 and 10 °C. The estimated time needed for biodegradation of half of the influent RDX concentration at this average  $k$  value is approximately 11.3 hr.

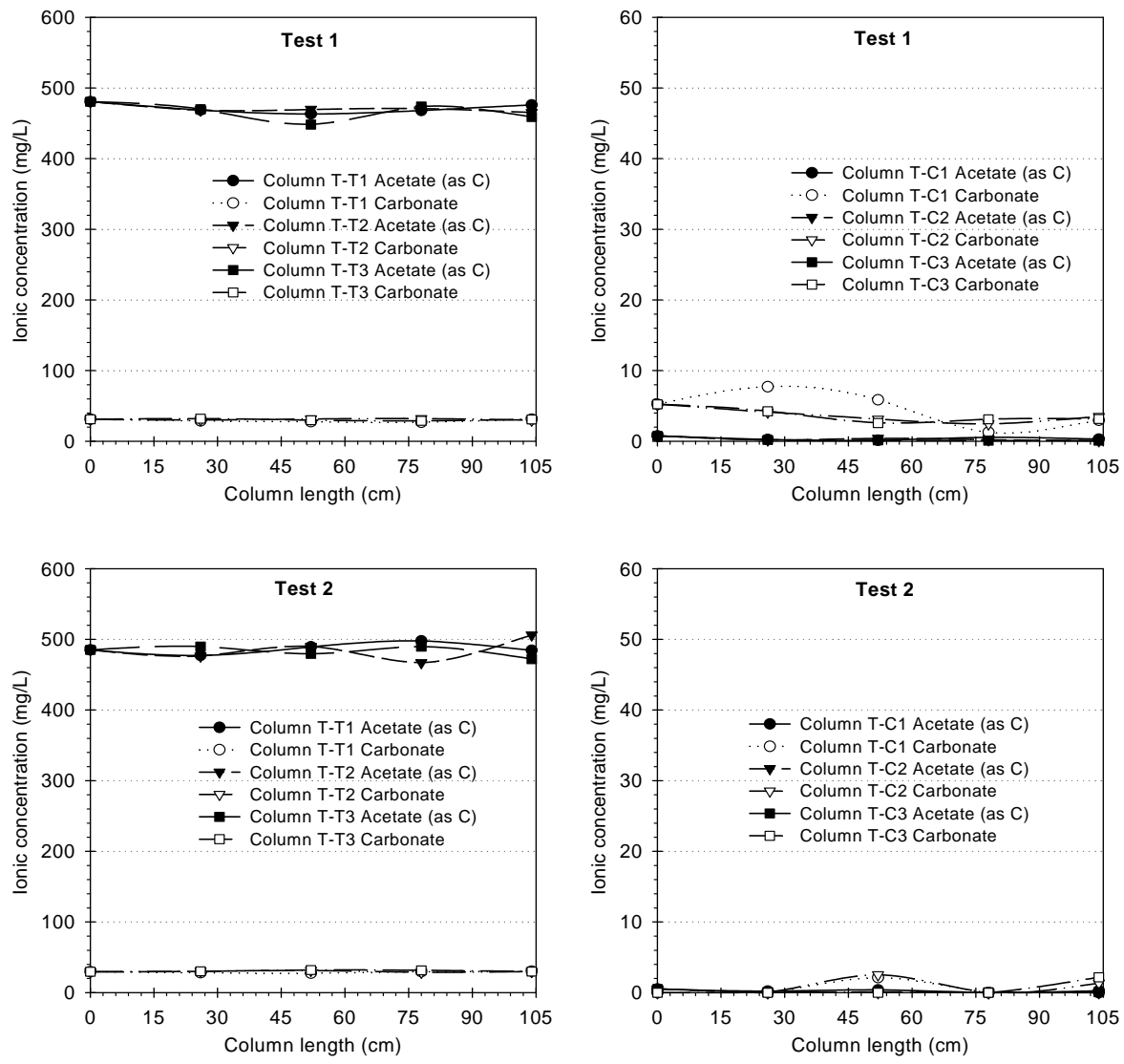
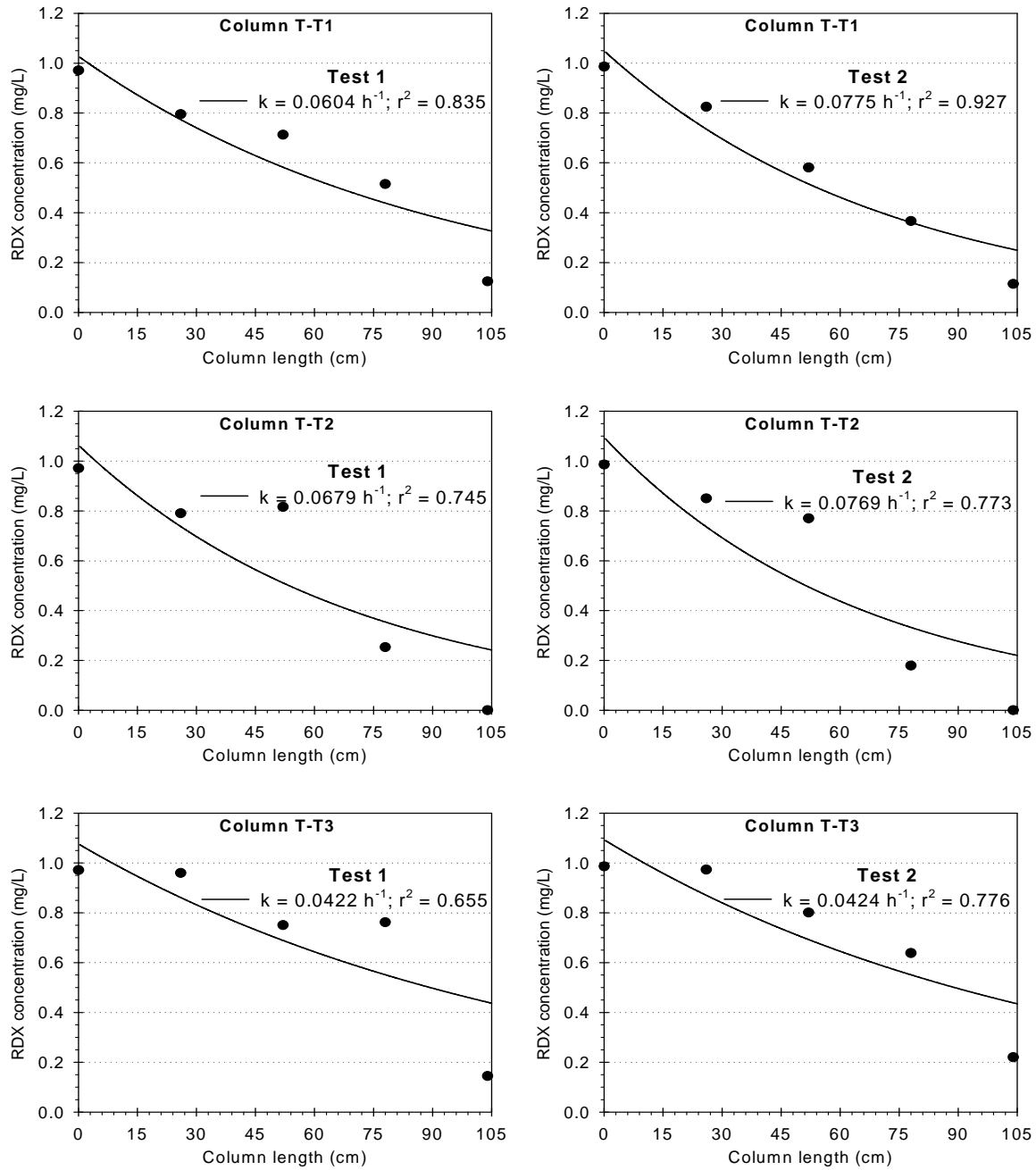


Figure 20. Axial concentration profile of acetate and carbonate at 5°C (Tests 1 and 2)





**Figure 21. RDX biodegradation kinetic analysis in treatment columns at 5 °C (Tests 1 & 2)**

The estimated  $k$  values at three different temperatures were significantly different (95% confidence) from each other. Statistical analysis was done by using Tukey Test for pairwise multiple comparisons. The results of ‘One Way Analysis of Variance’ showed that the

differences in the mean values of  $k$  ( $n = 6$ ) obtained at 5, 10, and 15 °C are statistically significant ( $P < 0.05$ ).

The influence of aquifer temperature on RDX biotransformation was estimated by fitting the Arrhenius model (Equation 3) to the average  $k$  values obtained at different temperatures. Figure 22 summarizes the relation between operating temperature and the estimated first-order biodegradation rate coefficients for RDX in treatment columns. As evident from Figure 22, aquifer temperature has a significant influence on the in situ biodegradation of RDX. For these experimental conditions, an activation energy of about 63.54 kJ/mol of RDX was estimated.

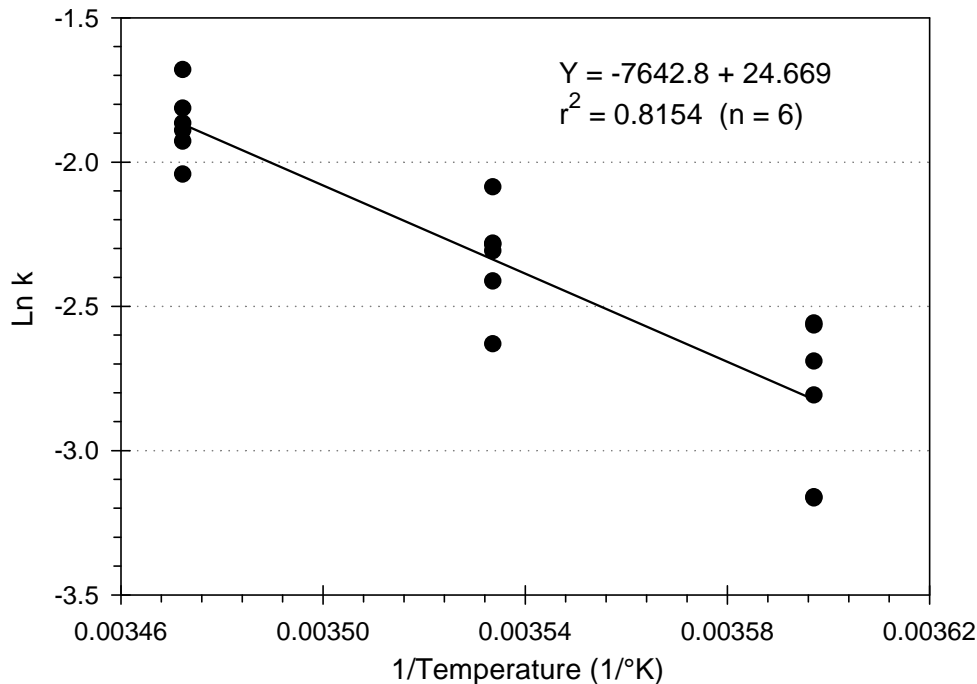


Figure 22. Temperature influence on RDX biotransformation kinetics

## Radiolabel Study

### *Column hydrodynamics*

RDX-contaminated water flow in both triplicate column sets during the 9-week study was around 0.2 mL/min, equivalent to a liquid velocity of 0.85 m/d (2.7 ft/d) (Figure 23). This water flow resulted in liquid residence time of approximately 24 hr in individual columns. Due to equipment breakdown only two columns were used for amendment treatment and control. The

slug of radiolabel RDX (~ 0.76  $\mu$ Ci) was introduced on day 51. After that 10 bed volumes of unlabeled RDX-contaminated groundwater were pumped through each column over the next 10 days to wash out any radioactivity sorbed on the aquifer material. As shown in Figure 23, groundwater flow rate during this time was slightly higher than 0.2 mL/min.

Anaerobic conditions were established in treatment columns by providing a carbon source to indigenous microorganisms, which then utilized oxygen, creating a reduced environment. In treatment columns,  $E_h$  drop was significant, ranging between -550 and -700 mV (Figure 23). The drop in redox potential was more significant in Column R-T2 (-700 mV) than in Column R-T1 (-550 mV). One possible reason may be a higher concentration of RDX degrading microorganisms that utilized oxygen in the presence of a readily available carbon source, creating very a reduced environment. This explanation of higher biomass was also evident from the back pressure data (Figure 23), which was highest in Column R-T2 probably due to biofouling. Since no carbon source was used in the control columns, the drop in redox potential was very small (between 70 and -70 mV) compared with those of the treatment columns.

Influent stream pH varied between 7 and 7.5 for treatment columns where RDX-contaminated water was amended with acetate as the electron donor (Figure 23). In the control columns, influent water pH was slightly higher, between 8 and 8.5. The effluent from treatment columns showed a slight increase in pH (8 to 8.5); however, in the control columns there was a slight decrease in effluent pH (6.5 to 7). The effluent from both treatment and control columns during the actual radiocarbon test (final 2 weeks of the study) was collected in an acid quencher (containing 1N HCl) to prevent the degradation of any untreated RDX in the effluent stream at high pH, and also to release any dissolved mineralization-carbon dioxide from the effluent

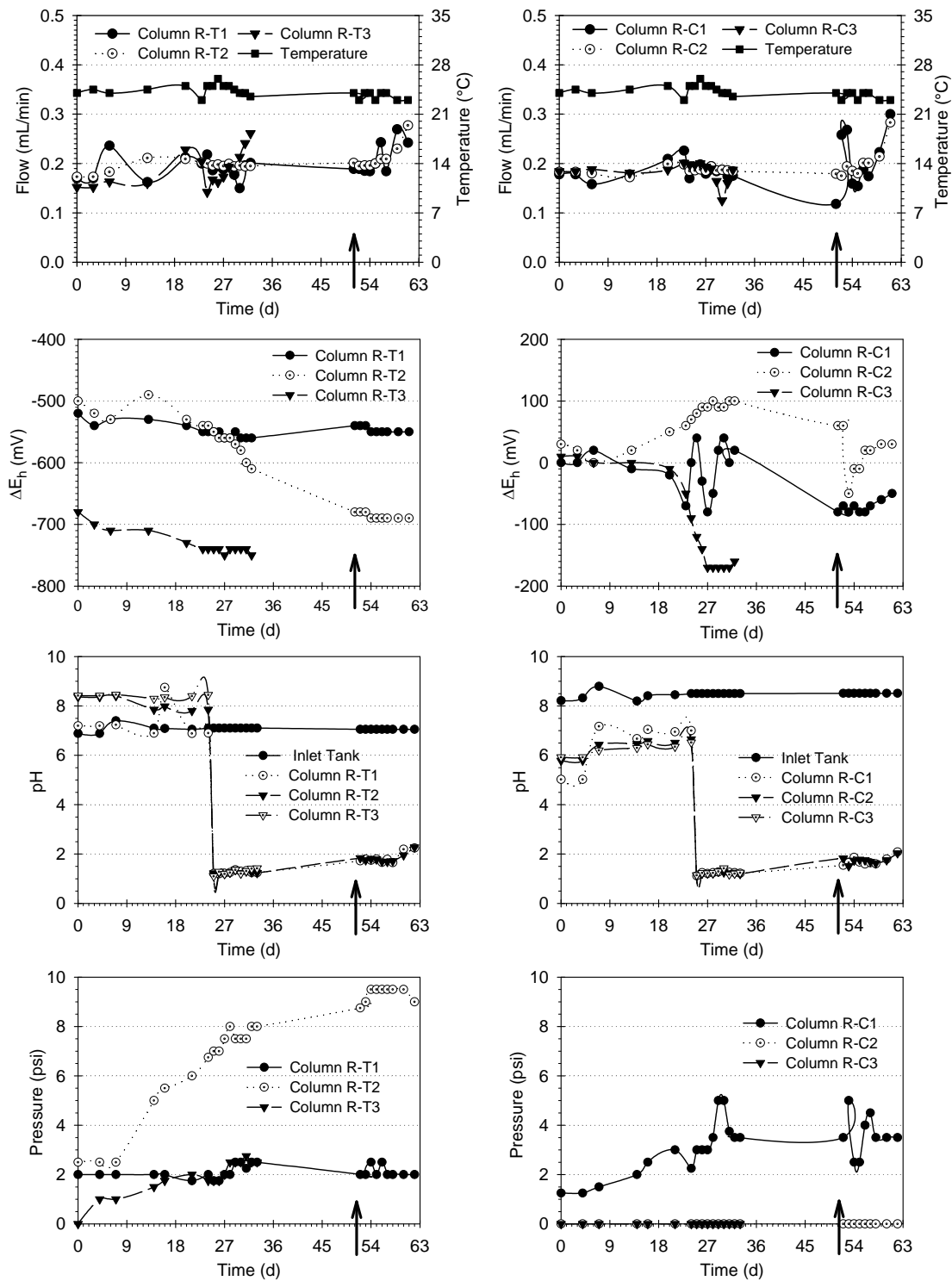


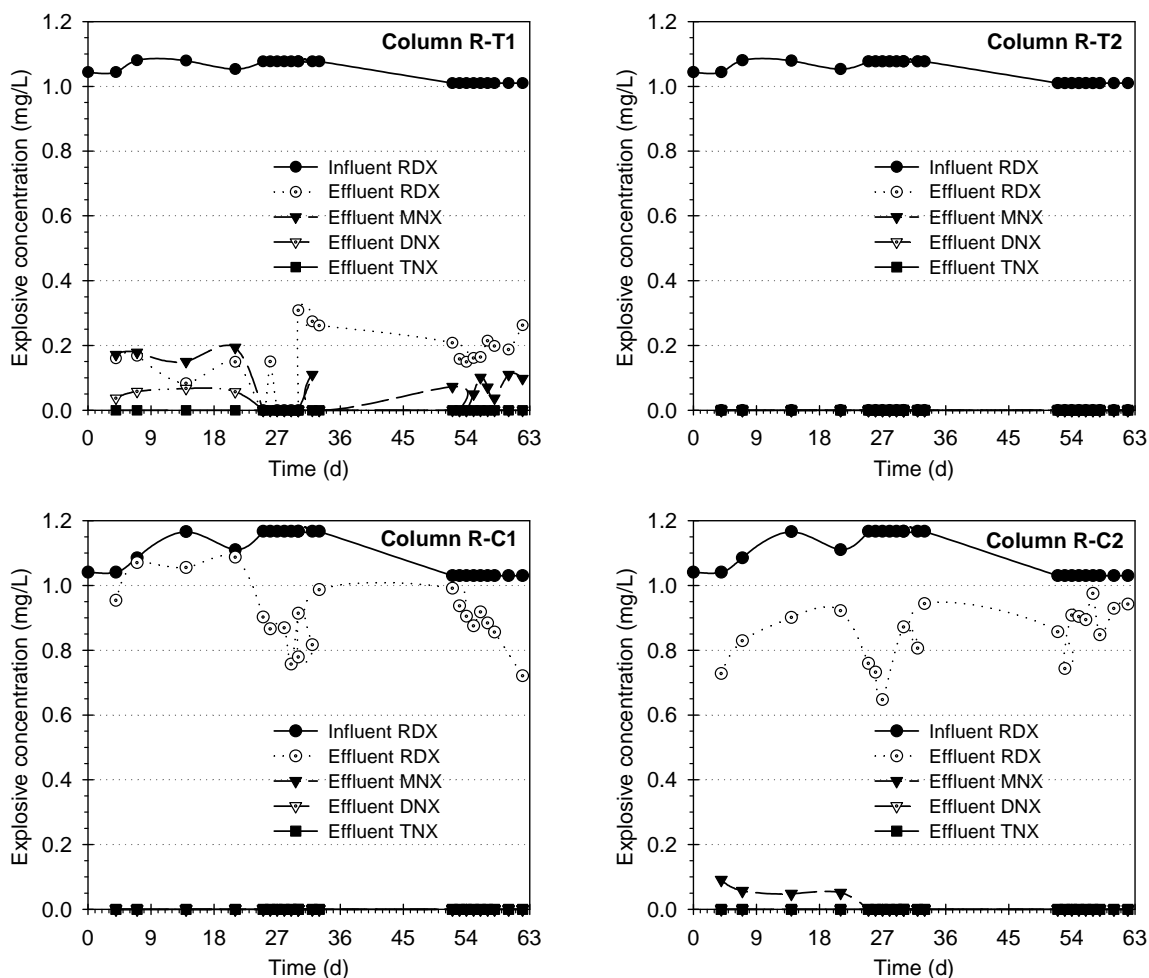
Figure 23. Feed water flow, change in redox, pH and backpressure in radiolabel columns

stream. The effluent stream pH (1.5 to 2) during the final 2 weeks of the test shown in Figure 23 actually is not the effluent stream pH rather the pH of the contents in the acid quencher.

There was no significant back pressure buildup due to biofouling in any of the columns except Column R-T2 where head loss increased steadily and remained around 70 kPa (10 psi) during the last 2 weeks (Figure 23). This increased back pressure could be the result of a higher biomass yield that coincided with the highest drop in redox potential in Column R-T2 because of increased biological activity consuming oxygen in the presence of the electron donor. Occasional hikes in the back pressure for Column R-C1 were due mainly to plugging of the porous PVC screen at the column inlets.

### ***RDX biotransformation***

RDX concentrations (around 1 mg/L) in the influent groundwater were reduced to below detection limits of 0.02 mg/L in Column R-T2 without the detection of any nitroso-substituted RDX derivatives. However, in Column R-T1 low concentrations of RDX, MNX, and DNX were observed in the effluent stream during acclimation stages, i.e., while the reductive environment was developing in the column (Figure 24). During the actual radiolabel test (final 2 weeks of the study) as the redox decreased, only low concentrations of RDX and MNX were observed in the effluent stream. In Column R-T2 the redox was very low compared with Column R-T1, which may explain the RDX biodegradation without the detection of any nitroso metabolites. Column R-T2 also exhibited steady increase in back pressure (Figure 24). One plausible reason behind these two manifest observations in Column R-T2 could be a higher biomass yield that caused RDX biodegradation without the detection of any nitroso transformation products and at the same time created a higher flow resistance resulting in higher back pressure along the column length. The assumption of high biomass yield is also substantiated by the lowest redox potential in Column R-T2 as a result of higher biological activity. The cumulative presence of untreated RDX and nitroso-substituted RDX metabolites in Column R-T1 accounted for about 20 percent of the influent RDX concentration. The unaccounted 80 percent of the inlet RDX might include volatile (including mineralized carbon dioxide) and nonvolatile non-nitroso-transformation products as proposed by other researchers (Hawari et al. 2000a, 2000b; McCormick et al. 1981). In Column R-T2, entire initial RDX concentration was transformed into volatile and nonvolatile non-nitroso-substituted transformation products.



**Figure 24. RDX and nitroso-derivatives concentration in influent and effluent from radiolabel columns**

In control columns very little biodegradation of RDX was observed throughout the course of study (Figure 24). Especially during the last 2 weeks of the study, when radiolabel was introduced, about 8-10 percent of the initial RDX concentration was biodegraded/transformed into products other than nonvolatile nitroso-substituted derivatives, because MNX, DNX, or TNX was not observed in the effluent stream.

During the 9-week study, RDX was removed from the groundwater and low levels of nitroso-substituted transformation products were detected in the treatment Column R-T1; however, in treatment Column R-T2 effluent none of the nitroso-derivates was observed. This variation in RDX end products within these two treatment columns was mainly redox dependent. In Column R-T1,  $\Delta E_h$  between influent and effluent stream was around  $-550$ , whereas  $\Delta E_h$  was very low ( $-700$  mV) in Column R-T2 where none of the nitroso-substituted transformation products was observed in the effluent stream. In control columns very little RDX was biodegraded. In these control columns  $\Delta E_h$  between influent and effluent was between  $50$  and  $-60$  mV. From these

results, it appears that two pathways that are highly redox dependent may be present. One pathway is sequential reductive transformation of nitro functional groups to nitroso-derivatives (Figure 2) as reported for various RDX-metabolizing cultures that use organic electron donors (Freedman and Sutherland 1998; Hawari et al. 2000a; Beller and Tiemeier 2002; McCormick et al. 1981). Another pathway may be the direct attack of the ring as proposed by Hawari et al. (2000b). This direct attack resulting in ring cleavage may be active only at low redox potentials. Similar results of non-nitroso-substituted reductive biotransformation of [ $^{14}\text{C}$ ]RDX by aquifer microorganisms have been reported by Beller (2002). MDNA, a non-nitroso ring cleavage intermediate has been recently identified by Oh et al. (2001) and Halasz et al. (2002).

### ***Radiocarbon ( $^{14}\text{C}$ ) distribution***

The distribution of radiocarbon ( $^{14}\text{C}$ ) in treatment and control columns is summarized in Figure 25. In each column a slug of 0.77  $\mu\text{Ci}$  (1.7 million dpm) of radiolabel RDX was added in the inlet tank. The final mass balance on radiocarbon ranged between 76 and 87 percent in treatment columns, and more than 91 percent in control columns. The radiocarbon activity was distributed into three different carbon fractions: (a) dissolved (as aqueous soluble compounds), (b) mineralized (as carbon dioxide), and (c) anabolized (assimilated on biomass and/or sorbed on suspended material). The distribution of these three carbon fractions was different in treatment and control columns.

The observed distribution of radiocarbon was quite different in the treatment columns. In Column R-T1 mass balance on  $^{14}\text{C}$  accounted for 87 percent of initial activity, with approximately 65 percent in the dissolved fraction and 22 percent as mineralized carbon dioxide (Figure 25). The mass balance of radiocarbon in Column R-T2 accounted for about 76 percent of initial  $^{14}\text{C}$  activity. In Column R-T2 the mineralized fraction (~46 percent) was much higher than the dissolved fraction (~30 percent). One plausible reason behind higher rate of mineralization in Column R-T2 may be higher concentration of biomass in this column that coincided with the higher back pressure because of biofouling as well as a higher drop in redox potential (Figure 23) as a result of higher utilization of oxygen by these RDX-degrading

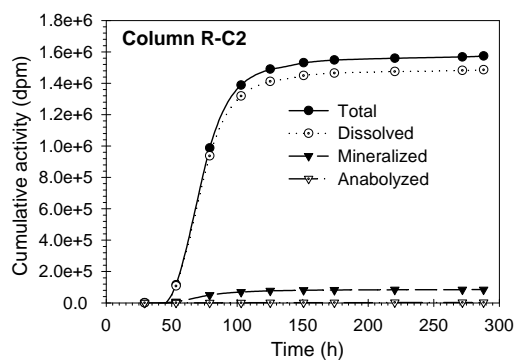
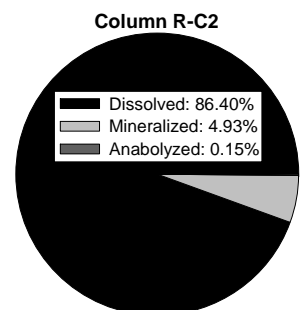
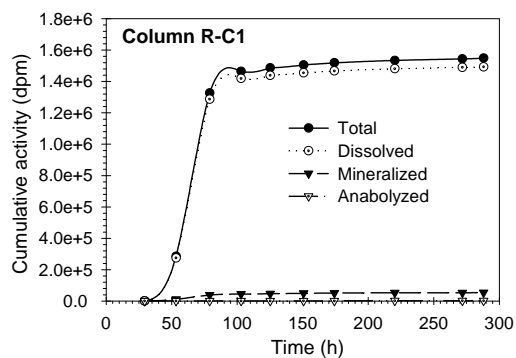
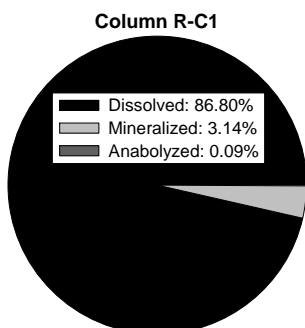
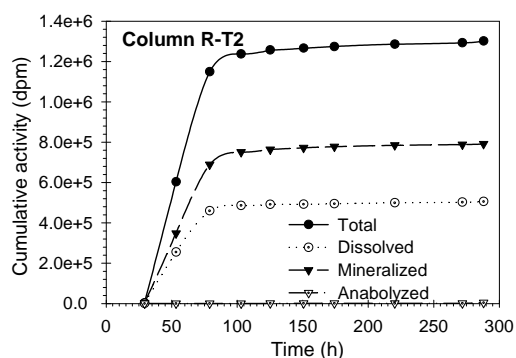
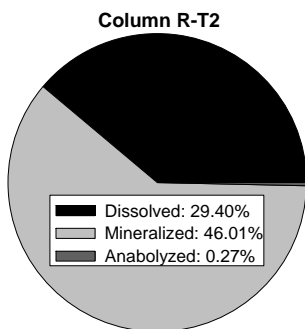
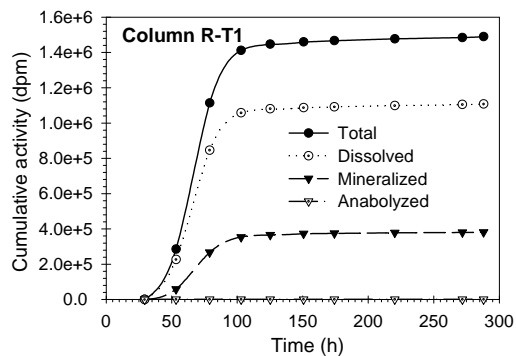
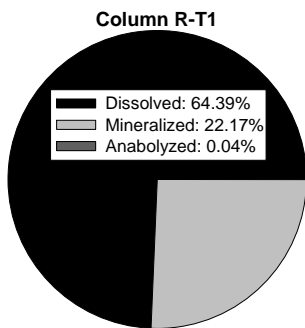


Figure 25. Distribution of  $^{14}\text{C}$  activity from  $[^{14}\text{C}]\text{RDX}$  in radiolabel columns



microorganisms. Even though a considerable amount of initial radiocarbon was mineralized to carbon dioxide by resident RDX-degrading microorganisms in both treatment columns, only a negligible amount was assimilated into biomass because the suspended fraction accounted for less than half a percent of initial activity (Figure 25).

Other researchers have measured mineralization of [ $^{14}\text{C}$ ]RDX under reducing conditions with varying results. McCormick et al. (1981) recovered 1.5 percent of initial radiocarbon as  $^{14}\text{CO}_2$  during anaerobic degradation of [ $^{14}\text{C}$ ]RDX. Similar results, with <2 percent mineralization of radiolabel RDX were reported by Beller (2002) using enrichment cultures with hydrogen as a sole electron donor. Kitts et al. (1994), studying three different bacterial species, recovered 5-9 percent of initial  $^{14}\text{C}$  as  $^{14}\text{CO}_2$  under anoxic conditions. Morley et al. (2002) recovered 8-30 percent of the initial [ $^{14}\text{C}$ ]RDX as  $^{14}\text{CO}_2$  in their batch experiments with ethanol and mixed carbon (mixture of glucose, glycerol, and succinate) as sole electron donors. An exceptionally high (60 percent) conversion of [ $^{14}\text{C}$ ]RDX to  $^{14}\text{CO}_2$  has been reported by Shen et al. (2000) in treating contaminated soil slurries using municipal anaerobic sludge. These studies demonstrate a wide range of mineralization potential of different microbial consortia using various carbon sources as electron donors.

The final mass balance closure in treatment columns indicates a failure to measure possible  $^{14}\text{C}$  end products. Other researchers have reported similar problems in accounting for all the radiocarbon end products in their batch experiment where the final mass balance closure was only 79 percent of the initial [ $^{14}\text{C}$ ]RDX (Morley et al. 2002). The unaccounted fraction of the initial  $^{14}\text{C}$  activity in these treatment columns probably was converted to some products other than mineralized carbon dioxide and nonvolatile nitroso-metabolites. Previously Beller (2002) has reported that about 0.8 percent of [ $^{14}\text{C}$ ]RDX was converted to volatile carbon other than carbon dioxide by enrichment cultures with hydrogen as the sole electron donor. However, in this study no attempt was made to identify these non-carbon dioxide volatile carbon compounds. In treatment columns, the dissolved fraction contained very low or undetectable concentrations of such nonvolatile nitroso-substitutes as MNX, DNX, or TNX. The RDX degraders (a mixed aquifer culture) present in the columns converted RDX to nonvolatile metabolites other than MNX, DNX, and TNX. Metabolites such as hydrazine, 1,1-dimethyl- and 1,2-dimethylhydrazine, MDNA, and formaldehyde that have previously been identified (Hawari, et al 2000a, 2000b; McCormick, et al. 1981) with anaerobic RDX biodegradation may have been operationally included with nonvolatile carbon in this study. No specific analyses were performed to identify these compounds, some of which are known to be unstable in aqueous solution.

In control columns, the majority (>86 percent) of the initial radiocarbon was in the dissolved phase, and very little (<5 percent) was mineralized. The fraction of  $^{14}\text{C}$  in biomass and on suspended matter was negligible (Figure 25). Because of the lack of a carbon source, the redox potential in the control columns was not conducive to degradation of RDX. Also in the absence of a carbon source the biomass was not able to cometabolize RDX effectively. Distribution of  $^{14}\text{C}$  over time, illustrated in Figure 25, shows a steady increase in the identified radiocarbon fractions over the first 100 hr in both treatment and control columns, which then stabilized over the next 200 hr without any significant increase.

## Conclusions

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The column study reported here in provides several elements of useful information on the fate of RDX during in situ reductive biotransformation in groundwater and the influence of aquifer temperature on RDX biotransformation process. The temperature study showed that the rate of RDX biotransformation is adversely affected by the lower aquifer temperatures. In amendment treatment columns, with every 5 °C drop in operating temperature RDX biodegradation rate coefficient was reduced by about 37 percent. The estimated first-order biodegradation rate coefficient for RDX at 15, 10 and 5°C were estimated to be 0.155, 0.098, and 0.061 1/hr, respectively. The activation energy, estimated from the temperature dependency of the rate coefficients evaluated using the Arrhenius model, was determined to be 63.54 kJ/mol.

The radiolabel study demonstrated that the fate of RDX subject to in situ biodegradation is highly dependent on redox conditions in the aquifer. In acetate-amended columns a considerable portion (23-46 percent) of initial radiocarbon was mineralized to <sup>14</sup>CO<sub>2</sub>, compared with <5 percent in amendment control columns. Moreover, the composition of the dissolved fraction was significantly different between amendment treatment and amendment control columns. In treatment columns, where the dissolved fraction of initial radiocarbon was estimated to be between 46 and 64 percent, no nitroso-substituted RDX transformation products were identified. In these treatment columns, where the drop in redox potential was between -550 and -700 mV, the nitroso-substituted intermediates were further degraded probably via cleavage of the triazine ring as reported by previous researchers (McCormick et al. 1981; Hawari et al. 2000a). In amendment control columns, where the reduction in redox potential was very low (70 to -70), the major portion of the dissolved fraction was RDX.

Based on the results of this study, it can be concluded that RDX can be substantially biotransformed under low redox conditions. Furthermore aquifer temperature has a significant influence on the rate of RDX biodegradation, and will therefore be a major factor in determining the length of the treatment zone in actual field applications. The necessary reduced conditions can be achieved by providing sufficient quantities of a readily biodegradable carbon source such as acetate to consume additional oxidants like oxygen and to exceed the demands for other ubiquitous inorganic electron acceptors such as nitrate and sulfate. Finally, to achieve the biodegradation of RDX and its nitroso derivatives, and to avoid the accumulation of toxic nitroso-substituted metabolites, a very low redox is mandatory.

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**APPENDIX E**  
**Supplemental Study Plan**



Biologically Active Zone Enhancement (BAZE) for In-Situ RDX Degradation in Groundwater  
ESTCP # CU-0110

# Appendix E: Supplemental Study Report



Environmental Laboratory  
US Army Engineer Research and  
Development Center (ERDC)  
Vicksburg, MS 39180

**Environmental Security Technology Certification Program**

**Treatability Study for Biologically Active Zone Enhancement  
(BAZE) for In-situ RDX Degradation in Ground Water  
(ESTCP #0110)**

**Supplemental Report:  
Mass Balance of RDX Biotransformation, and Influence of  
Aquifer Temperature on RDX Biodegradation in Groundwater**



Altaf Wani, Deborah Felt, and Jeffrey Davis

July 2003



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## Abstract

A series of column studies with site-specific aquifer material from the former Nebraska Ordnance Plant were performed to evaluate the influence of aquifer temperature on in situ RDX biodegradation, and to assess the ultimate fate of RDX in groundwater under biologically induced reductive conditions. In treatment columns RDX-contaminated water was amended with acetate as readily available carbon source, and in control columns no electron donor was used. The results of the temperature study demonstrated clear indications of adverse effects of lower aquifer temperature on biological activity of RDX-degraders. As the aquifer temperature decreased from 15 to 10 and eventually to 5 °C, the concentration of nitroso-substituted metabolites and untreated RDX increased in the effluent stream. The estimated first-order biodegradation rate coefficient  $k$  for RDX at 15 °C was 0.155 1/hr ( $\pm 0.019$ ,  $n = 3$ ). This rate coefficient decreased by about 37 percent to 0.098 1/hr ( $\pm 0.017$ ,  $n = 3$ ) at 10 °C, and by another 38 percent to 0.061 1/hr ( $\pm 0.016$ ,  $n = 3$ ) at 5 °C. An activation energy of 63.54 kJ/mol RDX was estimated from these reaction rate coefficients at three different aquifer temperatures. Results of the radiolabel study demonstrated that the ultimate fate of RDX under in situ reductive conditions is highly dependent on redox conditions in the aquifer. In treatment columns (redox change,  $\Delta E_h = -550$  to  $-700$  mV), 23-46 percent of initial radiocarbon was mineralized to  $^{14}\text{CO}_2$  as compared to <5 percent in control columns, where  $\Delta E_h$  ranged between 70 to  $-70$  mV. The dissolved fraction of initial radiocarbon in treatment columns estimated between 46 and 64 percent. No or very low levels of nitroso-substituted RDX transformation products were identified in dissolved fraction from treatment columns. In control columns dissolved fraction accounted for about 86 percent of initial  $^{14}\text{C}$  and was composed of mainly untreated RDX.

# 1 Introduction

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A large number of active and formerly used military installations are contaminated with explosive polynitroorganics. The most common munition-derived pollutants encountered at these sites are nitroaromatics like 2,4,6-trinitrotoluene (TNT), and nitramines such as hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and octahydro-1,3,5,7-tetranitro-tetrazocine (HMX). These explosive compounds have entered the environment from sites where they were manufactured, stored, disposed, or used in military training. Currently, there are 583 sites with confirmed explosives-contaminated groundwater at 82 installations nationwide; and at 22 other installations, 88 additional sites are suspected of groundwater contamination with explosives and organics (Defense Environmental Network and Information Exchange (DENIX) 2002).

RDX, a cyclic nitramine explosive, has contaminated groundwater, soil, and surface water at many military installations, promoting concerns about potential toxic effects. In a previous treatability study (Wani et al. 2002), it has been shown that in situ bioremediation of RDX can be achieved by inducing a reductive environment using a benign carbon source (electron donor) in the aquifer. Among different electron sources tested, acetate as a carbon amendment resulted in the necessary reduced conditions for RDX biotransformation without the generation of toxic byproducts. The prior treatability study was conducted at room temperature ( $22 \pm 1$  °C), and the influence of lower aquifer temperatures (8-10 °C) on RDX biotransformation kinetics was not evaluated. In addition, the treatability study indicated no formation of nitroso-substituted products and complete RDX ( $\sim 100$  µg/L) removal from the groundwater. It was hypothesized that the ultimate fate of RDX under such in situ conditions appears to be nonvolatile non-nitroso transformation products. To back up this hypothesis and to evaluate the ultimate fate of RDX under reductive biotransformation, a radiolabel RDX study was performed. The prior study resulted in two unresolved issues: (a) the influence of aquifer temperature on RDX biotransformation kinetics and (b) the ultimate fate of RDX under in situ bioremediation. Because of these two unresolved issues, a supplemental study was conducted to (a) evaluate the influence of aquifer temperature on in situ RDX biodegradation and (b) assess the ultimate fate of RDX in groundwater under biologically induced reductive conditions.

## 2 Literature Review

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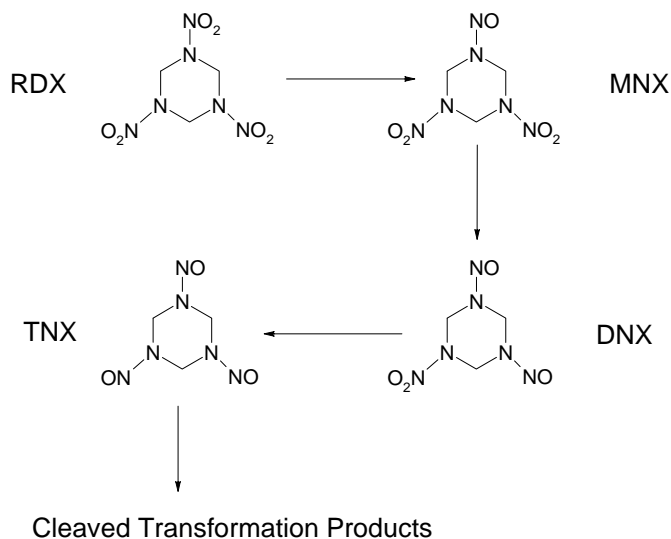
TNT, RDX and HMX, the most commonly encountered energetic contaminants in soil and groundwater, pose a significant cleanup challenge at many active and formerly used military sites in the United States and across the world. In the United States the contamination of soil and groundwater is attributed to World War II and the Korean conflict (Pennington 1999).

RDX, which is in the nitramine class of explosives, is widely used in munitions because of its explosive power, around 1.5 to 2 times that of TNT, and rapid detonating velocity, about 1.3 times that of TNT (U.S. Army 1984). RDX is of particular environmental concern because laboratory studies have established that it is generally resistant to microbial transformation in aerobic soils (McCormick et al. 1981) and it is not extensively sorbed on soils (sorption coefficient  $K_d$  of 0.83 to 0.95 L kg<sup>-1</sup>) (Singh et al. 1998, Sheremata et al. 2001). Remediating soil and water contaminated with RDX is of vital importance because ingestion of RDX can adversely affect the central nervous system, gastrointestinal tract, and kidneys. Common symptoms of RDX intoxication include nausea, vomiting, hyperirritability, headaches, and unconsciousness (Eitner 1989). RDX has also been associated with systemic poisoning usually affecting bone marrow and the liver (Agency for Toxic Substances and Disease Registry (ATSDR) 1996). The U.S. Environmental Protection Agency (EPA) has established drinking water health advisory of 2 µg/L for exposure to RDX (U.S. EPA 2002).

The fate and transport of RDX in the environment are influenced by many factors including photolysis by sunlight, hydrolysis, and biologically mediated degradation. Biodegradation of RDX is often attributed to cometabolism in the presence of a primary carbon source under various electron acceptor conditions. RDX can be biodegraded under anaerobic or anoxic conditions by facultative or anaerobic microorganisms (McCormick et al. 1981; Kitts et al. 1994; Freedman and Sutherland, 1998; Hawari et al. 2000a; Halasz et al. 2002; Beller 2002). Under aerobic conditions, RDX can be used as a sole source of nitrogen by aerobic microorganisms (Binks et al. 1995; Coleman et al. 1998; Brenner et al. 2000), or by fungus (Bayman et al. 1995; Fernando and Aust 1991; Sheremata and Hawari 2000).

Various laboratory studies have established that anaerobic RDX metabolism occurs more readily than aerobic metabolism, and that hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), and hexahydro-1,3,5-trinitroso-1,3,5-

triazine (TNX) are the transient biotransformation intermediates (Figure 1) under anaerobic conditions (Hawari et al. 2000a, 2000b; McCormick et al. 1981; Kitts et al. 1994; Morley et al. 2002; Young et al. 1997; Beller 2002; Freedman and Sutherland 1998; Beller and Tiemeier 2002). Recent studies have tentatively identified methylenedinitramine (MDNA) as the ring cleavage metabolites during the bioremediation of RDX with anaerobic sludge. These studies suggest different views of the stability of MDNA; it can occur as a transient metabolite (Halasz et al. 2002) or as a persistent transformation product that appears at substantial concentrations relative to RDX (Oh et al. 2001). Nonetheless, Beller and Tiemeier (2002) reported that under in situ conditions MDNA was not detected in any of the samples from the RDX-contaminated aquifer at Iowa Army Ammunition Plant (IAAP), although relatively high concentrations of MNX, DNX, and TNX were present. Although many researchers have established that RDX can be biodegraded through biological processes, successful application of these techniques to in situ treatment of contaminated soils and waters has yet to be proven in the field. The influence of such environmental conditions as aquifer temperature on RDX biodegradation has not been considered in previous research work. Moreover a better understanding of in situ biotransformation of RDX and the generation of transformation products requires the assessment of the ultimate fate of RDX.



**Figure 1. Anaerobic pathway**

### 3 Site Description and Sampling

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The former Nebraska Ordnance Plant (NOP) is located about 1 km (half a mile) south of Mead, NE, which is 48 km (30 miles) west of Omaha and 56 km (35 miles) northeast of Lincoln, NE. The NOP covers 69.9 square km (17,258 acres) in Saunders County. Currently, the land is owned by the University of Nebraska, Agricultural Research and Development Center, U.S. Army National Guard and Reserves, U.S. Department of Commerce, and private interests. The past operational history, and geological and hydrological characteristics of the NOP site are discussed in Wani et al. (2002).

Aquifer material at the former NOP site was collected from Area 1, near monitoring well MW-5B, from a depth of 11 to 12 m (36 to 40 ft) below ground surface. Soil columns were collected in 5-cm (2-in) diameter acetate liners by the direct-push method using a track-mounted mobile sampling device. Further details on aquifer material sampling are presented in the biologically active zone enhancement (BAZE) treatability study report (Wani et al. 2002). The soil columns were thoroughly sealed at both ends to prevent loss of water from the aquifer material during storage and shipping. Samples of aquifer material were transported to the Environmental Laboratory, Vicksburg, MS, U.S. Army Engineer Research and Development Center, via a refrigerated truck.

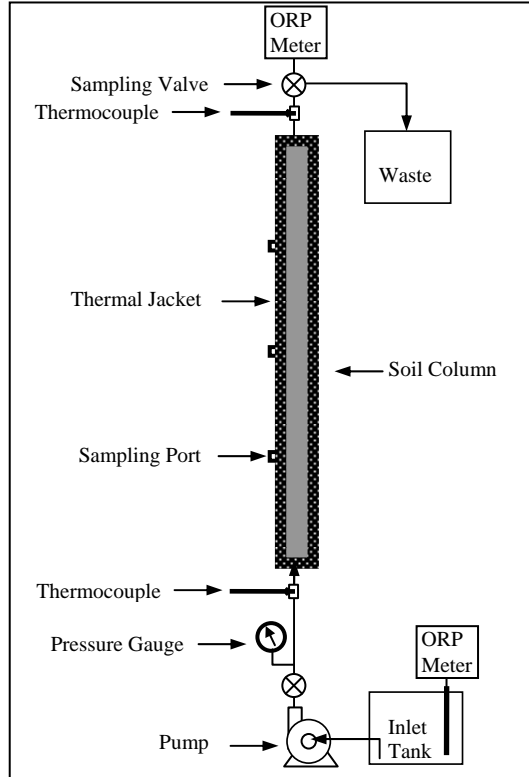


## 4 Materials and Methods

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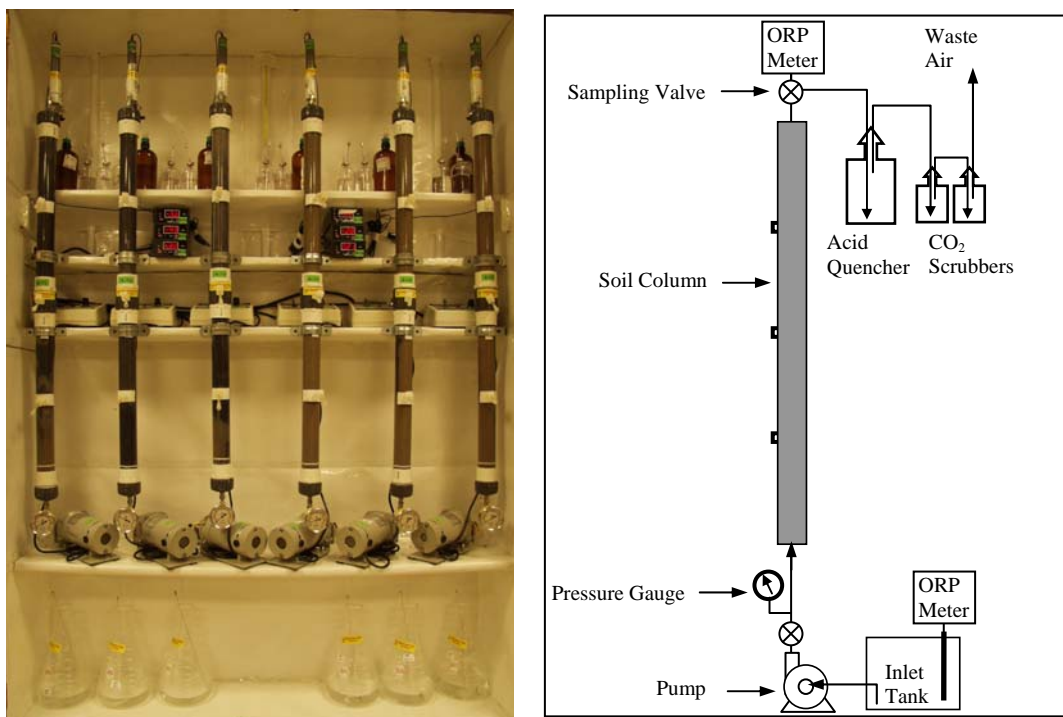
### 4.1 Experimental Setup

Two sets of triplicate columns were used to evaluate the effects of aquifer temperature on RDX biotransformation. In the first triplicate set, acetate was added as the carbon source (electron donor) while the second triplicate set served as amendment (carbon source) control. The polyvinyl chloride (PVC) columns were 104 cm (3.4 ft) long with an inside diameter of 3.8 cm (1.5 in.). Both ends of the columns were closed with PVC caps screened with porous (100  $\mu\text{m}$ ) PVC. Additional sampling ports, at 26 cm (10.2 in.), were placed along the entire column length resulting in three intermediate sampling ports in addition to the inlet and outlet ports for the development of the contaminant bed profile. Each column was individually wrapped with a thermal jacket composed of a cold water circulation unit covered with a 12-mm (0.5-in.) thick thermal insulation to prevent heat transfer from the environment. The difference in influent and effluent temperature was  $\pm 1$  °C. The detailed design of the column system with groundwater flow and other instrumentation is shown in Figure 2. Teflon-coated T-type thermocouples (Omega Engineering, Stamford, CT) equipped with digital panel monitors were installed at the inlet and outlet of each column, via flow-through cell, to record the temperature of influent and effluent groundwater streams. Pressure gauges were installed at the inlet to each individual column to examine the effects of microbial growth (biofouling) on groundwater flow, back pressure, and the hydrodynamic properties of the aquifer material. The outlet of each column was equipped with an oxidation-reduction potential (ORP) electrode via a flow-through cell to compare the reduced conditions along the column length with that of the inlet tank. Details on packing of these columns with site-specific aquifer material were presented in the initial BAZE treatability study (Wani et al. 2002). RDX-contaminated water was pumped through the columns using variable-control positive displacement pumps. Variable control on pump speed allowed the metering of desired water flow through each column.



**Figure 2. Experimental column setup for temperature study**

To assess the ultimate fate of RDX in groundwater under a biologically induced reductive environment, two separate sets of triplicate columns, as shown in Figure 3, were used. Similar to the temperature study, one set was used for amendment (carbon source) addition and the other set served as amendment (acetate) control. These PVC columns were of the same dimensions as described for the temperature study. These columns also had additional sampling ports at 26 cm (10.2 in.) for bed profile analysis. The schematics of this column system with RDX-contaminated water flow and other instrumentation are illustrated in Figure 3. Pressure gauges were installed at the inlet to each individual column to examine the changes in back pressure. The outlet of each column was equipped with an ORP electrode via a flow-through cell to compare the reduced conditions along the length of the column system with that of the inlet tank. These columns were packed with site-specific aquifer material (Wani et al. 2002). RDX-contaminated water was pumped through each column using variable-control positive displacement pumps. The column system along with pumps and inlet water reservoirs was securely installed in a cabinet to prevent release of any radioactivity.



**Figure 3. Experimental column setup for radiolabel RDX study**

## 4.2 Operation

RDX-contaminated water was prepared by spiking autoclaved organic-free reagent grade water with RDX stock solution. RDX-contaminated water with a concentration of about  $1.03 \pm 0.05$  mg/L was used in this study. The selection of acetate as the carbon source (electron donor) in this research work is based on other research that suggests that acetate is an excellent electron donor to stimulate in situ microbial reductive conditions (He et al. 2002; Wani et al. 2002). Acetate concentration of 500 mg/L (as carbon) was used in both temperature- and radiolabeled-studies to ensure that organic carbon is not the limiting factor. RDX-contaminated water flow through each column was initiated at  $\sim 0.2$  mL/min and maintained at this rate throughout the study. This water flow resulted in a velocity of about 0.85 m/d (2.7 ft/d), which is comparable with the NOP site groundwater velocity of approximately 0.61 m/d (2 ft/d).

Temperature-study columns were operated at three different temperatures (15, 10, and 5 °C) to evaluate the influence of aquifer temperature on RDX biotransformation kinetics. Each temperature test lasted for a month. Liquid samples were collected from inlet and outlet sampling ports every fifth day. After the columns reached the steady state, samples from intermediate ports along the column height were collected on the 23<sup>rd</sup> and 30<sup>th</sup> day for each

temperature test. Water samples were stored at 4 °C until explosives and amendment analysis. The operating conditions are summarized in Table 1.

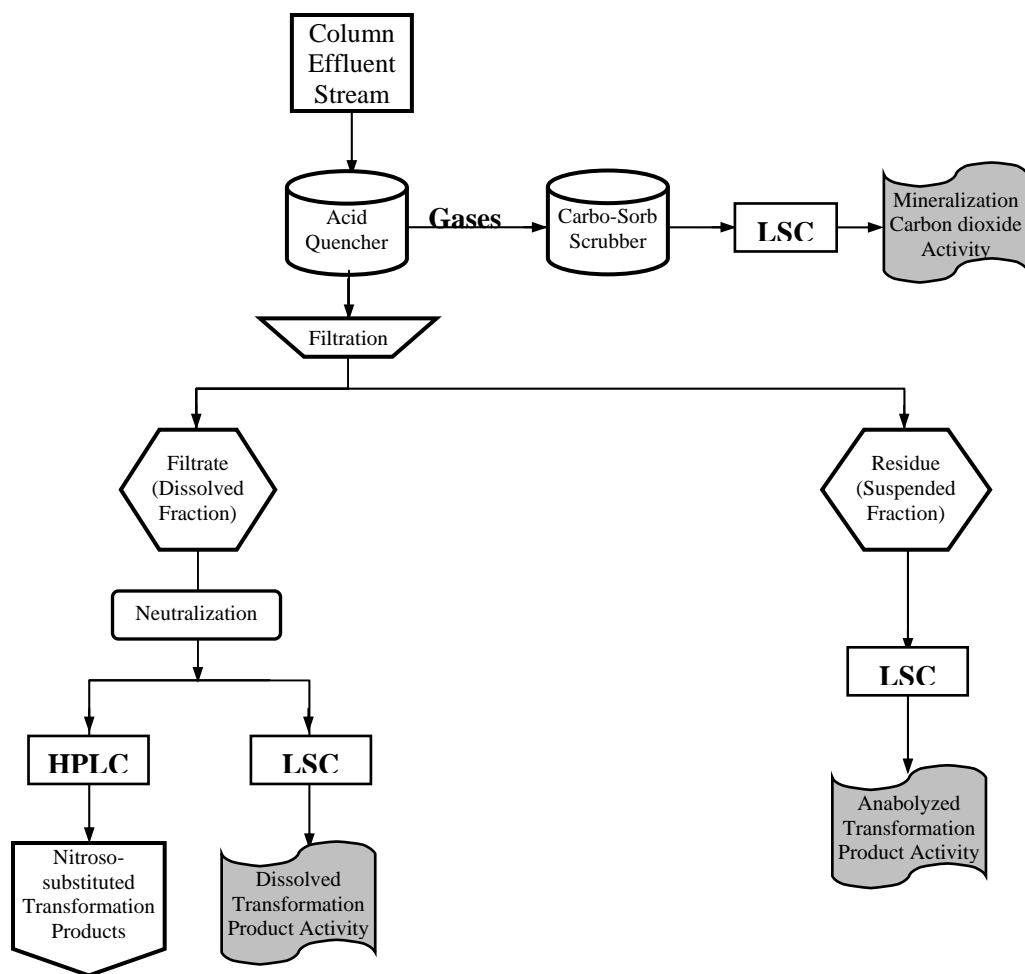
**Table 1. Column Operating Conditions**

Column	Groundwater Flow rate mL/min	RDX Concentration mg/L	Acetate Concentration mg/L C	[ <sup>14</sup> C]RDX Initial Activity dpm
<b>Temperature Columns</b>				
T-T1	0.20	~1.0	~500	None
T-T2	0.20	~1.0	~500	None
T-T3	0.20	~1.0	~500	None
T-C1	0.20	~1.0	0	None
T-C2	0.20	~1.0	0	None
T-C3	0.20	~1.0	0	None
<b>Radiolabel RDX Columns</b>				
R-T1	0.20	~1.0	~500	~1,700,000
R-T2	0.20	~1.0	~500	~1,700,000
R-T3	0.20	~1.0	~500	~1,700,000
R-C1	0.20	~1.0	0	~1,700,000
R-C2	0.20	~1.0	0	~1,700,000
R-C3	0.20	~1.0	0	~1,700,000

Amendment concentrations are nominal.

dpm = disintegrations per minute ( $\mu\text{Ci} = 2.2$  million dpm)

Radiolabeled-study columns were fed with RDX-contaminated ( $1.05 \pm 0.06$  mg/L) groundwater for 2 months to reach steady state. Once the columns reached steady state conditions with steady RDX removal from feed water, a slug of [<sup>14</sup>C]RDX (~ 0.76  $\mu\text{Ci}$ ) was introduced in to the inlet tank to each individual column. The effluent water stream, including any carbon dioxide evolved as a result of mineralization, was collected in a 500-mL glass sampler under an hydrochloric acid quenching solution (25 mL, 1N HCl) to release any dissolved carbon dioxide. The effluent gases from the acid quencher were passed through carbon dioxide scrubbers containing 100 mL Carbo-Sorb<sup>®</sup> (Packard Biosciences, Meriden, CT) to scrub out carbon dioxide from the gas stream. In another test it was found that Carbo-Sorb is a very efficient carbon dioxide scrubbing solution with a 99.99 percent recovery. At the end of the sampling, the sampling train (acid quencher-Carbo-Sorb scrubbers) was flushed with nitrogen gas to remove all the carbon dioxide from the acid quencher into the Carbo-Sorb scrubbers (Figure 4).



**Figure 4. Radiolabel RDX sample preparation and analysis flow chart**

The contents of the acid quencher (including the column effluent) were filtered (0.45  $\mu\text{m}$ ) to separate the suspended, mostly biomass (residue) and the dissolved (filtrate) fractions of RDX and its transformation products. The filtrate was neutralized with 1N NaOH. Liquid scintillation counting (LSC) was performed on aliquots from both the neutralized filtrate (dissolved fraction) and the residue (suspended fraction) to estimate the portion of [ $^{14}\text{C}$ ]RDX and its transformation products in the suspended and dissolved phases. A 4-mL aliquot of neutralized filtrate was mixed with 15 mL Ultima Gold<sup>®</sup> (Packard Biosciences) scintillation cocktail for radioactivity counting. The filter paper along with the residue was immersed in 15-mL Ultima Gold<sup>®</sup> scintillation cocktail for radioactivity counting. The contents of the Carbo-Sorb scrubbers were subjected to LSC to evaluate the fraction of [ $^{14}\text{C}$ ]RDX mineralized to [ $^{14}\text{C}$ ]CO<sub>2</sub>. A 10-mL aliquot from Carbo-Sorb scrubber was mixed with 10-mL Permafluor<sup>®</sup> scintillation cocktail (Packard Biosciences) for radioactivity counting. The total radioactivity from gaseous

(mineralization CO<sub>2</sub>), suspended (nitroso- and non-nitroso-substituted nonvolatile metabolites), and dissolved (nitroso- and non-nitroso-substituted nonvolatile metabolites) phases was summed up and compared with the initial radioactivity introduced as [<sup>14</sup>C]RDX. An aliquot from neutralized filtrate was analyzed for untreated RDX and nitroso-substituted (MNX, DNX, and TNX) nonvolatile metabolites using high-performance liquid chromatography (HPLC).

### 4.3 Analytical Techniques

Acetate, sulfate, nitrate, and nitrite in liquid samples were analyzed on a DIONEX Ion Chromatograph. Chemical separation and detection were achieved using an Ionpac AS11 analytical column (4 by 250 mm) and a Dionex conductivity detector (1.25 µL internal volume). The mobile phase consisted of NaOH at a flow rate of 1.5 mL/min. The sample volume was 25 µL of filtered (0.45 µm) sample. The instrument was calibrated daily from standards prepared from stock solutions. Check standards were run after every 10 samples.

The analysis of RDX and its nitroso-substituted transformation products was performed using a DIONEX HPLC system comprising of a P580 fluid pump, ASI-100 autosampler, and UVD340U absorbance detector. The injection volume was 25 µL. Chemical separation was achieved using a Supelco CN reverse-phase HPLC column (25 cm by 4.6 mm) with a Novapak C-18 precolumn for the primary column. The mobile phase comprised of 1:3 (volume per volume) methanol/organic-free reagent water at a flow rate of 1 mL/min. Explosives absorbance was monitored at 245 nm. For EPA Method 8330 analytes (U.S. EPA 1994), a seven-point calibration curve was used. The instrument was calibrated daily from standards prepared from stock solutions. Check standards were run after every 10 samples.

Sample radioactive concentration via liquid scintillation counting was done on 2500 TR Packard Scintillation Counter (Packard Biosciences). The counter was equipped with a barium external source to enable correction for machine efficiency. The liquid scintillation protocol collected data up to 156 meqV, which is the maximum energy for [<sup>14</sup>C]. Each sample was counted twice for 2 minutes.

Oxidation-reduction potential (E<sub>h</sub>) and pH were measured with electrodes that were calibrated weekly. Both ORP and pH were measured with Oakton WD-35100-00 model pH/ORP Controllers (Cole-Parmer, Vernon Hills, IL) with a measuring range of 0 to 14 for pH and -1250 to 1250 mV ORP. ORP was measured using a Cole-Parmer combination redox

electrode with platinum sensing surface and Ag/AgCl reference electrode. The value  $E_h$  was obtained by adding standard potential of the reference electrode  $E_R$  to the measured potential  $E$ . For this ORP electrode  $E_R$  at 25 °C (room temperature) is 202 mV. pH was determined with a Cole-Parmer combination electrode.

#### 4.4 Biotransformation Kinetics

The rate of RDX biotransformation was determined by sampling at the intermediate ports in the column system. A contaminant profile was developed and an advection-dispersion model (Equation 1) for contaminant transport with decay was fitted to the results:

$$\frac{\partial C}{\partial t} = \alpha v \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} - kC \quad (1)$$

where  $C$  = RDX concentration (mg/L),  $t$  = time elapsed (hr),  $\alpha$  = dispersivity (cm),  $v$  = interstitial velocity (cm/hr),  $x$  = distance from column inlet (cm),  $k$  = RDX first-order biodegradation rate coefficient (1/hr).

With the boundary conditions  $C(0,t) = C_0$  and  $\partial C/\partial x(\infty,t) = 0$ , at steady state, Equation 1 can be solved to Equation 2 as follows:

$$C = C_0 \exp\left(-\frac{v}{2\alpha} x \left[1 + \sqrt{1 + \frac{4k\alpha}{v^2}}\right]\right) \quad (2)$$

The bed-profile sampling for each temperature test was done twice on the 23<sup>rd</sup> and 30<sup>th</sup> days when the operating conditions were steady and columns had reached equilibrium conditions with steady RDX removal.

The rates of RDX biotransformation, estimated by fitting Equation 2 to the contaminant profile, at three different temperatures (15, 10, and 5 °C) were used to evaluate the influence of aquifer temperature on RDX biodegradation rate using the Arrhenius equation:

$$k = A \exp\left(-\frac{E_a}{RT}\right) \quad (3)$$

where  $A$  = Arrhenius constant,  $E_a$  = activation energy (J/mol),  $R$  = universal gas constant (J/mol-K),  $T$  = temperature (°K)

## 5 Results

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### 5.1 Temperature Study

#### 5.1.1 Column hydrodynamics

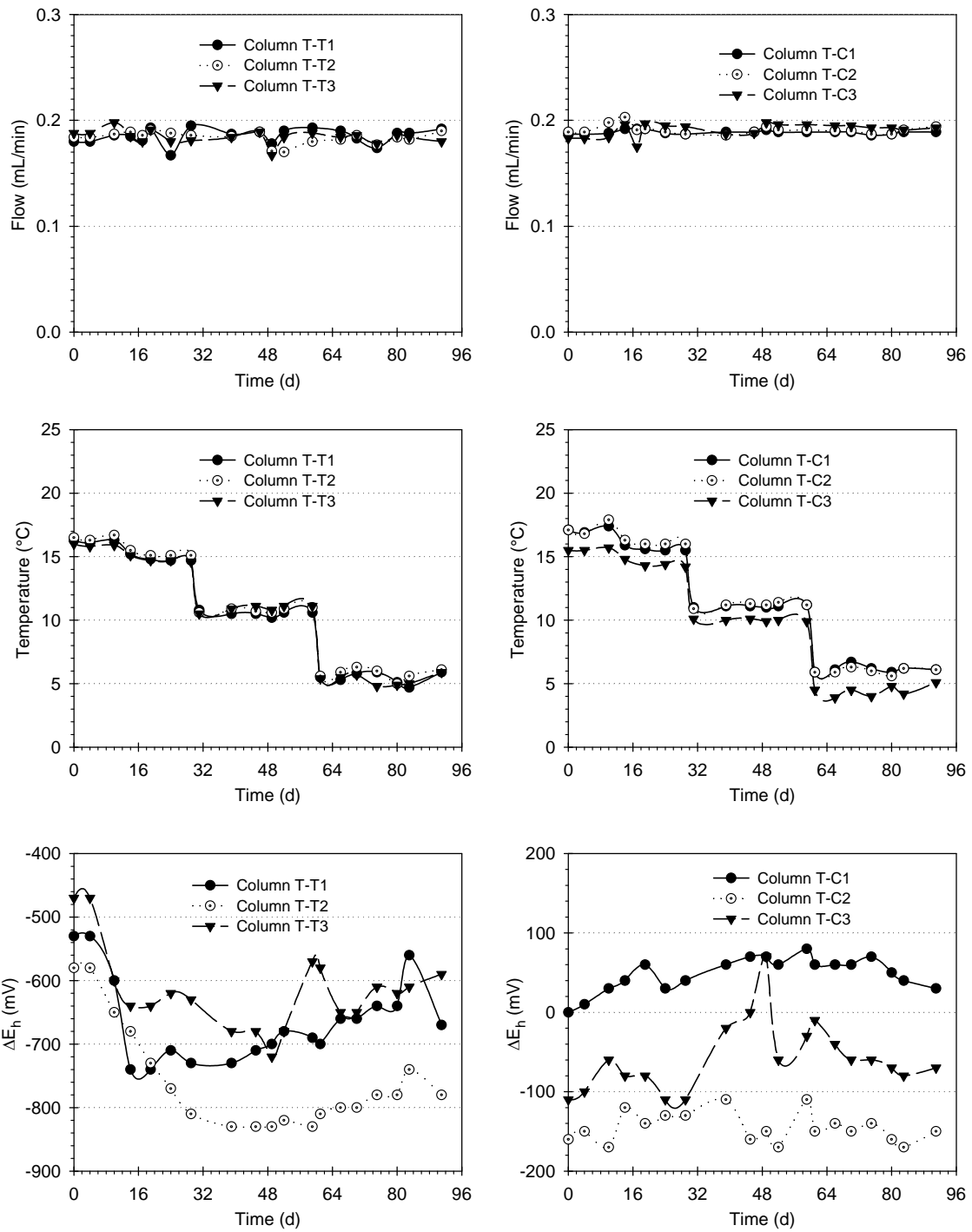
RDX-contaminated water flow during the entire 13-week study was approximately 0.2 mL/min in both triplicate column sets (Figure 5). This water flow resulted in an hydraulic residence time of  $24 \pm 1$  hr in individual columns. Figure 5 summarizes the groundwater temperature in each column. These temperature readings are the average of influent and effluent groundwater temperatures. The thermal jacket wrapped over the individual column was very efficient in maintaining the aquifer material and groundwater temperature in each column. The influent and effluent temperatures varied by 1 °C.

Reduced conditions were established in each column as shown in Figure 5. In treatment columns change in redox ( $\Delta E_h$ ) was between  $-600$  and  $-850$  mV. Anaerobic conditions were established in treatment columns by providing carbon source to indigenous microorganisms, which then used the oxygen, creating a reduced environment. The  $\Delta E_h$  in the control columns was very small (between 100 and  $-150$  mV) compared with that of the treatment columns.

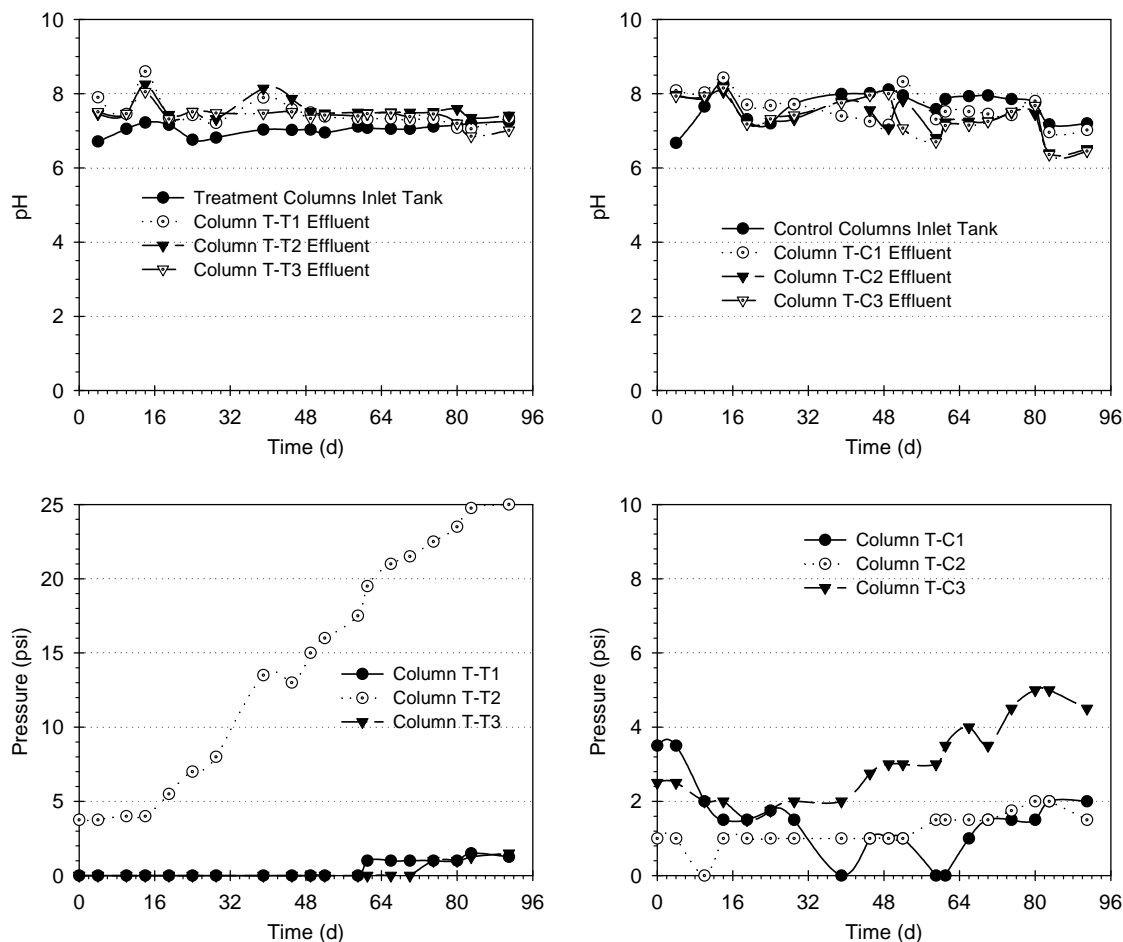
The influent stream pH varied between 6.5 and 7.5 for the treatment column set where RDX-contaminated water was amended with acetate (Figure 6). In the control column set the influent water pH was slightly higher (7.5 to 8). The effluent stream from the treatment column set showed a slight increase in pH (7.5 to 8). There was no measurable change in the effluent stream pH in the control columns (Figure 6).

There was no significant back pressure buildup due to biofouling in any of the columns, and head loss remained almost the same during the entire 13-week study, except in treatment column T-T2 (Figure 6). This steady increase in back pressure in Column T-T2 could be the result of a higher biomass yield that caused RDX biodegradation without the detection of any nitroso-metabolites (Figure 7). Occasional hikes in the back pressure were due mainly to plugging of the porous PVC screen at the column inlets due to extracellular secretions from biomass. After the porous PVC screens were cleaned or replaced, this flow resistance was removed and pressure loss across the columns dropped to initial levels.





**Figure 5. RDX-contaminated water flow, temperature, and change in redox potential for each column**

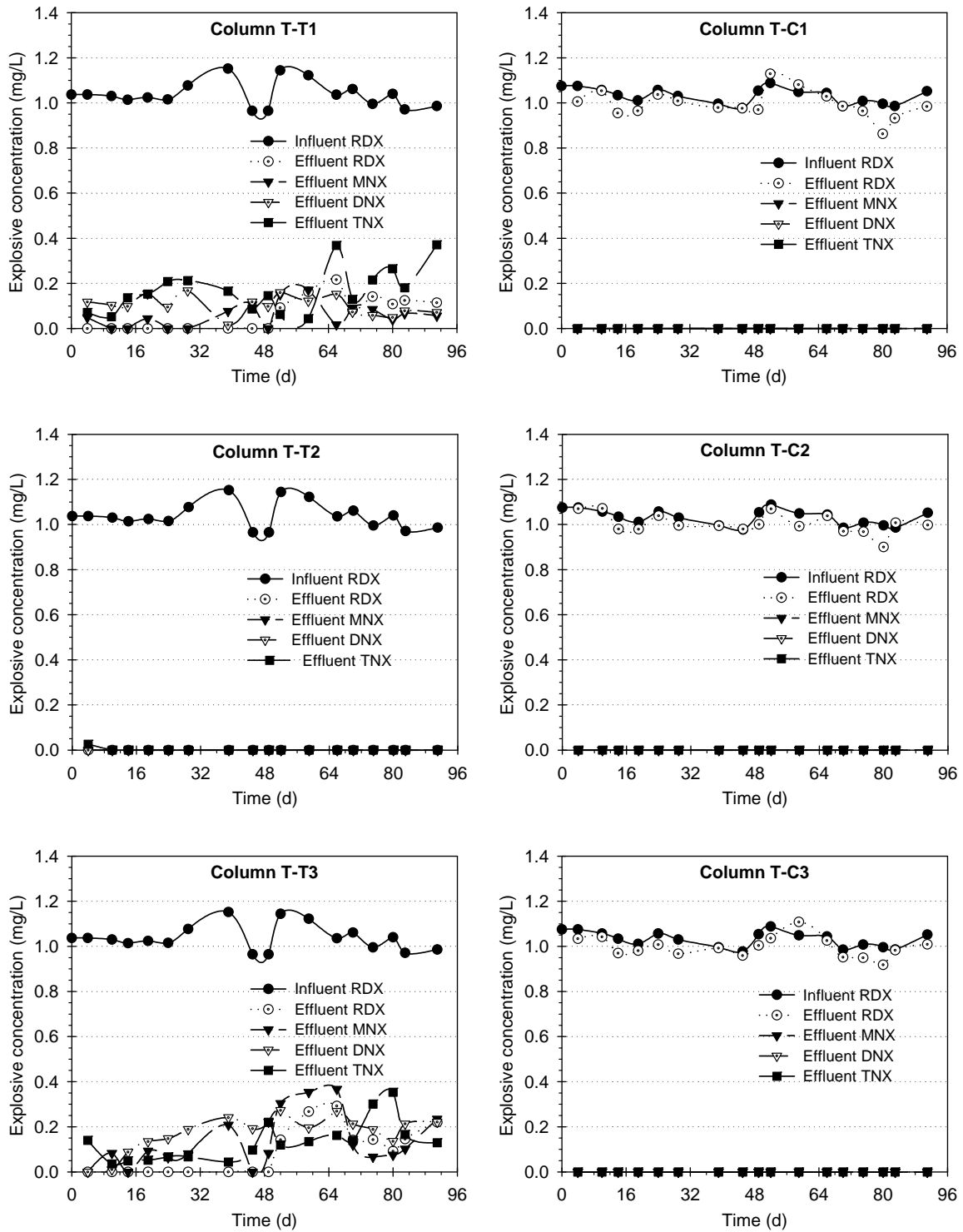


**Figure 6. Feed water pH and flow resistance (back pressure) for each column**

### 5.1.2 RDX biotransformation

RDX concentrations in the influent groundwater, ranging between 1 and 1.2 mg/L, were reduced to below detection limits of 0.02 mg/L, at 15 °C, in all treatment columns. At lower temperatures (10 and 5 °C) low concentrations of RDX were observed in the effluent streams from Columns T-T1 and T-T3. However, these lower temperatures did not have any effect on the removal efficiency of RDX in Column T-T2. In Column T-T2 influent RDX was removed without the presence of any nitroso-substituted RDX metabolites at all three temperatures tested. In the other two treatment columns (T-T1 and T-T3) low levels (~ 0.2 mg/L) of the nitroso-substituted transformation products (MNX, DNX, and TNX) were observed in the effluent stream throughout the study (Figure 7). The other noticeable difference in Column T-T2 compared with Columns T-T1 and T-T3 was the steady back pressure development during the 13-week study. One plausible reason behind these two manifest observations in Column T-

T2 could be a higher biomass yield that caused RDX biodegradation without the detection of any transformation products and at the same time created a higher flow resistance resulting in higher



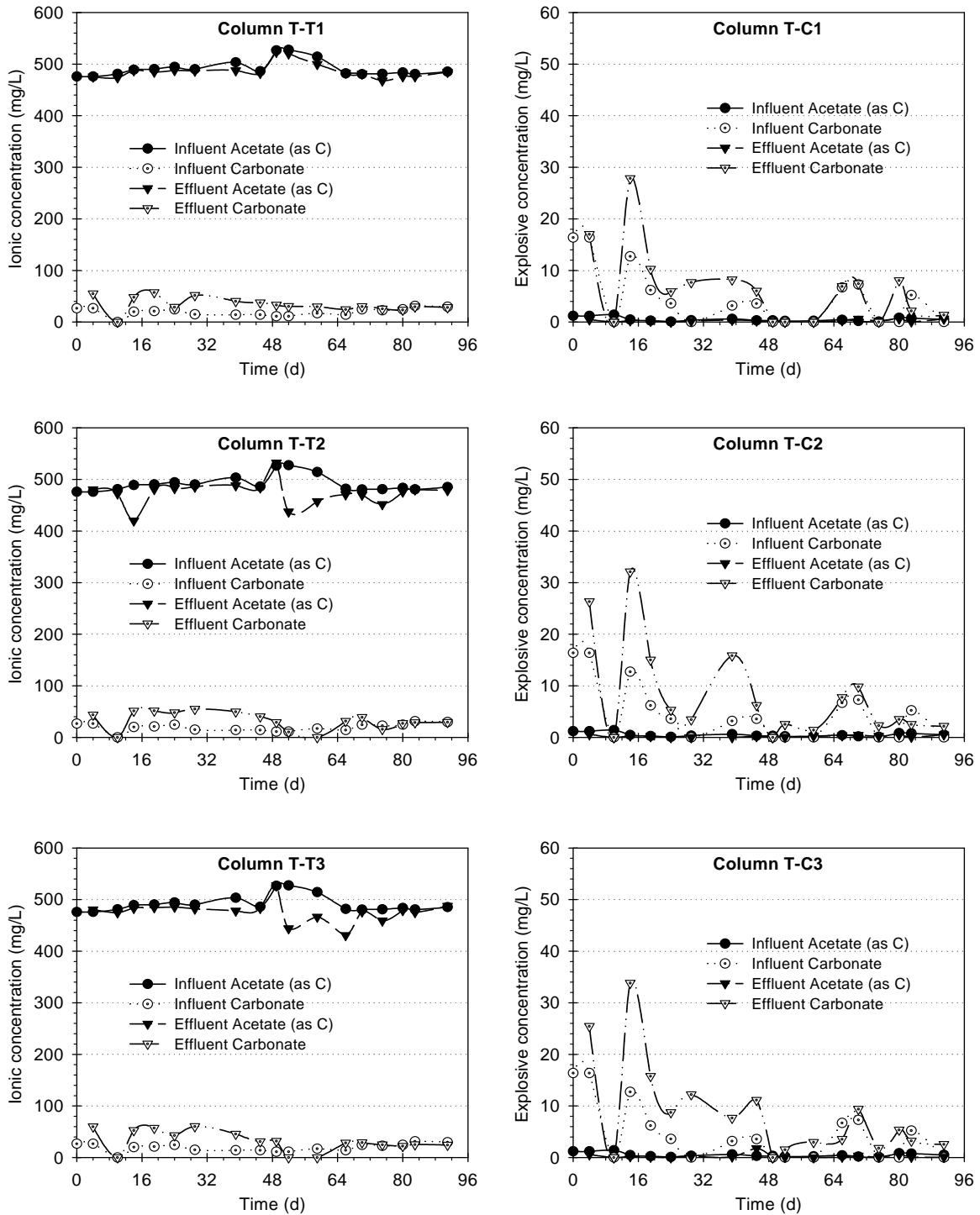
**Figure 7. RDX and nitroso-RDX intermediates concentration in influent and effluent streams**

back pressure along the column length. The assumption of high biomass yield is also substantiated by the lowest redox potential in Column T-T2 as a result of higher biological activity. The cumulative presence of nitroso-substituted transformation products in Column T-T1 and Column T-T3 accounted for about one-third of the influent RDX concentration on a molar basis. That leaves about 70 percent of the inlet RDX unaccounted for in terms of nitroso-substituted RDX intermediates, which might include other non-nitroso-transformation products as proposed by other researchers (Hawari et al. 2000a; McCormick et al. 1981).

In control columns no biodegradation of RDX was observed throughout the course of the study (Figure 7). During the entire study redox potential in control columns, where no electron donor was used, was very high compared with that of treatment columns (Figure 5). These results identify the need for low redox environment for reductive biotransformation of RDX in groundwater.

During the 13-week study, RDX was removed from the groundwater with the presence of low levels of all the three nitroso-substituted transformation products in treatment Columns T-T1 and T-T3; however, in treatment Column T-T2 effluent no MNX, DNX, or TNX was observed. This sequential reductive biotransformation has been reported for various RDX-metabolizing cultures that used organic electron donors (Freedman and Sutherland 1998; Hawari et al. 2000a, 2000b; Beller and Tiemeier 2002; McCormick et al. 1981). In all three control columns RDX was not biodegraded at all. In these control columns  $\Delta E_h$  between influent and effluent was between 100 and -150 mV. From these results, it seems the ultimate fate of RDX appears to be dependent on redox conditions. In treatment column systems, with  $\Delta E_h$  between influent and effluent between -600 and -850 mV, RDX was transformed into nitroso- and non-nitroso-substituted metabolites. In Column T-T2 where  $\Delta E_h$  between influent and effluent was the lowest (-850 mV) none of the nitroso-substituted transformation products was observed in the effluent stream. This might be because these nitroso-substituted intermediates are unstable at low redox and further undergo ring cleavage as postulated by other researchers (Hawari et al. 2000a, 2000b; McCormick et al. 1981). Oh et al. (2001) have tentatively identified a soluble intermediate MDNA as a result of ring cleavage. However, the formation and stability of MDNA as a biotransformation product of RDX under anaerobic conditions is not yet clear; it can occur as a transient intermediate (Halasz et al. 2002), or a stable transformation product (Oh et al. 2001).

In all three treatment columns, very little (~ 1 percent) of the inlet acetate concentration (500 mg/L as carbon) was used in the biological activity (Figure 8). Low (30-50 mg/L) levels of carbonate were observed in the effluent streams from these treatment columns.



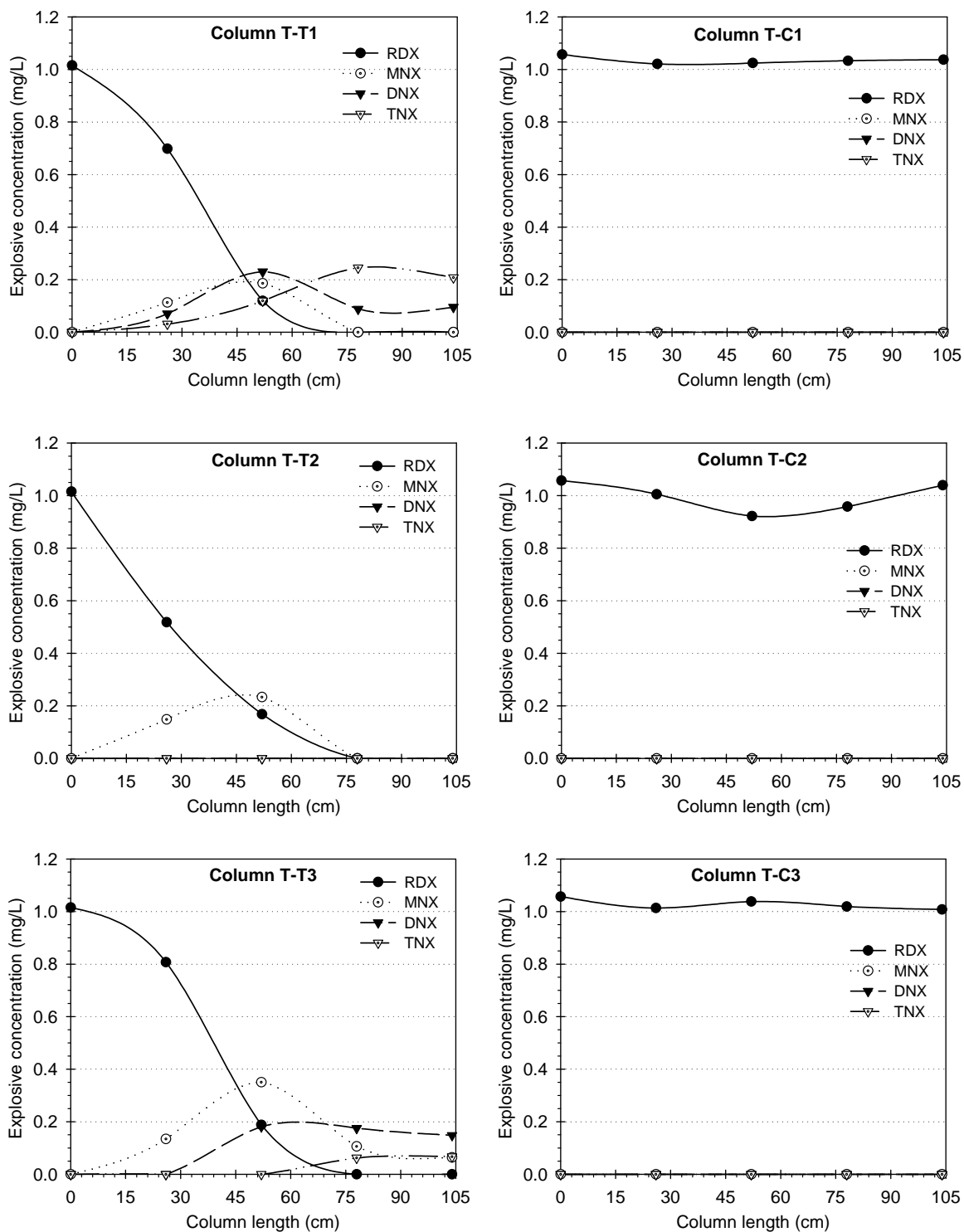
**Figure 8. Amendment concentration in influent and effluent streams**

### 5.1.3 RDX biodegradation kinetics

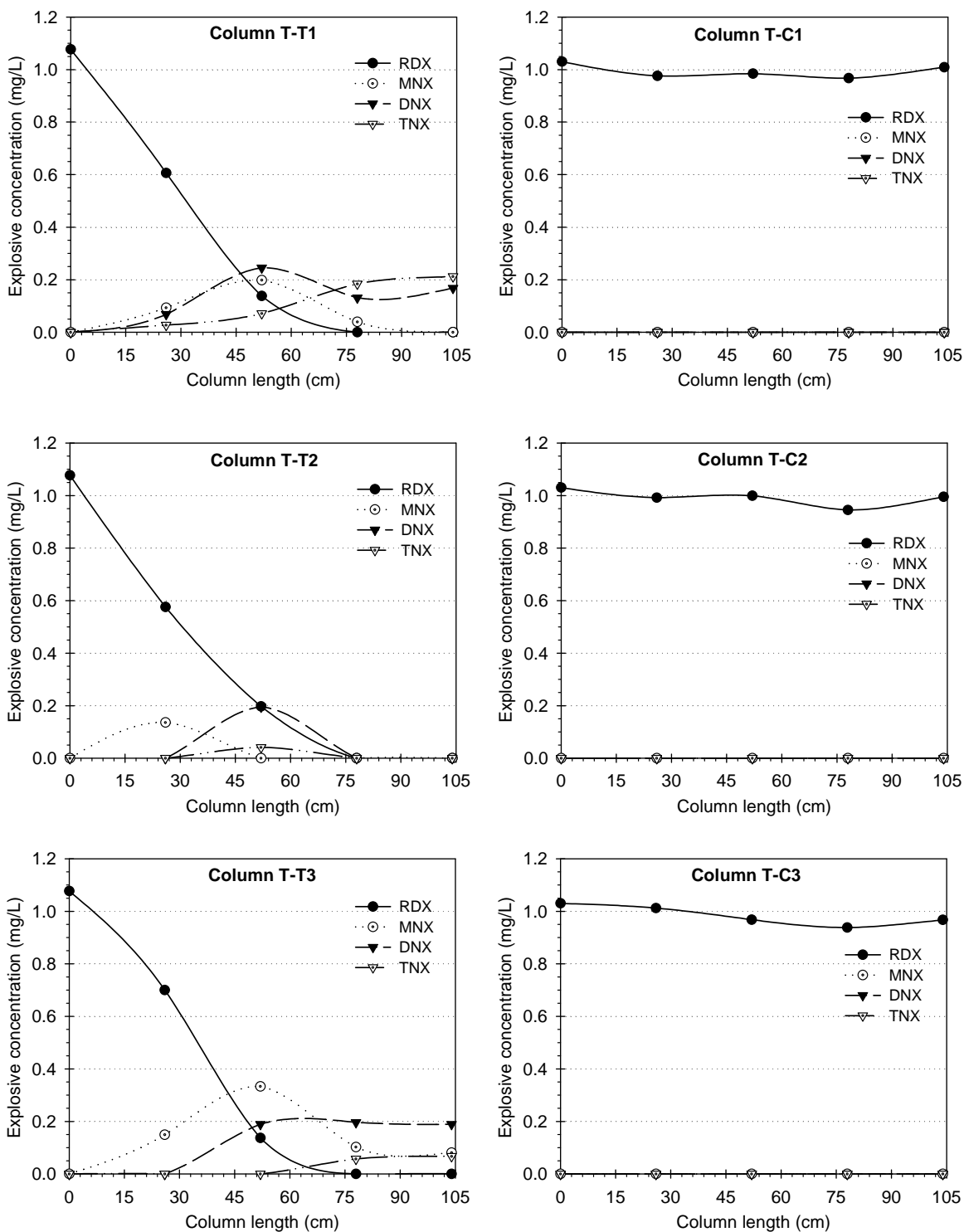
The rate of transformation of RDX in individual columns, under each temperature condition, was evaluated by fitting the advection-dispersion transport model with the contaminant decay model (Equation 2) to the axial RDX concentration profile along the column length. Two bed profile samplings were carried out at three different temperatures (15, 10, and 5 °C) to determine the average rate of RDX biotransformation with time of operation. Each temperature test lasted for 30 days, and bed profile samples were collected from intermediate ports along the column length at days 23 and 30.

Overtime, the two concentration profiles did not vary for the individual columns; however, Column T-T2 behaved differently from the other two treatment columns. The presence of acetate as a carbon source (electron donor) resulted in the transformation of RDX into different nitroso-substituted products in the treatment columns. In the control columns (where no acetate was added) no biotransformation of RDX was observed throughout the column length. In all the bed profile tests performed at various operating temperatures, the predominant transformation product identified at intermediate ports in Column T-T2 was MNX, but in Columns T-T1 and T-T3 a sequential biotransformation of RDX into MNX, DNX, and TNX was observed. This pattern of transformation products may be a result of presence of different microbial consortia because Column T-T2 was more reduced than Columns T-T1 and T-T3, which might have changed the microbial dynamics. Kitts, et al. (1994) observed the similar variable microbial ability to transform RDX. The researchers reported that two species (*Morganella morganii* and *Providencia rettgeri*) completely transformed RDX and subsequent nitroso-substituted intermediates, and a third one (*Citrobacter freundii*) partially transformed RDX and generated high concentrations of nitroso-substituted intermediates. Bed profile analysis at individual operating temperature is described in detail in the following paragraphs.

Axial RDX and its nitroso-transformation product concentration profiles during two bed profile tests carried out at 15 °C are shown in Figures 9 and 10. There was no significant difference between the two bed profile analyses for the individual columns. In Columns T-T1 and T-T3 the three nitroso-substituted metabolites were observed in a typical sequential manner with MNX followed by DNX and then TNX. However, in both the bed profile tests very low levels of MNX, and seldom DNX and TNX were observed in Column T-T2. Furthermore these transformation products were very short lived because of the very reduced conditions



**Figure 9. Axial concentration profile of RDX and its nitroso-substituted metabolites at 15°C (Test 1)**

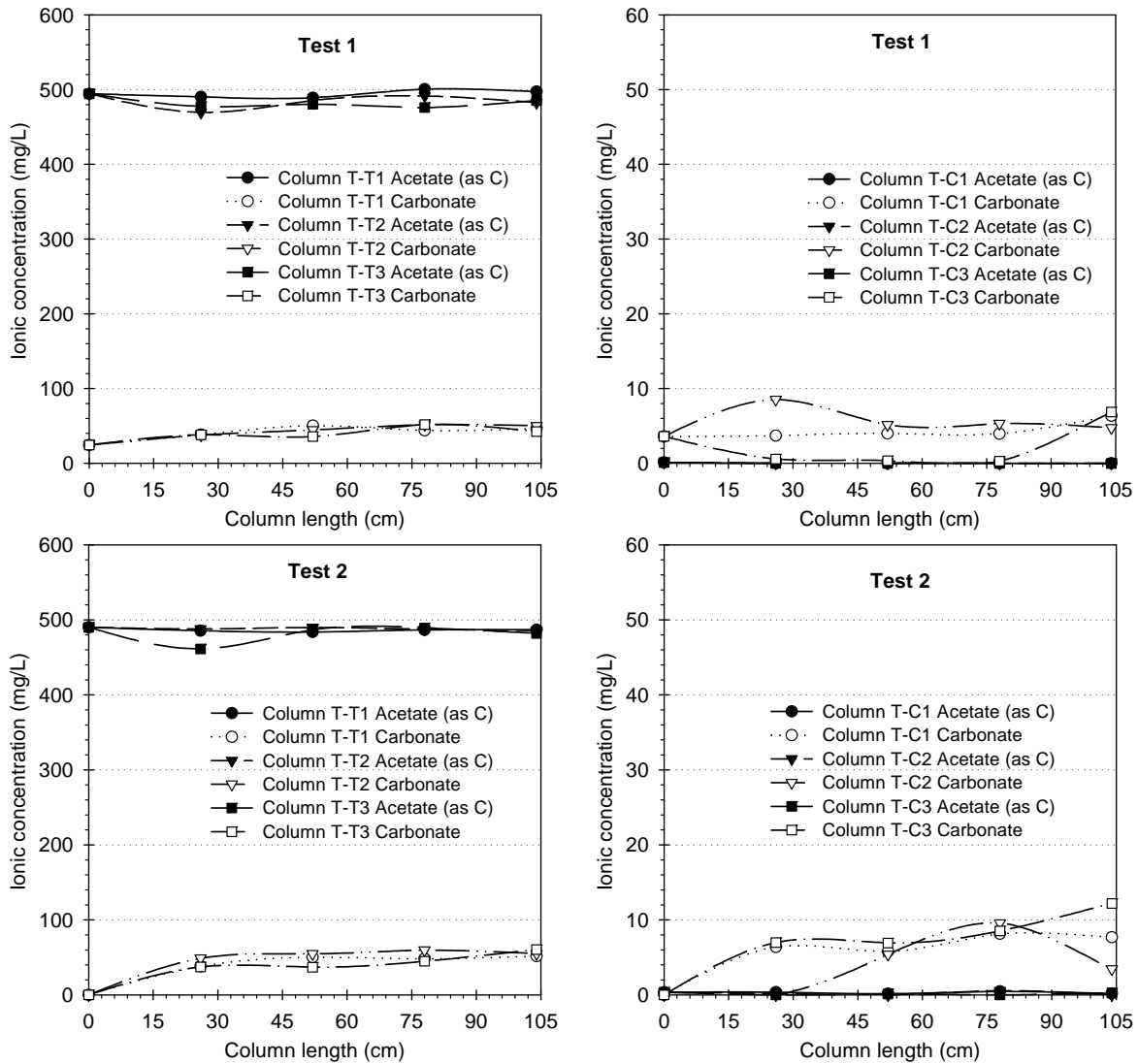


**Figure 10. Axial concentration profile of RDX and its nitroso-substituted metabolites at 15°C (Test 2)**

( $\Delta E_h = -850$  mV) in Column T-T2. In the control columns, no biotransformation of RDX was observed along the column length because of the lack of a reduced environment. In both bed



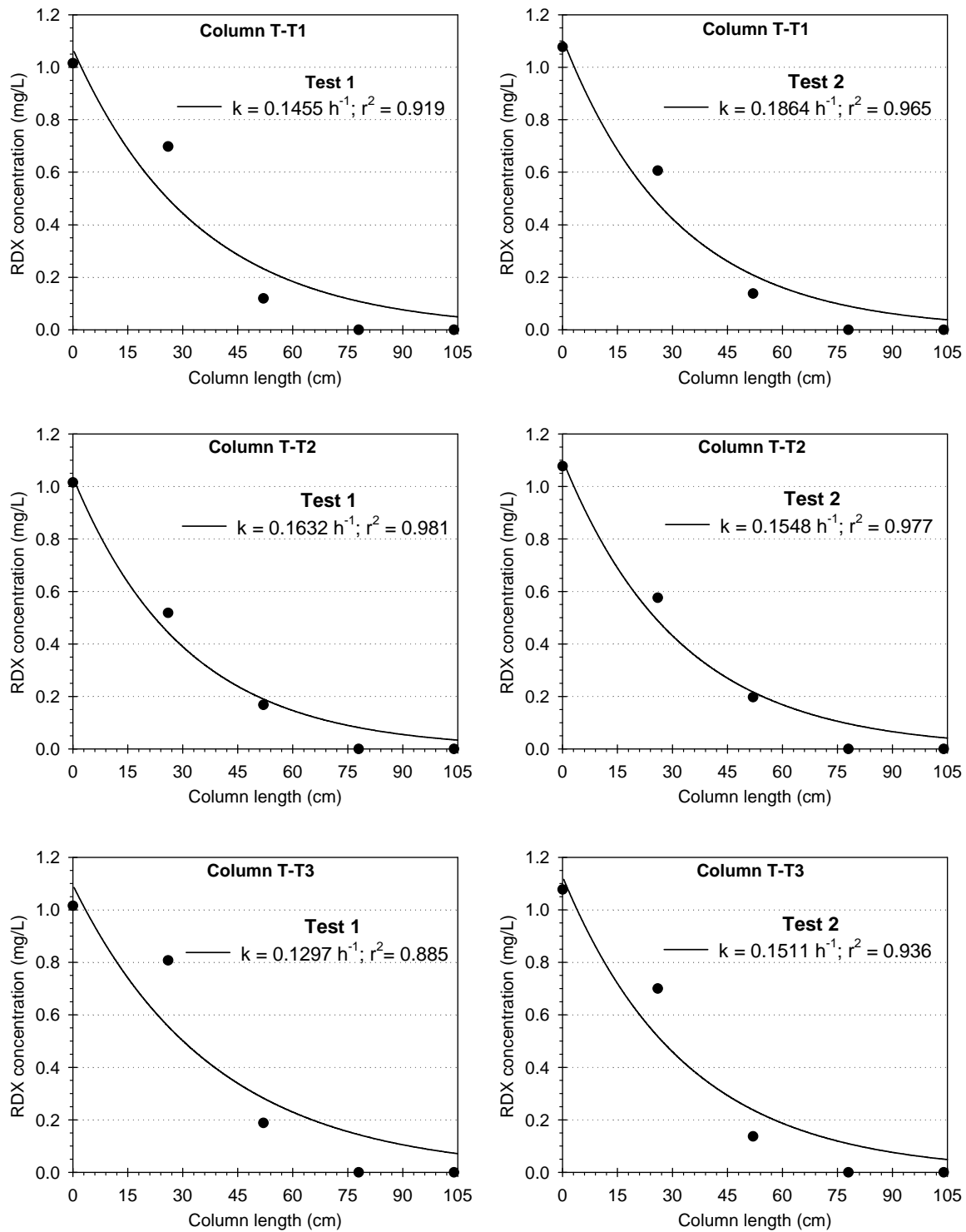
profile tests, less than 1 percent of influent acetate concentration (about 500 mg/L as carbon) was used by the biological activity in the treatment columns (Figure 11). Very low (~50 mg/L) levels of carbonate were observed at intermediate ports in treatment columns.



**Figure 11. Axial concentration profile of acetate and carbonate at 15°C (Tests 1 and 2)**

Figure 12 illustrates the RDX biodegradation kinetic data for treatment columns at 15 °C. The advection-dispersion transport model with contaminant decay given in Equation 2 fitted very well to RDX concentration data from both bed profile tests. The first-order degradation rate coefficient  $k$  for RDX varied between 0.1297 and 0.1864 1/hr for the three treatment columns, with an average  $k$  value of 0.155 1/hr (standard deviation of 0.019). At this average  $k$  value the

time needed for 50 percent removal of RDX is approximately 4.5 hr. RDX biodegradation kinetic parameters for individual columns are summarized in Table 2.



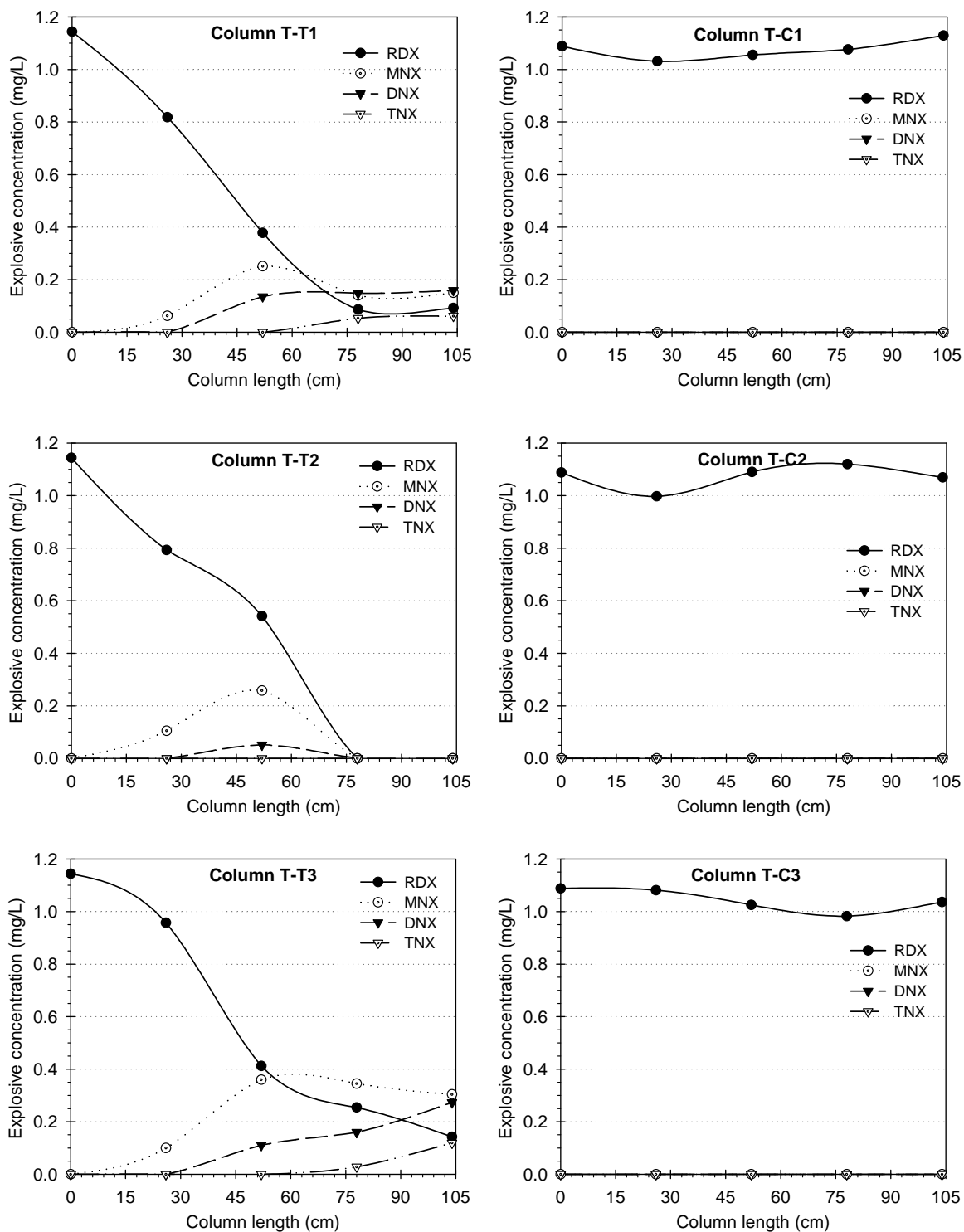
**Figure 12. RDX biodegradation kinetic analysis in treatment columns at 15 °C (Tests 1 and 2)**

**Table 2. RDX Biodegradation Rate Kinetics at Three Different Temperatures**

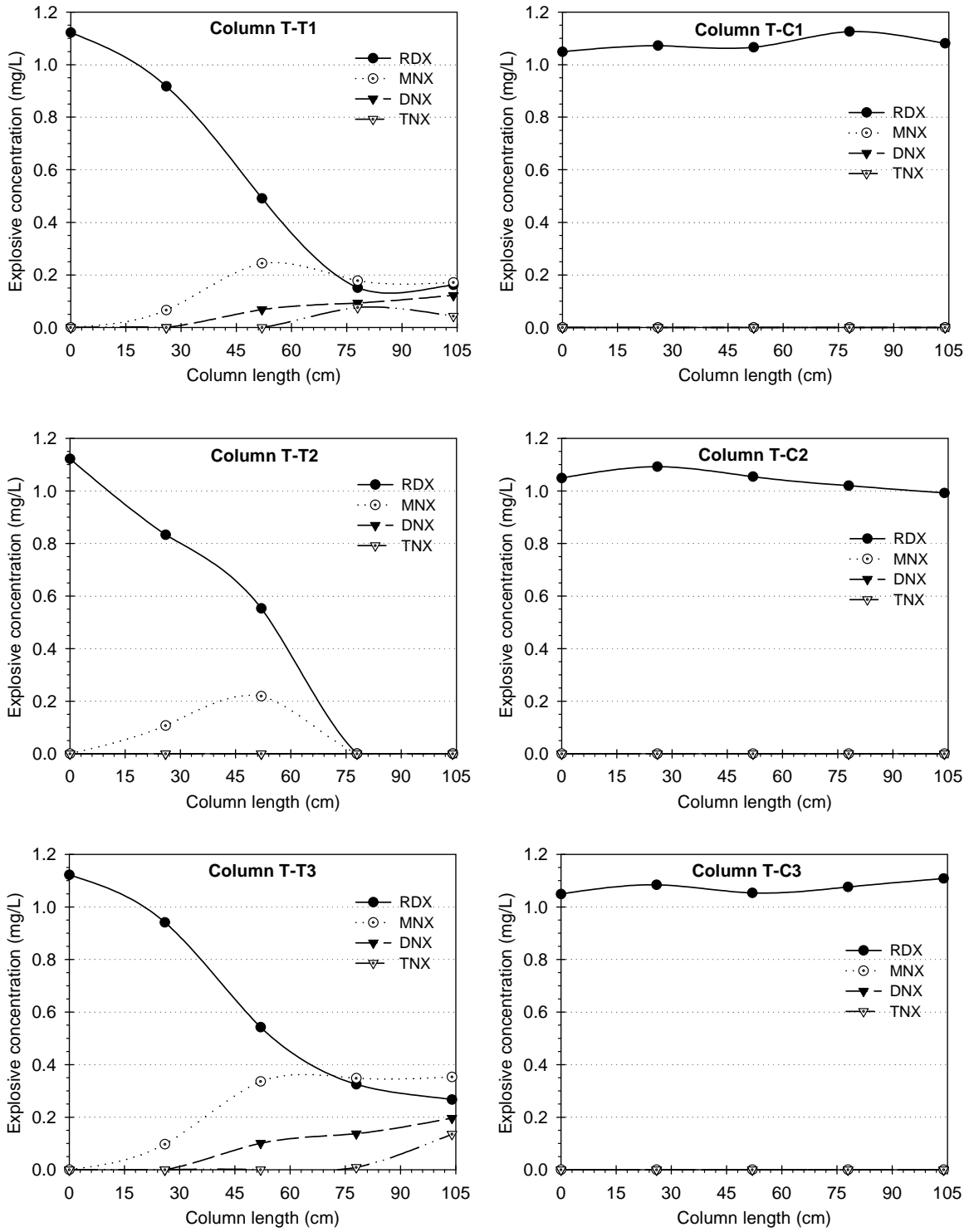
Column	First –order biodegradation rate coefficient, k (1/hr)					
	Temperature 15 °C		Temperature 10 °C		Temperature 5 °C	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
T-T1	0.1455	0.1864	0.1242	0.1022	0.0604	0.0775
T-T2	0.1632	0.1548	0.0995	0.1017	0.0679	0.0769
T-T3	0.1297	0.1511	0.0896	0.0721	0.0422	0.0424
Average	0.155 (±0.019)		0.098 (±0.017)		0.061 (±0.016)	

Average represents the mean of two tests for all the three treatment columns at a particulate temperature. Values in parenthesis are the standard deviation (n = 6).

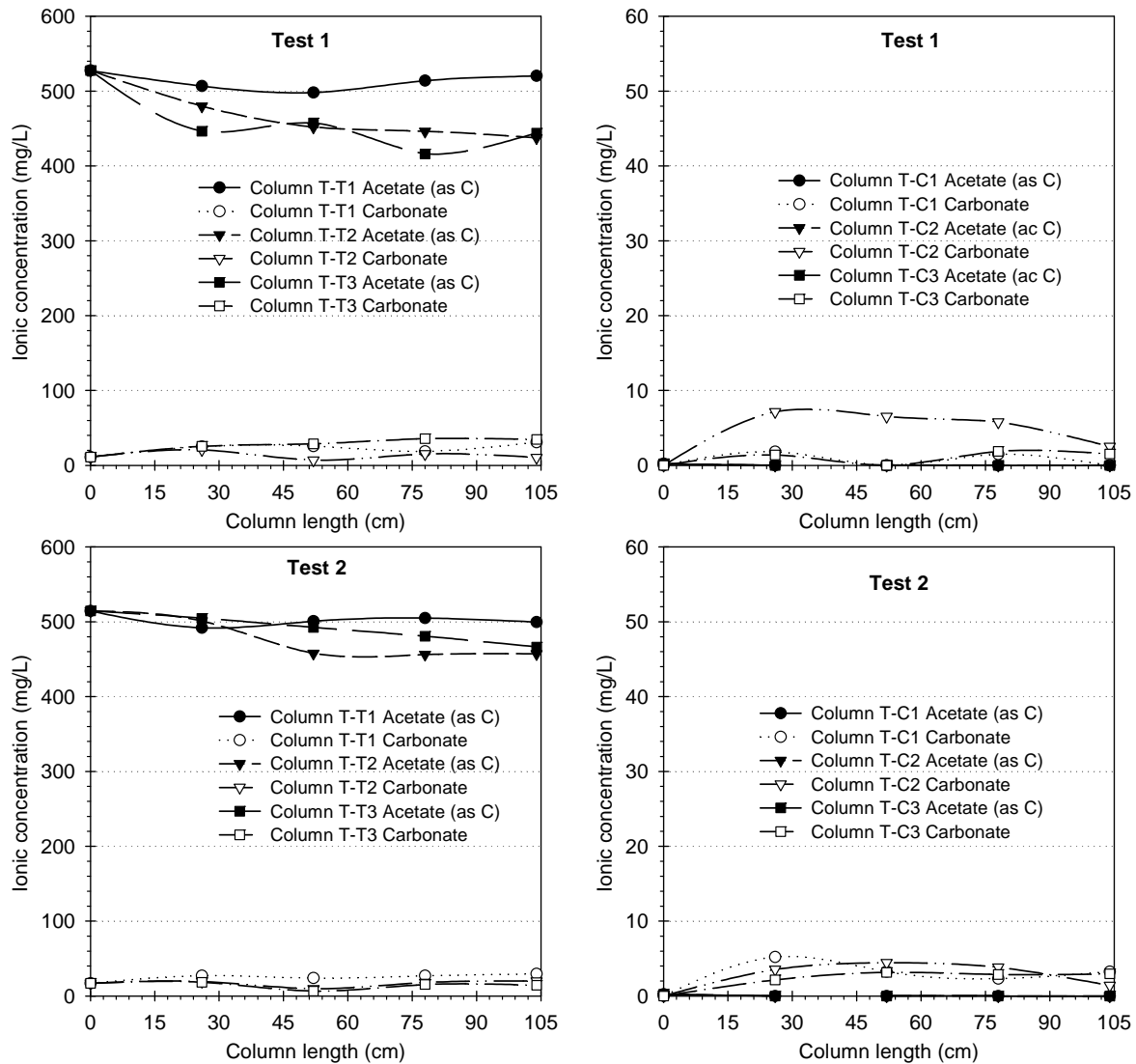
Bed profile tests conducted at 10 °C are shown in Figures 13 and 14. There was no noticeable difference in the axial concentration of RDX and its nitroso-substituted transformation products in treatment columns. Similar to 15 °C tests, in Columns T-T1 and T-T3 a typical sequential transformation of RDX into MNX, DNX, and TNX was observed. Contrary to 15 °C test, measurable levels of RDX were also observed in the effluent stream of these two columns. Furthermore, in both the bed profile tests the levels of these nitroso-substituted transformation products were higher than those found at 15 °C. In Column T-T2, although no RDX or nitroso-substituted metabolites were observed in the effluent stream, RDX degradation was considerably delayed along the column height. These results indicate the adverse effect of lower temperature on biological activity responsible for RDX biotransformation. No biotransformation of RDX was observed in either of the control columns because of lack of reduced conditions. In both bed profile tests, very little influent acetate (~500 mg/L as carbon) was utilized by the biological activity in the treatment columns (Figure 15). Significantly low (~50 mg/L) levels of carbonate were observed at intermediate ports in treatment columns.



**Figure 13. Axial concentration profile of RDX and its nitroso-substituted metabolites at 10°C (Test 1)**

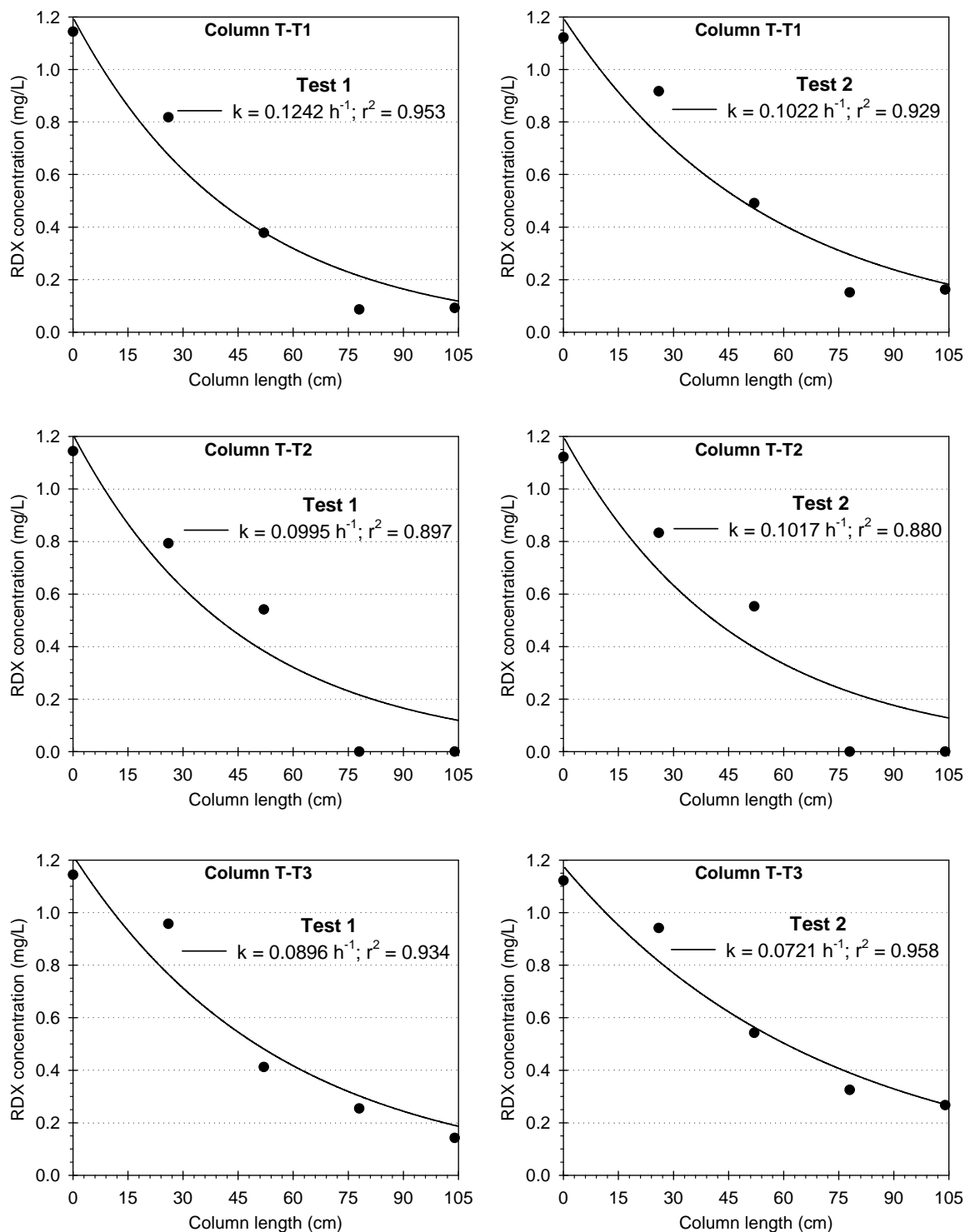


**Figure 14. Axial concentration profile of RDX and its nitroso-substituted metabolites at 10°C (Test 2)**



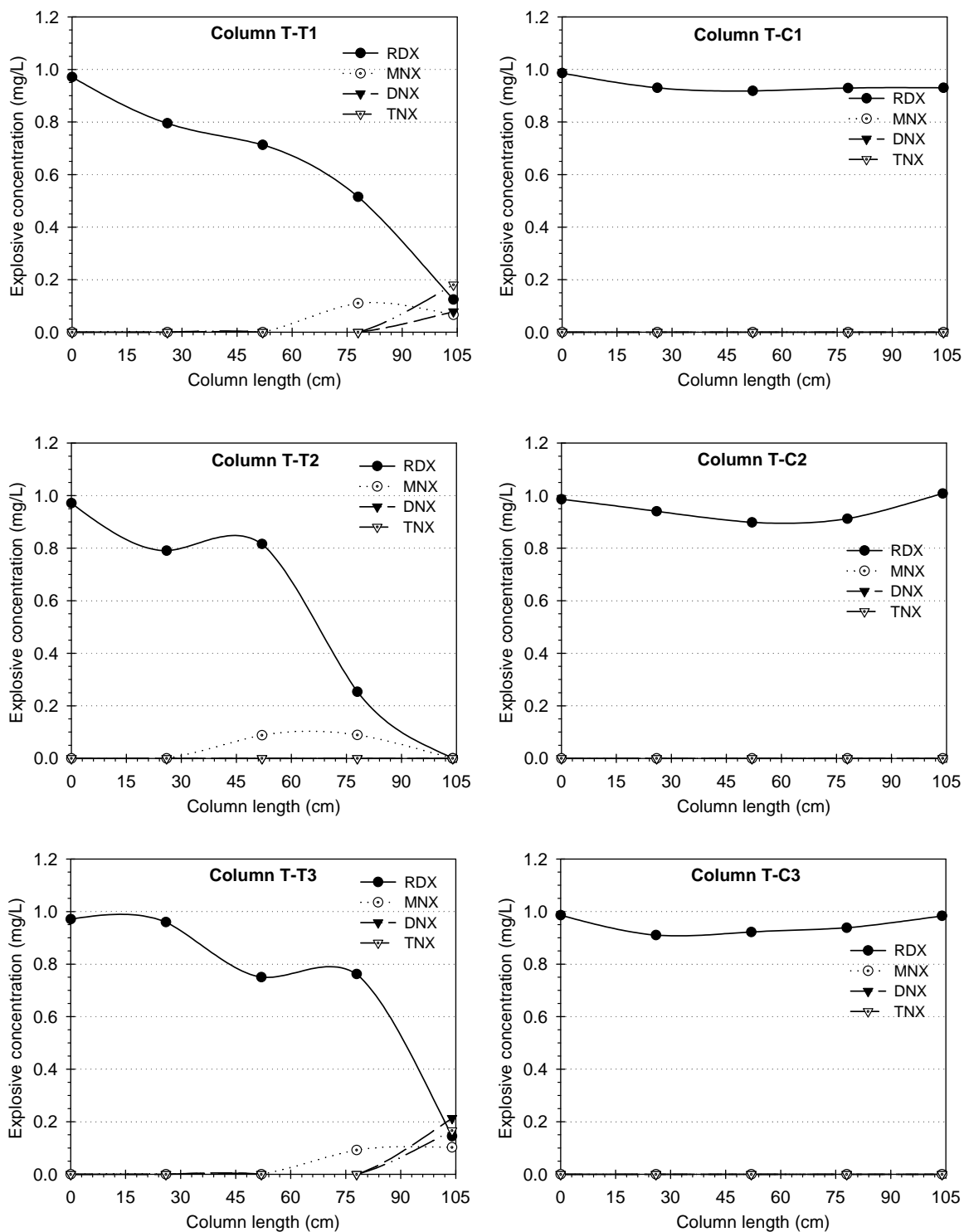
**Figure 15. Axial concentration profile of acetate and carbonate at 10 °C (Tests 1 and 2)**

RDX biodegradation kinetic data for treatment columns at 10 °C are shown in Figure 16. Equation 2 fitted very well to the axial RDX concentrations from both the bed profile tests for all the three treatment columns. The first-order biodegradation rate coefficient  $k$  values for RDX were significantly lower than those for 15 °C, and varied between 0.0721 and 0.1242 1/hr for the three treatment columns (Table 2). At the average  $k$  value of 0.098 1/hr (standard deviation of 0.017), time needed for the removal of half of influent RDX concentration is approximately 7 hr, roughly 50 percent longer than the time needed for the same percent removal at 15 °C. These results quantitatively demonstrate the adverse effects of lower aquifer temperature on biological activity and eventual RDX biotransformation rate.



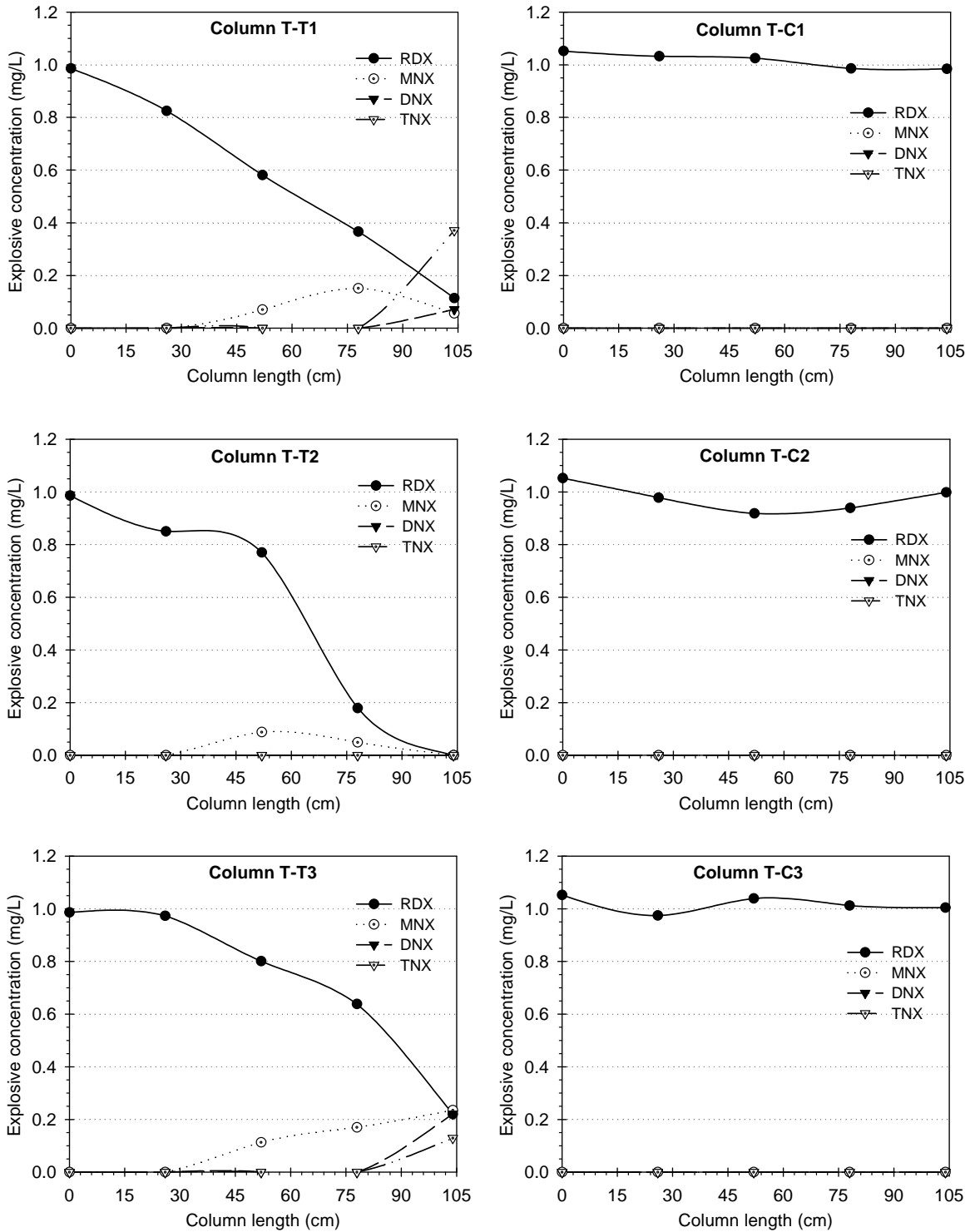
**Figure 16. RDX biodegradation kinetic analysis in treatment columns at 10 °C (Tests 1 and 2)**

At 5 °C two bed profile tests were performed. The results of axial concentrations of RDX, MNX, DNX, and TNX in treatment and control columns are shown in Figures 17 and 18.



**Figure 17. Axial concentration profile of RDX and its nitroso-substituted metabolites at 5°C (Test 1)**

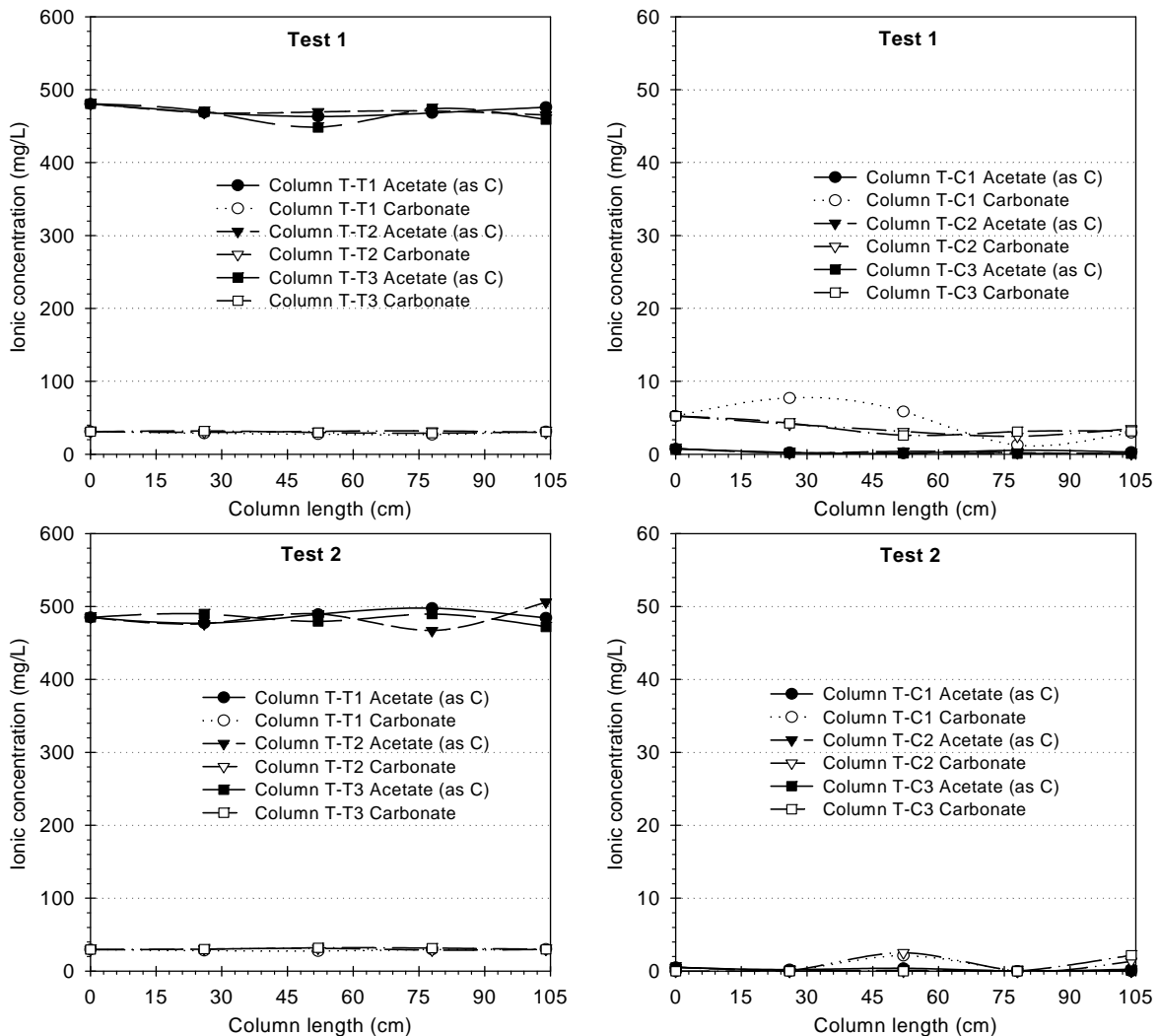




**Figure 18. Axial concentration profile of RDX and its nitroso-substituted metabolites at 5°C (Test 2)**

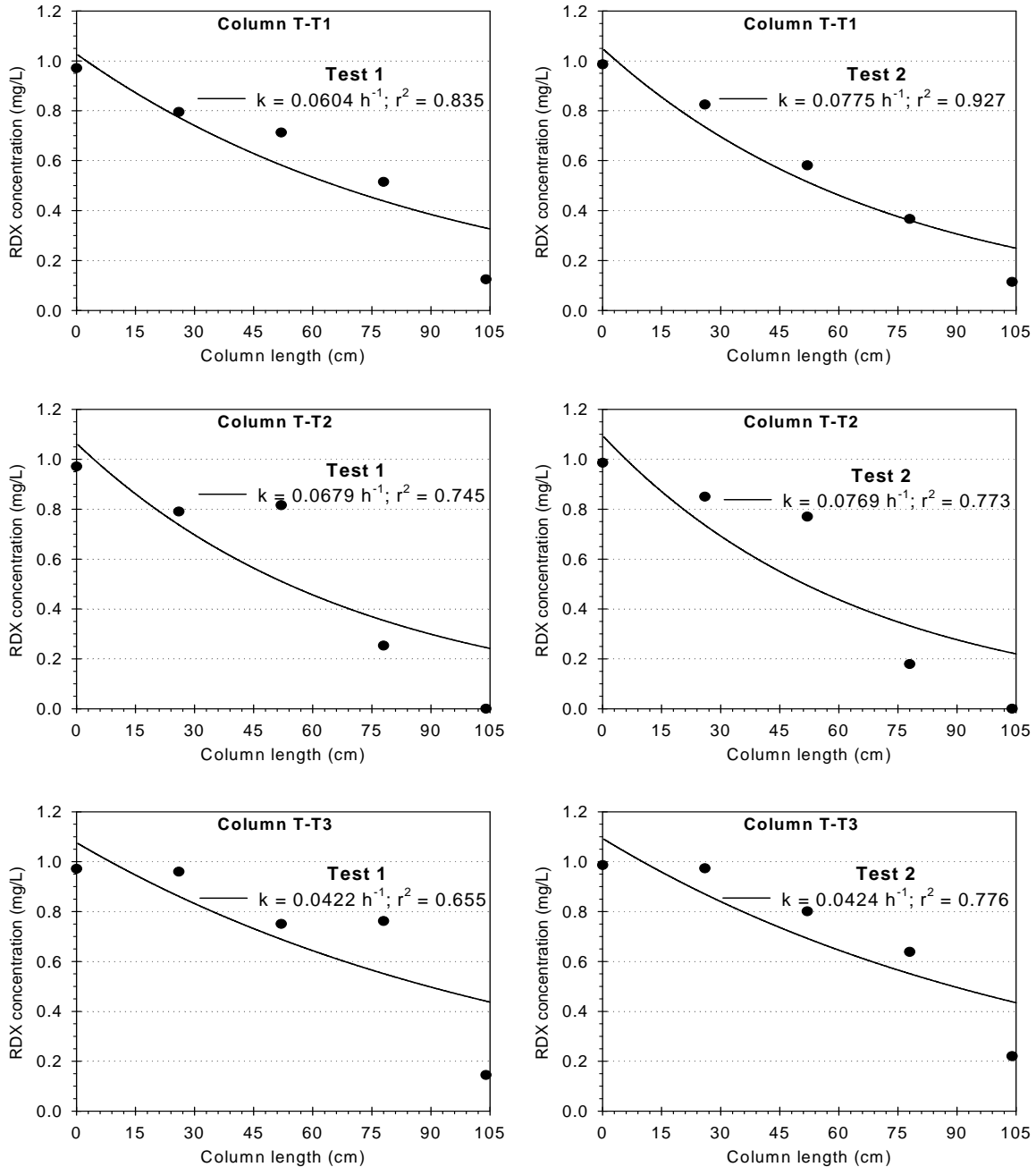
Explosives concentration profiles did not show any noticeable differences between the two bed profile analyses. Unlike the previous two tests conducted at 15 and 10 °C, low concentrations of

RDX and MNX were observed in the effluent stream of each column during the 5 °C test. Concentrations were generally lower in Column T-T2. Additionally, in Columns T-T1 and T-T3 measurable concentrations of DNX and TNX were found in the effluent stream. No DNX or TNX was observed in Column T-T2, and the transient concentrations of MNX at intermediate sampling ports were not present in the column effluent. As discussed previously, the different behavior of Column T-T2 resulted primarily from the very reduced conditions ( $\Delta E_h = -850$  mV) in this column compared with Columns T-T1 and T-T3. In the control columns, no biotransformation of RDX was observed along the entire column length because of lack of reduced conditions. In both bed profile tests, little of the influent acetate (~500 mg/L as carbon) was utilized by the biological activity in the treatment columns (Figure 19). Very low (~30 mg/L) levels of carbonate were observed at intermediate ports in treatment columns.



**Figure 19. Axial concentration profile of acetate and carbonate at 5°C (Tests 1 and 2)**

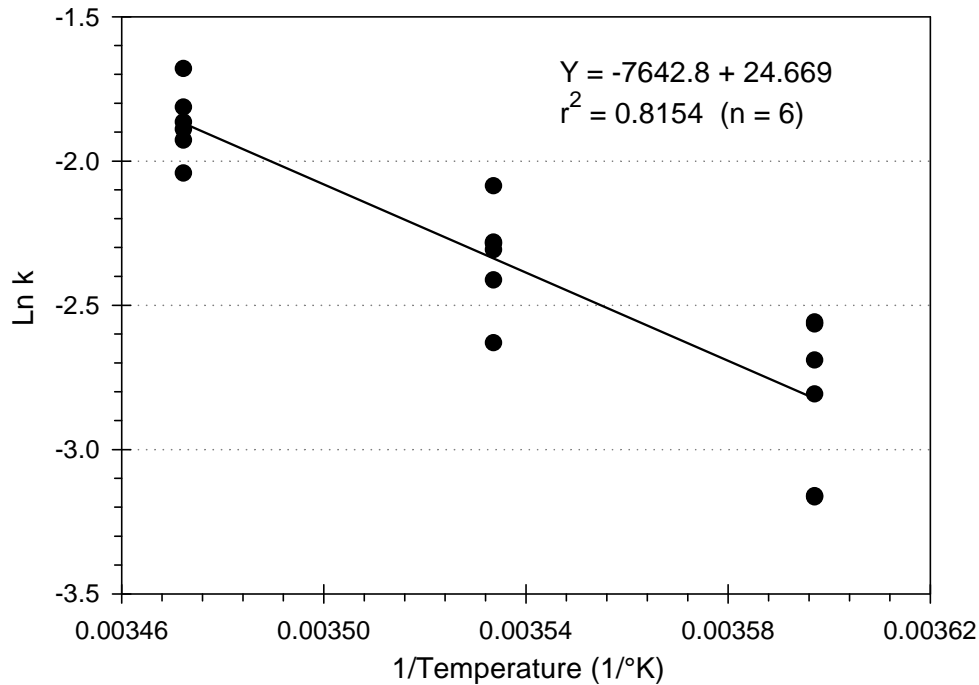
Figure 20 illustrates the RDX biodegradation kinetic analysis at 5 °C. The first-order degradation rate coefficient  $k$  for RDX varied between 0.0422 and 0.0775 1/hr (Table 2) for the three treatment columns, with an average  $k$  value of 0.061 1/hr (standard deviation of 0.016). These  $k$  values are significantly lower than the  $k$  values obtained at 15 and 10 °C. The estimated time needed for biodegradation of half of the influent RDX concentration at this average  $k$  value is approximately 11.3 hr.



**Figure 20. RDX biodegradation kinetic analysis in treatment columns at 5 °C (Tests 1 & 2)**

The estimated k values at three different temperatures were significantly different (95% confidence) from each other. Statistical analysis was done by using Tukey Test for pairwise multiple comparisons. The results of 'One Way Analysis of Variance' showed that the differences in the mean values of k (n = 6) obtained at 5, 10, and 15 °C are statistically significant (P<0.05).

The influence of aquifer temperature on RDX biotransformation was estimated by fitting the Arrhenius model (Equation 3) to the average k values obtained at different temperatures. Figure 21 summarizes the relation between operating temperature and the estimated first-order biodegradation rate coefficients for RDX in treatment columns. As evident from Figure 21, aquifer temperature has a significant influence on the in situ biodegradation of RDX. For these experimental conditions, an activation energy of about 63.54 kJ/mol of RDX was estimated.



**Figure 21. Temperature influence on RDX biotransformation kinetics**

## 5.2 Radiolabel Study

### 5.2.1 Column hydrodynamics

RDX-contaminated water flow in both triplicate column sets during the 9-week study was around 0.2 mL/min, equivalent to a liquid velocity of 0.85 m/d (2.7 ft/d) (Figure 22). This water flow resulted in liquid residence time of approximately 24 hr in individual columns. Due to equipment breakdown only two columns were used for amendment treatment and control. The slug of radiolabel RDX ( $\sim 0.76 \mu\text{Ci}$ ) was introduced on day 51. After that 10 bed volumes of unlabeled RDX-contaminated groundwater were pumped through each column over the next 10 days to wash out any radioactivity sorbed on the aquifer material. As shown in Figure 22, groundwater flow rate during this time was slightly higher than 0.2 mL/min.

Anaerobic conditions were established in treatment columns by providing a carbon source to indigenous microorganisms, which then utilized oxygen, creating a reduced environment. In treatment columns,  $E_h$  drop was significant, ranging between -550 and -700 mV (Figure 22). The drop in redox potential was more significant in Column R-T2 (-700 mV) than in Column R-T1 (-550 mV). One possible reason may be a higher concentration of RDX degrading microorganisms that utilized oxygen in the presence of a readily available carbon source, creating very a reduced environment. This explanation of higher biomass was also evident from the back pressure data (Figure 22), which was highest in Column R-T2 probably due to biofouling. Since no carbon source was used in the control columns, the drop in redox potential was very small (between 70 and -70 mV) compared with those of the treatment columns.

Influent stream pH varied between 7 and 7.5 for treatment columns where RDX-contaminated water was amended with acetate as the electron donor (Figure 22). In the control columns, influent water pH was slightly higher, between 8 and 8.5. The effluent from treatment columns showed a slight increase in pH (8 to 8.5); however, in the control columns there was a slight decrease in effluent pH (6.5 to 7). The effluent from both treatment and control columns during the actual radiocarbon test (final 2 weeks of the study) was collected in an acid quencher (containing 1N HCl) to prevent the degradation of any untreated RDX in the effluent stream at high pH, and also to release any dissolved mineralization-carbon dioxide from the effluent

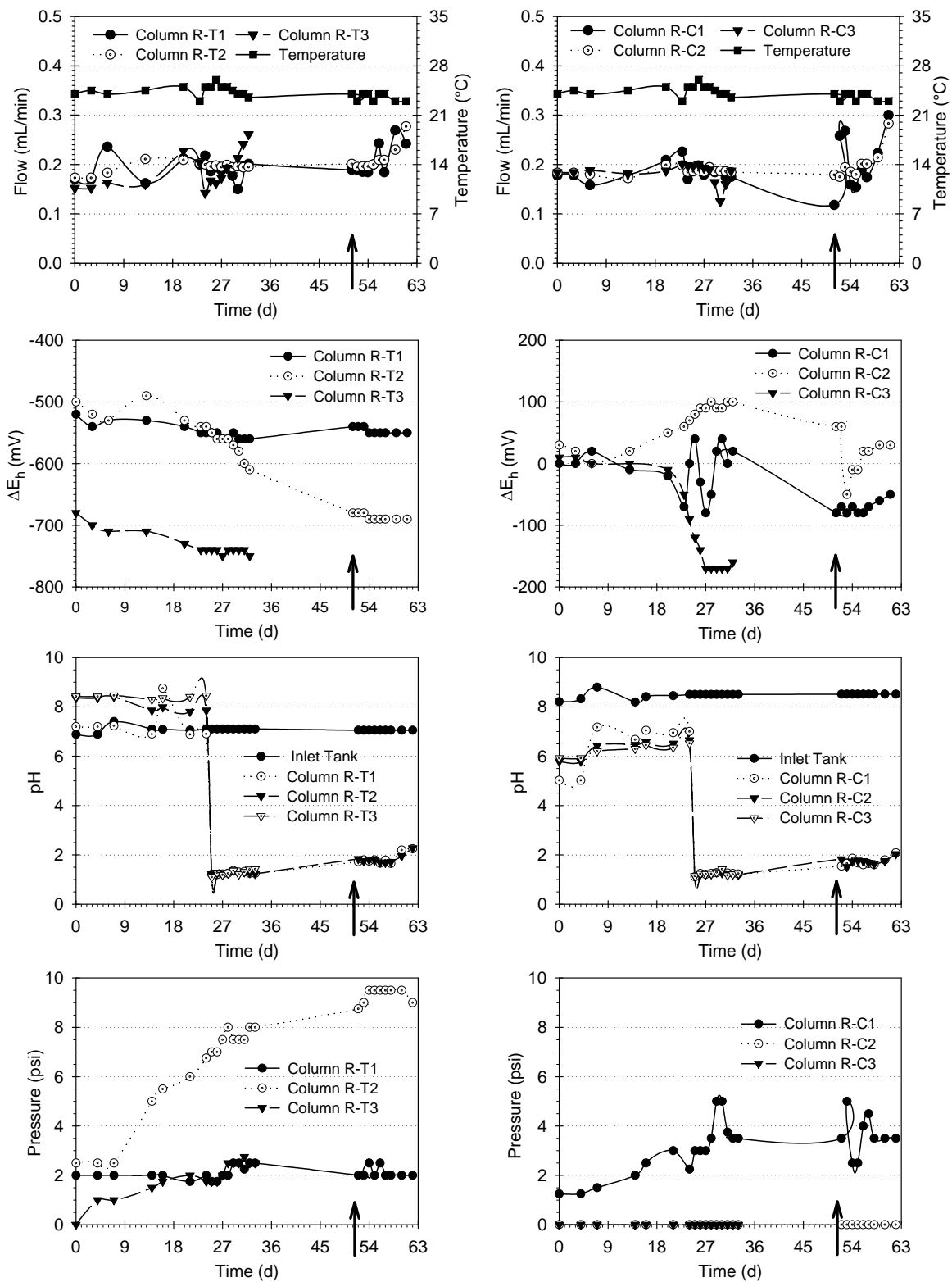


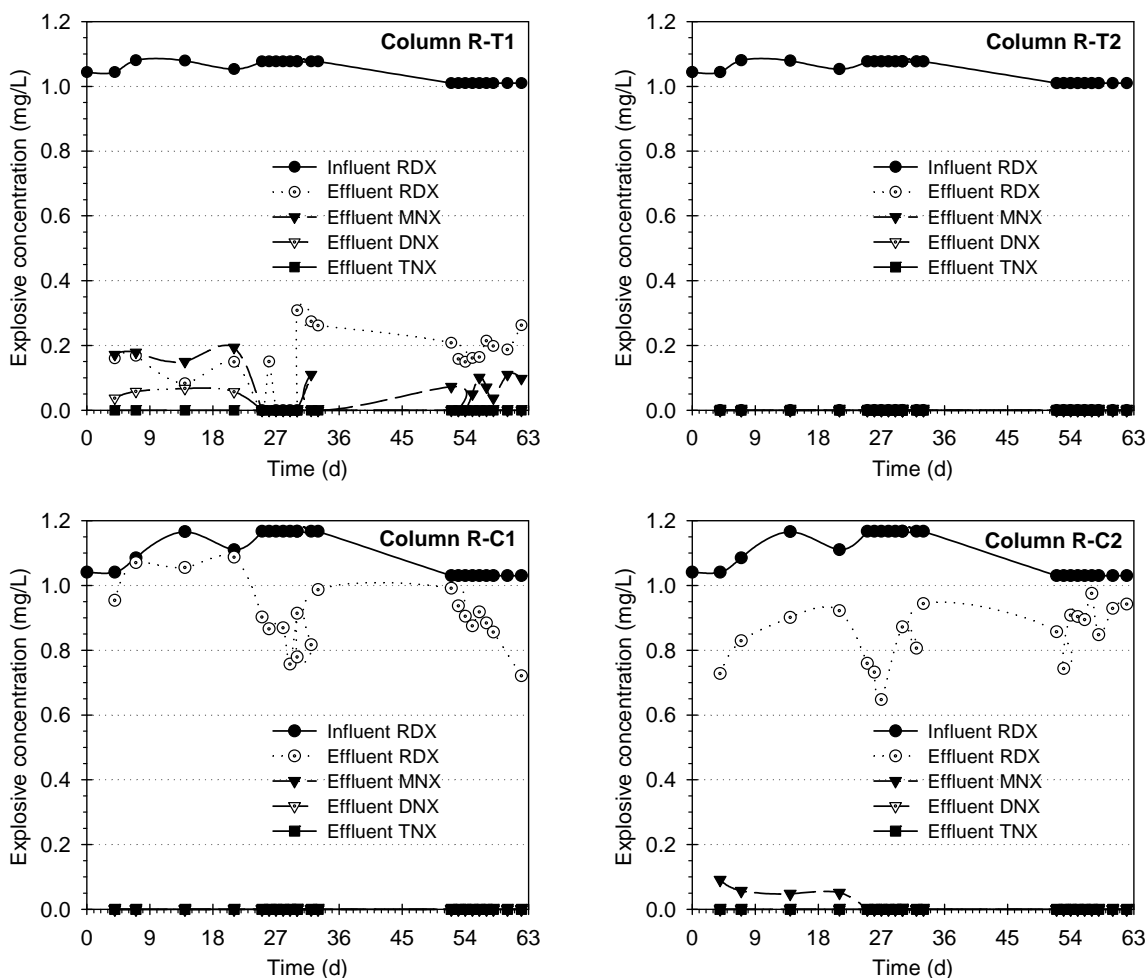
Figure 22. Feed water flow, change in redox, pH and backpressure in radiolabel columns

stream. The effluent stream pH (1.5 to 2) during the final 2 weeks of the test shown in Figure 22 actually is not the effluent stream pH rather the pH of the contents in the acid quencher.

There was no significant back pressure buildup due to biofouling in any of the columns except Column R-T2 where head loss increased steadily and remained around 70 kPa (10 psi) during the last 2 weeks (Figure 22). This increased back pressure could be the result of a higher biomass yield that coincided with the highest drop in redox potential in Column R-T2 because of increased biological activity consuming oxygen in the presence of the electron donor. Occasional hikes in the back pressure for Column R-C1 were due mainly to plugging of the porous PVC screen at the column inlets.

### **5.2.2 *RDX biotransformation***

RDX concentrations (around 1 mg/L) in the influent groundwater were reduced to below detection limits of 0.02 mg/L in Column R-T2 without the detection of any nitroso-substituted RDX derivatives. However, in Column R-T1 low concentrations of RDX, MNX, and DNX were observed in the effluent stream during acclimation stages, i.e., while the reductive environment was developing in the column (Figure 23). During the actual radiolabel test (final 2 weeks of the study) as the redox decreased, only low concentrations of RDX and MNX were observed in the effluent stream. In Column R-T2 the redox was very low compared with Column R-T1, which may explain the RDX biodegradation without the detection of any nitroso metabolites. Column R-T2 also exhibited steady increase in back pressure (Figure 23). One plausible reason behind these two manifest observations in Column R-T2 could be a higher biomass yield that caused RDX biodegradation without the detection of any nitroso transformation products and at the same time created a higher flow resistance resulting in higher back pressure along the column length. The assumption of high biomass yield is also substantiated by the lowest redox potential in Column R-T2 as a result of higher biological activity. The cumulative presence of untreated RDX and nitroso-substituted RDX metabolites in Column R-T1 accounted for about 20 percent of the influent RDX concentration. The unaccounted 80 percent of the inlet RDX might include volatile (including mineralized carbon dioxide) and nonvolatile non-nitroso-transformation products as proposed by other researchers (Hawari et al. 2000a, 2000b; McCormick et al. 1981). In Column R-T2, entire initial RDX concentration was transformed into volatile and nonvolatile non-nitroso-substituted transformation products.



**Figure 23. RDX and nitroso-derivatives concentration in influent and effluent from radiolabel columns**

In control columns very little biodegradation of RDX was observed throughout the course of study (Figure 23). Especially during the last 2 weeks of the study, when radiolabel was introduced, about 8-10 percent of the initial RDX concentration was biodegraded/transformed into products other than nonvolatile nitroso-substituted derivatives, because MNX, DNX, or TNX was not observed in the effluent stream.

During the 9-week study, RDX was removed from the groundwater and low levels of nitroso-substituted transformation products were detected in the treatment Column R-T1; however, in treatment Column R-T2 effluent none of the nitroso-derivates was observed. This variation in RDX end products within these two treatment columns was mainly redox dependent. In Column R-T1,  $\Delta E_h$  between influent and effluent stream was around  $-550$ , whereas  $\Delta E_h$  was very low ( $-700$  mV) in Column R-T2 where none of the nitroso-substituted transformation



products was observed in the effluent stream. In control columns very little RDX was biodegraded. In these control columns  $\Delta E_h$  between influent and effluent was between 50 and -60 mV. From these results, it appears that two pathways that are highly redox dependent may be present. One pathway is sequential reductive transformation of nitro functional groups to nitroso-derivatives (Figure 1) as reported for various RDX-metabolizing cultures that use organic electron donors (Freedman and Sutherland 1998; Hawari et al. 2000a; Beller and Tiemeier 2002; McCormick et al. 1981). Another pathway may be the direct attack of the ring as proposed by Hawari et al. (2000b). This direct attack resulting in ring cleavage may be active only at low redox potentials. Similar results of non-nitroso-substituted reductive biotransformation of [ $^{14}\text{C}$ ]RDX by aquifer microorganisms have been reported by Beller (2002). MDNA, a non-nitroso ring cleavage intermediate has been recently identified by Oh et al. (2001) and Halasz et al. (2002).

### **5.2.3 Radiocarbon ( $^{14}\text{C}$ ) distribution**

The distribution of radiocarbon ( $^{14}\text{C}$ ) in treatment and control columns is summarized in Figure 24. In each column a slug of 0.77  $\mu\text{Ci}$  (1.7 million dpm) of radiolabel RDX was added in the inlet tank. The final mass balance on radiocarbon ranged between 76 and 87 percent in treatment columns, and more than 91percent in control columns. The radiocarbon activity was distributed into three different carbon fractions: (a) dissolved (as aqueous soluble compounds), (b) mineralized (as carbon dioxide), and (c) anabolized (assimilated on biomass and/or sorbed on suspended material). The distribution of these three carbon fractions was different in treatment and control columns.

The observed distribution of radiocarbon was quite different in the treatment columns. In Column R-T1 mass balance on  $^{14}\text{C}$  accounted for 87 percent of initial activity, with approximately 65 percent in the dissolved fraction and 22 percent as mineralized carbon dioxide (Figure 24). The mass balance of radiocarbon in Column R-T2 accounted for about 76 percent of initial  $^{14}\text{C}$  activity. In Column R-T2 the mineralized fraction (~46 percent) was much higher than the dissolved fraction (~30 percent). One plausible reason behind higher rate of mineralization in Column R-T2 may be higher concentration of biomass in this column that coincided with the higher back pressure because of biofouling as well as a higher drop in redox potential (Figure 22) as a result of higher utilization of oxygen by these RDX-degrading

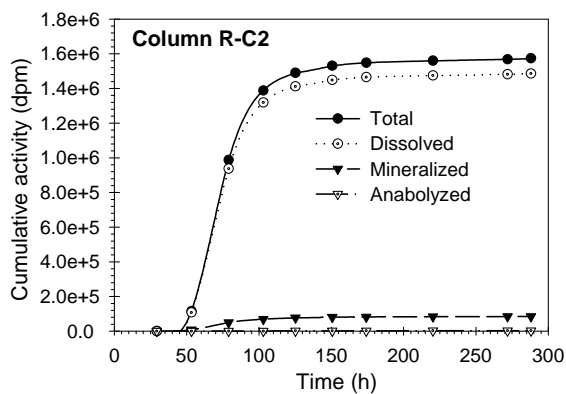
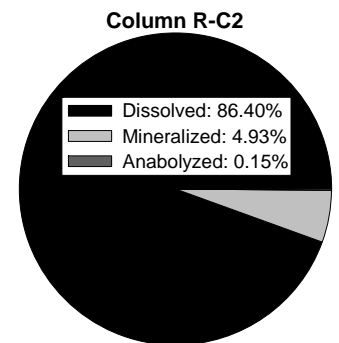
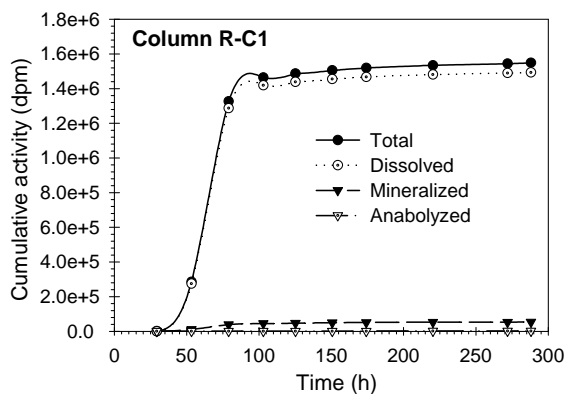
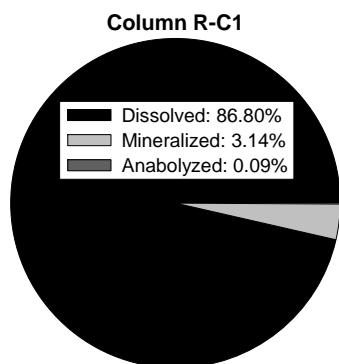
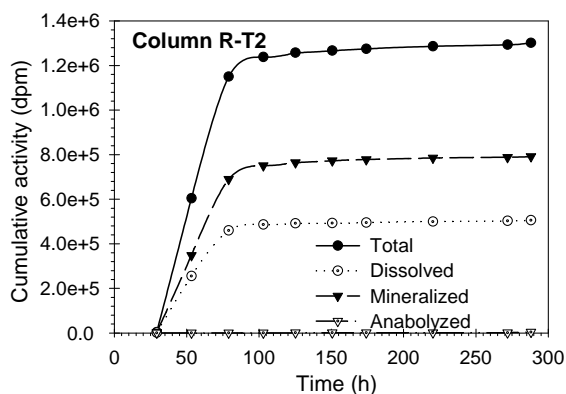
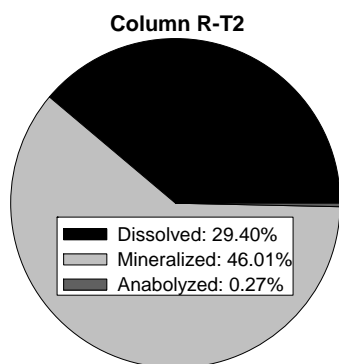
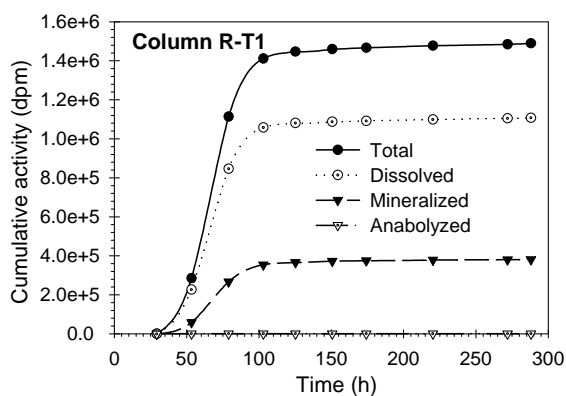
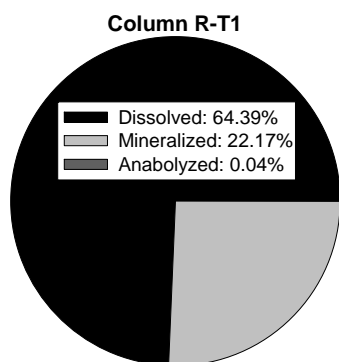


Figure 24. Distribution of  $^{14}\text{C}$  activity from  $[^{14}\text{C}]\text{RDX}$  in radiolabel columns

microorganisms. Even though a considerable amount of initial radiocarbon was mineralized to carbon dioxide by resident RDX-degrading microorganisms in both treatment columns, only a negligible amount was assimilated into biomass because the suspended fraction accounted for less than half a percent of initial activity (Figure 24).

Other researchers have measured mineralization of [ $^{14}\text{C}$ ]RDX under reducing conditions with varying results. McCormick et al. (1981) recovered 1.5 percent of initial radiocarbon as  $^{14}\text{CO}_2$  during anaerobic degradation of [ $^{14}\text{C}$ ]RDX. Similar results, with <2 percent mineralization of radiolabel RDX were reported by Beller (2002) using enrichment cultures with hydrogen as a sole electron donor. Kitts et al. (1994), studying three different bacterial species, recovered 5-9 percent of initial  $^{14}\text{C}$  as  $^{14}\text{CO}_2$  under anoxic conditions. Morley et al. (2002) recovered 8-30 percent of the initial [ $^{14}\text{C}$ ]RDX as  $^{14}\text{CO}_2$  in their batch experiments with ethanol and mixed carbon (mixture of glucose, glycerol, and succinate) as sole electron donors. An exceptionally high (60 percent) conversion of [ $^{14}\text{C}$ ]RDX to  $^{14}\text{CO}_2$  has been reported by Shen et al. (2000) in treating contaminated soil slurries using municipal anaerobic sludge. These studies demonstrate a wide range of mineralization potential of different microbial consortia using various carbon sources as electron donors.

The final mass balance closure in treatment columns indicates a failure to measure possible  $^{14}\text{C}$  end products. Other researchers have reported similar problems in accounting for all the radiocarbon end products in their batch experiment where the final mass balance closure was only 79 percent of the initial [ $^{14}\text{C}$ ]RDX (Morley et al. 2002). The unaccounted fraction of the initial  $^{14}\text{C}$  activity in these treatment columns probably was converted to some products other than mineralized carbon dioxide and nonvolatile nitroso-metabolites. Previously Beller (2002) has reported that about 0.8 percent of [ $^{14}\text{C}$ ]RDX was converted to volatile carbon other than carbon dioxide by enrichment cultures with hydrogen as the sole electron donor. However, in this study no attempt was made to identify these non-carbon dioxide volatile carbon compounds. In treatment columns, the dissolved fraction contained very low or undetectable concentrations of such nonvolatile nitroso-substitutes as MNX, DNX, or TNX. The RDX degraders (a mixed aquifer culture) present in the columns converted RDX to nonvolatile metabolites other than MNX, DNX, and TNX. Metabolites such as hydrazine, 1,1-dimethyl- and 1,2-dimethylhydrazine, MDNA, and formaldehyde that have previously been identified (Hawari, et al 2000a, 2000b; McCormick, et al. 1981) with anaerobic RDX biodegradation may have been

operationally included with nonvolatile carbon in this study. No specific analyses were performed to identify these compounds, some of which are known to be unstable in aqueous solution.

In control columns, the majority (>86 percent) of the initial radiocarbon was in the dissolved phase, and very little (<5 percent) was mineralized. The fraction of  $^{14}\text{C}$  in biomass and on suspended matter was negligible (Figure 24). Because of the lack of a carbon source, the redox potential in the control columns was not conducive to degradation of RDX. Also in the absence of a carbon source the biomass was not able to cometabolize RDX effectively. Distribution of  $^{14}\text{C}$  over time, illustrated in Figure 24, shows a steady increase in the identified radiocarbon fractions over the first 100 hr in both treatment and control columns, which then stabilized over the next 200 hr without any significant increase.

## 6 Conclusions

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The column study reported here in provides several elements of useful information on the fate of RDX during in situ reductive biotransformation in groundwater and the influence of aquifer temperature on RDX biotransformation process. The temperature study showed that the rate of RDX biotransformation is adversely affected by the lower aquifer temperatures. In amendment treatment columns, with every 5 °C drop in operating temperature RDX biodegradation rate coefficient was reduced by about 37 percent. The estimated first-order biodegradation rate coefficient for RDX at 15, 10 and 5°C were estimated to be 0.155, 0.098, and 0.061 1/hr, respectively. The activation energy, estimated from the temperature dependency of the rate coefficients evaluated using the Arrhenius model, was determined to be 63.54 kJ/mol.

The radiolabel study demonstrated that the fate of RDX subject to in situ biodegradation is highly dependent on redox conditions in the aquifer. In acetate-amended columns a considerable portion (23-46 percent) of initial radiocarbon was mineralized to  $^{14}\text{CO}_2$ , compared with <5 percent in amendment control columns. Moreover, the composition of the dissolved fraction was significantly different between amendment treatment and amendment control columns. In treatment columns, where the dissolved fraction of initial radiocarbon was estimated to be between 46 and 64 percent, no nitroso-substituted RDX transformation products were identified. In these treatment columns, where the drop in redox potential was between -550 and -700 mV, the nitroso-substituted intermediates were further degraded probably via cleavage of the triazine ring as reported by previous researchers (McCormick et al. 1981; Hawari et al. 2000a). In amendment control columns, where the reduction in redox potential was very low (70 to -70), the major portion of the dissolved fraction was RDX.

Based on the results of this study, it can be concluded that RDX can be substantially biotransformed under low redox conditions. Furthermore aquifer temperature has a significant influence on the rate of RDX biodegradation, and will therefore be a major factor in determining the length of the treatment zone in actual field applications. The necessary reduced conditions can be achieved by providing sufficient quantities of a readily biodegradable carbon source such as acetate to consume additional oxidants like oxygen and to exceed the demands for other ubiquitous inorganic electron acceptors such as nitrate and sulfate. Finally, to achieve the

biodegradation of RDX and its nitroso derivatives, and to avoid the accumulation of toxic nitroso-substituted metabolites, a very low redox is mandatory.

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**APPENDIX F**  
**Field Demonstration Plan**

**Environmental Security Technology Certification Program  
(ESTCP)**

# **Demonstration Plan**

**Biologically Active Zone Enhancement (BAZE) for In Situ RDX Degradation  
in Groundwater (ESTCP #0110)**



**Altaf Wani and Jeffrey Davis**

**August 13, 2003**

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## List of Acronyms

µg	Microgram
AOP	Advanced oxidation process
ARDC	Agricultural Research and Development Center
ASTM	American Society for Testing and Materials
BAT	Best available technology
BAZE	Biologically active zone enhancement
C	Carbon
CHAAP	Cornhusker Army Ammunition Plant
CoC	Chain of custody
DO	Dissolved oxygen
Eh	Redox potential
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
ft	Linear foot
FUDS	Formerly Used Defense Sites
GAC	Granular activated carbon
gpm	Gallons per minute
GW	Groundwater
HA	Health advisory
HASP	Health and safety plan
HPLC	High pressure liquid chromatograph
hr	Hour
IC	Ion chromatograph
IW	Injection well
L	Liter
lb	pound
mg	Milligram
min	Minute
MW	Monitoring well
NOP	Former Nebraska Ordinance Plant
ORP	Oxidation-reduction potential
OSHA	Occupational Health and Safety Administration
PCB	Polychlorinated biphenyls
PI	Principal investigator

PLFA	Phospholipid fatty acid
pmole	Pica mole
ppb	Parts per billion
ppm	Parts per million
QA	Quality assurance
QC	Quality control
RDX	Royal demolition explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
ROD	Record of decision
SOP	Standard operating procedure
TCE	Trichloroethene
TNB	Trinitrobenzene
TNT	Trinitrotoluene
UV	Ultra violet

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# 1 Introduction

## Background

Many active and formerly used federal facilities are plagued with a rapidly moving, relatively toxic, and expansive plume of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) contamination that threatens the available supply of potable water for surrounding communities. The U.S. Army currently has 583 sites with confirmed explosives-contaminated groundwater at 82 installations nationwide. At 22 other installations, 88 additional sites are suspected of groundwater contamination with explosives and organics (Defense Environmental Network and Information Exchange, DENIX 2003).

Currently, there is no generally accepted in situ process for the remediation of RDX in groundwater. Available remediation alternatives are limited to long-term groundwater pumping and ex situ treatment followed by discharge or re-injection of treated water. The Best Available Technology (BAT) is sorption to granular activated carbon (GAC). Shortcomings of this approach include high initial capital cost for system emplacement, high costs associated with disposal and/or regeneration of GAC, long-term operation and maintenance costs, and the anticipated long-term duration of proposed remediation activities (100 years at the former Nebraska Ordnance Plant (NOP)) (Graff, 2001).

The major toxicological effects of exposure to RDX are nausea, irritability, convulsions, unconsciousness, and amnesia. RDX has also been associated with systemic poisoning usually affecting bone marrow and the liver (ATSDR, 1996). Due to these effects shown in humans, the US EPA has established drinking water health advisories (HA) of 2 µg/L for exposure to RDX (EPA, 2002).

The fate and transport of RDX in the environment can be influenced by many factors including photolysis, hydrolysis, and biologically mediated degradation. Biodegradation of RDX is often attributed to cometabolism in the presence of a primary carbon source under various electron acceptor conditions. RDX can be biodegraded under anaerobic or anoxic conditions by facultative or anaerobic microorganisms (McCormick et al., 1981; Kitts et al., 1994; Freedman and Sutherland, 1998; Hawari et al., 2000; Halasz et al., 2002; Beller 2002). Under aerobic conditions, RDX can be used as a sole source of nitrogen by aerobic microorganisms (Binks et al., 1995; Coleman et al., 1998; Brenner et al., 2000), or by fungus (Bayman et al., 1995; Fernando and Aust 1991, Sheremata and Hawari 2000).

## Objectives of Demonstration

The objective of this demonstration is to evaluate the ability of biological activity to remediate (in situ) an RDX contaminated groundwater plume. The demonstration is designed to identify, collect, and verify the economic, operational, and performance data that will be used to transition this technology to potential users. The major factors being evaluated are cost and performance.

Through this technology demonstration, data will be collected regarding the ease of implementation, cost, and treatment effectiveness, which also will provide site-specific

information about these issues. Such issues can only be addressed through pilot-scale technology demonstrations.

The following are the evaluation points to be addressed by this demonstration:

1. Validate the treatability study predictions for the technology performance as established by the US Army Engineer Research and Development Center-Environmental Laboratory (ERDC-EL). A full description of the validation requirements is presented in Table 1-1.
2. Assess the biologically active zone enhancement (BAZE) process for the remediation of explosives contaminated groundwater.
  - a. Assess the ability of the BAZE process to reduce explosives concentration in groundwater to below the US EPA Health Advisory (HA) level (EPA 2002).
  - b. Monitor the effects of the BAZE process on environmentally available electron scavengers (dissolved oxygen, nitrate, sulfate, etc.)
  - c. Monitor the effects of BAZE process on secondary water quality parameter like mobilization of dissolved metals (iron, manganese, chromium) and BOD/COD levels.
  - d. Identify biota effects resulting from the BAZE process
  - e. Identify site characteristics that have an impact on treatment performance.
3. Quantify the costs associated with the use of the BAZE process for remediation of explosives contaminated groundwater.
  - a. Determine the capital costs associated with the BAZE remediation process
  - b. Determine the operation and maintenance cost associated with the BAZE process.
  - c. Identify site characteristics that affect treatment costs.

The BAZE demonstration will be conducted down gradient from load line 2 near MW-5B (Figure 0-1) at NOP. The former NOP is currently owned by the University of Nebraska and is the location of the Agriculture Research and Development Center (ARDC). Access may be limited due to research in the demonstration area concerning ornamental grasses. A small surface footprint is one requirement placed on this demonstration by the ARDC.

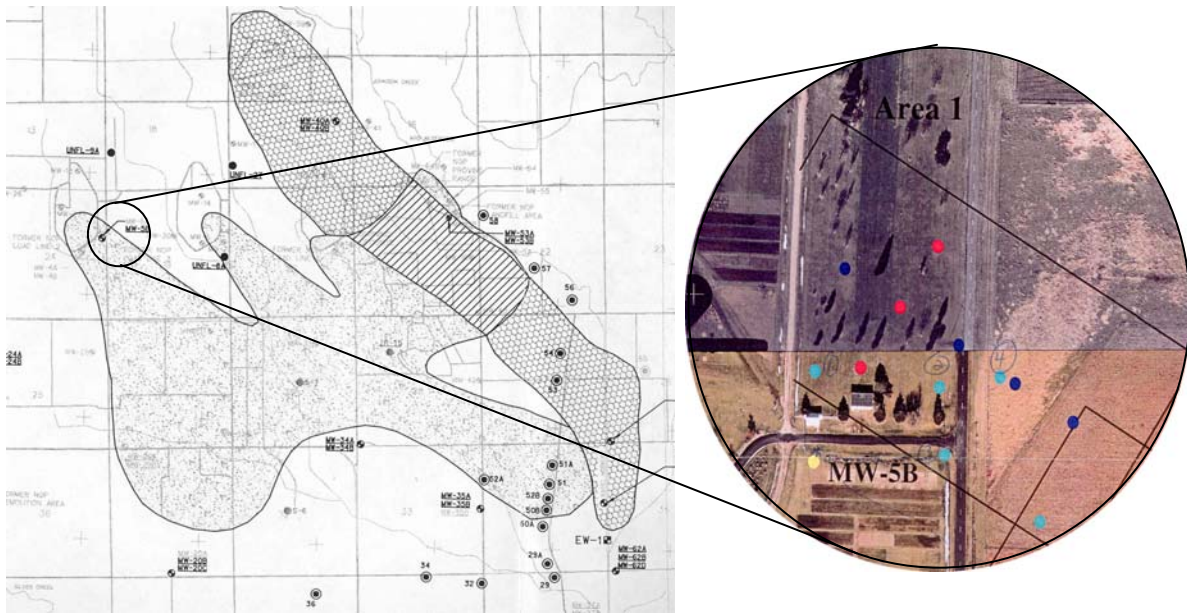
The anticipated advantages of the BAZE process are

1. Lower operating cost than associated with GAC treatment (pump & treat).
2. Lower capital costs than associated with GAC treatment.
3. In situ contaminant mass reduction.

4. Small surface footprint.
5. Regulatory acceptance

**Table 1-1. Summary of Validation Components**

Validation Component	ERDC-EL Study Results
Amendment Selection	Acetate
Removal Efficiency	The average removal efficiency in a column-based study was >99% (effluent concentration below detection, <1 µg/L) with a first-order rate coefficient of 0.281 hr <sup>-1</sup> .
Geologic and Hydrogeologic Effects	The hydraulic conductivity of the aquifer is not expected to be adversely affected by the BAZE process.
Basic Process Operating Parameters	The amendment concentration to be added is 500 mg/L as carbon. The amendment will be added monthly for logistical considerations and will be adjusted as necessary to meet the performance objectives.



**Figure 0-1. Nebraska Ordnance Plant Study Area**

## Regulatory Drivers

The former NOP is currently under US EPA Record of Decision (ROD) EPA/541/R-97/143 to contain/remediate explosives contaminated groundwater. This ROD states that the major components of the remediation system include: hydraulically containing contaminated groundwater that exceeds the Final Target Groundwater Cleanup Goals of 2 µg/L; focused extraction of groundwater in areas with relatively high concentrations of TCE and explosives; and treating all extracted groundwater using GAC adsorption, advanced oxidation processes (AOP), and air stripping. The treated groundwater may be disposed by beneficial reuse and/or surface discharge. Monitoring of the aquifer groundwater elevations and quality is required to ensure no hydrodynamic decline occurs.

### **Stakeholder/End-User Issues**

The US Army Corp of Engineer's Kansas City District is the project lead on the Formerly Used Defense Site (FUDS) project and requires that remedial technologies adhere to:

1. Local, state and federal regulatory guidelines.
2. Meet health advisory levels set forth in the ROD and by the EPA.
3. Have no detrimental effect on overall water quality
4. Have no detrimental effect to the hydrodynamic characteristics of the aquifer.
5. Small surface footprint.
6. Simple to operate.
7. Low cost to performance ratio.

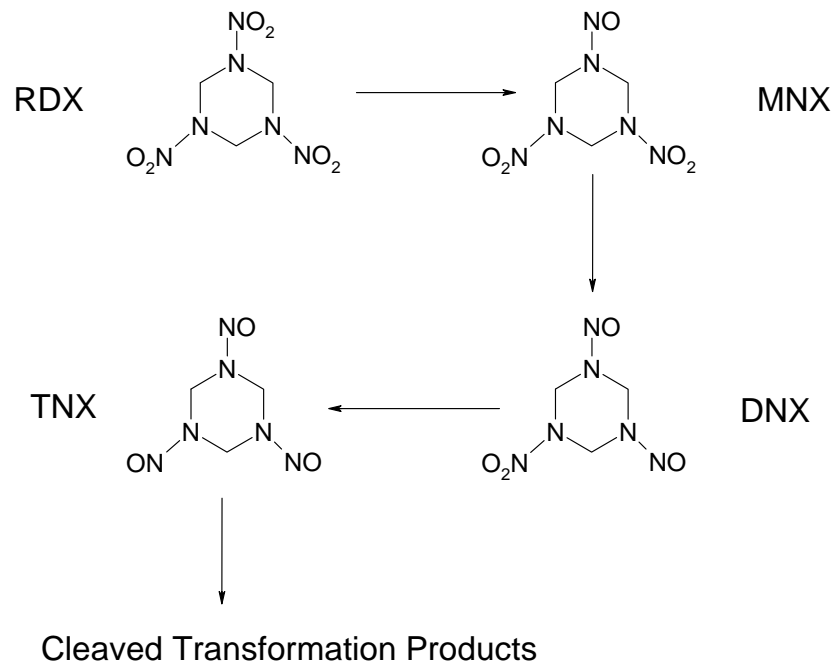
Following successful demonstration, the technology may be transitioned to the Kansas City District for implementation.

## 2 Technology Description

### Technology Development Application

Evidence of microbial degradation has been shown in experiments where contaminated river water was combined with 1% sediment from the same contaminated stream. Significant degradation of RDX occurred after a 20 day lag period. Little or no loss of RDX occurred in the river water alone or with amendment of yeast extract. Approximately 80% of the RDX added was transformed within two weeks after degradation started. In radio-labeled studies, 80% of the [ $^{14}\text{C}$ ]RDX added was evolved as  $^{14}\text{CO}_2$  when 1% river sediment was added to the flasks. Evolution of  $^{14}\text{CO}_2$  was preceded by a 10 day lag phase. It is believed that the river sediment provides a large seed of microorganisms capable of degrading RDX and nutrients for the growth of these microorganisms (Sikka et al. 1980).

Results from anaerobic studies suggested that degradation of RDX is a cometabolic process. Results indicated that a source of organic carbon and RDX had to be present at the same time to achieve RDX degradation. These results suggest that the importance of the organic carbon added was as a cometabolite and not just as a carbon nutrient to rapidly increase biomass. In flasks initially containing 10 mg/L RDX and 50 mg/L yeast extract, the RDX was completely transformed in three days. RDX has been found resistant to biodegradation under aerobic conditions (Spanggard et al. 1980). RDX in nutrient broth cultures disappeared in approximately four days when inoculated with anaerobic activated sewage sludge and incubated anaerobically. Transformation of RDX in nutrient broth was not observed when inoculated with aerobic activated sewage sludge and incubated aerobically. A pathway was proposed for anaerobic biological degradation of RDX (Figure 0-1). This pathway suggests that the one or more nitro groups are reduced to the point of destabilization of the triazine ring occurs, and the ring is fragmented by hydrolytic cleavage. Fragments of the ring are further reduced ultimately resulting in a mixture of hydrazines and methanol. Degradation intermediates identified were the mono-, di-, and tri-nitroso analogs of RDX, formaldehyde, methanol, hydrazine, and 1,1- and 1,2-dimethyl hydrazine (McCormick et al. 1981, Walker and Kaplan 1992).



**Figure 0-1. Anaerobic Pathway**

A bench-scale treatability study was performed using aquifer material and groundwater from the former NOP and Cornhusker Army Ammunition Plant (CHAAP), and submitted to the Environmental Security Technology Certification Program Office for Review. The “Treatability Study Report” can be found in (Appendix G). Phase II of the treatability study (Appendix H) evaluated the effects of aquifer temperature on rate of RDX biodegradation.

### Previous Testing of the Technology

A site-specific treatability study (Appendix G) was performed as the first phase of a four-year field demonstration project. The purpose of this treatability study was to determine the suitability of two formerly used federal ordinance facilities for pilot-scale demonstration/validation of in-situ remediation of RDX contaminated groundwater. The study examined the use of three different carbon sources as electron donors, and developed the biodegradation rate kinetics for RDX for the design of field demonstration. A series of column studies were conducted using site-specific soil and groundwater to determine the feasibility of using BAZE process to remediate RDX-contaminated groundwater. This treatability study examined the use of four amendments (acetate, ethanol, soluble starch, and acetate plus ammonium) as electron donors. All the amendments studied were able to achieve the necessary reducing conditions for remediating RDX inlet concentration of 100 µg/L to less than 1 µg/L. The addition of some amendments resulted in increased toxicity based on Microtox analysis. Ethanol addition itself did not result in increased toxicity but biological activity in this system did induce high toxicity to the test organism. The addition of soluble starch resulted in increased toxicity to the test organism that was partially removed by biological activity in the columns. The addition of

ammonium as a nitrogen source did not significantly increase the removal rate of RDX. Based on these observations acetate was chosen to be used in the field evaluation.

A Supplemental Study (Appendix H) was conducted to examine the effects of aquifer temperature on RDX biodegradation rates, and to examine the fate (mineralization) of RDX. The results of this supplemental study demonstrated that aquifer temperature has a significant effect on rate of RDX biodegradation. With a 5 °C decrease in aquifer temperature (15 to 10°C) RDX biodegradation rate coefficient was reduced by about 37%. At 5 °C the rate coefficient was approximately 1/3 of the rate coefficient estimated at 15 °C. Results of the radiolabel study (Appendix H) demonstrated that the ultimate fate of RDX in in-situ biodegradation is highly dependent on redox conditions in the aquifer. In treatment-columns with very low redox, 23-46% of initial radiocarbon was mineralized to <sup>14</sup>CO<sub>2</sub> as compared to <5% in control columns where redox was high (no carbon source). The dissolved fraction in the treatment columns varied between 46 and 64%, and did not contain any nitroso-substituted transformation products, indicating transformation to non-nitroso-metabolites via ring cleavage. The results of this supplemental study demonstrated that RDX can be biotransformed under low redox conditions.

### **Factors Affecting Cost and Performance**

Several factors are anticipated to determine the treatment costs. These factors are discussed below:

1. Capital cost: The cost of well drilling and preparation is a major capital expenditure. The depth of groundwater plume will have significant effect on the well drilling and preparation cost. Deeper the groundwater plume more expensive the well emplacement and vice versa.
2. Analytical costs: These costs are directly dependent on the RDX and co-contaminant concentrations. Lower RDX concentrations will need solid phase extraction prior to explosives analysis. Similarly the co-contamination will require the additional analysis for different analytes.
3. Operating cost: Operating cost will mainly encompass the costs associated with chemicals/amendments and the utilities such as water and electricity. The chemical/amendment costs will depend on the quantity of electron donor used, which in turn is a function of RDX concentration, co-existence of other electron acceptors like nitrate and sulfate, and the presence of co-contaminants like chlorinated solvents. The presence or absence of site infrastructure like electricity and portable water will also affect the operating costs associated with these utilities.
4. Treatment level: The treatment levels to be achieved are most of the time fixed by the regulatory guidance, and directly influence the percent removal required. The higher initial RDX concentrations will translate into higher percent removals required to meet the treatment levels, thereby using higher doses of organic carbon (electron donor).



5. Presence of co-contaminants: As described earlier presence of co-contaminants, especially those that scavenge electrons for reductive biotransformation, will significantly affect the operating costs by increasing the carbon source input.
6. Aquifer geochemistry: Presence of ubiquitous electron acceptors like nitrate, sulfate and other oxidants will influence the operating costs associated with the quantity of electron donor needed to achieve a required level of reduced conditions for reductive biotransformation of RDX. Co-existence of other inhibitory chemicals like heavy metals, extreme pH conditions will affect the performance of stimulation of resident microorganisms.

Several factors are anticipated to affect the performance of the treatment technology. These factors are:

1. Biological kinetics (treatment time, amount of amendment (electron donor) to inject)
2. Microbial population (expected to increase during treatment)
3. Treatment levels
4. Oxygen diffusion into the aquifer (increases the amount of amendment to be injected and reduces the treatment efficiency)

### **Advantages and Limitations of the Technology**

In situ bioremediation is an attractive technique for destruction of energetic compounds because it reduces the need for long term pump and treat operations along with the necessary disposal, reinjection, and/or reuse of groundwater. Although the treatment time of the bioremedial process is not expected to be improved over that for GAC the process can be targeted to areas within the plume of higher contaminant concentration.

The technology utilizes indigenous bacteria to create conditions in the subsurface conducive to the anaerobic biological destruction of explosive compounds. The technology has the added benefit of reducing nitrate concentration in the subsurface. Nitrate has been regulated under the Safe Drinking Water Act to 10 mg/L. Other major advantage of BAZE process, in addition to reducing nitrate concentrations in the subsurface, is the simultaneous reductive biotransformation of chlorinated solvents and perchlorates present in the aquifer in addition to explosives. This technology reduces the surface footprint to a series of wells and eliminates the need for large reservoirs containing GAC that must be treated off site. No wastes are generated in this process and thus reduced costs are expected. The amendments used for biostimulating the natural microorganisms present in the groundwater and aquifer material for RDX bioremediation do not produce any known toxic or hazardous byproducts, thus the BAZE process will not require any regulatory permits.

The main limitation of this technology is that it is a long-term process, and takes several months to achieve regulatory contaminant concentrations. However, the process has a high potential for regulatory acceptance because of its reliance on indigenous microorganisms.

Other potential limitations of the technology are:

**Biofouling:** The addition of organic matter in an aquifer results in the growth of microorganisms and may result in the plugging of pore-space. This limitation may be overcome by managing the amount and rate of injection to ensure transport of the microorganisms and amendments away from the injection area.

**Electron donor distribution:** Carbon source distribution in the subsurface could be a major challenge especially in the aquifers with very low or very high hydraulic conductivity. In case of stagnant aquifers (low hydraulic conductivity) aquifers, the natural flow of groundwater may not uniformly distribute the carbon source. Similarly, an aquifer with very high hydraulic conductivity might washout the electron donor prior to distribution within the entire aquifer.

**Presence of inhibitory compounds:** The aquifers with high levels of inhibitory compounds (heavy metals, extreme pH, etc.) for biological growth might create difficulties in stimulating the resident microorganisms and at times might lead to process failure.

**Impacts to secondary water quality parameters:** Since the BAZE process does not alter the aquifer pH significantly; the mobilization of metals may not be a great concern. However, the reductive environment created as a result of carbon source injection might lead to mobilization of iron thereby affecting secondary water quality.

**Gas production:** In presence of high nitrate levels, the denitrification process might lead to increased nitrogen gas production. Also in case of methanogenesis, significant quantities of methane gas can be produced under reduced conditions. These gases can lead to pore blockage and groundwater flow restrictions, especially in the aquifers with a low hydraulic conductivity.

**Transient toxicity increase:** The transformation of RDX to undetectable daughter products results in the formation of short-lived intermediates that have been shown to exhibit higher toxicity than the parent compound. These intermediates are short-lived and can be managed by restricting water usage.

**Co-contamination:** Co-contaminants may act as a sink to the injected amendment. Some co-contaminants are ubiquitous such as nitrate and sulfate.

### 3 Demonstration Design

#### Performance Objectives

The objective of this demonstration is to validate the ability of acetate injection to induce conditions capable of cost effectively remediating RDX contaminated groundwater in situ. The demonstration is designed to identify and verify the economic, operational, and performance data that will be used to transfer the technology to potential users. The major factors being evaluated are performance and cost.

Through this technology demonstration, issues such as ease of implementation, cost-effectiveness, and treatment efficiency will be studied; and also will provide site-specific information about these issues, which cannot be addressed in bench-scale treatability studies.

The main issues being addressed by this demonstration will be validation of the treatability study predictions and to determine if BAZE is an effective and economical remedial technology for RDX contaminated groundwater.

The following are the evaluation points to be determined in this demonstration:

1. Validate the treatability study predictions for technology performance as established by the United States Army Engineer Research and Development Center (ERDC).
2. Assess the performance of the BAZE process to remediate RDX contaminated groundwater.
  - a. Assess the ability of the BAZE process to reduce RDX concentrations below the US EPA Health advisory level of 2 µg/L.
  - b. Determine the effects the increased biological activity will induce locally into the aquifer matrix (i.e. decreased hydraulic conductivity, water mounding, etc.)
  - c. Examine the microbial population shifts both spatially and temporally induced by the introduction of acetate into the subsurface.
  - d. Examine the toxicological changes induced by the injection of sodium acetate into the aquifer.
  - e. Determine the site characteristics that may be detrimental or beneficial to the removal of RDX via biological activity.

**Table 3-1. Performance Objectives**

Primary Performance Criteria	Expected performance	Actual performance
% Reduction	98%	
Treated aquifer RDX conc.	2 µg/L	
Treated aquifer toxicity	none	

3. Quantify the cost of the BAZE process to remediate RDX contaminated groundwater.
  - a. Determine the capital cost associated with the implementation of the BAZE process.
  - b. Determine the operation and maintenance costs associated with the BAZE process.
  - c. Identify the site characteristics that affect treatment costs.
4. Assess local public and regulatory acceptance of the BAZE process.
- 5.

### **Selecting Test Site(s)**

An objective site screening and selection process was undertaken and is described in depth in Appendix G. The primary factors used in the selection process utilized data concerning contamination, hydrogeology, geochemistry and infrastructure. This selection process was used to determine two sites for conducting a treatability/feasibility study. The sites selected were 1) the former NOP, Mead, NE, and 2) CHAAP, Grand Island, NE. The results of the treatability/feasibility study (Appendix G) were used to determine the better site for the field demonstration. The results of the treatability study for these two sites were similar. NOP was selected for the field demonstration based on existing infrastructure and the possibility of implementation following the demonstration. A supplemental study (Appendix H) was performed to evaluate the effects of aquifer temperature on RDX biodegradation rates, and to examine the fate (mineralization) of RDX.

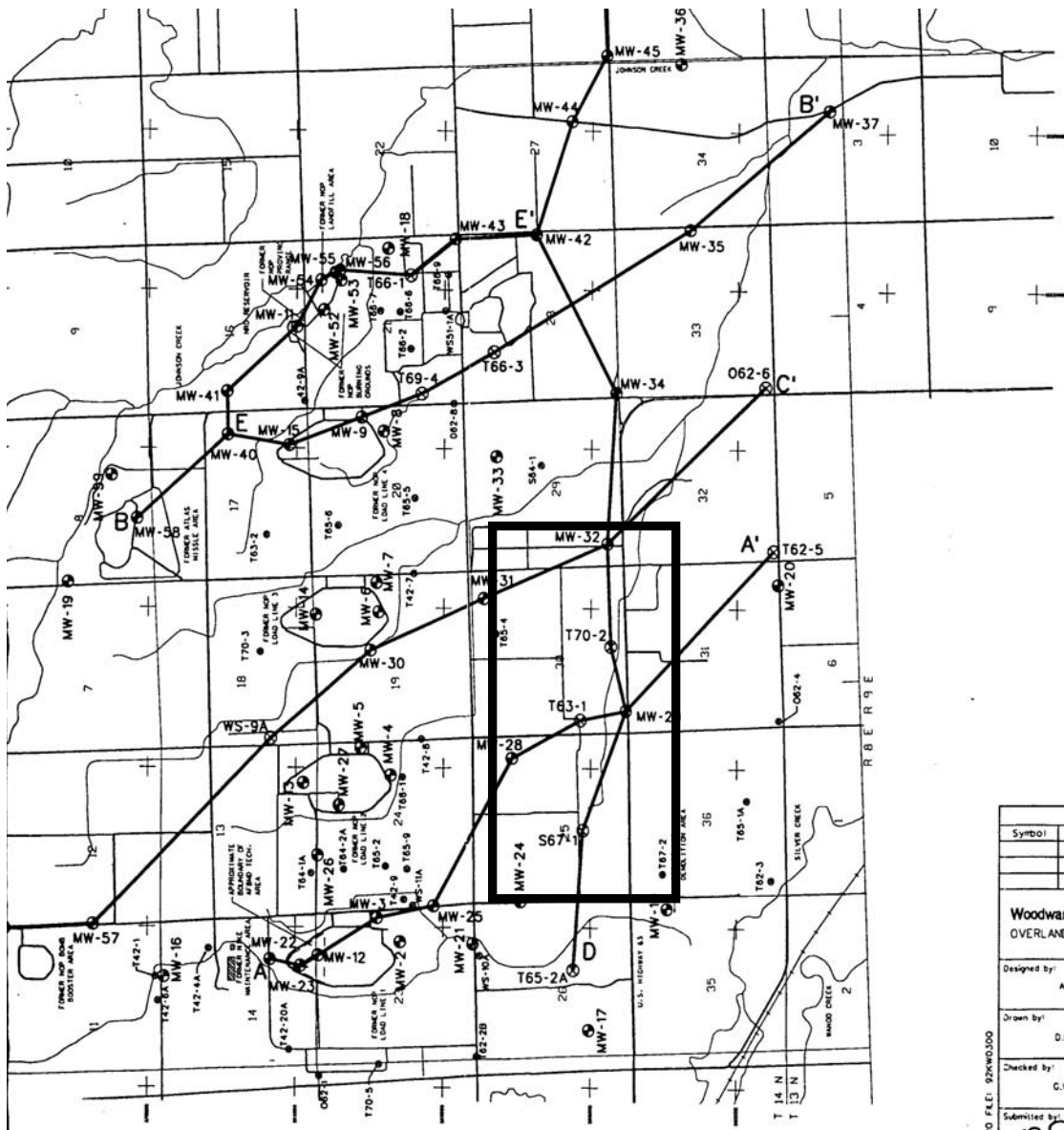
### **Test Site History/Characteristics**

The former NOP is located about one-half mile south of Mead, which is 30 miles west of Omaha and 35 miles northeast of Lincoln, NE. The former NOP covers 17,258 acres in Saunders County. Currently, the land is owned by the University of Nebraska, Agricultural Research and Development Center (ARDC), U.S. Army National Guard and Reserves, U.S. Department of Commerce, and private interests. The former NOP was a load, assemble, and pack facility, which produced bombs, boosters and shells (SIC#2892). Most of the raw materials used to manufacture the weapons at the former NOP were fabricated at other locations and shipped to the former NOP for assembly, however ammonium nitrate was produced on site for the first months of operation in 1943. The plant was operated intermittently for about 20 years until

1962. During World War II the production facilities were operated by Nebraska Defense Corporation. Production was terminated for the interim period 1945 through 1949. In 1950, the former NOP was reactivated in order to produce an assortment of weapons for use in the Korean conflict. NOP was placed on standby status in 1956 and declared excess to Army needs in 1959.

The BAZE test area is located in the northeastern portion of the former NOP site (Todd Valley) near monitoring wells MW-28, MW-29, MW-31, and T63-1 (Figure 0-1). The elevation of the test area is between 1070 and 1080 feet above mean sea level (MSL). The test site geology and hydrology is illustrated in Figure 0-2 through Figure 0-4. The geological units underlying the test area are a 10-15 ft deep layer of loess (buff to yellowish brown loamy deposit chiefly deposited by the wind) underlain by a 55-65 ft deep layer of fine sand. Below the fine sand layer is a 30-50 feet deep layer of sand and gravel. The water table is about 45-55 feet deep at the test site.

The bedrock beneath the test area consists of Cretaceous shales and sandstones of the Omandi Formation. The Omandi Formation is underlain by Pennsylvanian shales and limestones. The Omandi Formation has been divided into an upper shale and lower sandstone lithofacies at the site. The sandstone lithofacies of the Omandi Formation are fine to medium grained with some gravel at the base. The sandstone varies in thickness from 20 to 105 feet below ground surface (bgs). The shale lithofacies is a clayey nonclacareous shale with some interbedded thin silt and sand. The maximum thickness of shale is about 52 feet.



R 9 E RANGE 9 EAST

SOURCE: USGS 7.5 MIN QUADRANGLES (1969)  
FOR MEAD, ASHLAND EAST, ASHLAND  
WEST, AND MANN 1927 NAD, 1929 NGVD



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Symbol	Descriptions	Date	Appr


<b>Woodward-Clyde Consultants</b> OVERLAND PARK, KANSAS	U.S. ARMY ENGINEER DISTRICT CORPS OF ENGINEERS KANSAS CITY, MISSOURI
Designed by: A.W.	 REMEDIAL INVESTIGATION FOR OPERABLE UNIT NO. 2 - GROUNDWATER FMR, NEBRASKA ORDNANCE PLANT - MEAD, NEBRASKA
Drawn by: D.R.T.	
Checked by: G.W.W.	<b>LOCATIONS OF GEOLOGIC CROSS-SECTIONS</b>
Submitted by:	Scale: 1 INCH = 4000 FEET Date: MAY, 1993
O.F.E.I. 02NW0300	Sheet number: <b>1</b>

Figure 3-1. Location of BAZE test area

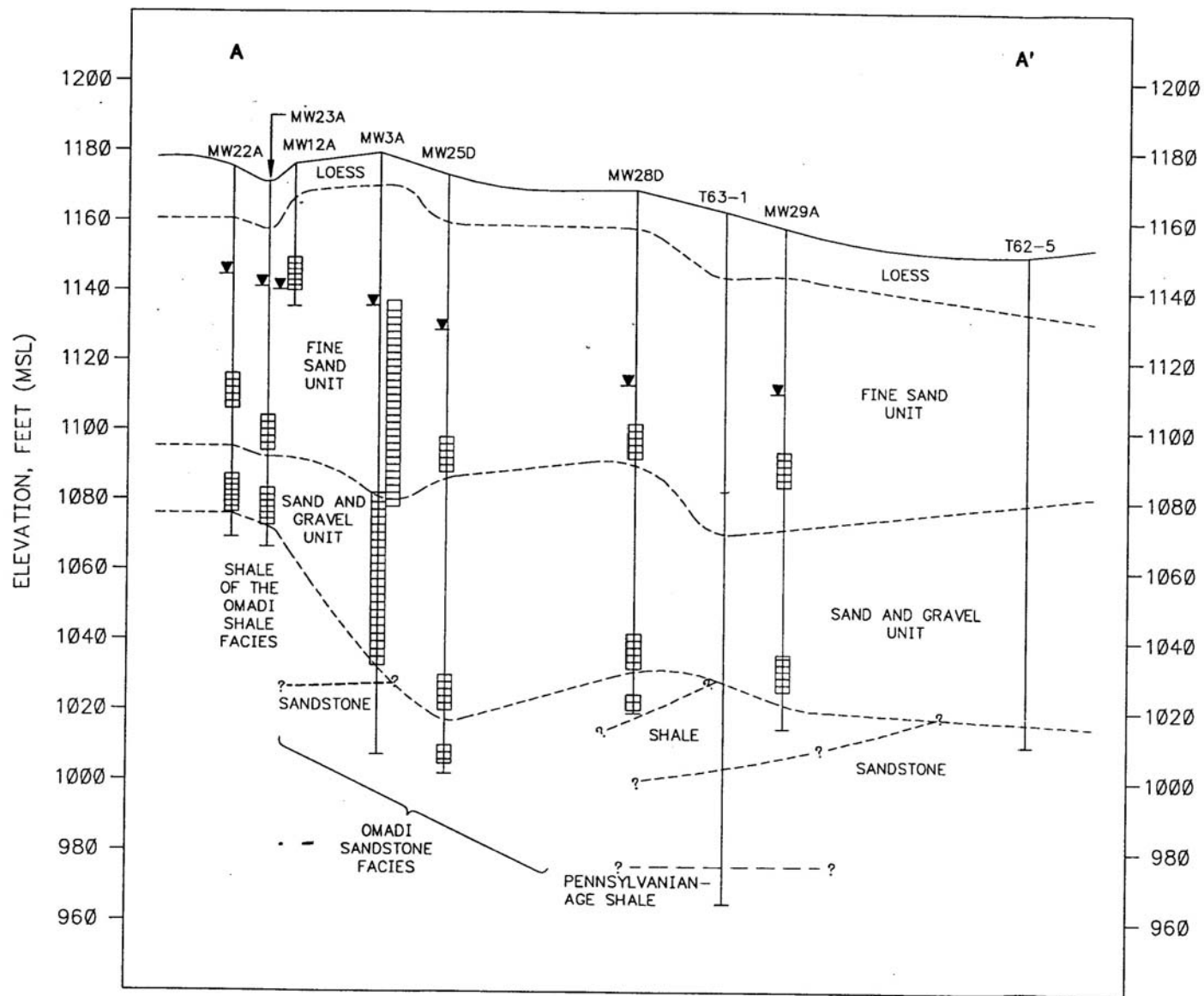


Figure 3-2. Geology and hydrology at existing monitoring wells in the test area

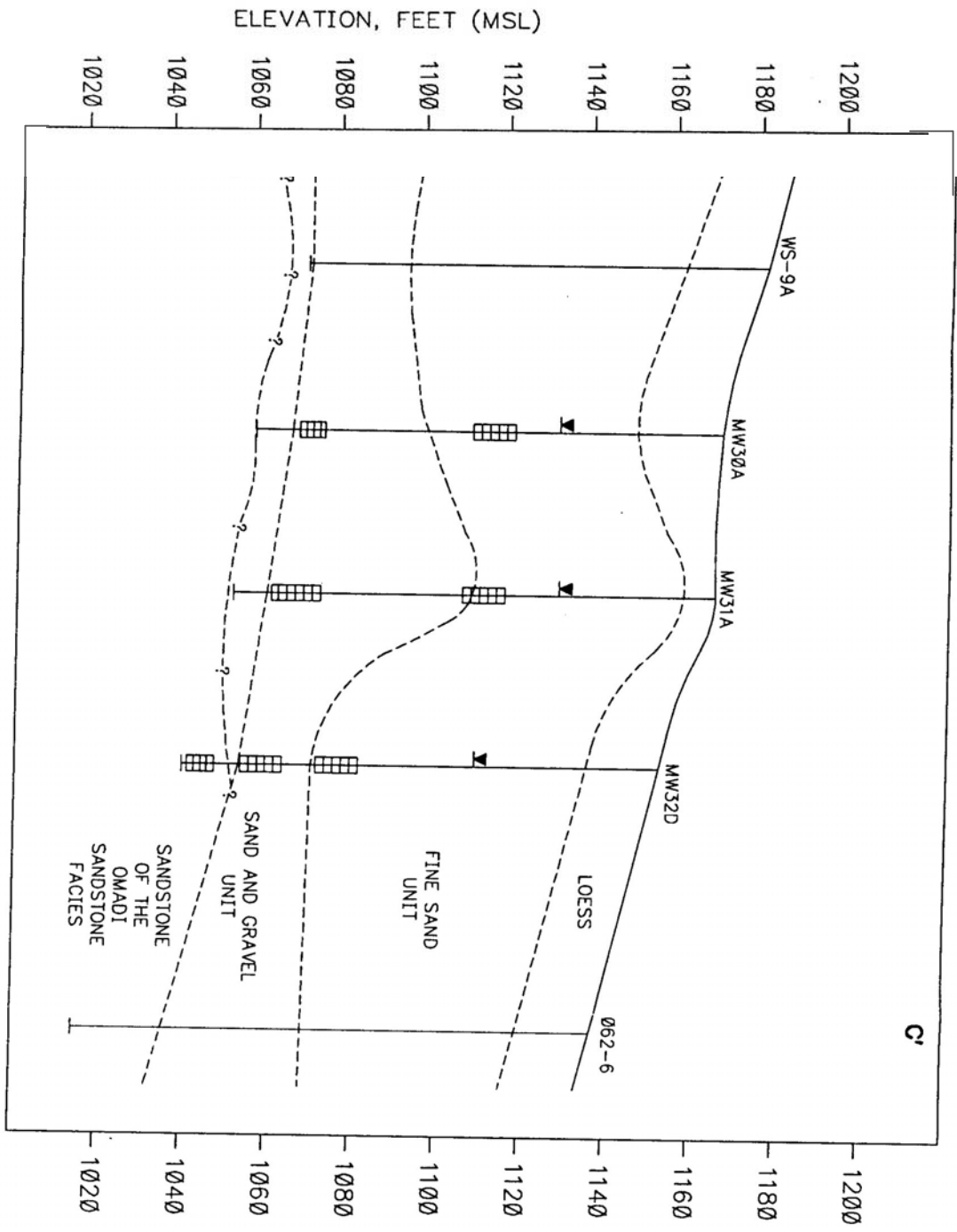


Figure 3-3. Geology and hydrology at existing monitoring wells in the test area



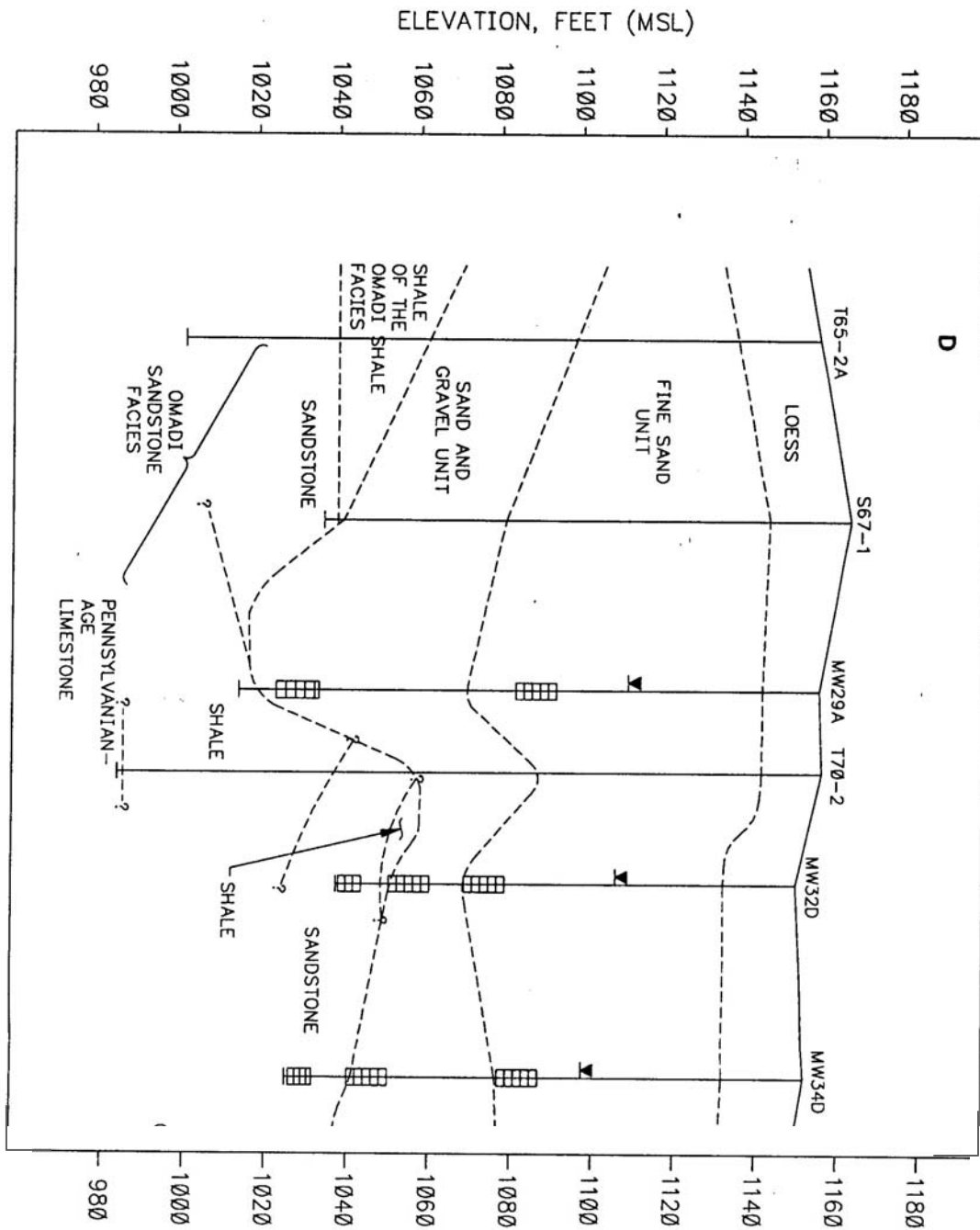


Figure 3-4. Geology and hydrology at existing monitoring wells in the test area

The hydraulic conductivity of Todd Valley fine sand unit is estimated at  $0.034 \text{ ft min}^{-1}$ , and the Todd Valley sand and gravel unit is  $0.08 \text{ ft min}^{-1}$ . The hydraulic conductivity of Omandi sandstone aquifer is estimated at  $0.044 \text{ ft min}^{-1}$ .

RDX is the only contaminant of concern at the test site. The concentration of RDX at the test site varies between 60 and 150 ppb. Hot spots with sufficient RDX concentration (at least above 20 ppb) will be located during the pre-demonstration sampling for laying the well field (URSGWC, 2000).

The results of 1991-92 evaluation study by USACE indicated that explosive contamination in soil is mostly limited to soils in and under drainage ditches and sumps in the load lines and the Bomb Booster area. It is believed that this contamination originated from the discharge of water used to wash away explosive dust and residue which resulted from the ordnance load, assemble, and pack process. RDX, 2,4,6-trinitrotoluene (TNT), and 1,3,5-trinitrobenzene (TNB) were the explosive contaminants most often detected. RDX, TNT and TCE were identified in the groundwater samples. The current RDX groundwater plume is depicted in Figure 0-1.

### **Present Operations**

The remediation of RDX contamination at the former NOP is occurring in two stages. The first stage (completed) is the remediation of contaminated soils and the second phase (on-going) is the containment/remediation of contaminated groundwater.

The Army Corp of Engineers began their cleanup effort in 1994. From 1994-1996, 1250 tons of PCB-contaminated soil was removed from the site and placed in a licensed hazardous waste landfill. An incinerator was built on-site in 1997 to remediate RDX and TNT contaminated soils. From October to December 1997, more than 16,000 tons of soil was treated by incineration at  $1,700 \text{ }^{\circ}\text{F}$ , completely destroying RDX. The treated soil was buried on-site and covered with fresh soil.

In October 1998, the Corps began groundwater cleanup operations. This cleanup operation is expected to last 90 to 120 years. This lengthy timeframe is required to prevent depletion of the groundwater aquifer. Current plans call for 11 containment wells to be drilled along the southern edge of the RDX groundwater plume. These wells are expected to stop further migration of the groundwater plume. Water from these containment wells (3,000 gpm) will be treated by adsorption to GAC. RDX contaminant mass in the groundwater plume will be reduced by placing 13 groundwater circulation wells in the interior of the plume that exhibit the highest concentrations. The circulation wells will treat the contaminated water on-site by UV-Oxidation and return the treated water back to the aquifer. The circulation wells will treat 2,650 gpm of contaminated water. Since the treated water is placed back into the aquifer, no groundwater declines should occur.

The primary concern with this remediation strategy is the length of time for the site to be remediated and maintaining the hydrodynamics of the aquifer. The principal cost factors in this treatment strategies include large upfront capital costs (construction of GAC treatment system), and the long-term operating costs of the containment system.

### **Pre-Demonstration Testing and Analysis**

A treatability study was performed to examine the most suitable organic amendment for injection into the subsurface to induce biological activity. Results of this study are presented in Appendix G. These results indicated that the injection of acetate would result in rapid degradation of RDX once anaerobic conditions are induced in the aquifer. Biofouling was determined not to be detrimental to the biodegradation process nor was there an increase in the toxicity, as measured by the Microtox assay.

A Supplemental Study (Appendix H) was conducted to assess the effects of aquifer temperature on RDX biodegradation rates, and to evaluate the ultimate fate (mineralization) of RDX. The results of this study demonstrated that aquifer temperature has a significant effect on rate of RDX biodegradation. With a 5 °C decrease in aquifer temperature RDX biodegradation rate coefficient was reduced by about 37%. Further the Results of this study demonstrated that the ultimate fate of RDX in in-situ biodegradation is highly dependent on redox conditions in the aquifer. In treatment columns with very low redox, 23-46% of initial radiocarbon was mineralized to <sup>14</sup>CO<sub>2</sub> as compared to <5% in control columns where redox was high (no carbon source). The dissolved fraction in the treatment columns did not contain any nitroso-substituted transformation products, indicating transformation to non-nitroso-metabolites via ring cleavage.

A pre-demonstration study will be performed to evaluate the local groundwater hydrology within the proposed test area. This investigation will also examine the RDX contamination within this test area. The investigation will be conducted by placing five to eight piezometers for groundwater elevation determination. This data will be used to determine the groundwater flow direction and velocity. Additional groundwater samples will be taken to measure the RDX contamination in the proposed test area.

## **Testing and Evaluation Plan**

### ***Demonstration Set-Up and Start-Up***

The construction of the demonstration site is expected to begin in the Summer of 2003. Construction will consist of well placement and injection system construction. Prior to installation of the well system a small-scale study (Section 3.5) will be performed to examine the local groundwater flow and contamination in the demonstration area. This testing phase should last no more than a week. After the local groundwater flow is determined a system of wells will be constructed. All wells will be developed to ensure no foreign material is introduced into the aquifer and to ensure flow into or from the wells is unobstructed. Following development of the wells samples will be taken to obtain the initial concentration of RDX and other geochemical data in the demonstration area. Injection will not commence until one month has elapsed since well installation.

### **BAZE Test Area Geology and Hydrology**

Cross-sections of the BAZE test area with local geology and hydrology are shown in Figure 0-2 through Figure 0-4. The saturated zone at the test site is about 45-55 feet below ground surface. RDX is the only contaminant of concern with concentration ranging between 60 and 150 ppb in

the groundwater at the test location. Groundwater flow, direction, and the contaminant concentration variations along soil column, if any, at the test location will be obtained from the pre-demonstration site sampling (Section 3.5). As illustrated in Figure 0-2 through Figure 0-4, the subsurface is quite homogenous with well-defined layers of loess underlain by fine sand layer within the saturated zone.

### Well Design

After the local groundwater flow is determined a system of wells, shown schematically in Figure 0-5 will be constructed. The well field will consist of three injection/recirculation wells, four inches in diameter, and thirteen monitor wells of 1.5 in. diameter. The monitor wells will be placed in the ground using direct push technology and the injection wells will be drilled hydraulically.

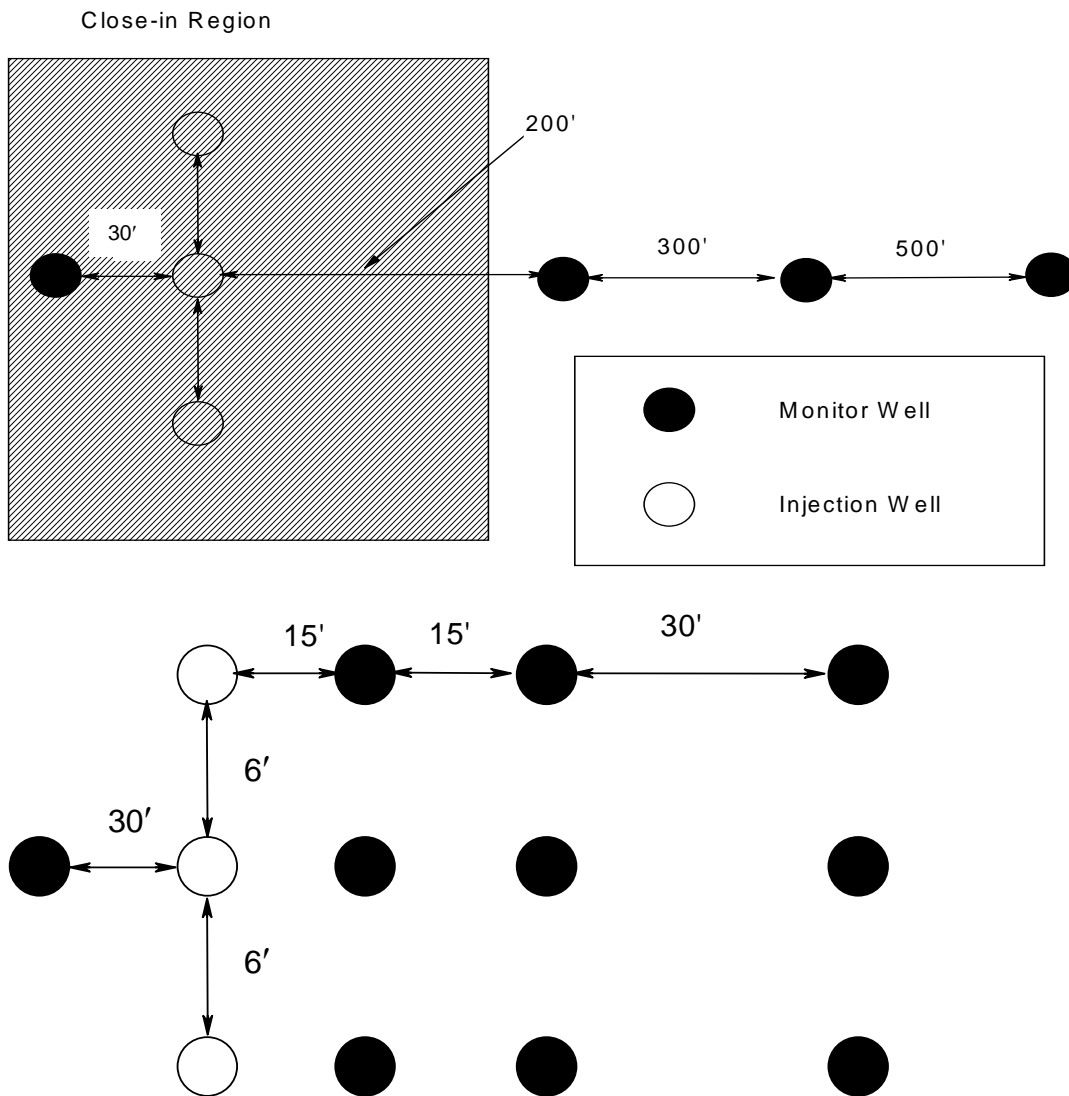


Figure 3-5. Schematic well field to be constructed at NOP BAZE demonstration site

From the local geology and hydrology of the test location (Figure 0-2 through Figure 0-4) the groundwater level is about 45-55 feet below ground surface. With consideration of this aquifer depth, wells will be drilled to a depth of 80 feet leaving at least 30 feet below the groundwater level. The well depth below the groundwater level at each well location will be screened for collecting groundwater samples at three depths (5, 10, and 15 feet) below the groundwater level. However, this planned total well depth will vary according to the saturated zone depth at the particular well location. Multiple depth sampling will be employed to collect the groundwater samples from three different depths. The actual sampling procedure is summarized in Section 3.6.6.1.

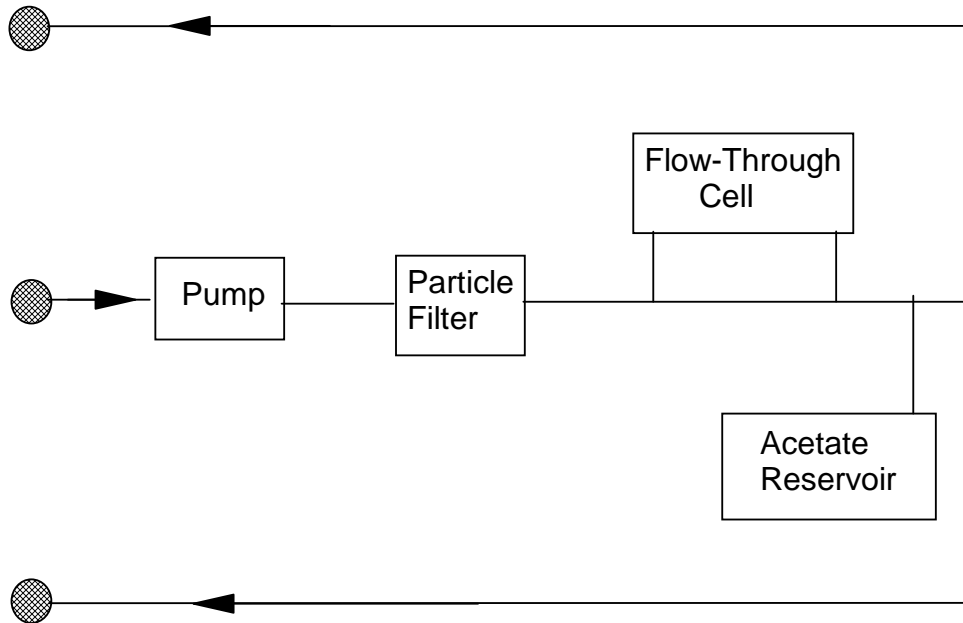
### **Injection System Design**

An injection/recirculation system has been designed and is shown in Figure 0-6. The 6 ft spacing for injection wells was selected assuming 3 feet radius zone of influence from each injection well. For achieving the lateral dispersion of the electron donor within the injection zone (about 18 feet) three lateral wells will be used for injection via recirculation. This system will draw aquifer water from the center well utilizing a centripetal pump and allow it to flow back to the aquifer through the outer wells. The groundwater drawn, at a known volumetric rate, from the central injection well will be mixed in-line with the concentrated amendment solution before re-injecting the electron donor-amended groundwater into the outer injection wells. Acetate will be injected via a feeder pump adding approximately 75 lbs of solubilized sodium acetate. This will be only one-pass injection of groundwater from the central injection well to outer injection wells. The volume of water drawn from the central injection well will be varied to achieve the 500 mg/L (as C) concentration of carbon in the carbon-amended groundwater that will be re-injected in the outer injection wells.

A flow through cell will be placed inline to examine the electrochemical properties of the injected/recirculated fluids real-time. The parameters to be examined are pH and conductivity. These parameters will be used to determine the volume of groundwater to be drawn from the central injection well in order to achieve the 500 mg/L carbon concentration in the re-injection water. The injection will be performed on a monthly basis.

Initial studies will be performed to examine the flow rate and length of time necessary to reach steady-state acetate concentrations. The mass of acetate to be injected will be continually evaluated to maintain 500 mg C/L.

The injection system shown in Figure 0-6 will be stored on site at facilities from the University of Nebraska -ARDC. The injection of amendments into the aquifer will be performed on a monthly basis by the University of Nebraska – Lincoln. Sampling will be performed on a similar basis. Electrical utilities are required for the operation of the injection system and are available in the demonstration area.



**Figure 3-6. Schematic Representation of Injection System**

### **Acetate (Carbon Source) Loading**

The target level of carbon in the carbon-amended groundwater to be re-injected in the outer injection wells is 0500 mg/L. This level is selected to make sure the carbon source is not limiting, however with the operation of the BAZE process this amount will be optimized and adjusted accordingly. Regular sampling downstream will indicate the utilization of carbon source. These levels of acetate did not result in excessive gas production in our lab study. Furthermore, the carbon source will also be utilized for reduction of ubiquitous electron acceptors like nitrate and sulfate, and other oxidants in the aquifer.

The mass and timing of injections will be adjusted from the presence of left over carbon in the downstream aquifer samples.

### ***Period of Operation***

The well field and injection system shall be installed and ready for operation on or about 31 July 2003. The injection of acetate into the aquifer shall begin one month following installation of the well field and be operated for 18 to 24 months.

### ***Amount/Treatment Rate of Material to be Treated***

The amount of material to be treated is estimated at 76 g RDX/month and 200,000 gal GW/month. This estimation is based on an average RDX concentration of 100 µg/L, groundwater flow of 2 ft/d, treated zone thickness of 30 feet and treated zone width of 15 feet.

### ***Residuals Handling***

Little or no residual materials are expected to be generated, as this technology is an in-situ process.

### ***Operating Parameters for the Technology***

The injection system will be operated on a monthly basis to maintain acetate concentration of 500 mg/L as C. This sizing of the pump will be large enough to replace the entire volume in the injection zone. Maintenance of the injection system will be performed as needed. A contract will be let with the University of Nebraska-Lincoln to perform the monthly injection of acetate and sampling of the aquifer in the demonstration zone under direct supervision of ERDC PI or Co-PI. Two personnel are required to operate the injection equipment and sample the aquifer.

### ***Sampling Plan***

The main purpose of sampling effort is to observe the RDX removal efficiency of the BAZE process, and to record the operating parameters for the development of technology for full-scale application. Sampling plan, including selection of analytical methods and sampling frequency is summarized in Table 3. Monthly sampling was chosen to monitor the changes in contaminant concentration and to provide an aggressive evaluation of the technology performance. Process control sampling for the BAZE demonstration will consist of groundwater sampling from 3 injection wells and 13 monitoring wells, as shown in Figure 0-5. Sampling will also include monitoring of temperature, redox potential (Eh), pH, dissolved oxygen (DO), and depth of groundwater in these wells.

**Table 3-2. Summary of Periodic Analyses**

Contaminant/Parameter	Analytical Method	Analytical Frequency
Explosives	SW846-8330	Monthly
RDX Transformation Products (MNX, DNX, TNX)	SW846-8330 Modified	Monthly
Nitrate	EPA Method 300.0	Monthly
Nitrite	EPA Method 300.0	Monthly
Sulfate	EPA Method 300.0	Monthly
Sulfide	HACH Method 8131	Monthly
Total Organic Carbon	SW846-9060	Monthly
Chemical Oxygen Demand (COD)	HACH Method 10067	Monthly
Dissolved Metals (Fe, Mn, As)	EPA Method 200.15	Monthly

Microbial Community	PLFA (White et al., 1996)	Biannually
Toxicological Profile	Micro/MutaTox (Azur Environmental 1998)	Quarterly
Water Level	Direct Measurement	Monthly
Water Temperature	Direct Measurement	Monthly
Eh	Electrode	Monthly
DO	Electrode	Monthly
Conductivity	Electrode	Monthly
pH	Electrode	Monthly

## Sample Collection

The objective of sampling at the demonstration site is to provide data for evaluation of the effectiveness of BAZE process for in-situ RDX bioremediation. Groundwater samples from 13 monitoring and 3 injection wells will be collected monthly over the period of the demonstration. Samples will be collected by the University of Nebraska under the direct supervision of ERDC PI or Co-PI.

Multiple level well sampling will be used to collect groundwater samples from three different levels along the well depth. The samples will be collected from the screened portion of the wells at three depths (5, 10, and 15 feet) below the groundwater level. Dedicated centrifugal pumps will be used to sample the groundwater from monitoring and injection wells. These pumps are electrically powered variable-speed pumps with all wetted parts made of stainless steel or Teflon. Slow suction sampling will be used to enhance lateral movement of water and to avoid vertical displacement of water column within the wells. The samples will be collected from each monitoring and injection well prior to the addition of carbon amendment. After injection only real-time Eh, pH, conductivity, and DO will be recorded from the injection wells.

The depth of water in the well will be measured by an electronic depth meter. Duplicate grab samples from each well will be collected in 1-L glass samplers. Samples may not need any specific preservation since the contaminant of concern is highly soluble and stable in water. In the field to restrict the biological activity, samples will be stored at near freezing temperatures in ice-chests. Samples will be properly labeled and tightly sealed to avoid any cross contamination during storage/shipment. Sample identification system will ensure tracking of a sample through collection, analysis, data validation, and data reduction. Each identification label will be unique within the scope of work. A typical sample label is shown in Figure 0-7. In the sample label MW represents monitoring well and IW indicates injection well. ## sign is the number of well (e.g., 00-12 for MW, and 01-03 for IW). A monitoring well upstream of the injection wells will be used as experimental control for baseline data and is designated as MW00.

All samples will be kept refrigerated overnight. Samples will be packaged for shipment in rigid, insulated plastic ice chests. Samples will be wrapped and padded to prevent glass-to-glass contact and reduce handling shock. Samples will be shipped to ERDC –EL laboratory, Vicksburg, MS via overnight delivery.



The logs of other direct real-time readings like temperature, conductivity, Eh, pH, DO, and water depth for individual wells on each sampling interval will be kept in a field log book. These readings will be recorded by University of Nebraska personnel assigned to this project. A copy of these reading will be send to ERDC PI or Co-PI at the end of each sampling.

Composite sample of the two-grab samples will be used for chemical, microbiological and/or toxicological analysis. Occasionally some of the samples will be analyzed in duplicate for quality assurance and quality control. Quality control groundwater samples will comprise 10% of all field samples taken.

### **Chain of Custody**

The chain of custody (CoC) is a record of the sampling information and requested laboratory analysis. The CoC also documents the release of the samples at the site by authorized persons through acceptance of the samples at the laboratory by authorized persons. An example of CoC to be used during the BAZE demonstration is presented in Figure 3-8.

### **Sample Analysis**

Groundwater samples collected from monitoring and injection wells will be analyzed by the laboratories, detailed below in Section 3.8, for chemical, microbiological, and toxicological parameters. The frequency of analysis is same as the frequency of sampling (Table 3). The chemical analysis methods are standard methods approved by US EPA and/or ASTM. The microbiological and toxicological methods are also standard methods used widely in environmental analysis.

Microbiological enumeration will be done using lipid biomarker technology, phospholipid fatty acid (PLFA) analysis that provides a holistic approach to the quantification of the in-situ microbial biomass, community structure and physiological state. The lipid biomarker approach can also provide data pertaining to the physiological state of the microbial community, onset of environmental stress, and exposures to xenobiotics (White et al., 1996). The results are reported as pmole (pica mole) of PLFA per gram of soil.

Toxicological assessment will be done by using MicroTox/MutaTox analysis over 5 and 15 min period. The bacterial bioluminescence is measured after each time interval using a MicroTox M500 Analyzer. The results are reported as EC<sub>50</sub> values, the effective concentration where 50% of the exposed fluorescence from the test microorganism is inhibited. Higher the EC<sub>50</sub> value, lower the acute toxicity. Samples will also be used for additional cell-based toxicology screens currently under development.

**NOP BAZE DEMONSTRATION**

**Sample ID:** MW##/IW## (circle one)

**Sampling Depth:** 5 / 10 / 15 (circle one)

Sample Matrix: Groundwater

**Sample Type:** Grab/Composite (circle one)

**Analysis Requested:** Explosives, Inorganics,  
Microbiology, Toxicology

**Date:** MM/DD/YY . **Time:** HH:MM hr .

Sampler's Initials: ABC .

**Experimental Controls**

The experimental control for obtaining the baseline data in this BAZE demonstration project is the monitoring well (MW00) upstream of the injection wells (Figure 0-5). It will be sampled at the beginning of the study as well as monthly at every sampling interval to develop the baseline RDX, and other chemical constituents concentration in the groundwater plume for assessing the performance of BAZE process in bioremediating RDX plume. The samples from this control monitoring well will undergo the same analysis protocol as the samples from other monitoring wells downstream of the injection wells.

**U.S. Army Corps of Engineers**

**Chain of Custody Record**  
(ER 1110-1-263)

<b>Proj. No.</b>		<b>Project Name</b>						
<b>Sampler : (signature)</b>								
<b>Date</b>	<b>Time</b>	<b>Pres.</b>	<b>ACC</b>	<b>Site Code/sample Number</b>	<b>Number of Containers</b>	/ / / / / / / /		<b>Remarks:</b>
<b>Sampler Relinquished by:</b>		<b>Date/Time</b>	<b>Received by: (Sig.)</b>	<b>Date/Time</b>	/ / / / / / / /			<b>Hazards Associated with Samples</b>
<b>Relinquished by: (Sig.)</b>		<b>Date/Time</b>	<b>Received by: (Sig.)</b>	<b>Date/Time</b>				
<b>Relinquished by: (Sig.)</b>		<b>Date/Time</b>	<b>Received for Laboratory by: (Sig.)</b>	<b>Date/Time</b>	/ / / / / / / /			<b>Remarks at time of receipt:</b>
<b>Relinquished by: (Sig.)</b>		<b>Date/Time</b>	<b>Received for Laboratory by: (Sig.)</b>	<b>Date/Time</b>				
<b>Custody Seal No.</b>		<b>Lab case No.:</b>						

ENR Form 5021-R, Oct 90

Proponent: CEMF-RTI

## **Data Quality Parameters**

Prior to sampling each well will be thoroughly purged (three well volumes) to remove the stagnant groundwater in order collect the representative samples. Ten percent of the total field samples will be used for QA/QC for data completeness as well as accuracy. For comparability the results from monitoring well samples will be compared to assess the effective zone of BAZE process, and finally these results will be compared with the control monitoring well data for estimating the BAZE process performance.

## **Calibration Procedures, Quality Control Checks, and Corrective Action.**

The instruments used for chemical, microbiological and toxicological analysis will be calibrated daily from standards prepared from stock solutions. Check standards will be run after every 10 samples to validate the repeatability of the instrument. Samples will be randomly selected for duplicate analysis to evaluate the analysis variation, if any.

Similarly the on-site real-time instruments like ORP electrodes, pH meters, DO meters, and electronic depth meters will be calibrated prior to sampling at each sampling interval for instrument reliability and repeatability.

## ***Demobilization***

Since the BAZE demonstration is an in-situ process, no residual materials will be generated. Site will not require any decontamination or restoration. All aboveground structures will be removed from the field after completion of the study. With permission from the site owners, the subsurface structures will be left undisturbed, if the owner wants to use these monitoring wells for future monitoring of the aquifer. If the site does not want to use the monitoring wells for future monitoring, the subsurface structures will be decommissioned according to the local regulations.

## ***Health and Safety Plan***

The detailed Health and Safety Plan (HASP) developed for this BAZE demonstration process is given in Appendix F.

## **Selection of Analytical/Testing Methods**

The analytical/testing methods that will be used in evaluating the performance of this demonstration study are the Standard Methods approved by ASTM or US EPA. Some of these methods might be slightly modified to meet the requirements of chemical analysis. These analytical methods are summarized in Appendix D.

## **Selection of Analytical/Testing Laboratory**

Chemical analysis of the samples taken during the BAZE demonstration will be analyzed by:

Environmental Chemistry Branch  
US Army Engineer Research and Development Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180

The laboratory will perform all chemical analysis on the groundwater samples collected from the monitoring and injection wells. The laboratory has the facilities, personnel, expertise, and resources to perform explosives, and inorganics analysis in soil and water.

Microbiological analysis of the collected groundwater samples from the demonstration site will be done by:

Environmental Processes and Effects Branch  
US Army Engineer Research and Development Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180

and the toxicological analysis on these groundwater samples will be performed by:

Environmental Risk Assessment Branch  
US Army Engineer Research and Development Center  
3909 Halls Ferry Road  
Vicksburg, MS 39180

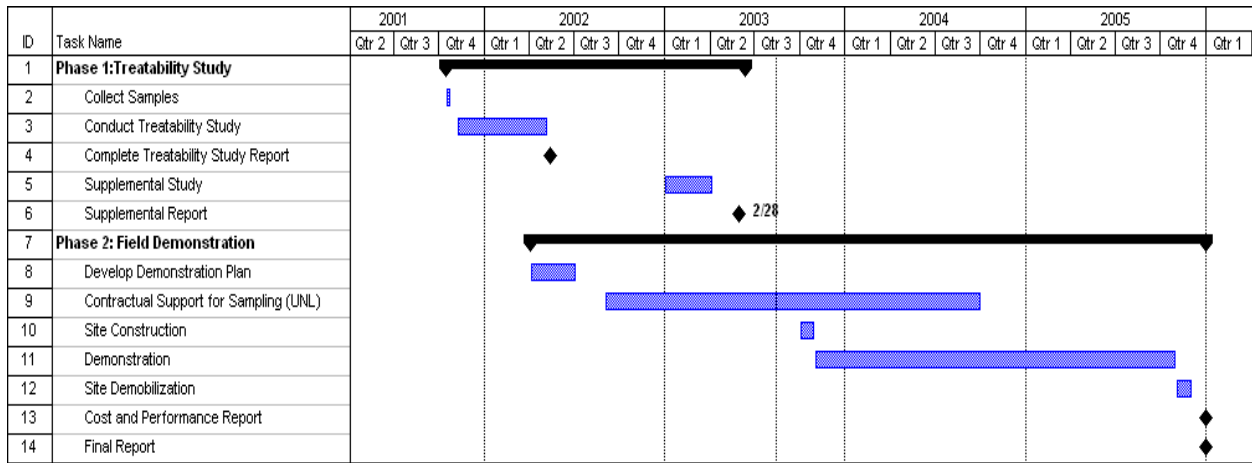
Both of these laboratories have the facilities, personnel, and expertise to perform microbiological and toxicological analysis on soil and water samples.

### **Management and Staffing**

The table summarizing tentative management and staffing for this demonstration plan is shown in Section 8.

### **Demonstration Schedule**

The following Gantt chart summarizes the BAZE process demonstration schedule with start dates and the duration of each activity from site construction to completion of demonstration study.



## 4 Performance Assessment

### Performance Criteria

The BAZE process performance in the field demonstration at NOP site will be assessed by the criteria tabulated in Table 4- below.

**Table 4-1. BAZE Process Performance Criteria in NOP Demonstration**

Performance Criteria	Description	Primary or Secondary
Contaminant Reduction	Identify the contaminants that the alternative technology will destroy or degrade.	Primary – RDX, TNT Secondary – Nitrate, Sulfate
Contaminant Mobility	Identify any contaminants whose mobility may be increased or decreased (even if not degraded) by the alternative technology.	Generally the BAZE process will not affect the mobility of any contaminant in the groundwater. The mobility of metals, if any, as a result of inducing reduced conditions will be carefully monitored throughout the regular sampling. However, the groundwater ORP will not be so low to induce the mobility of metals, because of the oxygen diffusion into the aquifer. Mobility of organic compounds present in aquifer will also be monitored for secondary water quality parameters.
Microbial Activity	Identify if the BAZE process will alter the resident microbial communities.	Microbial analysis will be conducted biannually. Alternatively, since the removal of RDX in turn is an indirect indicator of microbial activity and reliability, it might not be necessary to monitor microbial biomass monthly.
Hazardous Materials	Identify any hazardous materials that will remain or might be introduced by the alternative technology.	No hazardous materials will be introduced in the aquifer. However as a result of some process upset some RDX transformation products might accumulate in the aquifer system
Process Waste	Identify any process waste produced by the technology. If there is such a waste, describe its volume, any hazards that are associated	This is an in-situ process and the only amendment used is acetate, so no process waste will be produced throughout the BAZE demonstration.

	with it, and how it will be handled.	
Factors Affecting Technology Performance	Describe how technology performance is affected by operating conditions (e.g., flow rate, feed rate, through-put, temperature, etc.). Describe how matrix effects (e.g., soil type, particle size distribution, groundwater pH, DO, other contaminants, etc.) may affect technology performance.	Generally the operating conditions like flow, feed rate, through-put, aquifer temperature will have no affect on the BAZE performance, as the factors will be considered in adjusting the amendment quantity and feeding frequency. Aquifer material matrix like clayey soils will have some affect on the uniform distribution of the amendment in the aquifer. Groundwaters with high pH may also hinder the effectiveness of the BAZE process. High levels of DO and other electron scavengers (nitrate, sulfate) will ask for higher amendment doses to create reduced conditions.
Ease of Use	Describe the number of people required in the demonstration. Address the level of skills and training required to use the technology. Can technicians operate the equipment, or are operators having higher skills and education required? Is continuous monitoring of the process required? Indicate whether OSHA's health and safety training is required.	The BAZE technology implementation will not require large number of people. 2-3 persons capable of sampling the monitoring wells are sufficient. Also these operators do not need any specialized skills except the basic training of operating a pump, reading on-site real-time instruments like pH and ORP meters. OSHA's health and safety training will be an added advantage, as the operators will be working with contaminated groundwater and chemical amendments.
Versatility	Describe whether the technology can be used for other application(s) and whether it can be used at other locations. If not, could it be adapted? To what extent would the technology have to be adapted so that it can be used in other settings?	The BAZE technology does not have any specific boundaries of use. It can be used at any site with explosives contaminated groundwater plume. However, depending up on the concentration and the flow rate, amendment feed can be adjusted.
Maintenance	Discuss routine required	The BAZE technology is a low or no



	maintenance, including frequency and labor involved. Describe the level of training required for maintenance personnel.	maintenance in situ bioremediation process. The only maintenance need will be for pumps, monitoring wells, and on-site real-time reading instruments.
Scale-up Constraints	Describe potential issues of concern (e.g. engineering or throughput constraints, interferences) associated with scaling up the technology for full implementation, and how the issues of concern will be addressed in the demonstration.	Potentially there are no constraints on the scale up of the BAZE technology. The only engineering issue will be drilling of large number of monitoring wells to assess the effectiveness of BAZE process. However, the number of monitoring wells will depend up on the shape of groundwater plume e.g., a narrow plume will require less monitoring wells across the plume width as compared to a wide shallow plume to evaluate the explosive remediation across the entire plume.

### Performance Confirmation Methods

Groundwater samples collected from monitoring wells (MW) and injection wells (IW) will be analyzed monthly after each sampling event (Table 3) by off-site laboratories, detailed in Section 3.8, for chemical, microbiological, and toxicological parameters. The chemical analysis methods are standard methods approved by US EPA and/or ASTM. The microbiological and toxicological methods are also standard methods used widely in environmental analysis (Section 3.6.6.3).

The instruments used for chemical, microbiological and toxicological analysis will be calibrated daily from standards prepared from stock solutions. Check standards will be run after every 10 samples to validate the repeatability of the instrument. Some of the samples will be randomly selected for duplicate analysis to evaluate the analysis variation, if any.

Similarly the on-site instruments like ORP electrodes, pH meters, DO meters, and electronic depth meters will be calibrated prior to sampling at each sampling event for instrument reliability and repeatability.

The experimental control for obtaining the baseline data in this BAZE demonstration project is the monitoring well (MW00) upstream of the injection wells (Figure 0-5). The MW00 is 30 feet upstream of the injection wells. It will be sampled in the beginning as well as monthly at every sampling interval to develop the baseline RDX concentration, and other chemical constituents levels in the groundwater plume for assessing the performance of BAZE process in bioremediating RDX plume. The samples from this control-monitoring well (MW00) will undergo the same analysis protocol as the samples from other monitoring wells downstream of the injection wells.

10% of the total field samples will be used for QA/QC for data completeness as well as accuracy. For comparability the results from monitoring well samples will be compared to assess the effective zone of BAZE process, and finally these results will be compared with the control monitoring well data for estimating the BAZE process performance. Table 4- summarizes the expected performance levels of BAZE demonstration project and the analytical methods to evaluate BAZE effectiveness.

**Table 4-2. BAZE Demonstration Project Performance Levels and Confirmation Methods**

<b>Performance Criteria</b>	<b>Expected Performance Metric (pre demo)</b>	<b>Performance Confirmation Method*</b>
<b>PRIMARY CRITERIA (Performance Objectives)</b> <b>(Qualitative)</b>		
<b>Contaminant mobility</b>	BAZE process does not have any influence on contaminant mobility.	Analysis of samples from 12 monitoring wells (MW01-MW12) for explosives using EPA's SW846-8330 method
<b>Faster remediation (CU)</b>	RDX removal from about 100 µg/L to less than 2 µg/L which is the HA for RDX.	Analysis of samples from 12 monitoring wells (MW01-MW12) for explosives using EPA's SW846-8330 method
<b>Ease of Use</b>	Implementation of BAZE technology will not require any specialized training.	Experience from the operation of the demonstration unit will confirm or reject it.
<b>PRIMARY CRITERIA (Performance Objectives)</b> <b>(Quantitative)</b>		
<b>Target Contaminant</b> - % Reduction  - Regulatory standard	RDX Removal by 98%  Achieve US EPA's HA concentration (2 µg/L) for RDX.	Comparisons of RDX concentration between samples from monitoring wells (MW01-MW12) and control well MW00. Sample analysis using EPA's SW846-8330 method.
<b>Hazardous Materials</b> - Generated (CU)	None	Analysis for toxic degradation products of RDX by EPA's SW846-8330 method.
<b>Process Waste</b> - Generated	None	Observation in the field.
<b>Factors Affecting Performance</b> - Throughput	Not a concern, as most of the time throughout is fixed.	Sample analysis at flow rates present at each sampling

- Media size	NOP aquifer material is sandy. Even though clay reduces permeability, but will have no affect on amendment distribution.	interval, which may differ.  Permeability testing will not be done in the field, however we have done the permeability test on site-specific aquifer material in the treatability study.
- Media constituents	Media constituents will not affect BAZE process as the amendment is soluble in water and has no affinity for sorption.	Analysis of amendment (acetate) concentration from monitoring well samples across the plume length using EPA Method 300.0

**SECONDARY PERFORMANCE CRITERIA  
(Qualitative)**

<b>Secondary water quality parameters</b> - Dissolved metals mobility	Generally not expected because ORP will not be so low to induce mobility of dissolved metals.	Groundwater sample analysis for dissolved metals
- COD	Not a concern, because added carbon will be utilized by the resident microorganisms in inducing the reductive conditions	Regular groundwater sample analysis.
<b>Plume size (CU)</b>	Narrow and deep  Wide and shallow	Monitoring wells  Monitoring wells depending up on actual plume width
<b>Safety (all)</b> - Hazards  - Protective clothing	None  Class D	No hazardous chemicals will be used or produced. Other hazards will be assessed from demonstration operation.
<b>Versatility (all)</b> - Intermittent operation	Yes, amendment will be added on monthly basis	Demonstration operation results

- Other applications	BAZE process can be applied to any explosives contaminated aquifer with slight modifications on quantity and frequency of amendment addition.	BAZE demonstration results will confirm it
<b>Maintenance (all)</b> - Required	None, except for pump or other equipment breakdown.	Experience from demonstration operation
<b>Scale-Up Constraints</b> - Engineering	None, only more monitoring wells will be needed depending up on plume shape and size.	Monitor during demonstration operation.
- Flow rate	Actual flow rate will dictate the quantity of amendment needed.	Experience from the demonstration operation.
- Contaminant concentration	Not a concern as far as resident microorganisms are concerned. However, will affect the quantity and frequency of amendment addition.	Experience from the demonstration process

### Data Analysis, Interpretation, and Evaluation

The data obtained from the BAZE demonstration project will be presented as RDX removal as a function of time, length of plume, amendment concentration (acetate), and groundwater Eh, DO, and pH. This will allow for the development of correlations between RDX removal and these operating parameters.

Baseline for comparison of BAZE performance will be the sample analysis results from the monitoring well (MW00) upstream of the injection wells. The other alternative technology with which the BAZE performance results will be compared is the GAC adsorption.

## 5 Cost Assessment

### Cost Reporting

**Table 0-1. BAZE Demonstration Cost Assessment**

Cost Category	Sub Category	Details
START-UP COSTS	Mobilization	Includes (but not limited to) planning, contracting, personnel mobilization, transportation, permitting and site preparation.
CAPITAL COSTS	Capital Equipment Purchase	Pumps and Injection equipment
	Ancillary Equipment Purchase	Sampling Pumps DO Electrode/Meter ORP Electrode/Meter Conductivity Electrode/Meter
	Modifications	None expected
	Structures, Installation	Injection and Monitoring Well installation
	Engineering	Monitoring Well, and Injection System design
OPERATING COSTS Direct Environmental Activity Costs	Capital Equipment Rental	None expected
	Ancillary Equipment Rental	None expected
	Supervision	
	Operator Labor	Two operators required; Expected 24 hr/month
	Operator Training	HAZWOPER Groundwater Monitor Supervisor's Course
	Maintenance	Periodic pump maintenance
	Utilities	Intermittent electrical services required
	Raw Materials	None expected
	Process Chemicals	None expected
	Nutrients	75 lb of Sodium acetate/month
	Consumables, Supplies	Tygon tubing for sampling (~300 ft/month) Glassware for sampling Shipping containers
	Residual Waste Handling	None expected
	Offsite Disposal	None expected

	Sampling and Analysis	Monthly sampling Monthly analysis: Low-level explosives (8330) RDX transformation products (MNX, DNX, TNX) Nitrate, nitrite Sulfate, Sulfide Total organic carbon Acetate COD Quarterly analysis: Toxicological assessment (Micro/MutaTox) Biannually analysis: Microbial population shifts (PLFA) Quarterly and biannually analysis will be performed for demonstration purposes.
Indirect Environmental Activity Costs	Environmental and Safety Training	HAZWOPER
	OSHA Ambient Environment Sampling	Not required
	Waste manifesting (if any)	Not required
Demobilization		Well removal.
Other		

### **Cost Analysis**

The following cost analysis will be used in the ESTCP final report for cost and performance analysis.

### ***Cost Comparison***

The most commonly used technologies for remediating RDX in groundwater is pump-and-treat with GAC adsorption. The cost and performance analysis of the BAZE process will be compared with this technology.

### ***Cost Basis***

The cost basis for comparison will be \$ per 1000 gallon of contaminated groundwater treated. Although it is easy to estimate the number of gallons treated in pump-and-treat system, estimates will be used to evaluate the volumetric treatment rate for BAZE and other in-situ methods. In

these in-situ methods the nominal quantity of groundwater remediated will be estimated from aquifer depth (ft) and width (ft), and the groundwater flow rate (ft/d).

### ***Cost Drivers***

The primary cost drivers for the demonstration are site construction, principally well placement (capital costs), and sampling and analysis (operation and maintenance) costs.

### ***Life Cycle Costs***

BAZE process is an in-situ process that does not require any installation or demobilization of large size equipment or reactor. The only major capital cost is the construction of injection and monitoring wells. The equipment cost is very minimal. Pumps will be needed for sampling and other on-site real-time instruments for recording the Eh, pH, and DO of groundwater aquifer. As such there will be no major depreciation costs over the project life cycle. Additional costs for the treatment system include operation and maintenance. Past experience with in situ biotreatment indicate that these costs will be derived from monitoring and prevention of biofouling.

## 6 Implementation Issues

### Environmental Checklist

This in-situ BAZE process does not involve the use of any toxic or hazardous chemicals or foreign microorganisms. The only chemical used as the amendment is sodium acetate that is not regulated for application in groundwater. Construction of monitoring and injection wells is done by direct push system that does not excavate any soil from the site. There will be no atmospheric emission from the BAZE process from well construction to final demobilization. In this context no regulatory permits are needed for executing this demonstration project on the NOP site.

### Other Regulatory Issues

The BAZE process exploits the natural microorganisms present in the groundwater and aquifer material, as such this process has high public acceptance. The amendments added for biostimulating the resident microorganisms do not produce any known toxic or hazardous byproducts.

After the completion of the BAZE demonstration the cost and performance analysis will be shared with regulatory agencies such as the US EPA, Army Environmental Center, and other agencies for information dissemination and future application of BAZE process on full-scale levels.

Potential regulatory concerns could arise if this demonstration is transitioned to the site following demonstration. The primary concern is the requirement for an Underground Injection Control permit. A permit is not required for this demonstration because of the "research" nature of the demonstration.

### End-User Issues

The primary end-user for this innovative in-situ technology will be the formerly and/or currently used federal ordinance sites with explosives contaminated groundwater plumes. Currently there are 583 sites with confirmed explosives-contaminated groundwater at 82 installations nationwide. At 22 other installations, 88 additional sites are suspected of groundwater contamination with explosives and organics (Defense Environmental Network and Information Exchange, DENIX 2003).

The major concern for pump-and-treat with GAC adsorption, the current best available technology (BAT), is the length of operation and disposal of used GAC. The BAZE process does not produce any hazardous byproducts that need further disposal. The BAZE process is the extension of natural biodegradation and as such does not require any specialized equipments or custom-built prototypes.



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**APPENDIX G**  
**URS Group, Inc.**  
**Field Activities**  
**(available upon request)**

**APPENDIX H**  
**Interim Report**

**Environmental Security Technology Certification Program  
(ESTCP)**

**Interim Draft Report**

**Biologically Active Zone Enhancement (BAZE) for In Situ RDX Degradation  
in Groundwater (ESTCP #0110)**



**By**

**Mr. Roy Wade  
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**May 6, 2010**

# Introduction

The former Nebraska Ordnance Plant (NOP), located near Mead, Nebraska, was placed on the National Priorities List of Superfund Site in 1990. Contaminants in ground water including RDX were detected. U.S. Army Engineer Research and Development Center (ERDC) funded by Environmental Security Technology Certification Program (ESTCP) conducted studies to determine whether an enhanced biologically active zone process (BAZE) would degrade RDX contaminant in-situ. Bench-scale column studies were conducted utilizing soil samples collected at NOP. Sodium acetate was selected as the carbon source. The laboratory column studies indicated sodium acetate would enhance a biological zone to become active.

In 2003, The BAZE process was taken to the field. Groundwater samples were collected via direct push borings to evaluate RDX concentrations in groundwater. Samples were obtained from discrete depths ranging from 45-95 feet below ground surface (bgs). Six temporary piezometers were installed near the selected direct push hole and existing wells were utilized to aid in the evaluation of the local groundwater flow direction. Eleven monitoring (1 up gradient and 10 down gradient of BAZE system), 1 extraction, and 2 injection wells were installed to evaluate the BAZE system.

This interim report is to discuss the rationale of the BAZE process site location, installation of the monitoring, injections, and extraction wells, and BAZE system design. The current results of the monitoring well sampling and BAZE injection will also be discussed.

## Objective

The objective of this study is to evaluate the ability of biological activity to remediate (in situ) a RDX contaminated groundwater plume. The study is designed to identify, collect, and verify the economic, operational, and performance data that will be used to transition this technology to potential users. The major factors being evaluated are cost and performance.

The specific objectives are:

1. Validate the bench-scale study predictions for the technology performance,
2. Evaluate the ability of the BAZE process to reduce RDX concentration in groundwater to below EPA standards,
3. Monitor the effects of BAZE process on environmentally available electron scavengers (dissolved oxygen, nitrate, sulfate, etc.),
4. Identify potential biota effects resulting from the BAZE process,

5. Identify site characteristics that may have an impact on treatment performance,
6. Identify the hydrodynamic effects of the BAZE remediation process, and
7. Quantify the costs associated with the use of the BAZE process for remediation of explosives contaminated groundwater.

## **Site History**

The NOP site comprises of 17,000 acres is located ½ mile south of Mead, NE (Figure 1). The site operated between 1942 to 1956 as a munitions production plant for 4 bomb-loading lines during WWII and the Korean War. The Army stored munitions and ammonium nitrate production used the NOP site. The Air Force built and maintained 3 missile silos at the facility. Some of these activities used organic solvent in their processes. In 1962, the Army begin sell portion of the plants. The University of Nebraska owns approximately 9,000 acres that are used for agricultural research, Agricultural Research and Development Center (ARDC). The U.S. Army National Guard and Reserves and numerous individuals and corporations own the remaining acreage.

Bedrock beneath the northeastern portion of site (in Todd Valley) consists of Cretaceous shales and sandstones of the Omandi Formation. Pennsylvanian shales and limestones underlie the Omandi Formation. The Omandi Formation has been divided into an upper shale and lower sandstone lithofacies at the site. The sandstone lithofacies of the Omandi Formation are fine to medium grained with some gravel at the base. The sandstone varies in thickness from 20 to 105 feet below ground surface (bgs). The shale lithofacies is clayey nonclacareous shale with some interbedded thin silt and sand. The maximum thickness of shale is about 52 feet. The southeast portion of the site (in Platte River Valley) consists of sand and sandy gravel layer of 39-49 feet thickness. Overbank silts and clays, 10-17 feet thick, overlie the Platte River alluvial sand. The transmissivity of the Platte River alluvial aquifer, estimated through slug testing, is  $1.5 \times 10^4$  gallons per day per foot. The hydraulic conductivity of Todd Valley fine sand unit is estimated at 0.034 ft/min, and the Todd Valley sand and gravel unit is 0.08 ft/min. The hydraulic conductivity of Omandi sandstone aquifer is estimated at 0.044 ft/min (URSGWC, 2000).

The results of 1991-92 evaluation study by USACE indicated that explosive contamination in soil is mostly limited to soils in and under drainage ditches and sumps in the load lines and the Bomb Booster area. It is believed that this contamination originated from the discharge of water used to wash away explosive dust and residue which resulted from the ordnance load, assemble, and pack process. RDX, 2,4,6-trinitrotoluene (TNT), and 1,3,5-trinitrobenzene (TNB) were the explosive contaminants most often detected. RDX, TNT and TCE were identified in the groundwater samples.

## **Synopsis of Field Activity**



URS GROUP, INC and its subcontractors for the U.S. Army Corps of Engineers Kansas City District performed the field activities. Preliminary field investigation was conducted in September 2003 to delineate an area of elevated RDX concentrations to be used as the location of the BAZE demonstration. During this time, 13 direct push borings (GP-1 through GP-13) were completed using the Geoprobe method. Samples were collected and analyzed from discrete intervals ranging from 45-95 feet below ground surface (bgs).

Based on the chemical data, the area in the vicinity of GP-5 was selected by ERDC for the pilot study demonstration. Next, a network of temporary piezometers was installed near GP-5 to aid in the evaluation of the local groundwater flow direction. The piezometers were abandoned within 10 days of installation to comply with the State of Nebraska regulations. A site-wide groundwater flow map was created using monitoring wells and area staff gauges.

Next, 1 extraction, 2 injection, and 11 monitoring wells were installed between November and December 2003. One monitoring well boring was continuously sampled for sieve analysis. Each well was developed and sampled for initial parameters in December 2003.

Finally, the BAZE system was designed and constructed by URS for injecting the carbon source. The system was tested and ran successfully in the field.

## **Geoprobe Field Activity**

The Geoprobe push locations were based on previous investigations that indicated a RDX plume (Figure 2) and personal knowledge from the Kansas City District. The study area was anticipated to be located southeast of Load Line 2. The goal was to locate RDX concentration between 100-500  $\mu\text{g/L}$ . Groundwater samples were collected from 13 direct-push locations (GP-1 through GP-13) and analyzed for explosives using USEPA Method 8330 (Table 1). Up to six groundwater samples were collected from each boring location. The Geoprobe procedure consists of drilling to the appropriate depths using a 1-in diameter x 5-ft core, pulling the screen, purging the well casing, and collecting 1-litre sample of groundwater. Figures 3 and 4 show Geoprobe operation and Geoprobe sample locations, respectively. Table 2 shows the RDX concentration, corresponding depths, and GPS coordinates. The Geoprobe finding shows RDX concentration ranging from 50-450  $\mu\text{g/L}$  at depths between 54- to 80-ft bgs. The TNT, TNX, DNX, and MNX concentrations were not detected. Based on the RDX concentration in groundwater from the Geoprobe activity, sample location GP-5 was selected. The RDX concentrations from other locations were negligible to nondetect.

## **Temporary Piezometers**

Once the vicinity of the field demonstration (GP-5) was selected, temporary piezometers were installed to establish the local groundwater flow direction via Geoprobe procedure. A soil boring

was attempted for continuous sample at the surface to a depth of 80-ft bgs. The soil samples were not collected due to heaving sands.

Six 1-inch temporary piezometers were installed in a zigzag pattern (Figure 5). Thirty-feet of 0.010-inch slot screen with 20/40 filter pack was used in each temporary piezometers. The piezometers were screened at approximately 50 to 80-ft bgs. Each piezometer was developed. Two rounds of water level measurements were recorded (Table 3). In addition to the temporary piezometers, monitoring wells near the selected study area were also measured to generate the most representative potentiometric surface map (Figure 5).

<b>Table 1 Analytical Method</b>		
<b>CONTAMINANT/PARAMETER</b>	<b>ANALYTICAL METHOD</b>	<b>ANALYTICAL FREQUENCY</b>
Explosives	SW846-8330	Monthly
RDX Transformation Products (MNX, DNX, TNX)	SW846-8330 Modified	Monthly
Acetate	EPA Method 300.0	Monthly
Nitrate	EPA Method 300.0	Monthly
Nitrite	EPA Method 300.0	Monthly
Sulfate	EPA Method 300.0	Monthly
Total Organic Carbon	SW846-9060	Monthly
Metals	EPA Method 7470	Biannually
Microbial Community	PLFA (White 1995)	Biannually
Toxicological Profile	Micro/MutaTox	Biannually
Water Level	Direct Measurement	Monthly
Redox	Electrode	Monthly
Conductivity	Electrode	Monthly
Dissolved Oxygen	Electrode	Monthly
pH	Electrode	Monthly

## **Extraction and Injection Wells Installation**

One extraction well and two injection wells were installed to circulate treated groundwater through the treatment system and back into the subsurface. The wells were screened in the zone exhibiting the highest RDX concentration (55 to 75-ft bgs).

The extraction and injection wells were installed with a truck-mounted direct-rotary drilling rig using a nominal 10-in bit for the extraction well and a nominal 8-in bit for the injection wells

(Figure 6). The extraction and injection wells were constructed of 6-in and 4-in diameter, Schedule 40, PVC with flush-threaded riser pipe, 20-ft of 0.020-in of continuous-slotted screen, 2.5-ft sump, and #16-30 filter pack, respectively. The filter pack material consisted of clean, well-rounded silica sand sized to prevent infiltration of fines into the wells. The filter pack was installed 5- to 7-ft above the well screen. Sodium montmorillonite was used to form a 3-ft plug above the filter pack. The remainder of the annular space was sealed by pressure grouting bentonite via tremie pipe. Finally, a 4-ft square pad was formed. An 18-in diameter flush mount cover was placed in the concrete over each well and pad locked. The concrete pad sloped outward for surface drainage. Figure 7 shows photo of the extraction and injection wells installed. Each extraction and injection wells were developed by the drillers and surveyed by a licensed Nebraska registered land surveyor. Each well is registered with the Nebraska Department of Environmental Quality. The extraction well was labeled BAZE-EW-01. The injection wells were labeled BAZE-IW-01 and BAZE-IW-02.

<b>Table 2 Geoprobe Analytical Results</b>					
<b>Sample Location</b>	<b>Sample Date</b>	<b>Screen Depth</b>	<b>RDX Conc. µg/L</b>	<b>GPS Coordinates</b>	
				<b>Latitude</b>	<b>Longitude</b>
GP-1	9/29/2003	44'-48'	0.6	41° 10' 3.0"	96° 27' 46.9"
		54'-58'	0.1		
		64'-68'	5		
		54'-58'	2		
		64'-68'	83		
GP-3	9/29/2003	44'-48'	Non Detect	41° 09' 40.6"	96° 27' 43.7"
		64'-68'	Non Detect		
		74'-78'	47		
GP-4	9/30/2003	44'-48'	Non Detect	41° 09' 35.2"	96° 27' 43.3"

	10/2/2003	54'-58' 74'-78' 84'-88' 94'-98'	Non Detect 4 Non Detect Non Detect		
GP-5	9/30/2003  10/3/2003	44'-48' 54'-58' 64'-68' 74'-78' 84'-88' 94'-98'	No Sample 450 47 79 1 Non Detect	41° 09' 26.7"	96° 27' 19.1"
GP-6	9/30/2003	44'-48' 54'-58' 64'-68'	44 4 Non Detect	41° 09' 19.4"	96° 27' 17.1"
GP-7	9/30/2003	44'-48' 54'-58' 64'-68'	Non Detect 0.4 Non Detect	41° 10' 28.8"	96° 27' 55.0"
GP-8	10/2/2003	44'-48' 54'-58' 64'-68' 74'-78'	Non Detect Non Detect Non Detect Non Detect	41° 09' 40.6"	96° 27' 46.4"
GP-9	9/29/2003	44'-48' 54'-58' 64'-68' 74'-78' 84'-88' 94'-98'	No Sample Non Detect Non Detect Non Detect 11 Non Detect	41° 09' 31.3"	96° 27' 41.0"
GP-10	9/29/2003	54'-58' 64'-68' 74'-78' 84-88 94-98	Non Detect 1.1 Non Detect 0.32 Non Detect	41° 09' 31.0"	96° 27' 24.9"
GP-11	9/29/2003	54'-58' 64'-68' 74'-78' 84-88 94-98	Non Detect 1.1 Non Detect 1.2 Non Detect	41° 09' 14.0"	96° 27' 19.7"
GP-12	9/29/2003	64'-68' 74'-78' 84-88 94-98	Non Detect Non Detect Non Detect Non Detect	41° 09' 52.7"	96° 27' 40.5"
GP-13	9/29/2003	64'-68' 74'-78' 84-88 94-98	Non Detect Non Detect Non Detect Non Detect	41° 09' 42.8"	96° 27' 38.6"

Well ID	Depth to Water (10-8/10-16-03)	Top of Casing Elevation (Ft MSL)	Groundwater Elevation (10- 8-03)	Groundwater Elevation (10-16- 03)
PZ-1	46.77/46.80	1164.94	1118.17	1118.14
PZ-2	48.91/48.97	1166.00	1117.09	1117.03

PZ-3	50.39/50.47	1167.18	1116.79	1116.71
PZ-4	47.37/47.45	1163.62	1116.25	1116.17
PZ-5	46.92/47.00	1162.37	1115.45	1115.37
PZ-6	49.55/49.61	1164.18	1114.63	1114.57
MW-04A	39.42/not measured	1168.24	1128.82	not measured
MW-04B	39.55/not measured	1168.37	1128.82	not measured
MW-05A	37.29/not measured	1167.61	1130.32	not measured
MW-05B	37.42/not measured	1167.66	1130.24	not measured
MW-06A	41.31/not measured	1164.94	1123.63	not measured
MW-06B	41.47/not measured	1165.12	1123.65	not measured
MW-27A	41.83/not measured	1175.63	1133.80	not measured
MW-27B	41.83/not measured	1175.64	1133.81	not measured
MW-28A	52.44/not measured	1171.81	1119.37	not measured
MW-28B	52.93/not measured	1172.11	1119.18	not measured
MW-29A	50.68/not measured	1159.66	1108.98	not measured
MW-29B	51.58/not measured	1160.63	1109.05	not measured
MW-30A	41.89/not measured	1168.13	1126.24	not measured
MW-30B	41.75/not measured	1167.96	1126.21	not measured
MW-31A	50.05/not measured	1166.97	1116.92	not measured

MW-31B	50.21/not measured	1166.54	1116.33	not measured
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## Monitoring Well Installation

Eleven monitoring wells (1 up gradient and 10 down gradient from the treatment system) were installed to monitoring the progress of the BAZE system. Figure 8 shows the elevation and location of monitoring, extraction, and injection wells with GP-5 and the piezometers. The extraction, injection, and monitoring wells were screened in the zone based on the Geoprobe investigation. Table 2 shows that RDX was measured between 54- to 78-ft bgs. The well screens were installed from 55- to 75-ft bgs for the injections, extraction, MW-01 thru MW-04, and MW-11 wells. Monitoring wells MW-05 thru MW-10 were screened from 60- to 80-ft bgs.

The monitoring wells were installed with a truck-mounted hollow-stem drilling rig using nominal 8.25-in flight augers (Figure 9). The monitoring wells were constructed of 2-in diameter, Schedule 40 PVC with flush-threaded riser pipe; 20-ft of 0.010-in of continuous-slotted screen, and 16/30 filter pack. The filter pack material consisted of clean, well-rounded silica sand sized to prevent infiltration of fines into the wells. The filter pack was installed 8- to 10-ft above the well screen. The remainder of the annular space was sealed by pressure grouting bentonite via tremie pipe. Finally, a 2-ft square pad was formed. A flush mount cover was placed in the concrete over each well and pad locked. The concrete pad sloped outward for surface drainage Figures 7,9, and 10 show photo of the monitoring well installed. Each well was developed by the drillers and surveyed by a licensed Nebraska registered land surveyor. Each well is registered with the Nebraska Department of Environmental Quality. The monitoring wells are labeled BAZE-MW-01 through BAZE-MW-11.

Monitoring well #1 (MW-01) was continuously sampled for sieve analysis and biological parameters from the water table beginning at 50-ft bgs to 70-ft bgs in five-foot intervals. Sampling for sieve analysis was terminated prior to completing the final depth due to fine sand locking the sample core in the sample barrel, i.e., no sample recover. Figures 11-13 show the sieve analysis for 55 to 60-ft, 60 to 65-ft, and 65 to 70-ft bgs depths to be 98.7, 97.0, and 95.6% mostly fine sand, respectively. The sieve analysis confirms the design of the extraction and injections wells.

## Groundwater Sampling

Each monitoring well (MW-01 to MW-11) was sampled monthly except MW-11, which is sampled every quarter beginning June 2004. The monitoring wells sampling events begin December 2003 and are scheduled to end around July 2005. Each well was sampled using a stainless steel 1.5-in low-flow submersible pump and ½-in diameter x 10-ft long stainless steel

tubes (6 or 7 tubes). Prior to sampling, depth to the water table and total well depth were recorded. Next, three volumes of water were purged from each well at 70-ft bgs and one volume at 60-ft bgs from the injections, extraction, MW-01 thru MW-04, and MW-11 (Figure 1). Groundwater samples were collected at 74-ft and 64-ft bgs for MW-05 thru MW-10. The difference in elevation was an attempt to sample at the same depth in the water table. Physical parameters were recorded via flow-through cell prior to sampling. Table 4 shows the monitoring wells field data log from each sampling event. Currently, 13 rounds of groundwater sampling were completed and analyzed for nutrients including acetate, nitrate, nitrite, sulfate, TOC, explosives including MNX, DNX, and TNX, and one round of metal analytes (Tables 5-7). The nutrient results show that only nitrate concentration has reduced in the first cluster of wells (MW-02 through MW-04) and MW-10. Nitrate concentration went from ~20 mg/L to nondetect in February for MW-04. Beginning in April, nitrate concentration decreased to approximately 4.0 mg/L for MW-02 and MW-03 that are in the same cluster as MW-04. Nitrate concentration also decreased to approximately 4.0 mg/L in March for MW-10. The RDX concentration ranges from 50-350 ppb at approximately 60-ft and 70-ft bgs. Figures 14 and 15 show the corresponding RDX concentration and water elevation for January 2004 sampling event. Figure 16 shows a cross-section view of sampling location and corresponding RDX concentration for the injection and extraction wells during November 2004 sampling event. The injection and extraction wells were sampled at the 60-ft depth which corresponding to the distance that the acetate is injected. Figure 17 shows a cross-section view of both sampling locations and corresponding RDX concentration for monitoring wells 2-4 during November 2004 sampling event.

## **Groundwater Modeling**

A groundwater model was developed to evaluate multiple pumping and injection rates and to estimate the capture zone and recharge zones for the BAZE extraction and injection wells. After the model was calibrated using water level from the monitoring wells, the model simulated extraction flow rate of 10, 20, and 30 gpm. Groundwater was extracted from EW-01 and the flow was evenly split and returned to the aquifer through IW-01 and IW-02. Next, the capture zone was evaluated using MODPATH, which tracks particle travel time. The particles were tracked over a 2-year period.

The result shows the extraction and injection well zones of influence increases as the pumping rate and injection rate increase. When the flow was 10 gpm, the extraction well capture zone and the injection well recharge zone are 100-ft wide. The capture and recharge zones are 200 and 250-ft wide for pump flow of 20 and 30 gpm, respectively (Figure 18). The BAZE system pump flow is 25 gpm.

## BAZE Extraction and Injection System

The BAZE system was constructed during December 2003 and January 2004 (Figure 19). The system was tested and passed the leaks and operational tests. The system pump was installed and tested in EW01. The table below shows the results of the pump test.

The BAZE system consists of a 3-in submersible pump powered by a portable generator that pumps water from EW-01 via flexible tubing to the wellhead. The pump is suspended at 60-ft bgs by a stainless steel cable attached to the well cap. The pump tubing connects to the BAZE system PVC pipe carrying groundwater at 25 gpm through a pressure gauge, a particle filter, ball valve, flow meter, and sampling port EW-01. The groundwater flows through a tee that intersects the acetate solute feed system that is pumped with a transfer pump at a flow of 0.5 to 1.0 gpm from a 200-gallon tank through a filtering system, flow meter, backflow preventer and ball valves. The target flow is 0.5 gpm (Tables 8-18). The mixture intersects at the main PVC pipe tee and flows through an in-line static mixer to a flow-through cell where groundwater quality parameters are recorded every 15 minutes. Between the tee and each injection well, a ball valve, flow meter, and sampling ports IW-01 and IW-02 are installed. After the sampling ports, the treated groundwater flows to each injection well to a depth 60-ft bgs at approximately 12.5 gpm each (Tables 8-18). After acetate injecting for 3-6 hours, the system was allowed to circulate for several additional hours to assure mixing in the aquifer. The system operates a total of 12 hours (Figure 20). An average of 18,000 gallons of groundwater including injection were pumped.

The acetate solute is prepared in two 110-gallon tanks. Each tank is filled with 100-gallons of groundwater from EW-01. A 150-lbs of sodium acetate per tank is mixed for 15-20 minutes and allowed to settle overnight. The supernatant is transferred through a 20-micron filter to the 200-gallon feeder tank resulting in a 7% solution. Prior to injecting, the feeder tank is sampled for acetate. The acetate concentration is reduced to approximately 0.3% after the in-line static mixer. In other words, the acetate concentration been injected at IW-01 and IW-02 is approximately 0.3%.

Twelve rounds of acetate injection and circulation were completed. First quarterly and then hourly samples were collected from 3 sample ports until completion of injection and hourly from one sample port (EW01) thereafter. Samples were analyzed for acetate and TOC (Table 5). Figures 21 and 22 show the acetate injection results for the 12 rounds of injecting and recirculation. The result shows a 66% and 54% reduction in RDX concentration in the first cluster of wells (MW-02 to MW-04) and MW-10 approximately 50 ft and 200 ft from the BAZE system, respectively.



Elapsed Time, minutes	Depth to Water feet	Drawdown feet
1	50.01	3.23
2	50.07	3.29
3	50.09	3.31
4	50.10	3.32
5	50.10	3.32
6	50.11	3.33
7	50.12	3.34
8	50.13	3.35
9	50.13	3.35
10	50.13	3.35

Note: pump flow - 27 gpm and static water level – 46.78 ft

### Discussion - BAZE System General Performance

The BAZE system has operated with ease for twelve months. Based on analytical data, RDX concentration has reduced considerable for several wells and to below detection level for MW-03. For example, Figure 2 compares RDX, MNX, DNX, TNX, and ORP for MW-03 at 60-ft bgs. Monitoring well #1 (MW-01) that is up gradient from the treatment system has an average RDX concentration of approximately 300 µg/L (over a 12 month period). As RDX concentration decrease, ORP value decreases. The increase in MNX, DNX, and TNX concentrations were negligible. Figure 3 shows decrease in RDX concentration corresponds to an increase in TOC and acetate concentrations while nitrate decreases. Table 8 shows elevated levels of sodium in several wells that correspond to RDX reduction via present of acetate. Noticeable reduction in RDX concentration is observed in MW-02, MW-03, MW-04, MW-06, and MW-10. A gradual reduction in RDX concentration was noticed around May 2004. A more noticeable reduction in RDX concentration occurred after July 2004. Prior to July 2004, the BAZE system was inadvertently inducing air into the injection wells prohibiting the performance of the system. The injection pipes are located at 60-ft bgs which is approximately 10-ft below surface of the water table. The suction pressure was such that air was created an aerobic environment consuming the acetate and might have disrupted the anaerobic zone. The system was modified resulting in improved performance by detecting acetate concentration in downgradient monitoring wells.

## Recommendations For Future Operations

Based on the operation and analytical data, the BAZE system is having an effect on the reduction of RDX concentration. However, the system needs to be optimized. Beginning January 2005, the addition of acetate (carbon source) will be added every other month, i.e., first injection for year will be in February 2005. Based on the RDX reduction, acetate, TOC, and sodium concentrations, the carbon substrate is delivered to several downgradient wells. The bromide tracer test conducted in April 2004 was not conclusive. The tracer test will be repeated to evaluate the acetate travel time and groundwater flow. Finally, additional wells should be installed to better define the impact of the treatment, because current well field seems to be missing the aquifer flow direction. These additional monitoring wells should be installed 15-ft east of MW-06 (labeled MW-06A) and 30-ft east from MW-10 (labeled MW-10A).



Figure 1. Sampling at extraction well (EW-01)

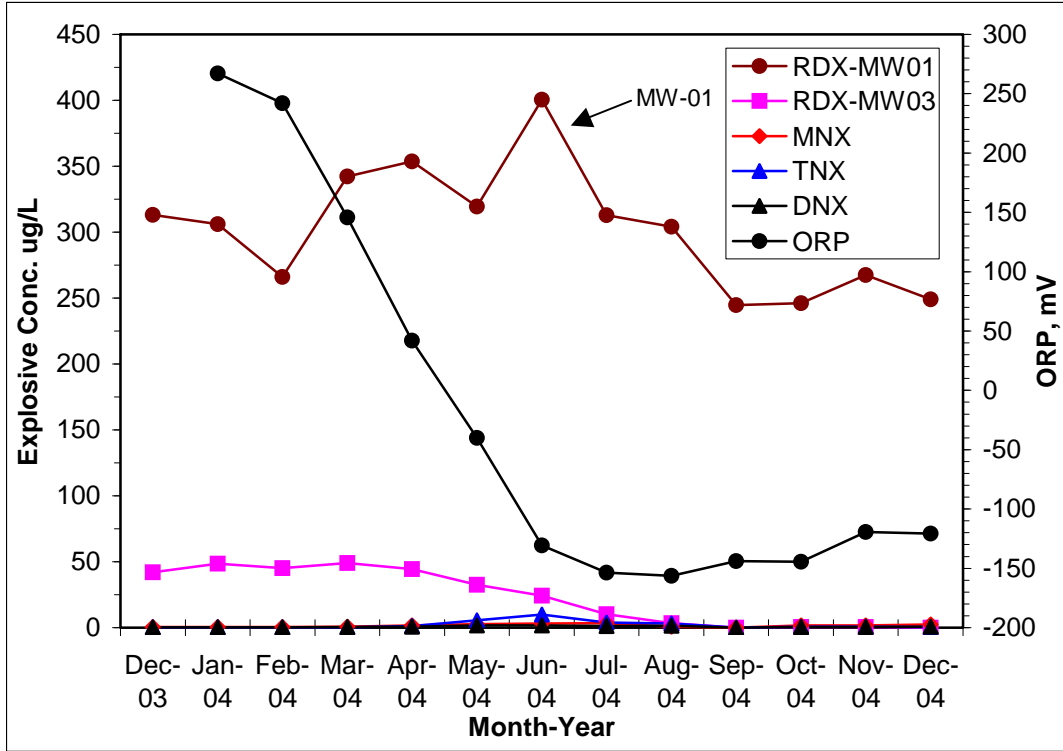


Figure 2. RDX, MNX, DNX, TNX, and ORP for MW-03 at 60-ft. RDX for MW-01 is shown for comparison

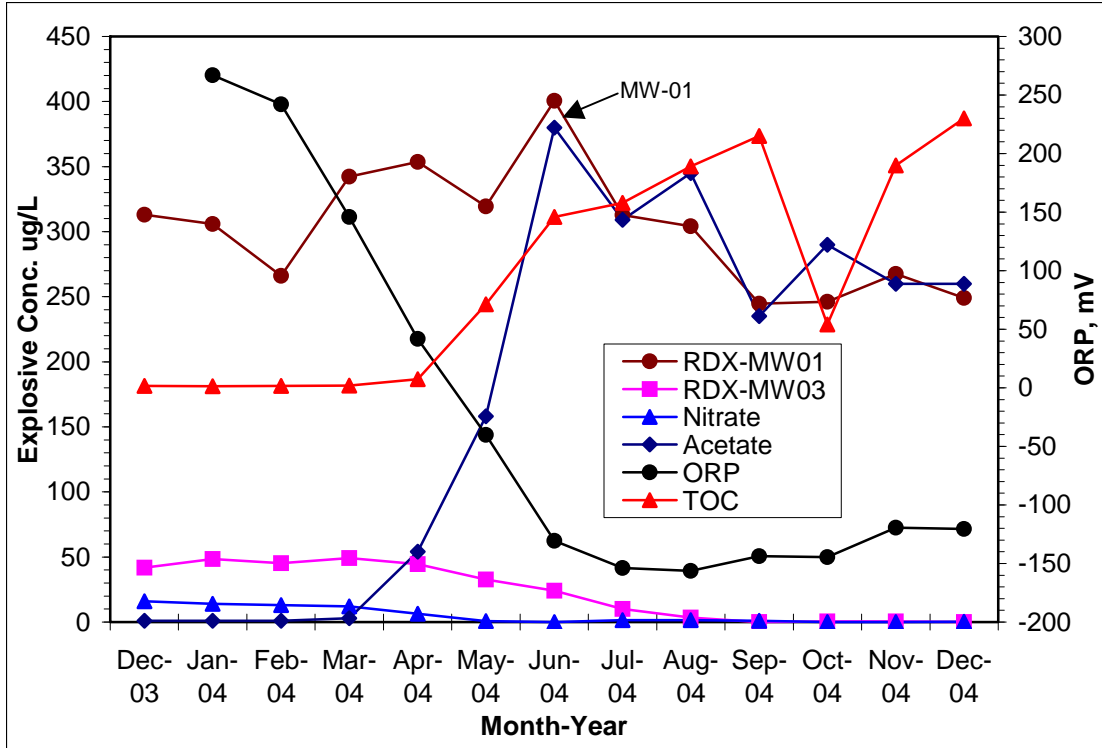


Figure 3. RDX, nitrate, acetate, TOC, and ORP comparison for MW-03 at 60-ft. . RDX for MW-01 is shown for comparison

## APPENDIX F1

**Table 4  
Field Data Log**

January 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.36	46.30	70	no reading	no reading	no reading	no reading	no reading
IW-02	73.41	46.72	70	no reading	no reading	no reading	no reading	no reading
EW-01	73.30	46.70	70	no reading	no reading	no reading	no reading	no reading
MW01	74.80	48.20	60	11.5	no reading	no reading	no reading	no reading
			70	10.3	no reading	no reading	no reading	232
MW02	73.30	47.10	60		no reading	no reading	no reading	
			70	11.7	no reading	no reading	no reading	250
MW03	70.80	47.10	60		no reading	no reading	no reading	
			70	11.7	no reading	no reading	no reading	267
MW04	73.20	47.12	60		no reading	no reading	no reading	
			70	11.7	no reading	no reading	no reading	247
MW05	77.40	48.90	64		no reading	no reading	no reading	
			74	11.5	no reading	no reading	no reading	254
MW06	77.90	49.36	64		no reading	no reading	no reading	
			74	11.5	no reading	no reading	no reading	237
MW07	79.00	50.64	64		no reading	no reading	no reading	
			74	11.8	no reading	no reading	no reading	246
MW08	78.10	50.12	64		no reading	no reading		
			74	11.9	no reading	no reading	6.92	262
MW09	78.10	50.60	64		no reading	no reading		
			74	11.8	no reading	no reading	6.94	257
MW10	77.90	50.70	64		no reading	no reading		
			74	11.9	no reading	no reading	7.05	264
MW11	74.60	45.90	60		no reading	no reading		
			70	11.9	no reading	no reading	7.15	245
February 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.36	46.29	70	no reading	no reading	no reading	no reading	no reading
IW-02	73.41	46.69	70	no reading	no reading	no reading	no reading	no reading
EW-01	73.30	46.70	70	no reading	no reading	no reading	no reading	no reading
MW01	74.90	48.34	60	no reading	no reading	no reading	no reading	no reading
			70	12.0	no reading	no reading	6.60	207
MW02	73.30	47.20	60		no reading	no reading		
			70	11.7	no reading	no reading	7.30	265
MW03	71.74	47.26	60		no reading	no reading		
			70	11.9	no reading	no reading	7.20	242
MW04	72.14	47.24	60		no reading	no reading		
			70	11.4	no reading	no reading	7.27	139
MW05	77.80	49.10	64		no reading	no reading		
			74	11.4	no reading	no reading	7.36	289
MW06	77.90	49.50	64		no reading	no reading		
			74	11.2	no reading	no reading	7.00	281
MW07	79.00	50.78	64		no reading	no reading		
			74	11.5	no reading	no reading	7.08	275
MW08	78.10	50.30	64		no reading	no reading		
			74	11.6	no reading	no reading	7.13	306
MW09	78.05	50.74	64		no reading	no reading		
			74	11.3	no reading	no reading	7.10	283
MW10	77.86	50.90	64		no reading	no reading		
			74	11.1	no reading	no reading	7.15	260
MW11	74.60	46.00	60		no reading	no reading		
			70	11.2	no reading	no reading	7.26	262

NS – denotes not sampled

**Table 4 (Cont'd)**

March 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.20	46.53	70	no reading	no reading	no reading	no reading	no reading
IW-02	73.40	46.96	70	no reading	no reading	no reading	no reading	no reading
EW-01	73.20	46.76	70	no reading	no reading	no reading	no reading	no reading
MW01	74.90	48.42	60					180.8
			70	12.41	0.514	15.8	6.05	193.0
MW02	73.24	47.28	60					141.8
			70	12.27	0.502	17.9	6.39	176.3
MW03	71.74	47.28	60					146.0
			70	12.37	0.503	14.4	6.42	145.8
MW04	73.18	47.28	60					0.8
			70	12.36	0.813	3.4	7.00	0.4
MW05	77.80	49.14	64					200.1
			74	12.46	0.493	17.5	6.43	204.9
MW06	77.90	49.54	64					178.2
			74	12.25	0.511	17.0	6.42	192.5
MW07	79.00	50.84	64					174.9
			74	12.12	0.514	16.1	6.47	175.8
MW08	78.04	50.32	64					151.8
			74	12.08	0.437	16.0	6.41	159.9
MW09	78.04	50.76	64					182.0
			74	12.02	0.512	18.6	6.28	176.9
MW10	77.80	50.90	64					137.5
			74	12.06	0.504	8.8	6.41	160.4
MW11	74.50	46.04	60					145.1
			70	11.94	0.507	7.4	6.72	146.3
April 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.15	46.60	70	12.33	0.583	1.8	7.08	-65.6
IW-02	73.40	47.05	70	12.17	0.508	1.5	6.74	70.1
EW-01	73.25	46.90	70	12.20	0.486	18.8	6.71	78.1
MW01	74.90	48.50	60					129.5
			70	12.30	0.512	17.6	6.46	128.1
MW02	73.20	47.38	60					156.0
			70	12.09	0.525	20.1	6.50	151.0
MW03	70.80	47.38	60					44.1
			70	12.23	0.652	9.7	6.53	41.9
MW04	73.20	47.38	60					no reading
			70	12.39	0.866	3.9	7.10	-103.1
MW05	77.80	49.26	64					168.0
			74	12.25	0.486	19.1	6.44	193.6
MW06	77.90	49.66	64					187.5
			74	12.34	0.511	19.0	6.49	no reading
MW07	79.00	50.94	64					108.0
			74	12.22	0.523	16.5	6.45	129.1
MW08	78.05	50.45	64					164.8
			74	12.23	0.429	17.9	6.41	164.3
MW09	78.10	50.90	64					159.7
			74	12.20	0.516	19.5	6.33	172.1
MW10	77.90	51.00	64					123.0
			74	12.24	0.575	8.9	6.78	132.0
MW11	74.60	46.16	60					159.1
			70	12.20	0.503	7.9	6.30	190.0

**Table 4 (Cont'd)**

May 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.10	46.85	70	12.37	0.766	0.8	6.90	-149.0
IW-02	73.25	47.25	70	12.28	0.659	3.0	6.71	-110.3
EW-01	73.15	47.10	70	12.27	0.497	17.7	6.50	25.4
MW01	74.70	48.80	60					134.5
			70	12.24	0.511	18.2	6.40	135.2
MW02	73.10	47.55	60					106.2
			70	12.29	0.570	15.1	6.58	119.2
MW03	71.60	47.60	60					-39.9
			70	12.17	0.916	5.5	6.79	-40.2
MW04	73.05	47.60	60					-134.2
			70	12.37	1.018	3.2	7.13	no reading
MW05	77.64	49.50	64					84.3
			74	12.17	0.506	19.1	6.46	79.8
MW06	77.75	49.95	64					104.9
			74	12.18	0.522	17.0	6.53	100.6
MW07	78.85	51.20	64					55.3
			74	12.18	0.538	14.5	6.58	64.0
MW08	77.95	50.65	64					179.7
			74	12.23	0.439	17.2	6.35	190.4
MW09	77.95	51.10	64					167.0
			74	12.24	0.518	18.6	6.41	173.0
MW10	77.70	51.25	64					129.3
			74	12.18	0.612	7.5	6.76	140.6
MW11	74.40	46.35	60					132.5
			70	12.18	0.490	7.5	6.78	135.6
June 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	no reading	no reading	no reading	no reading	no reading	no reading	no reading	no reading
IW-02	no reading	no reading	no reading	no reading	no reading	no reading	no reading	no reading
EW-01	73.09	47.79	70	no reading	no reading	no reading	no reading	no reading
MW01	74.62	48.80	60	12.62	0.500	61.8	6.81	63.6
			70	12.57	0.503	59.1	6.87	53.0
MW02	73.20	47.70	60					no reading
			70	12.28	0.679	35.8	6.62	56.3
MW03	70.80	47.70	60	12.45	4.800	2.7	7.10	-130.6
			70	12.33	1.199	1.1	7.05	-176.8
MW04	73.00	47.70	60	12.55	1.141	5.8	7.41	-167.5
			70	12.40	1.179	4.1	7.49	-183.0
MW05	77.75	49.60	64	12.39	0.497	67.2	6.73	92.3
			74	12.24	0.501	65.1	6.78	71.6
MW06	77.75	50.00	64	12.56	0.539	56.6	6.83	61.8
			74	12.52	0.526	58.0	6.83	74.3
MW07	78.75	51.27	64	12.29	0.599	40.3	6.96	27.0
			74	12.31	0.581	40.5	6.94	44.2
MW08	77.91	50.80	64	12.64	0.433	60.9	6.72	71.8
			74	12.35	0.429	59.9	6.76	62.7
MW09	77.95	51.22	64	12.27	0.508	64.7	6.67	85.6
			74	12.29	0.508	65.1	6.72	65.4
MW10	77.70	51.36	64	12.34	0.661	27.8	7.04	93.0
			74	12.31	0.674	23.7	7.06	101.0
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS



**Table 4 (Cont'd)**

July 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.10	47.10	70	no reading	no reading	no reading	no reading	no reading
IW-02	no reading	no reading	70	no reading	no reading	no reading	no reading	no reading
EW-01	73.10	47.30	70	no reading	no reading	no reading	no reading	no reading
MW01	74.10	48.95	60	12.50	no reading	9.48	no reading	142.8
			70	12.41	no reading	9.34	no reading	156.5
MW02	73.15	47.80	60	12.26	no reading	3.16	4.35	-60.6
			70	12.28	no reading	3.39	4.56	-66.5
MW03	71.60	47.85	60	12.39	no reading	0.20	5.02	-153.7
			70	12.37	no reading	0.21	4.92	-166.7
MW04	73.00	47.80	60	12.37	no reading	1.03	4.99	-190.6
			70	12.34	no reading	0.92	5.15	-198.0
MW05	77.80	49.75	64	12.41	no reading	10.53	4.26	59.6
			74	12.31	no reading	10.42	4.35	57.7
MW06	77.75	50.10	64	12.43	no reading	8.54	4.29	12.6
			74	12.31	no reading	9.12	4.30	34.0
MW07	78.00	51.40	64	12.46	no reading	4.29	4.30	-25.8
			74	12.30	no reading	5.62	4.30	-17.4
MW08	77.90	50.90	64	12.35	no reading	9.85	4.31	102.3
			74	12.23	no reading	9.20	4.30	96.8
MW09	77.90	51.30	64	12.37	no reading	10.03	4.29	109.5
			74	12.25	no reading	10.10	4.33	113.5
MW10	77.70	51.45	64	12.37	no reading	9.48	4.16	88.2
			74	12.23	no reading	9.34	4.26	97.9
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
August 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.15	47.20	70	12.27	0.693	4.2	7.04	-179.0
IW-02	73.40	47.65	70	12.24	0.663	1.2	7.34	-221.2
EW-01	73.25	47.45	70	12.15	0.492	62.6	6.80	-3.5
MW01	74.40	48.65	60	10.02	0.525	69.4	7.05	no reading
			70	11.40	0.510	63.4	7.06	no reading
MW02	73.20	47.90	60	no reading	0.880	20.9	6.91	-121.1
			70	no reading	0.914	22.3	6.93	-139.7
MW03	71.6	47.95	60	12.32	1.177	3.0	7.14	-156.3
			70	12.14	1.209	1.9	7.15	-197.1
MW04	73.10	47.90	60	12.33	1.116	8.8	7.70	-189.3
			70	12.21	1.209	4.8	7.75	-207.4
MW05	77.70	49.80	64	10.9	0.530	73.2	7.09	9.7
			74	11.35	0.524	76.2	7.27	-5.1
MW06	77.80	50.20	64	4.96	0.707	67.3	7.04	-32.2
			74	8.46	0.591	61.3	6.99	-20.5
MW07	78.85	51.50	64	5.98	0.928	27.9	7.18	-51.2
			74	5.42	0.807	44.1	7.02	-30.7
MW08	78.10	51.00	64	12.33	0.387	92.3	no reading	223.7
			74	12.51	0.389	97.2	no reading	299.8
MW09	77.95	51.45	64	12.17	0.444	97.1	no reading	222.8
			74	12.36	0.442	94.6	no reading	244.0
MW10	77.65	51.60	64	12.27	0.644	22.2	no reading	212.8
			74	12.32	0.643	30.8	no reading	235.8
MW11	74.90	46.70	60	12.17	0.419	39.5	no reading	209.9
			70	12.30	0.418	80.0	no reading	205.1

**Table 4 (Cont'd)**

September 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm3	DO (%)	pH	ORP (mV)
IW-01	73.36	47.40	70	no reading	2.452	4.5	7.13	-214.6
IW-02	73.41	47.90	70	no reading	2.921	0.6	7.32	-226.2
EW-01	73.09	47.80	70	no reading	0.958	12.3	7.09	-60.7
MW01	74.50	49.25	60		0.525	6.2	6.94	33.3
			70	11.49	0.529	5.9	7.00	28.7
MW02	73.20	48.10	60		0.829	3.7	6.99	-90.8
			70	10.34	0.981	2.5	6.97	-133.7
MW03	71.60	48.15	60		1.250	0.3	7.21	-143.8
			70	11.28	1.270	0.6	7.25	-179.8
MW04	73.15	49.20	60		1.168	0.9	7.64	-185.1
			70	11.39	1.223	0.7	7.67	-188.8
MW05	77.40	49.98	64		0.397	94.6	6.13	162.5
			74	12.30	0.392	90.9	5.91	168.1
MW06	77.90	50.40	64		0.482	47.5	6.12	-30.4
			74	12.33	0.475	23.2	6.31	-37.5
MW07	79.00	51.68	64		0.686	36.1	6.48	-44.1
			74	12.29	0.549	35.1	6.54	-20.7
MW08	78.10	51.17	64		0.338	95.2	6.45	150.4
			74	12.20	0.323	84.3	6.30	137.0
MW09	78.10	51.60	64		0.388	86.7	6.27	170.6
			74	12.21	0.382	87.6	6.28	161.1
MW10	77.90	51.76	64		0.609	20.2	6.66	148.0
			74	12.24	0.606	17.7	6.73	135.9
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
October 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm3	DO (%)	pH	ORP (mV)
IW-01	73.36	47.50	70	no reading	no reading	no reading	5.81	-88.6
IW-02	73.41	48.00	70	no reading	no reading	no reading	7.50	-199.1
EW-01	73.09	47.75	70	no reading	no reading	no reading	7.01	11.5
MW01	74.50	49.45	60	no reading	no reading	no reading	7.01	38.1
			70	no reading	no reading	no reading	7.13	23.8
MW02	73.20	48.40	60	no reading	no reading	no reading	6.96	-77.0
			70	no reading	no reading	no reading	6.94	-83.0
MW03	71.60	48.25	60	no reading	no reading	no reading	7.30	-144.4
			70	no reading	no reading	no reading	7.29	-153.9
MW04	73.15	48.40	60	no reading	no reading	no reading	7.90	-165.7
			70	no reading	no reading	no reading	7.99	-183.3
MW05	77.40	50.10	64	no reading	0.401	93.4	5.95	195.7
			74	no reading	0.402	93.0	6.08	191.0
MW06	77.90	50.50	64	no reading	0.528	36.0	6.43	-81.4
			74	no reading	0.510	21.3	5.66	-83.4
MW07	79.00	51.80	64	no reading	0.570	22.7	6.71	-61.6
			74	no reading	0.508	29.8	6.62	-37.9
MW08	78.10	51.30	64	no reading	0.335	87.0	6.34	110.0
			74	no reading	0.326	82.6	6.32	105.2
MW09	78.10	51.80	64	no reading	0.387	79.0	6.40	129.2
			74	no reading	0.382	82.2	6.39	126.2
MW10	77.90	51.90	64	no reading	0.597	19.8	6.83	-57.3
			74	no reading	0.600	17.0	6.87	-73.3
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS

**Table 4 (Cont'd)**

November 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.36	48.60	70	12.25	no reading	4.6	6.91	-154.7
IW-02	73.41	49.10	70	12.28	0.622	2.0	7.04	-146.0
EW-01		48.90	70	12.15	0.378	87.7	6.72	116.7
MW01	74.50	49.60	60	no reading	0.378	87.6	6.62	35.0
			70	12.26	0.377	90.2	6.67	23.7
MW02	73.20	48.35	60	no reading	0.716	38.3	6.68	-47.4
			70	12.40	0.723	34.2	6.70	-53.7
MW03	71.60	48.35	60	no reading	0.858	3.8	6.97	-119.3
			70	12.30	0.885	5.7	6.96	-126.6
MW04	73.15	48.30	60	no reading	0.853	12.4	7.36	-163.2
			70	12.34	0.867	13.7	7.34	-166.8
MW05	77.40	49.30	64	14.78	0.561	58.5	6.53	133.6
			74	14.81	0.566	58.5	6.45	125.2
MW06	77.90	50.70	64	14.86	0.804	40.2	6.91	-105.1
			74	14.56	0.767	31.8	6.45	-130.6
MW07	79.00	51.90	64	14.31	0.743	33.7	7.01	-63.6
			74	14.61	0.785	32.7	6.49	-35.4
MW08	78.10	51.40	64	14.40	0.449	53.6	6.42	105.7
			74	14.13	0.462	47.3	6.65	83.7
MW09	78.10	51.85	64	14.40	0.524	43.9	5.82	153.2
			74	14.50	0.526	49.7	5.72	161.2
MW10	77.90	52.00	64	14.25	0.829	16.5	7.13	-81.6
			74	14.38	0.815	21.8	5.23	-15.5
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
December 2004								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.15	no reading	70	12.21	0.912	4.2	6.89	-150.0
IW-02	73.40	no reading	70	12.29	0.593	0.6	6.98	-156.3
EW-01	73.25	no reading	70	12.23	0.377	81.0	6.05	140.8
MW01	74.90	no reading	60	no reading	no reading	no reading	no reading	no reading
			70	no reading	no reading	no reading	no reading	no reading
MW02	73.20	no reading	60	12.20	0.753	32.3	6.68	-59.4
			70	12.30	0.702	37.4	6.62	-32.6
MW03	70.80	no reading	60	12.27	0.858	1.2	6.92	-120.6
			70	12.41	0.862	2.0	6.93	-109.9
MW04	73.20	no reading	60	no reading	no reading	no reading	no reading	no reading
			70	no reading	no reading	no reading	no reading	no reading
MW05	77.80	50.45	64	12.25	0.409	88.2	6.92	184.6
			74	12.11	0.408	89.4	6.79	170.7
MW06	77.90	50.90	64	12.24	0.589	21.6	6.76	-49.5
			74	12.28	0.586	20.1	7.00	-42.6
MW07	79.00	52.10	64	12.37	0.661	15.3	6.78	-79.3
			74	12.29	0.630	14.2	6.72	-65.1
MW08	78.05	51.50	64	12.29	0.337	80.3	6.52	144.8
			74	12.37	0.341	78.9	6.57	135.3
MW09	78.10	52.00	64	12.38	0.387	73.0	6.59	119.3
			74	12.27	0.381	73.5	6.61	124.1
MW10	77.90	52.10	64	12.23	0.775	20.0	6.92	-88.6
			74	12.28	0.604	16.2	6.97	-104.3
MW11	74.60	47.30	60	12.18	0.951	41.9	6.80	119.5
			70	12.10	0.658	39.4	6.71	105.1

**Table 4 (Cont'd)**

January 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	72.90	47.92	70	12.50	4.221	2.3	6.93	-12.5
IW-02	73.10	48.35	70	10.32	4.551	2.0	6.90	-107.1
EW-01	73.20	48.15	70	12.26	4.625	83.8	6.64	46.9
MW01	74.65	48.75	60	no reading	4.645	1.9	6.80	52.2
			70	no reading	4.635	1.9	6.81	44.4
MW02	73.15	48.63	60	no reading	4.930	0.8	6.91	-58.3
			70	no reading	5.022	0.8	6.91	-75.3
MW03	71.63	48.63	60	no reading	no reading	no reading	no reading	no reading
			70	no reading	4.716	0.1	7.05	-125.6
MW04	73.00	48.61	60	no reading	4.807	0.2	7.27	-149.5
			70	no reading	4.805	0.2	7.27	-160.8
MW05	77.70	50.50	64	no reading	0.637	1.8	6.71	165.3
			74	no reading	0.787	1.8	6.59	173.6
MW06	77.75	50.90	64	12.33	0.668	12.2	6.72	-109.3
			74	12.31	0.669	14.2	6.73	-123.8
MW07	78.80	52.17	64	12.28	0.764	8.9	7.08	-118.7
			74	12.31	0.751	9.4	7.03	-117.9
MW08	77.90	51.71	64	12.21	0.321	no reading	6.83	no reading
			74	12.21	0.321	85.7	6.83	44.7
MW09	77.90	52.15	64	12.27	0.370	75.1	6.92	10.2
			74	12.21	0.366	78.5	6.88	18.7
MW10	77.95	52.30	64	12.31	0.586	21.1	7.19	-118.1
			74	12.19	0.610	17.5	7.21	-133.3
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
February 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	72.92	47.95	70	11.84	0.475	7.7	7.20	-108.5
IW-02	73.00	48.37	70	12.02	0.219	-0.5	7.32	-88.5
EW-01	73.10	48.17	70	11.83	0.220	57.8	7.01	41.5
MW01	74.65	49.80	60	11.94	0.462	55.4	7.06	30.5
			70	11.78	0.464	56.1	7.17	20.9
MW02	73.10	48.68	60	12.15	0.707	23.5	7.10	-114.9
			70	12.27	0.717	22.5	7.19	-126.3
MW03	71.63	48.68	60	12.17	1.052	2.6	7.36	-137.7
			70	12.33	1.110	3.1	7.32	-153.6
MW04	73.00	48.68	60	12.15	0.933	7.6	7.67	-171.9
			70	12.25	1.011	3.6	7.76	-196.5
MW05	77.70	50.52	64	12.13	0.495	59.7	6.95	53.2
			74	12.22	0.499	60.6	6.96	-45.5
MW06	77.75	50.95	64	12.21	0.787	11.0	6.77	-78.7
			74	12.32	0.796	4.9	6.69	-82.8
MW07	78.80	51.20	64	12.18	0.923	6.5	7.20	-124.5
			74	12.36	0.854	2.8	6.99	-103.6
MW08	77.90	51.75	64	11.84	0.043	56.5	7.03	40.5
			74	11.90	0.045	56.7	7.05	29.0
MW09	77.90	52.20	64	11.83	0.052	7.9	7.34	-4.0
			74	11.93	0.052	5.5	7.32	-5.5
MW10	77.95	52.35	64	11.80	0.741	13.5	7.39	-131.1
			74	11.94	0.657	9.4	7.61	-147.9
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS

**Table 4 (Cont'd)**

March 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	72.96	48.04	70	12.10	0.633	5.9	7.39	-159.2
IW-02	73.09	48.46	70	12.10	0.627	4.6	7.36	165.0
EW-01	73.12	48.28	70	12.03	0.509	59.9	7.02	7.5
MW01	74.65	49.89	60	12.21	0.503	55.9	7.05	27.5
			70	12.16	0.504	54.7	7.09	23.3
MW02	73.12	48.75	60	12.19	0.850	23.7	7.18	-96.0
			70	12.17	0.825	22.8	7.24	-108.0
MW03	71.63	48.77	60	12.18	1.276	4.1	7.31	-140.9
			70	12.25	1.265	3.5	7.31	-144.2
MW04	73.03	48.78	60	12.24	1.016	8.0	7.71	-170.1
			70	12.22	1.050	7.5	7.76	-175.0
MW05	77.68	50.62	64	12.07	0.548	61.1	6.70	34.0
			74	12.13	0.552	62.7	6.80	24.6
MW06	77.75	51.04	64	12.11	0.863	9.2	6.61	-76.3
			74	12.17	0.862	6.5	6.69	-76.7
MW07	78.88	52.32	64	12.19	0.914	7.0	6.74	-105.0
			74	12.20	0.899	4.3	6.80	-102.6
MW08	77.97	51.82	64	12.05	0.451	55.4	6.90	15.7
			74	12.03	0.449	54.8	6.99	7.9
MW09	77.95	52.28	64	12.07	0.481	50.5	6.94	0.8
			74	12.03	0.478	57.2	6.97	6.0
MW10	77.65	52.44	64	12.15	0.836	17.9	7.25	-134.7
			74	12.06	0.851	15.0	7.40	-145.4
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
April 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.15	48.10	70	11.96	0.550	9.4	7.18	-127.5
IW-02	73.40	48.35	70	12.07	0.523	9.5	7.09	136.2
EW-01	73.25	48.52	70	11.99	0.518	61.9	7.08	12.1
MW01	74.90	no reading	60	12.43	0.501	55.5	7.14	23.8
			70	12.26	0.504	54.4	7.22	12.6
MW02	73.20	48.81	60	12.49	0.769	22.4	7.20	-131.1
			70	12.34	0.769	23.5	7.22	-143.1
MW03	70.80	48.85	60	12.56	1.139	3.8	7.44	-166.6
			70	12.53	1.157	5.2	7.49	-175.8
MW04	73.20	48.82	60	12.27	1.055	12.6	7.62	-198.3
			70	12.37	1.082	15.0	7.64	-186.2
MW05	77.80	50.70	64	12.44	0.551	61.4	7.00	26.4
			74	12.32	0.533	61.3	7.02	14.9
MW06	77.90	51.30	64	12.49	0.891	7.1	6.68	-117.0
			74	12.34	0.892	6.3	6.68	-118.9
MW07	79.00	52.40	64	12.49	0.935	4.0	6.92	-163.8
			74	12.46	0.897	3.5	6.82	-161.5
MW08	78.05	51.90	64	12.24	0.454	55.2	6.95	28.8
			74	12.29	0.454	54.8	7.00	18.8
MW09	78.10	52.34	64	12.25	0.480	49.9	6.96	14.2
			74	12.20	0.474	50.8	7.02	18.8
MW10	77.90	52.45	64	12.37	0.806	13.0	7.40	-159.0
			74	12.35	0.828	12.1	7.45	-150.8
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS

**Table 4 (Cont'd)**

May 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.36	48.18	70	12.39	0.577	15.5	7.13	-217.3
IW-02	73.41	48.41	70	12.39	0.505	38.1	6.92	-181.5
EW-01		48.62	70	12.30	0.381	110.8	6.99	-25.1
MW01	74.50	50.04	60	12.44	0.375	100.3	6.95	22.4
			70	12.37	0.375	98.0	6.99	15.6
MW02	73.20	48.92	60	12.40	0.507	49.1	7.19	-183.9
			70	12.39	0.504	47.5	7.20	-190.1
MW03	71.60	48.92	60	12.56	0.759	10.7	7.20	-215.6
			70	12.44	0.830	10.6	7.22	-229.2
MW04	73.15	48.91	60	12.49	0.657	28.1	7.30	-198.1
			70	12.42	0.783	26.4	7.37	-211.6
MW05	77.40	50.82	64	12.47	0.413	103.4	6.80	-24.7
			74	12.47	0.640	23.5	6.93	-198.4
MW06	77.90	51.22	64	12.56	0.778	24.6	6.80	-170.7
			74	12.42	0.764	19.7	6.80	-175.8
MW07	79.00	52.50	64	12.53	0.659	16.9	7.03	-197.4
			74	12.35	0.413	112.6	6.86	-31.1
MW08	78.10	52.02	64	12.30	0.338	100.0	6.82	-1.2
			74	12.27	0.336	95.7	6.95	-9.5
MW09	78.10	52.45	64	12.39	0.358	90.1	6.93	1.0
			74	12.31	0.335	93.2	6.90	1.7
MW10	77.90	52.62	64	12.38	0.575	29.8	7.08	-135.5
			74	12.37	0.583	30.6	7.16	-146.9
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
June 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.15	48.20	70	12.26	0.551	9.7	5.27	-51.9
IW-02	73.40	48.45	70	12.37	0.531	8.2	6.87	-172.5
EW-01	73.25	48.65	70	12.25	0.516	55.2	6.73	50
MW01	74.90	50.10	60	12.66	0.373	88.2	6.78	132.2
			70	12.61	0.373	86.1	6.81	113.7
MW02	73.20	49.00	60	12.40	0.558	18.4	7.13	-128.4
			70	12.40	0.561	24.3	7.25	-142.2
MW03	70.80	49.00	60	12.50	0.945	4.7	7.41	-223.8
			70	12.52	1.103	6.5	7.41	-232.1
MW04	73.20	49.00	60	12.56	0.756	5.9	7.56	-212.3
			70	12.58	0.874	6.7	7.60	-224.9
MW05	77.80	50.85	64	12.61	0.541	63.6	7.23	36.9
			74	12.47	0.548	59.3	7.47	20.9
MW06	77.90	51.27	64	12.53	1.044	14.8	7.27	-174.2
			74	12.41	1.073	12.4	7.53	-195.0
MW07	79.00	52.58	64	12.66	1.072	4.6	7.27	-205
			74	12.50	1.046	7.1	7.19	-209.4
MW08	78.05	52.10	64	12.56	0.339	81.0	6.69	184.8
			74	12.65	0.336	78.3	6.72	177.6
MW09	78.10	52.54	64	12.69	0.361	77.7	6.76	135.5
			74	12.59	0.355	78.1	6.73	141.0
MW10	77.90	52.70	64	12.73	0.535	17.0	7.14	-108.6
			74	12.70	0.539	13.5	7.19	-121.0
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS

**Table 4 (Concluded)**

July 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.36	48.38	70	12.45	0.547	1.1	7.02	-111.5
IW-02	73.41	48.62	70	12.45	0.463	0.6	7.03	-131.3
EW-01		48.80	70	12.45	0.463	87.7	6.83	13.4
MW01	74.50	50.26	60	12.61	0.372	83.9	6.73	215.3
			70	12.57	0.371	83.9	6.71	216.9
MW02	73.20	49.08	60	12.60	0.400	45.5	7.08	20.8
			70	12.41	0.406	51.5	7.12	20.7
MW03	71.60	49.07	60	12.59	0.767	1.1	7.24	-127.8
			70	12.46	0.770	0.6	7.24	-128.8
MW04	73.15	49.09	60	12.54	0.724	7.4	7.36	-158.3
			70	12.49	0.761	7.0	7.38	-164.1
MW05	77.40	50.98	64	12.41	0.405	93.2	6.66	119.2
			74	12.46	0.407	93.1	6.64	97.6
MW06	77.90	51.38	64	12.67	0.755	5.5	6.87	-83.2
			74	12.59	0.746	5.5	6.85	-91.4
MW07	79.00	52.65	64	12.80	0.802	1.3	6.88	-90.3
			74	12.67	0.791	0.8	6.84	-81.2
MW08	78.10	52.15	64	12.52	0.340	81.0	6.59	175.2
			74	12.56	0.338	79.7	6.62	152.8
MW09	78.10	52.60	64	12.57	0.359	76.2	6.75	88.8
			74	12.59	0.359	75.8	6.80	61.0
MW10	77.90	52.76	64	12.73	0.522	16.7	7.17	-108.7
			74	12.62	0.516	16.6	7.19	-114.0
MW11	NS	NS	NS	NS	NS	NS	NS	NS
	NS	NS	NS	NS	NS	NS	NS	NS
August 2005								
Well ID-Depth	Total Depth, ft	Depth to Water, ft	Sample Depth, ft	Temp (°C)	Cond. mS/cm <sup>3</sup>	DO (%)	pH	ORP (mV)
IW-01	73.15	49.42	70	12.49	0.412	4.3	7.01	-65
IW-02	73.40	48.67	70	12.43	0.395	6.5	6.99	-102.5
EW-01	73.25	48.83	70	12.40	0.392	84.4	6.93	44
MW01	74.90	52.25	60	12.51	0.380	80.7	6.75	150
			70	12.40	0.375	81.4	6.83	135.4
MW02	73.20	49.12	60	12.48	0.460	30.1	7.15	-25.9
			70	12.56	0.458	32.7	7.19	-27.0
MW03	70.80	49.16	60	12.51	0.754	1.6	7.34	-150.3
			70	12.55	0.758	1.9	7.34	-150.9
MW04	73.20	49.12	60	12.49	0.526	7.4	7.47	-161.3
			70	12.49	0.532	7.6	7.44	-164.0
MW05	77.80	51.04	64	12.33	0.406	90.7	6.60	-341.1
			74	12.33	0.408	90.3	6.67	-346.8
MW06	77.90	51.44	64	12.40	0.745	10.2	6.96	-467.4
			74	12.43	0.750	8.0	6.99	-471.5
MW07	79.00	52.71	64	12.60	0.769	2.3	6.98	-550.6
			74	12.55	0.782	1.6	6.92	-547.3
MW08	78.05	52.21	64	12.25	0.340	80.4	6.43	179.9
			74	12.25	0.340	78.3	8.38	141.0
MW09	78.10	52.66	64	12.44	0.367	76.7	6.78	182.2
			74	12.44	no reading	no reading	no reading	no reading
MW10	77.90	52.82	64	12.64	0.527	17.7	7.19	-109.9
			74	12.48	0.527	15.7	7.20	-118.6
MW11	74.60	48.00	60	12.42	0.385	43.5	7.10	14.1
			70	no reading	no reading	no reading	no reading	no reading

**Table 5  
Nutrient Results**

Well ID-Depth	Acetate Concentration, mg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW01-070	<1.0	0.7J	<1.0	<1.0	<1.0	<1.0	<1.0
MW02-060	0.3J	0.3J	<1.0	<1.0	13	21	47.7
MW02-070	<1.0	0.4J	<1.0	<1.0	11	18.7	29.9
MW03-060	<1.0	<1.0	<1.0	3.0	54	158	380
MW03-070	<1.0	<1.0	<1.0	<1.0	56	163	372
MW04-060	<1.0	<1.0	88	114	100	167	336
MW04-070	<1.0	<1.0	62	95	91	186	339
MW05-064	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW05-074	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW06-064	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW06-074	0.4J	0.3J	<1.0	<1.0	<1.0	<1.0	<1.0
MW07-064	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW07-074	0.5J	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW08-064	<1.0	<1.0	<1.0	<1.0	0.99	<1.0	<1.0
MW08-074	0.3J	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW09-064	<1.0	<1.0	<1.0	<1.0	<1.0	0.5	0.4
MW09-074	0.4J	<1.0	<1.0	<1.0	<1.0	<1.0	0.5
MW10-064	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.5
MW10-074	0.4J	<1.0	<1.0	<1.0	<1.0	<1.0	0.5
MW11-060	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	
MW11-070	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	
Well ID-Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW01-070	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW02-060	184	167	109	150	170	200	140
MW02-070	195	161	135	140	170	170	140
MW03-060	309	345	235	290	260	260	270
MW03-070	306	350	226	280	260	260	270
MW04-060	299	264	200	240	230	270	240
MW04-070	309	275	210	240	230	270	<1.0
MW05-064	<1.0	<1.0	<1.0	0.4	<1.0	<1.0	0.3
MW05-074	0.8	<1.0	<1.0	<1.0	<1.0	<1.0	120
MW06-064	<1.0	<1.0	<1.0	64	61	86	120
MW06-074	0.7	<1.0	7.1	59	85	92	140
MW07-064	<1.0	20.9	56	49	67	110	140
MW07-074	13.6	11.5	40	36	54	110	<1.0
MW08-064	1.0	<1.0	<1.0	<1.0	0.3	<1.0	<1.0
MW08-074	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW09-064	0.6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
MW09-074	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	39
MW10-064	0.9	<1.0	<1.0	<1.0	<1.0	18	47
MW10-074	<1.0	<1.0	<1.0	<1.0	2.2	20	<1.0
MW11-060		<1.0				<1.0	
MW11-070		<1.0				<1.0	



**Table 5  
Nutrient Results**

Well ID-Depth	Acetate Concentration, mg/L						
	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05
MW01-060	0.38	<1.0	<1.0	<1.0	<1.0	<0.30	<1.0
MW01-070	<0.30	<1.0	<1.0	0.4	<1.0	<0.30	<1.0
MW02-060	83	150	110	73	<1.0	<0.30	21
MW02-070	83	140	110	73	<1.0	<0.30	13
MW03-060	270	310	260	190	170	160	140
MW03-070	270	300	270	230	200	160	150
MW04-060	200	120	180	85	28	85	9.4
MW04-070	200	130	190	140	39	96	23
MW05-064	<0.30	<1.0	<1.0	<1.0	0.4	0.4	<1.0
MW05-074	0.34	<1.0	0.4	<1.0	<1.0	<0.30	<1.0
MW06-064	110	130	140	220	200	180	190
MW06-074	130	130	140	220	210	180	200
MW07-064	140	140	140	140	180	180	170
MW07-074	120	140	140	130	180	180	170
MW08-064	<0.30	<1.0	0.5	<1.0	<1.0	<0.30	<1.0
MW08-074	<0.30	<1.0	0.5	<1.0	<1.0	<0.30	<1.0
MW09-064	<0.30	<1.0	<1.0	<1.0	<1.0	<0.30	0.5
MW09-074	0.31	<1.0	<1.0	<1.0	<1.0	0.51	<1.0
MW10-064	25	68	60	51	19	<0.30	30
MW10-074	35	71	67	57	8.7	<0.30	32
MW11-060							<1.0
MW11-070							<1.0

**Table 5 (Cont'd)**

Well ID-Depth	Bromide Concentration, mg/L						
	Mar-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04
MW01-060	0.07	0.19	0.08	0.10	0.40	0.06	0.07
MW01-070	0.07	0.17	0.06	0.13	0.32	<0.10	0.06
MW02-060	0.10	0.25	0.41	0.81	1.60	1.90	1.80
MW02-070	0.06	0.32	0.26	0.86	1.70	2.20	1.50
MW03-060	0.09	2.14	2.10	2.70	2.50	1.70	0.86
MW03-070	0.05	2.18	2.10	2.20	2.30	2.00	0.83
MW04-060	0.06	1.08	1.70	0.65	0.22	0.36	0.20
MW04-070	0.09	1.16	1.70	0.64	0.29	0.60	0.36
MW05-064	0.05	0.16	0.03	0.10	0.05	<0.10	0.05
MW05-074	0.06	0.15	0.06	0.14	<0.10	0.11	0.09
MW06-064	0.06	0.16	0.05	0.63	0.40	0.26	0.36
MW06-074	0.05	0.15	0.06	0.49	0.32	0.24	0.43
MW07-064	0.06	0.26	0.32	0.31	0.22	0.17	0.29
MW07-074	0.04	0.29	0.23	0.27	0.28	0.20	0.27
MW08-064	0.04	<0.10	0.04	0.09	0.08	0.04	0.13
MW08-074	0.07	0.21	<0.10	0.11	0.05	0.06	0.05
MW09-064	0.05	0.17	0.05	0.14	0.14	0.10	0.14
MW09-074	0.08	0.17	0.06	0.14	0.17	0.14	0.14
MW10-064	0.06	0.25	0.28	0.60	0.43	0.31	0.34
MW10-074	0.06	0.24	0.32	0.56	0.32	0.34	0.36
MW11-060	0.06		0.03				<0.10
MW11-070	<0.10		0.05				0.08
Well ID-Depth	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Aug-05
MW01-060	<0.1	0.043	<0.10	<0.10	0.07	0.05	0.08
MW01-070	0.07	0.25	<0.10	<0.10	0.07	0.07	0.1
MW02-060	0.83	0.25	0.19	0.14	0.12	0.48	5.7
MW02-070	0.88	0.24	0.13	<0.10	0.17	0.61	4.8
MW03-060	0.51	0.25	0.22	0.62	18	27	14
MW03-070	0.51	0.3	0.28	0.38	17	25	14
MW04-060	<0.1	<0.020	10	13	12	4.4	2.2
MW04-070		0.056	9.3	15	12	4.2	1.8
MW05-064	<0.1	0.049	<0.10	<0.10	0.24	0.05	0.05
MW05-074	0.05	0.029	<0.10	<0.10	0.07	<0.10	0.05
MW06-064	0.58	0.62	0.67	2	2.5	1.9	1.5
MW06-074	0.55	0.8	0.63	2.1	2.6	2	1.4
MW07-064	0.59	0.56	0.81	2.8	1.2	1.2	1.4
MW07-074	0.62	0.51	0.73	1.7	1.2	1.1	1.5
MW08-064	<0.1	0.06	<0.10	<0.10	0.04	0.02	0.06
MW08-074	<0.1	0.08	<0.10	<0.10	0.04	0.05	0.06
MW09-064	<0.1	0.12	<0.10	<0.10	0.07	0.1	0.06
MW09-074	<0.1	0.12	0.073	<0.10	0.08	0.09	0.06
MW10-064	<0.1	0.29	0.25	0.35	2	1.4	2.9
MW10-074	0.28	0.28	0.3	0.3	2.2	1.5	3.2
MW11-060							0.03
MW11-070							0.05

**Table 5 (Cont'd)**

Well ID-Depth	Nitrate Concentration, mg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	22	19.3	20	20	20	20.0	20.0
MW01-070	21	19.2	20	20	20	19.6	20.1
MW02-060	20	16.5	16	15	13	11.7	3.2
MW02-070	20	16.6	16	15	13	12.4	<0.02
MW03-060	16	14.0	13	12	6.5	0.70	<0.02
MW03-070	17	14.1	13	12	7.4	3.9	<0.02
MW04-060	21	18.2	<0.02	5.1	4.5	2.7	3.8
MW04-070	21	18.3	<0.02	3.7	5.6	2.6	3.8
MW05-064	22	19.1	19	19	20	20.9	22
MW05-074	22	19.1	19	19	20	21.4	23
MW06-064	21	17.5	17	17	17	15.5	15
MW06-074	21	17.7	18	17	17	16.3	16
MW07-064	29	16.8	16	16	16	14.1	11
MW07-074	19	16.7	16	16	16	14.5	12
MW08-064	14	12.7	13	13	13	12.6	13
MW08-074	14	12.5	13	12	12	12.2	13
MW09-064	23	20	20	20	20	20	20
MW09-074	23	20	20	20	20	20	20
MW10-064	19	16.6	17	9.2	7.7	7.3	6.7
MW10-074	19	16.7	17	9.1	7.3	6.7	6.1
MW11-060	7.0	7.5	7.7	7.8	7.6	7.6	
MW11-070	8.0	6.7	7.4	7.3	7.3	7.0	
Well ID-Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	20	20	20	0.26	17	17	16
MW01-070	20	20	20	<0.02	17	17	16
MW02-060	<0.02	<0.02	<0.02	0.77	1.0	3.4	3.8
MW02-070	2.5	<0.02	<0.02	3.0	2.0	3.7	3.9
MW03-060	1.5	1.4	1.1	<0.02	<0.02	0.3	<0.02
MW03-070	1.6	1.4	1.1	<0.02	0.35	0.4	<0.02
MW04-060	2.1	<0.02	<0.02	0.31	1.8	2.1	1.5
MW04-070	2.0	<0.02	<0.02	0.10	3.0	2.3	23
MW05-064	23	24	25	25	24	24	24
MW05-074	24	24	25	25	25	24	1.5
MW06-064	13	10	0.60	<0.02	<0.02	2.9	1.4
MW06-074	14	11	<0.02	<0.02	<0.02	2.2	1.3
MW07-064	7.5	7.1	5.5	4.7	3.9	3.2	1.4
MW07-074	11	8.1	6.5	5.6	3.8	3.4	13
MW08-064	13	13	14	13	13	13	13
MW08-074	13	13	13	12	12	13	13
MW09-064	19	18	18	16	15	14	13
MW09-074	19	18	18	17	15	15	4
MW10-064	5.3	4.2	3.9	3.9	2.7	4.3	3.2
MW10-074	5.1	3.7	4.8	3.7	2.6	3.6	16
MW11-060		7.8				7.3	
MW11-070		7.4				6.8	

**Table 5 (Cont'd)**

Well ID-Depth	Nitrate Concentration, mg/L						
	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05
MW01-060	17	17	17	18	17	17	17
MW01-070	17	17	17	18	17	17	17
MW02-060	<0.010	5	5.5	6.2	4.3	8.3	7.9
MW02-070	<0.010	4.9	5.5	6.2	3.2	8.4	8.2
MW03-060	<0.010	0.27	<0.020	0.37	<0.02	<0.01	<0.02
MW03-070	<0.010	0.24	0.11	0.28	<0.02	<0.01	<0.02
MW04-060	<0.010	<0.02	<0.020	2.5	<0.02	<0.01	<0.02
MW04-070	<0.010	<0.02	<0.020	2.3	<0.02	0.03	1.5
MW05-064	25	23	24	26	25	23	24
MW05-074	25	24	25	26	25	25	25
MW06-064	<0.010	1.4	1.3	1.9	<0.02	1.4	<0.02
MW06-074	<0.010	1.1	0.94	1.9	<0.02	0.81	1.2
MW07-064	<0.010	0.47	0.4	0.77	<0.02	<0.01	0.21
MW07-074	<0.010	0.16	0.047	0.82	0.024	<0.01	0.027
MW08-064	13	13	13	14	14	13	14
MW08-074	13	13	13	14	13	13	13
MW09-064	13	13	13	14	15	15	16
MW09-074	14	13	13	15	15	15	17
MW10-064	<0.010	4	3.4	3.8	0.087	<0.01	3.4
MW10-074	<0.010	3.7	3.2	3.3	<0.02	0.06	3.1
MW11-060							7.3
MW11-070							6.9

**Table 5 (Cont'd)**

Well ID-Depth	Nitrite Concentration, mg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	<0.02	<0.02	<0.02	0.21	<0.02	<0.02	<0.02
MW01-070	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MW02-060	0.03	<0.02	<0.02	0.24	0.33	0.222	0.84
MW02-070	0.07	<0.02	<0.02	0.21	<0.02	0.23	<0.02
MW03-060	0.04	<0.02	0.24	0.26	0.41	2.09	<0.02
MW03-070	0.04	<0.02	0.24	0.23	0.44	0.35	<0.02
MW04-060	<0.02	<0.02	<0.02	0.38	<0.02	0.37	<0.02
MW04-070	<0.02	<0.02	<0.02	0.64	<0.02	0.36	<0.02
MW05-064	<0.02	<0.02	<0.02	0.21	<0.02	<0.02	<0.02
MW05-074	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MW06-064	<0.02	<0.02	<0.02	<0.02	0.33	0.23	<0.02
MW06-074	<0.02	<0.02	0.23	<0.02	0.32	0.23	<0.02
MW07-064	<0.02	<0.02	0.25	0.22	<0.02	0.34	0.31
MW07-074	<0.02	<0.02	0.26	<0.02	0.33	0.36	0.33
MW08-064	<0.02	<0.02	<0.02	<0.02	<0.02	0.21	<0.02
MW08-074	<0.02	<0.02	<0.02	0.2	<0.02	<0.02	<0.02
MW09-064	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.31
MW09-074	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MW10-064	<0.02	<0.02	<0.02	0.26	0.33	0.25	0.32
MW10-074	<0.02	<0.02	<0.02	0.26	0.36	0.23	0.32
MW11-060	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	
MW11-070	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	
Well ID-Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	<0.02	<0.02	<0.02	0.79	<0.02	<0.02	<0.02
MW01-070	<0.02	0.23	<0.02	<0.02	<0.02	<0.02	<0.02
MW02-060	2.26	<0.02	<0.02	2.10	1.90	0.40	0.33
MW02-070	1.46	2.30	<0.02	0.57	0.85	0.49	0.27
MW03-060	0.60	0.68	0.04	0.71	<0.02	<0.02	<0.02
MW03-070	0.50	0.64	<0.02	0.64	0.40	0.31	<0.02
MW04-060	<0.02	<0.02	<0.02	0.82	<0.02	0.24	0.69
MW04-070	<0.02	<0.02	<0.02	0.64	0.38	0.28	<0.02
MW05-064	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MW05-074	<0.02	0.26	<0.02	<0.02	<0.02	<0.02	<0.02
MW06-064	0.45	0.73	3.00	<0.02	<0.02	0.16	<0.02
MW06-074	0.28	0.85	<0.02	<0.02	<0.02	0.20	0.22
MW07-064	<0.02	0.31	0.33	0.53	0.33	0.23	<0.02
MW07-074	0.40	0.34	0.71	0.68	0.56	0.25	<0.02
MW08-064	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MW08-074	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MW09-064	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.024
MW09-074	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02
MW10-064	0.32	0.27	<0.02	<0.02	<0.02	0.10	<0.02
MW10-074	0.32	0.28	<0.02	0.17	<0.02	0.07	<0.02
MW11-060		<0.02				<0.02	
MW11-070		<0.02				<0.02	

**Table 5 (Cont'd)**

Well ID-Depth	Nitrite Concentration, mg/L						
	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05
MW01-060	<0.010	<0.02	<0.020	<0.02	<0.02	<0.01	<0.02
MW01-070	<0.010	<0.02	<0.020	<0.02	<0.02	<0.01	<0.02
MW02-060	<0.010	0.29	0.22	0.51	0.27	0.74	0.76
MW02-070	<0.010	0.29	0.24	0.55	0.01	0.96	0.83
MW03-060	<0.010	<0.02	<0.020	0.12	<0.02	<0.01	<0.02
MW03-070	<0.010	<0.02	<0.020	0.18	<0.02	<0.01	<0.02
MW04-060	<0.010	<0.02	<0.020	0.11	<0.02	0.07	<0.02
MW04-070	<0.010	<0.02	<0.020	0.13	<0.02	0.13	0.16
MW05-064	<0.010	<0.02	<0.020	<0.02	<0.02	<0.01	<0.02
MW05-074	<0.010	<0.02	<0.020	<0.02	<0.02	<0.01	<0.02
MW06-064	<0.010	0.16	0.12	0.17	<0.02	<0.01	0.72
MW06-074	<0.010	0.17	0.17	1.3	<0.02	0.29	0.15
MW07-064	<0.010	0.13	<0.020	0.079	<0.02	<0.01	<0.02
MW07-074	<0.010	<0.02	<0.020	0.11	<0.02	<0.01	<0.02
MW08-064	<0.010	0.022	<0.020	<0.02	<0.02	<0.01	<0.02
MW08-074	<0.010	<0.02	<0.020	<0.02	<0.02	<0.01	<0.02
MW09-064	0.03	0.016	0.047	0.03	0.017	<0.01	<0.02
MW09-074	0.018	0.018	0.047	0.023	0.022	<0.01	<0.02
MW10-064	<0.010	0.13	0.089	0.11	0.059	1.10	0.039
MW10-074	<0.010	0.16	0.067	0.17	<0.02	1.80	0.02
MW11-060							<0.02
MW11-070							<0.02

**Table 5 (Cont'd)**

Well ID-Depth	Sulfate Concentration, mg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	22	22	22	23	11	23	23
MW01-070	22	22	23	23	11	23	23
MW02-060	20	20	21	20	10	20	20
MW02-070	20	20	21	21	10	20	20
MW03-060	17	17	18	18	8.9	18	22
MW03-070	17	17	18	18	9.0	21	21
MW04-060	20	20	21	20	9.8	18	22
MW04-070	20	20	21	20	9.9	18	20
MW05-064	23	22	23	23	11	23	23
MW05-074	22	23	23	23	11	23	23
MW06-064	23	22	23	23	11	23	23
MW06-074	23	23	23	23	11	23	23
MW07-064	22	22	23	23	11	23	21
MW07-074	22	22	23	23	11	23	22
MW08-064	22	22	22	22	11	22	22
MW08-074	22	22	22	22	11	22	22
MW09-064	22	22	22	22	11	22	23
MW09-074	22	22	23	22	11	22	23
MW10-064	20	21	21	21	10	21	20
MW10-074	20	21	21	21	10	18	20
MW11-060	31	30	31	31	15	31	
MW11-070	31	31	31	31	15	31	
Well ID-Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	23	23	23	5.1	22	23	22
MW01-070	23	23	23	15	22	23	22
MW02-060	18	15	9.6	8.6	8.2	7.8	10
MW02-070	18	15	9.5	8.6	7.9	9.1	10
MW03-060	9.0	5.3	4.5	3.3	3.6	3	1.8
MW03-070	8.3	5.0	3.9	3.2	3.4	3	1.7
MW04-060	14	8.9	6.8	5.8	5.1	5.2	4.4
MW04-070	13	7.9	5.5	5.1	9.1	5.5	
MW05-064	23	23	24	23	23	23	23
MW05-074	23	23	24	23	23	23	23
MW06-064	22	21	16	15	13	13	4.5
MW06-074	23	21	17	15	13	13	4.3
MW07-064	19	16	15	14	12	11	5.8
MW07-074	20	18	17	15	14	12	5.9
MW08-064	22	22	22	21	20	21	20
MW08-074	22	22	22	21	21	21	20
MW09-064	23	22	22	20	19	19	19
MW09-074	23	23	22	21	19	19	19
MW10-064	18	17	11	8.3	7.4	8.3	7.5
MW10-074	18	16	12	8.1	6.1	7.4	6.2
MW11-060		31				29	
MW11-070		31				30	

**Table 5 (Cont'd)**

Well ID-Depth	Sulfate Concentration, mg/L						
	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05
MW01-060	22	21	22	21	21	21	21
MW01-070	22	21	22	22	21	21	21
MW02-060	11	11	14	17	21	22	18
MW02-070	11	11	13	17	21	22	19
MW03-060	1.9	1.1	3.5	6.1	5.8	4.6	5.4
MW03-070	1.9	1.1	3.4	5.4	4.8	3.9	5.4
MW04-060	5.5	5	6.7	5.1	7.4	3.9	7.6
MW04-070	5.7	5.1	6.1	4.1	5.4	3.5	8.1
MW05-064	24	22	24	25	23	23	23
MW05-074	24	23	24	25	23	23	23
MW06-064	2.8	3.3	2.8	5.1	5.2	4.2	5.2
MW06-074	2.6	3	2.3	5	4.7	4.1	4.9
MW07-064	2.8	2.6	3.2	4.9	1.9	1.1	0.69
MW07-074	3.2	2.6	3	5.1	1.6	0.91	0.26
MW08-064	21	20	21	22	21	21	21
MW08-074	21	20	21	22	21	21	21
MW09-064	19	18	20	22	21	21	22
MW09-074	19	19	20	22	21	21	21
MW10-064	6.8	6.1	6	6.2	6	6.1	5.7
MW10-074	5.7	5.8	5.5	5.8	5.5	6.1	5.4
MW11-060							29
MW11-070							30



**Table 5 (Cont'd)**

Well ID-Depth	Total Organic Carbon Concentration, mg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	1.6	1.4	1.3	1.4	1.4	1.4	1.4
MW01-070	1.6	1.4	1.5	1.4	1.4	1.9	1.4
MW02-060	1.7	1.7	1.6	1.7	2.2	7.0	22
MW02-070	1.7	1.6	1.6	1.7	2.1	5.5	21
MW03-060	1.6	1.5	1.6	1.9	7.3	71	146
MW03-070	1.5	1.5	1.6	1.9	5.2	63	159
MW04-060	1.4	1.4	52	52	21	55	128
MW04-070	1.4	1.4	34	59	7.6	82	135
MW05-064	1.5	1.5	1.5	1.7	1.5	1.6	1.4
MW05-074	1.5	1.4	1.4	1.5	1.3	1.5	1.4
MW06-064	1.6	1.6	1.6	1.6	1.5	1.8	2.6
MW06-074	1.6	1.5	12	1.6	1.4	1.6	2.3
MW07-064	1.5	1.5	1.7	1.6	1.5	1.8	2.5
MW07-074	1.5	1.5	1.6	1.5	1.7	1.8	2.3
MW08-064	---	1.4	1.3	1.3	1.5	1.2	1.3
MW08-074	1.4	1.3	1.4	1.3	1.4	1.2	1.3
MW09-064	1.6	1.5	1.8	1.5	1.5	1.4	1.4
MW09-074	1.6	1.6	1.6	1.6	1.5	1.5	1.5
MW10-064	1.6	1.6	1.5	1.6	1.8	1.9	2.5
MW10-074	1.6	1.5	1.5	1.7	1.9	2.1	2.4
MW11-060	1.5	1.4	1.4	1.4	1.4	1.3	
MW11-070	1.4	1.5	1.4	1.4	1.4	1.2	
Well ID-Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	1.32	1.26	1.40	1.40	1.4	1.6	1.5
MW01-070	1.35	1.37	1.30	1.40	1.4	1.8	1.4
MW02-060	89.2	79.4	65.00	18	100	130	85
MW02-070	88.2	71.6	82.00	17	100	100	84
MW03-060	158	189	215.00	54	190	230	260
MW03-070	161	194	214.00	52	200	220	270
MW04-060	147	126	147.00	40	150	230	210
MW04-070	148	137	163.00	43	170	230	220
MW05-064	1.34	1.39	1.60	1.5	1.6	1.8	1.4
MW05-074	1.36	1.46	1.50	22	1.6	1.6	1.5
MW06-064	2.97	3.82	6.10	81	46	40	76
MW06-074	2.62	3.30	13.00	82	73	54	78
MW07-064	3.15	5.46	15.00	76	40	79	95
MW07-074	3.37	4.96	6.60	76	26	81	95
MW08-064	1.34	1.22	1.40	31	1.4	1.3	1.4
MW08-074	1.30	1.22	1.30	30	1.3	1.3	1.2
MW09-064	1.51	1.58	1.50	40	1.6	1.8	1.8
MW09-074	1.56	1.46	1.50	38	1.6	1.7	1.7
MW10-064	2.58	2.96	3.50	77	3.9	3.8	11
MW10-074	2.94	2.98	3.20	77	3.8	4.9	16
MW11-060		1.31				1.5	
MW11-070		1.29				1.5	

**Table 5 (Cont'd)**

Well ID-Depth	Total Organic Carbon Concentration, mg/L						
	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05
MW01-060	1.4	1.6	1.5	1.4	1.2	1.4	1.3
MW01-070	1.4	1.4	1.4	1.3	1.4	1.4	1.3
MW02-060	44	77	42	30	2.6	2.2	3.8
MW02-070	47	73	31	30	2.8	2.4	3.3
MW03-060	210	260	200	120	110	100	96
MW03-070	200	260	190	150	140	100	96
MW04-060	120	88	110	34	14	54	17
MW04-070	130	92	110	66	17	63	16
MW05-064	1.6	1.6	1.5	1.3	1.6	1.5	1.5
MW05-074	1.6	1.4	1.7	1.4	1.5	1.5	1.5
MW06-064	72	86	75	140	140	110	120
MW06-074	86	89	78	140	150	120	120
MW07-064	94	87	88	74	140	130	110
MW07-074	85	93	93	70	130	130	115
MW08-064	1	1.4	1.3	1.2	1.2	1.3	1.2
MW08-074	1.3	1.3	1.2	1.2	1.2	1.3	1.3
MW09-064	1.6	1.5	1.4	1.4	1.3	1.4	1.4
MW09-074	1.6	1.6	1.4	1.3	1.3	1.4	1.4
MW10-064	15	49	21	20	9.3	8.5	12
MW10-074	22	53	29	27	7.2	7.9	13
MW11-060							1.3
MW11-070							1.4

**Table 6  
Explosive Results**

Well ID/Depth	RDX Concentration, µg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	313	306	266	342	354	319	400
MW01-070	399	321	328	360	365	352	403
MW02-060	61.5	53.5	58	58	56.5	57.8	62.1
MW02-070	67.1	57.4	60	63	61.5	61.0	66.7
MW03-060	41.9	48.5	45.1	49	44.5	32.6	24.2
MW03-070	46.1	44.6	45.4	49	51.2	41.9	27.3
MW04-060	89.9	101	90.9	119	34	22.8	27.2
MW04-070	110	110	110	117	55	19.6	24.0
MW05-064	171	165	140	169	153	151	177
MW05-074	172	170	161	169	165	152	180
MW06-064	148	150	145	154	151	144	170
MW06-074	160	154	154	163	161	152	178
MW07-064	233	237	229	238	225	216	227
MW07-074	240	289	239	240	234	219	249
MW08-064	133	137	128	141	139	133	153
MW08-074	136	137	134	142	141	135	157
MW09-064	126	128	128	109	131	129	154
MW09-074	129	133	132	136	139	134	157
MW10-064	115	117	109	119	104	77.5	78.4
MW10-074	122	117	113	121	104	76.0	73.3
MW11-060	70.0	71.1	73.4	79	80.6	76.8	---
MW11-070	68.0	68.6	72.9	80	81.6	78.3	---
Extraction Well	127	---	135	135	150	---	143
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	313	304	245	246	268	249	213
MW01-070	323	313	293	269	248	256	217
MW02-060	27.9	15.9	9.45	7.29	7.27	5.19	9.37
MW02-070	28.3	15.5	12.2	7.26	7.13	6.20	9.32
MW03-060	10.2	3.34	---	0.53	0.44	BDL	BDL
MW03-070	9.55	3.75	1.19	0.5	0.29	BDL	BDL
MW04-060	30.1	7.08	5.41	3.91	2.64	2.71	1.32
MW04-070	26.9	13.5	4.71	3.29	2.41	2.68	1.19
MW05-064	151	145	161	162	164	165	156
MW05-074	151	148	163	161	164	168	156
MW06-064	141	115	82	43	54	39	6.83
MW06-074	146	126	86	64	56	40	7.20
MW07-064	181	152	152	175	165	132	70.5
MW07-074	192	176	179	196	194	139	77.4
MW08-064	129	140	144	144	142	139	143
MW08-074	133	137	145	143	146	143	141
MW09-064	129	137	145	144	150	146	144
MW09-074	131	140	153	153	155	151	150
MW10-064	52.5	45	36	43	34	55	40.8
MW10-074	50.5	41	55	48	34	39	32.6
MW11-060	---	93	---	---	---	83	---
MW11-070	---	78	---	---	---	83	---
Extraction Well	133	83	108	104	118	---	---

<b>Table 6 (Cont'd)</b>							
<b>Well ID-Depth</b>	<b>RDX Concentration, µg/L</b>						
	<b>Feb-05</b>	<b>Mar-05</b>	<b>Apr-05</b>	<b>May-05</b>	<b>Jun-05</b>	<b>Jul-05</b>	<b>Aug-05</b>
MW01-060	174	171	183	165	165	195	189
MW01-070	204	189	196	190	177	203	193
MW02-060	9.23	12.9	16.7	16.3	21.2	32.8	36.0
MW02-070	10.9	11.5	16.6	17.7	24.5	42.7	38.5
MW03-060	0	0	0	0.56	1.01	1.05	1.31
MW03-070	0	1.00	0.38	0.77	1.06	1.05	1.75
MW04-060	0.94	1.33	5.04	4.52	1.99	12.3	6.42
MW04-070	1.06	1.50	3.39	4.48	0.96	11.3	5.25
MW05-064	144	128	135	143	138	161	161
MW05-074	144	125	134	138	137	160	163
MW06-064	4.87	3.61	2.08	2.93	3.08	7.18	9.87
MW06-074	4.99	3.66	1.96	2.35	3.15	7.96	7.39
MW07-064	57.9	18.9	21.3	24.8	15.1	4.57	4.28
MW07-074	81.0	21.3	24.6	27.8	15.5	3.94	2.93
MW08-064	146	132	134	148	141	153	143
MW08-074	143	134	136	137	134	147	145
MW09-064	142	133	129	147	132	151	151
MW09-074	148	135	132	153	138	157	154
MW10-064	33.5	37.7	32.6	37.8	31.4	36.5	30.2
MW10-074	35.0	35.3	30.4	33.8	30.0	36.6	32.0
MW11-060							75.9
MW11-070							76.0

**Table 6 (Cont'd)**

Well ID/Depth	HMX Concentration, µg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	41.30	44.00	46.19	54.95	57.28	54.30	61.98
MW01-070	51.00	45.50	48.33	55.73	58.78	56.85	62.72
MW02-060	13.20	11.57	11.84	11.52	11.60	11.58	12.59
MW02-070	14.50	12.50	12.62	12.83	12.45	12.60	13.77
MW03-060	6.56	7.54	7.01	8.21	7.82	6.85	8.79
MW03-070	7.51	6.92	7.14	8.07	8.96	7.84	7.86
MW04-060	23.50	26.30	26.45	30.19	17.49	10.08	8.39
MW04-070	28.80	28.25	30.52	31.10	22.35	9.38	7.35
MW05-064	5.05	5.44	6.80	7.08	7.14	7.38	8.20
MW05-074	5.08	5.74	6.31	6.95	7.32	7.04	7.70
MW06-064	16.40	16.72	16.08	16.78	16.78	16.49	18.92
MW06-074	18.40	17.10	16.72	17.36	17.59	17.19	19.41
MW07-064	37.40	40.46	40.14	41.91	42.32	40.82	41.74
MW07-074	37.30	43.50	40.76	41.29	42.68	40.71	44.32
MW08-064	6.87	6.98	6.52	7.15	7.17	7.02	7.78
MW08-074	6.77	6.82	6.82	7.10	7.23	7.18	8.13
MW09-064	7.33	7.90	7.93	8.28	8.08	7.95	8.76
MW09-074	7.48	7.58	7.58	7.88	7.93	7.77	8.84
MW10-064	25.40	24.13	22.43	24.60	23.15	21.82	22.45
MW10-074	25.50	24.23	23.28	24.66	23.61	22.13	22.40
MW11-060	4.81	4.91	4.88	5.05	5.09	4.91	---
MW11-070	4.73	4.59	4.68	5.06	5.04	4.89	---
Extraction Well	23.8	---	---	---	---	---	---
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	52.3	52.1	47.2	49.5	53.2	51.1	47.1
MW01-070	54.1	54.8	7.67	55.1	55.3	54.2	50.1
MW02-060	9.74	9.67	7.39	9.44	12.0	9.95	7.78
MW02-070	9.75	9.30	5.48	9.85	11.9	8.94	6.96
MW03-060	5.95	6.23	---	5.40	6.90	6.00	3.65
MW03-070	6.35	6.35	3.18	4.94	7.44	5.13	3.53
MW04-060	10.3	4.47	2.42	2.26	3.89	2.10	0.91
MW04-070	9.26	6.98	7.59	1.15	3.66	1.53	0.92
MW05-064	7.17	7.13	7.31	6.98	11.8	9.37	6.62
MW05-074	6.92	6.97	14.14	7.52	11.8	9.44	7.05
MW06-064	16.9	15.1	13.95	14.7	15.07	15.0	10.5
MW06-074	17.2	16.1	32.18	18.6	15.87	21.9	11.6
MW07-064	33.5	31.3	35.86	33.2	34.9	28.9	19.0
MW07-074	35.5	33.7	8.19	37.3	39.3	29.1	20.6
MW08-064	7.57	7.92	8.33	8.80	10.4	12.4	8.29
MW08-074	7.33	7.78	8.25	9.54	11.5	12.4	8.31
MW09-064	7.83	8.56	8.17	9.09	9.77	10.3	6.82
MW09-074	7.76	8.17	8.19	8.41	9.43	11.0	6.60
MW10-064	14.2	11.5	9.00	10.1	11.4	10.7	8.38
MW10-074	14.2	11.5	---	9.84	10.8	8.99	6.74
MW11-060	---	5.22	---	---	---	8.19	---
MW11-070	---	4.98	---	---	---	8.26	---
Extraction Well	---	---	---	---	---	---	---

<b>Well ID-Depth</b>	<b>HMX Concentration, µg/L</b>						
	<b>Feb-05</b>	<b>Mar-05</b>	<b>Apr-05</b>	<b>May-05</b>	<b>Jun-05</b>	<b>Jul-05</b>	<b>Aug-05</b>
MW01-060	39.6	42.6	43.5	42.9	44.3	55.0	54.5
MW01-070	45.8	45.7	47.4	49.0	48.9	58.0	57.0
MW02-060	6.98	8.4	6.44	5.88	8.15	9.67	10.4
MW02-070	7.73	8.35	6.31	6.32	8.91	10.4	10.4
MW03-060	3.17	0	0	1.12	1.19	0	0
MW03-070	2.86	0	0	1.16	1.13	0.53	1.17
MW04-060	0.93	0	0	0.83	0.78	0.90	2
MW04-070	0.89	0	0	0.92	1.43	0.65	1.73
MW05-064	7.67	9.55	7.65	8.46	8.65	9.60	10.9
MW05-074	7.41	8.95	7.55	8.11	8.61	8.84	10.5
MW06-064	11.5	0	8.4	5.89	4.69	3.54	4.06
MW06-074	12.8	11.6	8.61	5.89	5.02	5.36	4.71
MW07-064	17.7	21.6	20.0	12.6	12.6	12.3	12.0
MW07-074	21.9	24.5	23.9	13.7	15.5	15.0	13.8
MW08-064	10.1	8.05	8.47	10.1	9.52	9.63	11.0
MW08-074	10.1	9.95	8.87	9.07	9.77	9.76	11.6
MW09-064	8.09	7.4	6.91	8.03	8.01	8.15	9.27
MW09-074	8.15	6.35	6.8	8.48	8.78	8.62	9.74
MW10-064	8.25	7.15	6.21	7.50	7.65	7.16	7.24
MW10-074	8.34	6.45	6.16	6.89	6.74	7.25	7.21
MW11-060							6.24
MW11-070							6.09

**Table 6 (Cont'd)**

Well ID/Depth	DNX Concentration, µg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	0.77	0.95	0.91	1.24	1.28	1.17	1.30
MW01-070	1.02	0.98	1.01	1.31	1.31	1.27	1.34
MW02-060	0.31	0.34	0.33	0.37	0.66	0.70	1.01
MW02-070	0.30	0.35	0.36	0.38	0.75	0.69	1.05
MW03-060	0.21	0.29	0.27	0.37	0.65	1.60	1.63
MW03-070	0.22	0.26	0.30	0.35	0.73	1.45	1.67
MW04-060	0.31	0.42	0.51	1.27	1.42	0.57	0.72
MW04-070	0.39	0.46	0.66	1.12	1.20	0.68	0.70
MW05-064	0.87	0.95	0.80	1.10	1.06	1.03	1.16
MW05-074	0.87	0.96	0.88	1.06	1.14	1.04	1.18
MW06-064	0.93	0.80	0.74	0.92	0.96	0.96	1.07
MW06-074	0.79	0.82	0.81	1.00	1.02	0.99	1.10
MW07-064	0.79	0.93	0.91	1.06	1.57	1.16	1.12
MW07-074	0.86	0.94	0.95	1.05	1.41	1.20	1.21
MW08-064	0.72	0.84	0.81	1.06	1.09	1.08	1.16
MW08-074	0.78	0.84	0.84	1.08	1.08	1.04	1.19
MW09-064	0.68	0.75	0.73	0.82	0.99	0.99	1.11
MW09-074	0.71	0.76	0.75	0.93	1.04	0.98	1.11
MW10-064	0.45	0.50	0.50	0.72	1.03	2.83	1.58
MW10-074	0.47	0.51	0.51	0.75	1.02	2.96	1.63
MW11-060	0.23	0.26	0.25	0.28	0.57	0.57	---
MW11-070	0.22	0.25	0.27	0.30	0.56	0.53	---
Extraction Well	0.20	---	1.20	BDL	BDL	---	0.60
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	1.06	1.05	0.68	BDL	0.80	1.38	0.73
MW01-070	1.11	1.08	0.80	3.40	0.81	1.70	0.80
MW02-060	2.44	1.85	1.33	1.80	1.59	1.02	0.58
MW02-070	2.09	1.71	1.40	2.18	1.74	0.92	0.63
MW03-060	1.13	1.35	---	0.50	0.48	0.72	0.60
MW03-070	1.28	1.39	0.72	0.51	0.59	0.83	0.44
MW04-060	1.04	0.93	1.01	0.76	0.97	0.36	0.40
MW04-070	0.97	1.24	1.13	0.75	0.72	0.50	0.42
MW05-064	1.01	0.92	0.74	1.22	1.59	1.04	0.92
MW05-074	1.01	0.93	0.77	2.28	1.69	1.04	1.00
MW06-064	0.80	0.85	0.67	1.46	1.39	0.88	1.03
MW06-074	0.86	0.85	1.48	1.70	1.37	1.28	0.98
MW07-064	1.18	0.94	0.92	3.03	1.55	2.11	1.31
MW07-074	1.36	1.00	0.94	3.47	1.76	1.45	1.47
MW08-064	0.99	0.94	0.72	4.80	0.80	0.90	1.00
MW08-074	1.05	0.90	0.77	4.49	1.03	0.93	0.95
MW09-064	0.93	0.92	0.74	3.50	0.84	1.01	0.94
MW09-074	0.91	0.94	0.78	3.01	0.91	0.92	0.98
MW10-064	0.79	0.62	0.40	1.10	0.83	0.79	0.63
MW10-074	0.77	0.59	0.44	1.22	0.88	0.83	0.48
MW11-060	---	0.45	---	---	---	0.33	
MW11-070	---	0.18	---	---	---	0.32	
Extraction Well	1.70	1.50	1.30	1.40	0.90	---	

<b>Table 6 (Cont'd)</b>							
<b>Well ID-Depth</b>	<b>DNX Concentration, µg/L</b>						
	<b>Feb-05</b>	<b>Mar-05</b>	<b>Apr-05</b>	<b>May-05</b>	<b>Jun-05</b>	<b>Jul-05</b>	<b>Aug-05</b>
MW01-060	0.72	0.95	0.58	0.7	0.48	0.8	0.96
MW01-070	0.81	1.1	0.68	0.68	0.55	0.83	1.02
MW02-060	0.51	1.55	0.6	0.28	0.2	0.64	1.01
MW02-070	0.56	1.4	0.62	0.39	0.06	0.89	1.03
MW03-060	0.65	1.4	0	1.04	0.14	0.91	0.74
MW03-070	0.79	1.35	0.42	1.12	0.22	1.13	1.02
MW04-060	0.42	0.8	0	0.14	0.06	0.6	0.92
MW04-070	0.38	1	0.47	0.16	0.08	0.82	0.55
MW05-064	1.06	1.1	0.66	1.05	0.76	1.26	1
MW05-074	0.96	1.05	0.76	1.19	0.63	1.17	1.24
MW06-064	0.84	0.9	1.11	0.51	0.68	0.69	1.75
MW06-074	0.99	0.9	1.06	0.76	0.46	1.24	0.92
MW07-064	1.77	2.15	2.3	1.78	1.15	0.83	1.26
MW07-074	2.15	2.4	5.77	1.86	1.31	0.75	0.58
MW08-064	1.00	0.8	0.71	1.13	0.72	0.99	0.7
MW08-074	1.06	0.85	0.79	1.12	0.64	0.88	0.95
MW09-064	1.02	0.9	1.01	1.05	0.7	1	0.95
MW09-074	0.94	0.8	0.91	0.94	0.86	0.96	0.86
MW10-064	0.61	1.25	0.56	0.14	0.28	0.6	0.83
MW10-074	0.54	1.05	0.49	0.75	0.2	0.75	0.9
MW11-060							0.62
MW11-070							0.84



**Table 6 (Cont'd)**

Well ID/Depth	MNX Concentration, ug/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	0.37	0.44	0.41	0.65	0.71	0.62	0.83
MW01-070	0.50	0.45	0.46	0.68	0.72	0.69	0.82
MW02-060	0.21	0.15	0.19	0.23	0.31	0.66	0.84
MW02-070	0.21	0.16	0.21	0.23	0.32	0.56	0.79
MW03-060	0.18	0.15	0.18	0.27	1.28	5.50	9.91
MW03-070	0.20	0.14	0.15	0.22	1.12	4.99	8.71
MW04-060	0.22	0.19	0.27	0.59	36.38	25.13	13.82
MW04-070	0.24	0.20	0.32	0.52	33.96	27.32	13.23
MW05-064	0.57	0.51	0.42	0.58	0.59	0.57	0.78
MW05-074	0.48	0.50	0.51	0.56	0.63	0.56	0.78
MW06-064	0.47	0.44	0.42	0.52	0.55	0.53	1.44
MW06-074	0.49	0.45	0.44	0.54	0.57	0.56	1.31
MW07-064	0.44	0.41	0.42	0.54	2.23	2.55	2.16
MW07-074	0.43	0.44	0.44	0.52	1.79	2.12	1.79
MW08-064	0.48	0.46	0.47	0.54	0.60	0.57	0.76
MW08-074	0.48	0.45	0.49	0.55	0.60	0.56	0.76
MW09-064	0.43	0.43	0.47	0.44	0.57	0.56	0.89
MW09-074	0.45	0.42	0.47	0.53	0.58	0.57	0.90
MW10-064	0.27	0.22	0.26	0.36	0.40	1.98	10.10
MW10-074	0.27	0.24	0.27	0.37	0.40	2.02	10.73
MW11-060	0.21	0.13	0.20	0.19	0.27	0.28	---
MW11-070	0.17	0.12	0.15	0.21	0.31	0.28	---
Extraction Well	0.20	---	1.60	BDL	0.40	---	BDL
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	2.12	2.09	1.35	1.77	1.99	1.88	1.59
MW01-070	2.17	2.16	1.54	1.95	1.89	2.20	1.64
MW02-060	3.51	3.79	2.43	1.99	1.33	1.08	0.92
MW02-070	3.37	3.67	2.66	2.26	1.50	1.64	0.76
MW03-060	3.39	0.83	---	1.76	1.66	2.32	1.63
MW03-070	3.19	1.39	1.62	1.87	1.85	2.44	2.28
MW04-060	3.31	1.26	0.98	0.72	0.48	0.80	0.89
MW04-070	2.98	2.59	1.32	0.70	0.45	0.84	0.77
MW05-064	1.80	1.78	1.45	1.99	1.98	2.07	1.77
MW05-074	1.78	1.77	1.50	1.96	1.98	2.14	1.82
MW06-064	1.51	2.13	1.83	3.46	4.08	3.62	2.69
MW06-074	1.55	2.17	3.02	4.85	5.18	4.62	2.94
MW07-064	2.08	2.12	1.97	3.43	5.55	5.57	5.07
MW07-074	2.31	2.18	2.09	3.63	6.38	5.48	4.64
MW08-064	1.84	1.97	1.51	2.17	2.13	2.57	2.11
MW08-074	1.89	1.93	1.51	2.19	2.14	2.64	2.03
MW09-064	1.62	1.83	1.42	1.90	1.91	2.39	1.82
MW09-074	1.63	1.83	1.49	1.97	2.10	1.96	1.92
MW10-064	1.93	1.46	0.72	1.16	1.32	1.24	1.14
MW10-074	1.95	1.43	0.80	1.20	1.31	0.98	0.82
MW11-060	---	0.78	---	---	---	0.90	---
MW11-070	---	0.76	---	---	---	1.61	---
Extraction Well	1.00	0.40	1.40	0.40	0.70	---	---

<b>Table 6 (Cont'd)</b>							
<b>Well ID-Depth</b>	<b>MNX Concentration, µg/L</b>						
	<b>Feb-05</b>	<b>Mar-05</b>	<b>Apr-05</b>	<b>May-05</b>	<b>Jun-05</b>	<b>Jul-05</b>	<b>Aug-05</b>
MW01-060	1.38	1.45	1.01	1.43	1.18	1.47	1.38
MW01-070	1.47	1.30	1.11	1.23	1.20	1.51	1.40
MW02-060	0.64	1.25	1.28	0.91	0.93	0.9	0.93
MW02-070	0.85	1.15	1.32	1.02	1.07	1.36	0.91
MW03-060	0.77	0	4.43	3.4	3.48	0	2.59
MW03-070	1.76	0	6.42	3.52	4.22	0	2.69
MW04-060	1.02	0	0	0.34	0	0.4	0.46
MW04-070	0.96	0	0	0.84	0.75	0.80	0
MW05-064	1.73	1.4	1.42	1.8	1.48	1.81	2
MW05-074	1.71	1.45	1.34	1.54	1.37	1.81	1.88
MW06-064	2.24	1.95	1.03	0.94	0.53	1.83	1.5
MW06-074	2.42	2.05	0.97	0.46	0.60	2.36	1.77
MW07-064	6.73	6.2	4.08	3.19	2.42	1.71	0.76
MW07-074	8.76	6.90	5.14	3.23	2.77	1.57	0.76
MW08-064	2.09	1.95	1.64	1.86	1.65	2.18	1.76
MW08-074	2.03	1.80	1.60	1.68	1.46	1.82	1.73
MW09-064	1.84	1.85	1.39	1.73	1.62	1.94	1.81
MW09-074	1.87	1.85	1.51	1.86	1.72	2.12	1.94
MW10-064	1.17	1.50	0.87	1.02	0.74	0.94	0.78
MW10-074	1.00	1.50	0.87	1.13	0.72	0.98	1.19
MW11-060							0.93
MW11-070							0.89

**Table 6 (Cont'd)**

Well ID/Depth	TNX Concentration, ug/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	0.37	0.44	0.41	0.65	0.71	0.62	0.83
MW01-070	0.50	0.45	0.46	0.68	0.72	0.69	0.82
MW02-060	0.21	0.15	0.19	0.23	0.31	0.66	0.84
MW02-070	0.21	0.16	0.21	0.23	0.32	0.56	0.79
MW03-060	0.18	0.15	0.18	0.27	1.28	5.50	9.91
MW03-070	0.20	0.14	0.15	0.22	1.12	4.99	8.71
MW04-060	0.22	0.19	0.27	0.59	36.38	25.13	13.82
MW04-070	0.24	0.20	0.32	0.52	33.96	27.32	13.23
MW05-064	0.57	0.51	0.42	0.58	0.59	0.57	0.78
MW05-074	0.48	0.50	0.51	0.56	0.63	0.56	0.78
MW06-064	0.47	0.44	0.42	0.52	0.55	0.53	1.44
MW06-074	0.49	0.45	0.44	0.54	0.57	0.56	1.31
MW07-064	0.44	0.41	0.42	0.54	2.23	2.55	2.16
MW07-074	0.43	0.44	0.44	0.52	1.79	2.12	1.79
MW08-064	0.48	0.46	0.47	0.54	0.60	0.57	0.76
MW08-074	0.48	0.45	0.49	0.55	0.60	0.56	0.76
MW09-064	0.43	0.43	0.47	0.44	0.57	0.56	0.89
MW09-074	0.45	0.42	0.47	0.53	0.58	0.57	0.90
MW10-064	0.27	0.22	0.26	0.36	0.40	1.98	10.10
MW10-074	0.27	0.24	0.27	0.37	0.40	2.02	10.73
MW11-060	0.21	0.13	0.20	0.19	0.27	0.28	---
MW11-070	0.17	0.12	0.15	0.21	0.31	0.28	---
Extraction Well	0.10	---	0.40	0.20	0.10	---	0.30
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	0.75	0.78	BDL	BDL	BDL	0.69	0
MW01-070	0.72	0.80	BDL	BDL	BDL	0.81	0.34
MW02-060	1.00	1.36	1.36	1.19	1.24	0.69	0.25
MW02-070	0.96	1.32	1.11	1.06	1.17	0.49	0.31
MW03-060	4.00	3.20	---	0.81	0.73	0.51	0
MW03-070	3.78	2.97	1.98	0.78	0.68	0.34	0
MW04-060	5.19	2.55	0.92	0.29	0.26	0.24	0
MW04-070	4.50	2.24	0.76	0.18	0.22	0.15	0
MW05-064	0.71	0.73	0.51	0.46	0.95	0.48	0.29
MW05-074	0.70	0.70	0.50	0.77	0.93	0.56	0.4
MW06-064	1.35	1.12	0.82	1.78	0.17	0.13	0.18
MW06-074	1.21	0.99	1.21	1.52	BDL	0.57	0.19
MW07-064	3.07	1.31	2.63	1.65	2.66	1.62	0.68
MW07-074	3.84	1.28	2.52	1.66	2.72	1.26	0.4
MW08-064	0.73	0.70	0.56	0.77	2.26	BDL	0.4
MW08-074	0.70	0.72	0.54	0.68	2.23	BDL	0.29
MW09-064	0.91	1.36	1.01	1.50	2.05	BDL	0.48
MW09-074	0.91	1.33	1.05	1.24	1.94	BDL	0.49
MW10-064	6.92	6.26	2.61	0.73	BDL	0.59	0.5
MW10-074	6.87	6.48	2.45	0.70	BDL	0.48	0.35
MW11-060	---	0.35	---	---	---	0.33	
MW11-070	---	0.34	---	---	---	0.32	
Extraction Well	---	0.20	0.20	0.30	0.20	---	

<b>Table 6 (Cont'd)</b>							
<b>Well ID-Depth</b>	<b>TNX Concentration, µg/L</b>						
	<b>Feb-05</b>	<b>Mar-05</b>	<b>Apr-05</b>	<b>May-05</b>	<b>Jun-05</b>	<b>Jul-05</b>	<b>Aug-05</b>
MW01-060	0.17	0	0.2	0	0	0	0
MW01-070	0.26	0	0.21	0	0	0	0
MW02-060	0.18	0	0	0	0	0	0.16
MW02-070	0.17	0	0	0	0	0	0
MW03-060	0	0	0	0	0	0	0
MW03-070	0	0	0	0	0	0	0
MW04-060	0	0	0	0.34	0.39	0.27	0
MW04-070	0	0	0	0.12	0	0.44	0
MW05-064	0.26	0	0.41	0.54	0.54	0.71	0.57
MW05-074	0.28	0	0.41	0.42	0.58	0.7	0.56
MW06-064	0.15	0	0.78	0.56	0.34	0.47	0.87
MW06-074	0.18	0.75	0.77	0.41	0.59	0.9	0.74
MW07-064	0.39	1	1.09	1.16	1.09	1.58	1.18
MW07-074	0.35	1.15	1.44	1.29	1.46	1.77	1.2
MW08-064	0.31	0	0.47	0.60	0.3	0.6	0.65
MW08-074	0	0	0.34	0.55	0.37	0.54	0.58
MW09-064	0.52	0.85	0.96	1.25	1.4	1.13	1.04
MW09-074	0.47	0.8	0.85	1.23	1.58	1.25	0.94
MW10-064	0.4	0	0	0	0	0.34	0
MW10-074	0.36	0	0.26	0	0	0.36	0.46
MW11-060							0.36
MW11-070							0

**Table 6 (Cont'd)**

Well ID/Depth	3,4-DNT Concentration, µg/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	5.07	4.95	4.89	4.35	4.40	4.24	5.27
MW01-070	4.98	5.02	4.88	4.43	4.47	4.19	5.27
MW02-060	5.02	4.95	4.89	4.41	4.46	4.09	5.22
MW02-070	4.88	5.00	5.02	4.47	4.44	4.24	5.22
MW03-060	4.86	5.03	5.06	4.40	3.90	3.26	5.40
MW03-070	4.81	5.05	4.86	4.45	4.19	3.73	5.15
MW04-060	4.83	4.94	3.92	2.96	3.90	4.24	5.37
MW04-070	4.88	5.02	3.00	2.90	4.24	4.23	5.19
MW05-064	4.74	4.93	4.82	4.45	3.99	4.16	5.23
MW05-074	4.91	4.97	4.79	4.36	4.43	4.21	5.31
MW06-064	4.78	5.05	5.08	4.36	4.48	4.19	5.32
MW06-074	4.77	5.11	4.99	4.24	4.52	4.22	5.38
MW07-064	4.81	5.07	4.95	4.60	4.33	4.16	5.33
MW07-074	4.78	5.04	5.06	4.66	4.43	4.13	5.38
MW08-064	4.99	5.00	4.71	4.55	4.34	4.13	5.19
MW08-074	5.01	5.11	4.83	4.58	4.46	4.21	5.26
MW09-064	4.80	5.02	4.88	4.58	4.55	4.24	5.12
MW09-074	4.91	5.09	4.90	4.69	4.53	4.23	5.12
MW10-064	5.02	5.03	4.89	4.56	4.55	4.28	5.24
MW10-074	5.01	5.03	4.88	4.59	4.54	4.15	5.09
MW11-060	4.99	5.07	4.84	4.58	4.52	4.16	---
MW11-070	5.06	5.04	4.85	4.62	4.54	4.24	---
Extraction Well	4.88	---	---	---	---	---	---
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	4.48	4.81	5.10	4.77	24.1	24.03	25.0
MW01-070	4.45	4.76	5.13	5.11	24.1	24.28	24.4
MW02-060	3.59	4.38	4.03	4.69	4.53	24.34	24.1
MW02-070	3.50	4.19	4.07	4.84	4.53	24.73	23.3
MW03-060	4.57	4.54	---	4.97	4.75	24.26	24.1
MW03-070	4.51	4.58	5.31	5.19	4.80	24.23	23.9
MW04-060	4.49	3.94	3.99	4.79	4.59	24.57	23.4
MW04-070	4.34	3.93	4.43	4.78	4.57	24.68	24.0
MW05-064	4.44	4.44	5.10	4.96	4.90	24.43	24.5
MW05-074	4.53	4.55	5.13	4.90	4.80	24.68	25.1
MW06-064	4.47	4.48	5.09	3.86	23.91	24.27	24.2
MW06-074	4.41	4.53	5.07	5.03	24.3	23.14	24.9
MW07-064	4.57	4.47	5.25	4.93	23.9	24.23	25.4
MW07-074	4.47	4.53	5.23	4.98	24.5	24.95	24.9
MW08-064	4.51	4.73	4.92	5.08	23.4	24.66	24.7
MW08-074	4.53	4.67	4.94	5.01	24.4	24.48	25.4
MW09-064	4.45	4.77	5.00	5.18	24.4	24.29	25.0
MW09-074	4.45	4.76	5.09	5.11	24.0	24.66	24.9
MW10-064	4.41	4.69	5.05	4.97	23.9	23.89	25.1
MW10-074	4.42	4.78	5.08	5.06	24.0	21.83	24.4
MW11-060	---	4.86	---	---	---	24.92	---
MW11-070	---	5.09	---	---	---	24.85	---
Extraction Well	---	---	---	---	---	---	---

<b>Table 6 (Cont'd)</b>							
<b>Well ID-Depth</b>	<b>3,4-DNT Concentration, µg/L</b>						
	<b>Feb-05</b>	<b>Mar-05</b>	<b>Apr-05</b>	<b>May-05</b>	<b>Jun-05</b>	<b>Jul-05</b>	<b>Aug-05</b>
MW01-060	24.2	25.6	23.1	23.8	23.0	26.3	25.5
MW01-070	24.5	26.5	23.9	24.1	22.5	26.5	22.9
MW02-060	24.1	25.3	22.5	20.1	22.5	25.5	23.6
MW02-070	24.0	25.0	22.9	22.0	21.9	24.8	23.5
MW03-060	24.4	24.1	21.8	20.8	21.5	23.9	21.2
MW03-070	24.5	23.3	21.0	21.2	21.6	23.2	22.5
MW04-060	23.2	22.1	19.8	20.7	18.7	22.7	21.8
MW04-070	24.8	20.5	19.3	21.3	18.1	20.4	24.5
MW05-064	25.0	26.6	22.2	24.9	23.0	24.4	25.8
MW05-074	24.5	25.5	23.0	24.5	23.1	21.9	21.2
MW06-064	25.1	26.1	22.9	22.6	22.6	26.6	23.8
MW06-074	24.2	26.2	22.6	22.6	20.6	24.5	22.2
MW07-064	24.4	25.5	22.2	22.7	21.3	24.8	22.8
MW07-074	24.4	25.9	22.3	21.4	21.0	23.8	24.0
MW08-064	24.8	26.1	24.0	24.6	22.6	24.6	24.9
MW08-074	24.3	25.8	23.6	22.1	22.9	23.8	21.9
MW09-064	25.1	26.1	23.8	24.8	23.2	23.9	22.4
MW09-074	25.1	26.3	24.0	25.2	23.1	24.4	24.9
MW10-064	24.8	25.8	23.8	25.1	22.9	25.2	24.6
MW10-074	25.0	25.5	24.1	25.6	22.9	24.1	24.9
MW11-060							24.0
MW11-070	24.2	25.6	23.1	23.8	23.0	26.3	25.5

**Table 6 (Cont'd)**

Well ID/Depth	4-A-DNT Concentration, ug/L						
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
MW01-060	3.54	3.52	3.23	4.07	4.16	3.79	4.85
MW01-070	4.58	3.71	3.82	4.22	4.31	4.18	4.99
MW02-060	0.80	0.73	0.74	0.74	0.66	0.65	0.61
MW02-070	0.76	0.76	0.76	0.84	0.73	0.74	0.76
MW03-060	0.44	0.54	0.51	0.56	BDL	BDL	BDL
MW03-070	0.44	0.53	0.51	0.52	0.16	0.20	BDL
MW04-060	1.12	1.23	0.16	0.48	0.17	BDL	BDL
MW04-070	1.36	1.35	0.16	0.38	0.10	BDL	BDL
MW05-064	BDL	1.07	1.00	1.24	1.16	1.18	1.39
MW05-074	1.03	1.06	1.11	1.23	1.23	1.18	1.43
MW06-064	0.00	1.50	1.42	1.55	1.50	1.44	1.74
MW06-074	1.58	1.49	1.49	1.60	1.61	1.52	1.86
MW07-064	0.00	2.56	2.50	2.65	2.45	2.26	2.47
MW07-074	2.52	2.55	2.57	2.70	2.53	2.35	2.77
MW08-064	0.62	0.67	0.59	0.75	0.73	0.65	0.80
MW08-074	0.59	0.58	0.63	0.70	0.67	0.70	0.75
MW09-064	BDL	0.76	0.75	0.75	0.80	0.82	0.97
MW09-074	BDL	0.80	0.77	0.96	0.86	0.83	0.98
MW10-064	1.37	1.39	1.27	1.33	0.72	0.57	0.67
MW10-074	1.47	1.42	1.31	1.38	0.67	0.59	0.61
MW11-060	0.40	0.42	0.42	0.51	0.45	0.43	---
MW11-070	0.44	0.42	0.35	0.49	0.44	0.41	---
Extraction Well	---	---	---	---	---	---	---
Well ID/Depth	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05
MW01-060	3.75	3.75	3.09	2.88	3.30	3.00	2.78
MW01-070	3.87	3.87	3.69	3.25	3.01	3.16	2.82
MW02-060	BDL	0.16	BDL	BDL	BDL	BDL	0
MW02-070	0.17	BDL	BDL	BDL	BDL	BDL	0
MW03-060	BDL	BDL	---	BDL	BDL	BDL	0
MW03-070	BDL	BDL	BDL	BDL	BDL	BDL	0
MW04-060	BDL	BDL	BDL	BDL	BDL	BDL	0
MW04-070	BDL	0.10	BDL	BDL	BDL	BDL	0
MW05-064	1.21	1.15	1.33	1.21	1.23	1.36	1.23
MW05-074	1.19	1.24	1.33	1.23	1.23	1.36	1.35
MW06-064	1.46	1.25	0.91	BDL	BDL	BDL	0
MW06-074	1.52	1.39	0.84	BDL	BDL	BDL	0
MW07-064	1.97	1.51	1.30	1.38	1.17	0.79	0
MW07-074	2.08	1.70	1.67	1.45	1.35	0.75	0
MW08-064	0.61	0.74	0.82	0.70	0.69	0.86	0.68
MW08-074	0.61	0.77	0.78	0.68	0.94	0.86	0.93
MW09-064	0.81	0.92	0.84	0.81	1.06	0.86	0.78
MW09-074	0.84	0.91	1.02	0.89	0.95	0.92	0.81
MW10-064	0.47	0.48	0.45	0.32	BDL	BDL	0
MW10-074	0.42	0.42	0.54	0.39	BDL	BDL	0
MW11-060	---	0.56	---	---	---	BDL	---
MW11-070	---	0.54	---	---	---	0.66	---
Extraction Well	---	---	---	---	---	---	---

**Table 6 (Concluded)**

Well ID-Depth	4-A-DNT Concentration, µg/L						
	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05
MW01-060	2.44	2.46	2.11	1.63	1.39	3.09	2.2
MW01-070	2.76	2.72	2.24	1.5	1.58	1.86	3.23
MW02-060	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW02-070	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW03-060	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW03-070	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW04-060	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW04-070	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW05-064	1.36	1.46	1.25	0.81	1.11	BDL	1.45
MW05-074	1.28	1.61	1.16	0.96	0.99	0.53	1.62
MW06-064	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW06-074	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW07-064	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW07-074	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW08-064	0.69	BDL	0.44	0.71	0.46	BDL	0.73
MW08-074	0.9	BDL	0.91	BDL	BDL	BDL	0.72
MW09-064	1.13	1	0.95	1.09	0.57	0.72	BDL
MW09-074	1.23	1.2	0.63	0.91	0.8	0.54	BDL
MW10-064	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW10-074	BDL	BDL	BDL	BDL	BDL	BDL	BDL
MW11-060							BDL
MW11-070							0.61

**Table 7  
Metal Results – June 2004**

Analyte	Metal Concentration at 70 ft Water Depth, ppb										
	MW-01	MW-02	MW-03	MW-04	MW-05	MW-06	MW-07	MW-08	MW-09	MW-10	MW-11
Aluminum	<90	<90	<90	<90	<90	<90	<90	<90	<90	70	<90
Antimony	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Arsenic	<15	9	21	45	<15	15	21	4	4	31	3
Barium											
Beryllium	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cadimium	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Calcium											
Chromium	3	<10	<10	<10	2	<10	<10	2	<10	<10	<10
Cobalt	<15	7	3	<15	<15	10	10	<15	<15	9	<15
Copper	<10	<10	<10	<10	6	<10	<10	7	4	5	5
Iron											
Lead	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Magnesium											
Manganese											
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<10	9	8	4	<10	73	14	<10	<10	19	<10
Potassium											
Selenium	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	7
Silver	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sodium											
Thallium	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Vanadium	5	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Zinc	3	<10	3	<10	9	4	<10	<10	<10	51	<10

\* - denotes an estimated value



**Table 7**  
**Metal Results – December 2004**

Analyte	Metal Concentration at 70 ft Water Depth, ppb										
	MW-01	MW-02	MW-03	MW-04	MW-05	MW-06	MW-07	MW-08	MW-09	MW-10	MW-11
Aluminum	240	<90	<90	274	<90	<90	<90	<90	<90	70	<90
Antimony	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Arsenic	<15	*9	21	45	<15	15	21	*4	*4	31	*3
Barium	379	708	585	669	282	1310	726	200	291	545	192
Beryllium	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cadmium	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Calcium	48900	64300	45100	46300	63600	87200	69900	52000	61500	58900	65100
Chromium	*3	<10	<10	<10	*2	<10	<10	*2	<10	<10	<10
Cobalt	<15	*7	*3	<15	<15	*10	*10	<15	<15	*9	<15
Copper	<10	<10	<10	<10	*6	<10	<10	*7	*4	*5	*5
Iron	277	1640	5180	5190	<120	1720	4370	<120	*90	4370	<120
Lead	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Magnesium	16800	21900	16300	16800	13100	23100	22500	10700	13200	19500	11200
Manganese	31	3320	4050	4570	*3	8400	4850	*3	118	4810	*4.9
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<10	*9	*8	*4	<10	73	14	<10	<10	19	<10
Potassium	9290	9790	8510	7640	10400	11300	9660	9180	9450	8210	9380
Selenium	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	*7
Silver	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sodium	19200	148000	212000	242000	15900	45000	88500	14400	23000	85200	16400
Thallium	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Vanadium	*5	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Zinc	241	<50	<50	275	<90	<50	<50	<50	<50	71	<50

\* - denotes an estimated value

**Table 7**  
**Metal Results – August 2005**

Analyte	Metal Concentration at 60 ft Water Depth, ppb										
	MW-01	MW-02	MW-03	MW-04	MW-05	MW-06	MW-07	MW-08	MW-09	MW-10	MW-11
Aluminum	<90	204	<90	<90	<90	<90	<90	<90	<90	<90	<90
Antimony	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Arsenic	<15	7	23	36	<15	30	33	<15	3	45	<15
Barium	363	351	348	378	276	1340	894	212	287	487	195
Beryllium	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cadmium	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Calcium	49500	38800	29800	23700	66000	71100	74300	53700	53100	49100	68300
Chromium	2	<10	<10	<10	2	<10	<10	2	2	<10	<10
Cobalt	<15	<15	<15	<15	<15	10	16	<15	<15	3	<15
Copper	<10	7	<10	<10	<10	<10	<10	<10	<10	<10	<10
Iron	<120	372	1770	2290	<120	4610	5280	165	<120	3860	<120
Lead	<10	5	<10	4	<10	<10	<10	<10	<10	<10	<10
Magnesium	16100	13000	10900	8970	12900	19300	23000	10900	12500	15300	11300
Manganese	<4	571	2480	3230	2	3510	3650	3	69	1710	2
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	<10	6	4	5	<10	11	12	<10	<10	8	<10
Potassium	9350	7350	5990	4770	10600	8530	7890	9660	10100	7220	9650
Selenium	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	6
Silver	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sodium	18100	73000	206000	127000	15600	142000	129000	14400	18100	83300	16700
Thallium	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Vanadium	4	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Zinc	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

\* - denotes an estimated value

**Table 8**  
**BAZE - Acetate Injection - February 2004**

Date	Time	Cond. mS/cm3	Temp °C	pH	DO Conc %	ORP mV	Pump Flow - gpm				
							IW01	IW02	EW01	Acet. Feed	
2/26/2004	13:45	7.700	11.63	7.72	15.70	278.0					
	14:15	7.770	11.68	7.71	15.80	228.2	12.60	13.29	24.89	1.06	
	15:00	7.610	11.71	7.67	15.90	210.8	13.07	12.73	24.89	1.01	
	16:00	7.670	11.67	7.62	16.00	202.4	12.93	13.17	24.99	1.01	
	17:00	0.763	11.68	6.29	15.90	246.2	12.70	12.68	25.45	0.00	
	18:00	0.916	11.78	6.30	15.90	242.7	12.72	12.68	25.35		
	19:00	0.977	11.77	6.31	16.50	230.2	12.66	12.73	25.35		
	20:00	0.990	11.77	6.32	17.00	231.3	12.25	13.24	25.30		
	21:00	0.956	11.77	6.33	17.70	230.9	12.76	12.52	25.30		
	22:00	0.968	11.77	6.35	16.70	249.7	12.81	12.73	25.35		
	23:00	1.053	11.77	6.35	18.30	243.0	12.81	12.73	25.30		
	2/27/2004	0:00	1.145	11.77	6.35	16.30	251.5	12.71	12.16	25.25	
		1:00	1.159	11.77	6.38	16.70	235.9	12.71	12.83	25.25	
2:00		1.156	11.68	6.40	16.40	256.1	12.63	12.81	25.15		
3:00		1.107	11.76	6.40	16.40	242.0	12.66	12.78	25.30		
4:00		1.110	11.76	6.40	16.40	239.4	12.56	12.83	25.30		
5:00		1.120	11.76	6.41	16.60	243.6	12.61	12.88	25.25		
6:00		1.117	11.77	6.42	16.50	244.0	12.61	12.83	25.25		
7:00		1.103	11.77	6.43	16.60	241.2	12.46	12.98	25.25		
8:00		1.075	11.81	6.43	16.10	231.8	12.46	12.93	25.20		
9:00		1.052	11.87	6.44	16.30	203.8	12.41	13.03	25.20		
10:00		1.042	11.89	6.44	16.30	205.1	12.41	12.98	25.20		
11:00		1.036	11.89	6.44	15.80	205.6	12.41	12.93	25.25		
12:00		1.032	11.90	6.44	15.90	184.3	12.31	13.03	25.20		
13:00		1.019	11.94	6.46	18.30	173.9	12.46	12.88	25.15		
14:00	1.016	11.95	6.44	15.20	203.1	12.41	13.09	25.20			

**Table 9**  
**BAZE - Acetate Injection - March 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
3/24/2004	13:18	0.499	11.99	6.40	1.98	187				
	13:33	8.422	12.34	7.80	1.92	185	12.89	12.45	23.74	no reading
	13:48	8.537	12.36	7.79	1.89	155				
	14:03	8.547	12.35	7.79	1.86	143	12.95	12.85	23.81	
	14:18	8.658	12.38	7.79	1.85	133	12.90	12.32	23.89	no reading
	14:33	8.702	12.39	7.79	1.82	131				
	14:48	8.747	12.40	7.79	1.78	130				
	15:03	8.768	12.41	7.70	1.75	135	12.76	12.63	23.99	no reading
	15:18	8.776	12.43	7.76	1.73	129				
	15:33	8.860	12.43	7.75	1.70	131				
	15:48	8.873	12.44	7.74	1.67	131				
	16:03	8.925	12.54	7.73	1.64	135	12.81	12.42	23.89	0.00
	16:18	0.691	11.97	6.38	1.62	162				
	16:33	0.717	11.98	6.39	1.59	172				
	16:48	0.746	11.94	6.40	1.57	177				
	17:03	0.775	11.93	6.41	1.54	180	12.07	12.05	23.99	
	17:18	0.810	11.92	6.41	1.52	182				
	17:33	0.840	11.90	6.42	1.51	183				
	17:48	0.873	11.90	6.42	1.49	184				
	18:03	0.900	11.88	6.43	1.48	184	12.01	12.05	23.99	
	18:18	0.923	11.87	6.44	1.47	186				
	18:33	0.948	11.87	6.45	1.46	186				
	18:48	0.974	11.89	6.45	1.45	187				
	19:03	1.008	11.89	6.46	1.44	187	12.05	12.07	23.98	
	19:18	1.031	11.88	6.47	1.43	187				
	19:33	1.058	11.88	6.48	1.43	187				
	19:48	1.071	11.89	6.49	1.42	187				
	20:03	1.074	11.89	6.50	1.41	187	12.10	11.97	23.94	
	20:18	1.083	11.89	6.51	1.41	186				
	20:33	1.076	11.90	6.51	1.40	186				
	20:48	1.069	11.90	6.52	1.39	185				
	21:03	1.059	11.90	6.52	1.38	184	12.66	11.86	23.99	
	21:18	1.060	11.90	6.53	1.38	184				
	21:33	1.062	11.90	6.54	1.38	183				
	21:48	1.062	11.90	6.53	1.38	183				
	22:03	1.076	11.90	6.53	1.38	183	12.15	12.22	24.24	
	22:18	1.095	11.90	6.53	1.38	183				
	22:33	1.125	11.90	6.53	1.39	182				
	22:48	1.154	11.90	6.54	1.39	182				
	23:03	1.186	11.90	6.54	1.39	183	12.10	12.12	24.24	
23:18	1.218	11.90	6.54	1.39	182					
23:33	1.248	11.90	6.55	1.39	182					
23:48	1.269	11.91	6.55	1.39	182					
3/25/2004	0:03	1.277	11.90	6.56	1.40	181	12.10	12.12	24.09	
	0:18	1.281	11.91	6.56	1.40	181				
	0:33	1.274	11.91	6.56	1.40	181				
	0:48	1.259	11.91	6.57	1.40	180				
	1:03	1.246	11.91	6.57	1.40	180	12.15	12.02	24.04	
	1:18	1.232	11.91	6.58	1.40	179				
	1:33	1.219	11.92	6.58	1.40	179				
	1:48	1.212	11.91	6.58	1.40	178				
	2:03	1.202	11.92	6.58	1.40	178	12.15	12.07	23.99	
	2:18	1.197	11.92	6.59	1.40	173				
	2:33	1.192	11.91	6.59	1.40	172				
	2:48	1.190	11.92	6.59	1.40	172				
	3:03	1.191	11.92	6.59	1.40	171	12.15	12.07	24.04	
	3:18	1.195	11.92	6.59	1.40	171				
	3:33	1.201	11.92	6.60	1.40	171				
	3:48	1.207	11.92	6.60	1.40	170				
	4:03	1.212	11.92	6.60	1.40	170	12.10	12.07	24.04	
	4:18	1.224	11.92	6.60	1.39	169				
	4:33	1.228	11.92	6.60	1.39	169				
	4:48	1.232	11.92	6.60	1.39	168				

	5:03	1.235	11.92	6.61	1.39	167	12.10	12.02	24.04	
	5:18	1.239	11.92	6.60	1.38	167				
<b>Table 9 (Concluded)</b>										
Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc	ORP	Pump Flow - gpm			
					mg/L	mV	IW01	IW02	EW01	Acet. Feed
3/25/2004	5:33	1.239	11.92	6.61	1.38	166				
	5:48	1.243	11.93	6.61	1.37	166				
	6:03	1.240	11.93	6.61	1.37	167	12.10	12.07	24.04	
	6:18	1.231	11.93	6.61	1.37	168				
	6:33	1.228	11.93	6.61	1.36	168				
	6:48	1.221	11.93	6.61	1.35	167				
	7:03	1.212	11.94	6.62	1.34	166	12.15	12.07	24.14	
	7:18	1.209	11.94	6.61	1.33	166				
	7:33	1.199	11.94	6.61	1.33	165				
	7:48	1.190	11.94	6.62	1.32	164				
	8:03	1.183	11.95	6.62	1.32	163	12.05	11.97	24.04	
	8:18	1.173	11.95	6.62	1.31	162				
	8:33	1.168	11.95	6.62	1.29	161				
	8:48	1.165	11.96	6.62	1.29	160				
	9:03	1.158	11.96	6.62	1.28	159	12.03	11.96	23.99	
	9:18	1.157	11.97	6.62	1.27	158				
	9:33	1.155	11.97	6.62	1.26	157				
	9:48	1.153	11.98	6.62	1.25	156				
	10:03	1.154	11.98	6.63	1.24	155	12.20	12.02	24.22	
	10:18	1.153	11.97	6.62	1.23	154				
	10:33	1.157	11.98	6.62	1.22	153				
	10:48	1.153	11.98	6.62	1.22	151				
	11:03	1.152	12.01	6.63	1.20	150	12.15	12.12	23.99	
	11:18	1.152	12.01	6.63	1.20	148				
11:33	1.151	12.01	6.63	1.18	147					
11:48	1.151	12.01	6.63	1.18	145					
12:03	1.148	12.02	6.63	1.17	144	12.10	12.12	24.22		
12:18	1.146	12.01	6.63	1.16	142					
12:33	1.149	12.00	6.63	1.15	140					
12:48	1.145	11.99	6.63	1.14	139					

**Table 10**  
**BAZE - Acetate Injection - April 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
4/29/2004	7:43	0.497	11.90	6.34	1.92	165				
	7:58	0.531	11.91	6.41	1.85	136				
	8:13	0.502	11.91	6.32	1.80	155				
	8:28	0.502	11.92	6.33	1.76	158				
	8:43	0.514	11.90	6.34	1.72	159				
	8:58	5.511	12.08	7.67	1.68	136	12.96	12.93	25.10	0.52
	9:13	5.258	12.13	7.65	1.64	120	12.96	13.03	25.05	0.58
	9:28	5.132	12.11	7.63	1.62	113	12.66	12.68	24.99	0.58
	9:43	5.178	12.11	7.64	1.59	108				
	9:58	5.182	12.11	7.64	1.57	106	12.91	12.98	25.10	0.58
	10:13	5.126	12.11	7.63	1.56	104				
	10:28	5.215	12.11	7.63	1.54	103	12.96	12.98	25.10	0.52
	10:43	5.205	12.11	7.61	1.52	102				
	10:58	5.197	12.11	7.61	1.50	101	12.96	13.03	24.99	0.58
	11:13	5.216	12.10	7.60	1.48	101				
	11:28	5.239	12.11	7.59	1.46	101	12.96	12.93	24.99	0.52
	11:43	5.230	12.11	7.58	1.45	101				
	11:58	5.295	12.11	7.58	1.44	101	12.91	12.98	24.99	0.58
	12:13	5.306	12.11	7.57	1.43	101				
	12:28	5.297	12.11	7.56	1.42	101	12.91	12.98	24.99	0.58
	12:43	5.319	12.11	7.56	1.41	101				
	12:58	5.438	12.12	7.57	1.41	101	12.93	12.96	24.99	0.52
	13:13	2.073	11.98	7.31	1.41	95				0.00
	13:28	0.794	11.91	6.46	1.39	128	12.66	12.68	25.00	
	13:43	0.820	11.91	6.47	1.38	135				
	13:58	0.845	11.91	6.47	1.37	138	12.61	12.63	25.10	
	14:13	0.874	11.91	6.48	1.37	140				
	14:28	0.898	11.91	6.49	1.36	141	12.51	12.68	25.05	
	14:43	0.919	11.91	6.49	1.36	141				
	14:58	0.935	11.91	6.50	1.35	140	12.41	12.63	25.05	
	15:13	0.951	11.90	6.51	1.35	140				
	15:28	0.962	11.91	6.51	1.35	139	12.56	12.63	25.05	
	15:43	0.974	11.90	6.51	1.35	138				
	15:58	0.995	11.91	6.52	1.35	137	12.61	12.63	25.10	
	16:13	1.007	11.91	6.52	1.35	136				
	16:28	1.028	11.92	6.53	1.35	135	12.66	12.68	24.99	
16:43	1.048	11.92	6.53	1.35	134					
16:58	1.074	11.92	6.54	1.36	132	12.56	12.68	25.05		
17:13	1.095	11.90	6.54	1.36	131					
17:28	1.120	11.90	6.54	1.36	130	12.61	12.63	25.10		
17:43	1.132	11.90	6.55	1.36	129					
17:58	1.149	11.91	6.55	1.36	128	12.61	12.73	25.05		
18:13	1.159	11.90	6.55	1.37	127					
18:28	1.166	11.90	6.56	1.36	127	12.61	12.57	25.02		
18:43	1.172	11.89	6.56	1.37	126					
18:58	1.177	11.90	6.57	1.36	125	12.66	12.68	25.10		
19:13	1.179	11.90	6.57	1.37	124					
19:28	1.185	11.90	6.57	1.37	123	12.61	12.63	25.10		
19:43	1.193	11.90	6.58	1.37	122					
19:58	1.196	11.90	6.58	1.37	123	12.68	12.61	25.05		

**Table 11**  
**BAZE - Acetate Injection - May 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
5/27/2004	7:20	5.250	12.17	7.77	7.44	138	12.66	13.34	25.10	0.63
	7:35	5.108	12.18	7.74	6.06	115				
	7:50	5.121	12.22	7.73	5.88	109	12.96	12.83	24.94	0.63
	8:05	5.059	12.18	7.73	5.73	105	12.96	12.93	24.94	0.58
	8:20	5.213	12.29	7.75	5.58	103	12.91	12.78	24.94	0.63
	8:35	5.191	12.28	7.74	5.44	98				
	8:50	5.175	12.28	7.74	5.35	90	13.07	12.73	24.89	0.69
	9:05	5.165	12.29	7.74	5.30	86				
	9:20	5.136	12.27	7.73	5.18	79	13.12	12.63	24.79	0.63
	9:35	5.069	12.25	7.72	5.09	75				
	9:50	5.083	12.22	7.71	5.02	78	13.07	12.78	24.89	0.69
	10:05	5.126	12.21	7.71	4.98	84				
	10:20	5.142	12.27	7.69	5.09	88	13.07	12.83	24.84	0.69
	10:35	5.084	12.24	7.68	4.83	89				
	10:50	5.043	12.25	7.67	4.77	91	13.12	12.78	24.89	0.69
	11:05	0.036	17.88	7.39	5.71	99				
	11:20	4.881	12.30	7.69	4.67	87	13.07	12.73	24.84	0.63
	11:35	4.816	12.32	7.66	4.72	78				
	11:50	0.671	12.00	6.63	4.59	98	12.76	12.68	24.89	0.00
	12:05	0.698	11.99	6.64	4.57	108				
	12:20	0.714	12.02	6.67	4.56	114				
	12:35	0.745	12.06	6.66	4.52	120				
	12:50	0.775	12.07	6.65	4.49	125	12.76	12.32	24.99	
	13:05	0.808	12.08	6.65	4.47	127				
	13:20	0.834	12.07	6.66	4.45	125				
	13:35	0.856	12.07	6.66	4.44	124				
	13:50	0.878	12.08	6.66	4.42	125	12.76	12.37	24.99	
	14:05	0.892	12.08	6.66	4.40	124				
	14:20	0.907	12.08	6.66	4.38	123				
	14:35	0.925	12.08	6.67	4.38	123				
	14:50	0.951	12.08	6.67	4.38	123	12.76	12.58	24.94	
	15:05	0.968	12.09	6.67	4.37	122				
	15:20	1.004	12.10	6.68	4.37	122				
	15:35	1.031	12.10	6.68	4.37	121				
	15:50	1.065	12.10	6.68	4.37	121	12.71	12.42	24.94	
16:05	1.092	12.11	6.69	4.38	120					
16:20	1.104	12.10	6.69	4.39	119					
16:35	1.126	12.11	6.69	4.39	117					
16:50	1.126	12.10	6.70	4.40	116	12.71	12.37	24.94		
17:05	1.143	12.10	6.70	4.40	115					
17:20	1.141	12.10	6.71	4.39	114					
17:35	1.146	12.09	6.71	4.38	112					
17:50	1.150	12.07	6.71	4.38	112	12.76	12.47	24.89		
18:05	1.161	12.00	6.72	4.40	111					
18:20	1.169	11.98	6.72	4.39	110					
18:35	1.172	11.97	6.73	4.39	110	12.76	12.47	24.94		

**Table 12**  
**BAZE - Acetate Injection - June 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
6/23/2004	7:34	0.00	20.910	7.25	8.09	268	12.41	12.57	24.84	
	7:49	5.51	12.270	7.82	6.15	157	12.81	12.88	24.64	0.69
	8:04	5.49	12.250	7.80	5.97	130	12.86	12.88	24.64	0.79
	8:19	5.51	12.310	7.79	5.79	115	12.91	12.93	24.64	0.85
	8:34	4.47	12.260	7.72	5.64	105	12.81	12.73	24.64	0.58
	8:49	4.71	12.300	7.75	5.47	87	12.81	12.83	24.69	0.63
	9:04	4.70	12.240	7.75	5.34	69	12.81	12.78	24.69	0.63
	9:19	4.69	12.270	7.75	5.21	62				
	9:34	4.61	12.240	7.75	5.12	55	12.76	12.88	24.69	0.63
	9:49	4.67	12.290	7.73	5.02	57				
	10:04	4.65	12.300	7.75	4.93	51	12.81	12.73	24.64	0.58
	10:19	4.65	12.310	7.75	4.87	47				
	10:34	4.67	12.300	7.75	4.83	39	12.71	12.73	24.64	0.63
	10:49	4.68	12.300	7.75	4.76	32				
	11:04	4.67	12.290	7.75	4.73	26	12.76	12.83	24.64	0.58
	11:19	4.71	12.330	7.76	4.66	20				
	11:34	4.75	12.380	7.74	4.61	10	12.91	12.63	24.64	0.58
	11:49	4.73	12.390	7.72	4.55	9				
	12:04	5.43	12.500	7.77	4.51	14	13.07	12.83	24.64	0.79
	12:19	5.46	12.500	7.77	4.49	8				
	12:34	0.70	12.020	6.72	4.45	53	12.51	12.42	24.74	0.00
	12:49	0.73	11.980	6.72	4.44	44				
	13:04	0.76	12.010	6.72	4.41	50	12.51	12.37	24.79	
	13:19	0.79	12.040	6.73	4.41	53				
	13:34	0.82	11.980	6.72	4.41	42	12.56	12.37	24.74	
	13:49	0.84	11.960	6.73	4.40	33				
	14:04	0.86	11.950	6.73	4.39	27	12.56	12.42	24.74	
	14:19	0.89	12.000	6.72	4.38	38				
	14:34	0.91	11.960	6.75	4.37	23				
	14:49	0.93	12.030	6.77	4.35	32				
	15:04	0.95	12.080	6.72	4.35	42	12.56	12.32	24.74	
	15:19	0.97	12.110	6.70	4.34	55				
	15:34	1.00	12.110	6.69	4.33	66				
	15:49	1.03	12.110	6.68	4.34	72				
16:04	1.06	12.120	6.68	4.35	75	12.61	12.32	24.74		
16:19	1.09	12.120	6.69	4.36	77					
16:34	1.11	12.110	6.69	4.36	78					
16:49	1.13	12.100	6.69	4.35	78					
17:04	1.14	12.100	6.69	4.35	79	12.56	12.27	24.74		
17:19	1.14	12.090	6.70	4.34	78					
17:34	1.15	12.060	6.70	4.34	77					
17:49	1.15	12.030	6.70	4.34	76					
18:04	1.16	12.030	6.70	4.34	76	12.56	12.32	24.74		
18:19	1.16	12.010	6.70	4.32	76					
18:34	1.16	12.020	6.71	4.31	75					
18:49	1.17	12.010	6.71	4.30	76	12.61	12.52	24.74		

**Table 13**  
**BAZE - Acetate Injection - July 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
7/28/2004	7:02	0.489	11.94	6.49	6.40	144			24.14	
	7:17	7.011	12.12	7.56	6.16	92				
	7:32	4.388	12.16	7.62	5.99	71	12.15	12.98	24.29	0.31
	7:47	4.330	12.17	7.60	5.82	70	13.58	11.56	24.19	0.31
	8:02	4.292	12.22	7.59	5.66	71	12.81	12.12	24.24	0.31
	8:17	4.354	12.27	7.59	5.50	71	12.81	12.12	24.24	0.31
	8:32	4.253	12.25	7.58	5.38	71	12.81	12.12	24.24	0.31
	8:47	4.207	12.23	7.56	5.27	72	12.71	12.22	24.24	0.31
	9:02	4.142	12.28	7.56	5.18	73	12.76	12.17	24.24	0.31
	9:17	4.446	12.28	7.57	5.10	72	12.81	12.12	24.24	0.31
	9:32	4.370	12.34	7.56	5.03	72	12.81	12.12	24.24	0.31
	9:47	4.348	12.36	7.56	4.97	71	12.86	12.12	24.29	0.42
	10:02	4.355	12.37	7.55	4.92	69	12.86	12.27	24.19	0.42
	10:17	4.345	12.39	7.54	4.87	66				
	10:32	4.283	12.40	7.54	4.80	63	12.76	12.32	24.64	0.52
	10:47	4.282	12.40	7.53	4.76	61				
	11:02	4.271	12.41	7.53	4.69	58	12.26	13.29	24.54	0.42
	11:17	4.222	12.40	7.52	4.66	54				
	11:32	4.202	12.42	7.51	4.63	53	12.76	12.22	24.44	0.42
	11:47	4.192	12.46	7.51	4.60	51				
	12:02	4.202	12.44	7.50	4.57	49	13.32	12.16	24.99	0.21
	12:17	4.147	12.45	7.48	4.56	51				
	12:32	0.693	12.08	6.45	4.53	93	13.12	11.51	24.44	0.00
	12:47	0.717	12.07	6.44	4.52	95				
	13:02	0.747	12.04	6.45	4.54	96	16.19	8.52	24.99	
	13:17	0.770	12.03	6.45	4.54	97				
	13:32	0.793	12.02	6.48	4.52	97				
	13:47	0.818	12.00	6.47	4.52	100				
	14:02	0.841	12.01	6.47	4.52	104	12.46	12.12	24.29	
	14:17	0.858	12.04	6.48	4.51	106				
	14:32	0.879	12.01	6.48	4.52	110				
	14:47	0.904	12.03	6.48	4.54	115				
	15:02	0.926	12.09	6.49	4.52	115	11.80	12.63	24.34	
	15:17	0.955	12.08	6.50	4.54	112				
15:32	0.980	12.10	6.51	4.53	108					
15:47	1.000	12.06	6.52	4.54	105					
16:02	1.026	12.05	6.53	4.53	102	11.85	12.83	24.44		
16:17	1.038	12.05	6.54	4.53	102					
16:32	1.055	12.08	6.52	4.53	102					
16:47	1.063	12.10	6.56	4.53	98					
17:02	1.076	12.09	6.57	4.52	96	11.85	12.52	24.44		
17:17	1.073	12.07	6.56	4.51	95					
17:32	1.081	12.05	6.57	4.50	93					
17:47	1.080	12.05	6.57	4.49	92					
18:02	1.081	12.03	6.58	4.47	91	16.35	8.87	25.05		



**Table 14**  
**BAZE - Acetate Injection - August 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
8/26/04	8:30	no reading	no reading	no reading	no reading	no reading	12.25	11.86	23.89	0.37
	8:45	no reading	no reading	no reading	no reading	no reading	12.76	12.12	23.84	0.42
	9:00	no reading	no reading	no reading	no reading	no reading	12.71	12.12	23.84	0.58
	9:15	no reading	no reading	no reading	no reading	no reading	12.66	12.12	23.79	0.31
	9:30	no reading	no reading	no reading	no reading	no reading	12.66	12.12	23.79	0.31
	9:45	no reading	no reading	no reading	no reading	no reading				
	10:00	no reading	no reading	no reading	no reading	no reading	12.66	12.12	23.94	0.42
	10:15	no reading	no reading	no reading	no reading	no reading				
	10:30	no reading	no reading	no reading	no reading	no reading	12.71	12.12	23.84	0.52
	10:45	no reading	no reading	no reading	no reading	no reading				
	11:00	no reading	no reading	no reading	no reading	no reading	12.71	12.12	23.84	0.52
	11:15	5.030	11.22	7.73	5.22	23				
	11:30	4.979	11.74	7.73	5.02	21	12.77	12.12	23.89	0.52
	11:45	4.981	11.85	7.73	4.92	19				
	12:00	4.936	11.89	7.73	4.87	17	12.71	12.12	23.84	0.52
	12:15	4.955	11.93	7.72	4.80	18				
	12:30	1.603	11.60	7.28	4.73	35	12.66	12.12	23.79	0.63
	12:45	5.232	11.96	7.73	4.71	20				
	13:00	5.248	11.95	7.72	4.65	13	12.66	12.12	23.79	0.63
	13:15	0.647	11.33	6.87	4.62	30	11.87	12.36	23.99	0.00
	13:30	0.661	10.69	6.75	4.77	48	12.00	12.25	24.04	
	13:45	0.688	10.50	6.77	4.81	42				
	14:00	0.686	11.71	6.78	4.47	39	11.95	12.22	23.99	
	14:15	0.717	11.36	6.78	4.55	37				
	14:30	0.776	10.64	6.79	4.73	35				
	14:45	0.795	10.64	6.79	4.71	36				
	15:00	0.824	10.54	6.79	4.74	38	12.00	12.17	24.04	
	15:15	0.842	10.42	6.78	4.76	37				
	15:30	0.865	10.26	6.78	4.77	36				
	15:45	0.856	11.61	6.77	4.40	42				
	16:00	0.878	11.70	6.77	4.37	42	12.05	12.22	23.99	
	16:15	0.899	11.82	6.77	4.37	44				
	16:30	0.923	11.81	6.79	4.34	42				
	16:45	0.950	11.79	6.79	4.32	41				
	17:00	0.975	11.77	6.80	4.32	37	12.00	12.17	23.99	
	17:15	1.001	11.77	6.80	4.31	35				
	17:30	1.024	11.76	6.81	4.31	32				
	17:45	1.041	11.76	6.81	4.30	30				
	18:00	1.054	11.77	6.81	4.28	31	12.00	12.17	23.99	
	18:15	1.064	11.75	6.81	4.26	33				
	18:30	1.074	11.74	6.80	4.24	36				
	18:45	1.079	11.75	6.81	4.21	35				
	19:00	1.085	11.73	6.81	4.20	35	11.95	12.12	23.99	
	19:15	1.093	11.70	6.80	4.17	35				
	19:30	1.097	11.67	6.80	4.16	38				
	19:45	1.104	11.58	6.80	4.16	43				
	20:00	1.115	11.45	6.80	4.16	47	12.00	12.22	23.99	

**Table 15**  
**BAZE - Acetate Injection - September 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
9/24/2004	6:45						12.58	12.79	24.44	0.31
	7:00						12.61	12.93	24.44	0.79
	7:15						12.61	12.93	24.49	0.74
	7:30						12.51	12.83	24.54	0.31
	7:45						12.46	12.83	24.54	0.31
	8:00						12.51	12.83	24.54	0.31
	8:15									
	8:30						12.46	12.83	24.54	0.42
	8:45									
	9:00						12.46	12.78	24.54	0.42
	9:15									
	9:30						12.41	12.88	24.54	0.42
	9:45									
	10:00						12.51	12.83	24.54	0.47
	10:15									
	10:30						12.51	12.83	24.54	0.47
	10:45									
	11:00						12.25	12.42	24.59	0.52
	11:15									
	11:30						12.25	12.42	24.59	0.00
	11:45									
	12:00						12.25	12.42	24.59	
	12:15									
	12:30									
	12:45									
	13:00						12.25	12.42	24.59	
	13:15									
	13:30									
	13:45									
	14:00						12.51	12.51	24.54	
	14:15									
	14:30									
14:45										
15:00						12.47	12.30	24.59		
15:15										
15:30										
15:45										
16:00						12.47	12.30	24.59		
16:15										
16:30										
16:45										
17:00						12.25	12.47	24.59		
17:15										
17:30										
17:45										
18:00						12.15	12.47	24.59		
18:15										
18:30										
18:45						12.15	12.47	24.59		

Meter Malfunction

**Table 16**  
**BAZE - Acetate Injection - October 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
10/27/2004	7:30						12.42	12.51	24.19	0.52
	7:45						12.42	12.51	24.19	0.52
	8:00						12.46	12.52	24.24	0.52
	8:15						12.46	12.52	24.24	0.52
	8:30						12.46	12.52	24.24	0.52
	8:45						12.51	12.51	24.24	0.52
	9:00						12.51	12.52	24.24	0.58
	9:15						12.51	12.51	24.24	0.42
	9:30						12.52	12.52	24.24	0.52
	9:45									
	10:00						12.41	12.63	24.24	0.52
	10:15									
	10:30						12.52	12.52	24.24	0.52
	10:45									
	11:00						12.41	12.63	24.24	0.52
	11:15									
	11:30						12.41	12.57	24.29	0.52
	11:45									
	12:00						12.41	12.57	24.24	0.52
	12:15									
	12:30						12.20	12.21	24.29	0.00
	12:45									
	13:00						12.20	12.21	24.29	
	13:15									
	13:30									
	13:45									
	14:00						12.15	12.32	24.34	
	14:15									
	14:30									
	14:45									
	15:00						12.15	12.32	24.34	
	15:15									
	15:30									
	15:45									
	16:00						12.20	12.27	24.34	
	16:15									
	16:30									
	16:45									
	17:00						12.20	12.27	24.34	
	17:15									
17:30										
17:45										
18:00						12.25	12.22	24.34		
18:15										
18:30										
18:45										
19:00						12.25	12.22	24.34		
19:15										
19:30						12.25	12.22	24.34		

Meter Malfunction

**Table 17**  
**BAZE - Acetate Injection - November 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
11/17/2004	7:15	0.502	11.91	6.68	8.98	40				
	7:30	3.524	11.97	7.60	8.34	-32	12.51	12.22	24.29	0.37
	8:15	3.406	11.99	7.60	7.29	-32	12.51	12.22	24.24	0.37
	8:30	3.413	11.99	7.59	7.08	-29	12.51	12.22	24.24	0.38
	8:57	3.335	12.00	7.58	6.89	-27				
	9:00	3.283	12.00	7.57	6.88	-27	12.51	12.22	24.24	0.37
	9:15	3.262	12.01	7.57	6.68	-24				
	9:30	3.294	12.02	7.57	6.57	-22	12.51	12.22	24.24	0.37
	9:45	3.271	12.02	7.57	6.45	-21				
	10:00	3.243	12.03	7.57	6.32	-20	12.50	12.26	24.27	0.42
	10:15	3.236	12.06	7.56	6.23	-19				
	10:30	3.262	12.06	7.56	6.19	-17	12.51	12.26	24.27	0.42
	10:45	3.033	12.04	7.53	6.13	-14				
	11:00	3.024	12.03	7.52	6.07	-12	12.46	12.42	24.74	0.45
	11:15	3.886	12.05	7.61	6.07	-14				
	11:30	3.756	12.05	7.59	5.99	-12	12.46	12.42	24.74	0.52
	11:45	3.930	12.06	7.59	5.93	-11				
	12:00	3.907	12.06	7.59	5.87	-9				
	12:15	3.981	12.08	7.58	5.86	-7				
	12:30	3.949	12.07	7.57	5.74	-5	12.46	12.47	24.29	0.52
	12:45	3.991	12.07	7.56	5.75	-3				
	13:00	3.996	12.09	7.55	5.74	-2				
	13:15	3.922	12.09	7.54	5.71	0				
	13:30	3.961	12.08	7.53	5.69	1	12.46	12.47	24.29	0.52
	13:45	4.048	12.07	7.53	5.70	3				
	14:00	4.040	12.07	7.52	5.66	4				
	14:15	4.143	12.07	7.52	5.63	5				
	14:30	0.852	11.96	6.72	5.57	22	12.51	12.42	24.27	0.53
	14:45	0.874	11.95	6.67	5.52	31				
	15:00	0.899	11.95	6.68	5.55	35				
	15:15	0.924	11.96	6.68	5.49	36				
	15:30	0.949	11.96	6.69	5.53	37	12.42	12.42	24.29	0.00
	15:45	0.974	11.95	6.69	5.43	37				
	16:00	0.999	11.95	6.70	5.46	37				
16:15	1.028	11.95	6.70	5.47	37					
16:30	1.048	11.95	6.71	5.44	39	12.22	12.22	24.29		
16:45	1.067	11.94	6.71	5.41	40					
17:00	1.083	11.94	6.72	5.36	40					
17:15	1.101	11.94	6.72	5.33	40					
17:30	1.117	11.95	6.73	5.36	40	12.20	12.21	24.34		
17:45	1.134	11.95	6.73	5.32	40					
18:00	1.152	11.95	6.74	5.28	40					
18:15	1.171	11.95	6.74	5.30	39					
18:30	1.188	11.95	6.74	5.28	39	12.22	12.21	24.34		
18:45	1.201	11.95	6.74	5.24	39					
19:00	1.215	11.95	6.75	5.22	39	12.20	12.21	24.34		
19:30						12.22	12.21	24.34		

**Table 18**  
**BAZE - Acetate Injection - December 2004**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
12/11/2004	7:40						12.15	12.42	23.63	----
	8:38	4.895	-13.44	1.37	153.48	288	12.00	12.37	23.79	----
	8:53	-9.742	-42.84	-7.73	-15.26	618				
	9:08	-9.066	-42.83	-7.13	-14.81	597				
	9:23	-8.772	-42.88	-9.22	-14.31	750				
	9:38	1.460	7.16	2.71	6.85	236	12.15	12.32	23.58	0.80
	9:53	1.452	6.71	7.33	6.94	15				
	10:08	1.492	6.92	7.51	6.62	9				
	10:23	5.298	6.93	8.06	6.22	-13				
	10:38	5.383	6.98	8.07	6.10	-19	12.00	12.32	23.58	0.74
	10:53	5.314	7.03	8.07	5.99	-19				
	11:08	5.427	7.09	8.07	5.89	-19				
	11:23	5.343	7.16	8.07	5.88	-18				
	11:38	5.478	7.10	8.08	5.75	-18	12.15	12.47	23.53	0.88
	11:53	6.388	7.13	8.13	5.61	-19				
	12:08	6.365	7.28	8.13	5.51	-18				
	12:23	6.406	7.25	8.15	5.39	-16				
	12:38	6.415	7.26	8.13	5.45	-14	12.15	12.37	23.53	0.88
	12:53	6.391	7.18	8.12	5.42	-10				0.00
	13:08	6.346	7.38	8.12	5.31	-7				
	13:23	6.294	7.58	8.11	5.18	-4				
	13:38	5.303	7.70	8.06	5.11	-2	11.80	12.07	23.73	
	13:53	0.699	7.85	7.01	4.99	26				
	14:08	0.719	7.68	7.01	5.07	32				
	14:23	0.741	7.84	7.02	4.94	36				
	14:38	0.764	7.94	7.03	4.89	39	11.75	11.97	23.68	
	14:53	0.785	7.86	7.03	4.90	41				
	15:08	0.813	7.92	7.03	4.86	43				
	15:23	0.765	11.77	7.05	3.49	43				
	15:38	0.787	11.71	7.05	3.48	45	11.75	11.97	23.68	
	15:53	0.817	11.70	7.06	3.48	46				
	16:08	0.845	11.71	7.06	3.46	46				
	16:23	0.870	11.69	7.07	3.46	47				
	16:38	0.892	11.72	7.07	3.42	46	11.70	11.97	23.68	
	16:53	0.914	11.67	7.08	3.42	47				
	17:08	0.939	11.67	7.08	3.41	47				
17:23	0.970	11.66	7.08	3.40	47					
17:38	0.989	11.66	7.09	3.37	47	11.70	11.81	23.58		
17:53	1.016	11.66	7.09	3.34	47					
18:08	1.029	11.65	7.09	3.35	47					
18:23	1.047	11.65	7.10	3.35	47					
18:38	1.060	11.65	7.10	3.33	47	11.70	11.97	23.63		
18:53	1.074	11.65	7.10	3.32	46					
19:08	1.092	11.65	7.11	3.30	46					
19:23	1.101	11.65	7.11	3.30	46					
19:38	1.111	11.66	7.12	3.28	45	11.70	11.97	23.60		

<b>Table 19</b>										
<b>BAZE - Acetate Injection - February 2005</b>										
Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
2/17/2005	9:20						12.2	12.57	24.14	0.57
	9:24	4.28	11.640	7.99	8.01	52				
	9:39	4.42	11.650	8.04	5.00	5				
	9:54	3.68	11.680	8.03	4.75	-3	12.15	12.52	24.14	0.59
	10:09	4.19	11.700	8.03	4.81	-6				
	10:24	4.44	11.710	8.01	4.74	-8	12.25	12.57	24.14	0.58
	10:39	4.42	11.740	8.00	4.66	-10				
	10:54	3.58	11.750	7.99	4.62	-13				
	11:09	3.57	11.760	7.99	4.55	-17				
	11:24	3.56	11.780	7.98	4.48	-17	12.25	12.45	24.14	0.58
	11:39	3.53	11.780	7.97	4.42	-19				
	11:54	3.53	11.800	7.96	4.37	-20				
	12:09	3.50	11.810	7.95	4.31	-19				
	12:24	3.53	11.830	7.94	4.36	-18	12.41	12.32	24.19	0.58
	12:39	3.53	11.850	7.94	4.21	-15				
	12:54	3.53	11.880	7.93	4.19	-13				
	13:09	3.53	11.890	7.92	4.16	-11				
	13:24	3.54	11.890	7.91	4.13	-9	12.41	12.32	24.16	0.57
	13:39	4.28	11.920	7.89	4.10	-7				
	13:54	4.27	11.930	7.88	4.06	-4				
	14:09	4.26	11.940	7.88	3.98	-1				
	14:24	4.28	11.940	7.88	4.03	4	12.41	12.27	24.14	0.56
	14:39	4.30	11.960	7.86	3.98	8				
	14:54	4.37	11.970	7.86	4.03	12				
	15:09	0.67	11.910	6.40	4.04	88				
	15:24	0.69	11.900	6.38	4.01	97	12.20	12.09	24.19	
	15:39	0.71	11.900	6.36	4.06	102				
	15:54	0.73	11.890	6.34	4.05	105				
	16:09	0.76	11.900	6.34	4.08	106				
	16:24	0.77	11.880	6.33	4.06	108	12.00	12.17	24.24	
16:39	0.80	11.880	6.33	4.05	111					
16:54	0.83	11.870	6.34	4.04	112					
17:09	0.85	11.790	6.39	4.05	110					
17:24	0.88	11.830	6.36	4.11	110	12.20	12.07	24.24		
17:39	0.89	11.820	6.36	4.01	103					
17:54	0.92	11.790	6.36	4.09	99					
18:09	0.94	11.770	6.39	3.98	93					
18:24	0.95	11.770	6.40	3.98	87	12.15	12.12	24.19		
18:39	0.97	11.770	6.34	4.25	89					
18:54	0.99	11.770	6.37	4.03	91					
19:09	1.01	11.770	6.30	3.94	98					
19:24	1.03	11.770	6.26	3.97	103	12.15	12.12	24.14		
19:39	1.04	11.770	6.26	4.05	105					
19:54	1.04	11.770	6.27	4.00	108					
20:09	1.05	11.770	6.26	3.99	112					
	20:24	1.06	11.770	6.27	3.97	114	12.10	12.17	24.19	

<b>Table 20</b>										
<b>BAZE - Acetate Injection - April 2005</b>										
Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
4/28/2005	6:50	4.211	11.87	8.13	5.16	-20	12.36	12.42	23.89	0.74
	7:05	4.298	11.86	8.13	5.15	-19	12.26	12.42	23.89	0.74
	7:20	4.328	11.86	8.13	5.15	-18	12.30	12.37	23.89	0.65
	7:35	4.323	11.86	8.12	5.19	-18				
	7:50	4.303	11.87	8.12	5.18	-14	12.25	12.37	23.94	0.57
	8:05	4.321	11.88	8.12	5.13	-14				
	8:20	4.333	11.87	8.12	5.06	-15				
	8:35	4.33	11.87	8.12	4.98	-17				
	8:50	4.307	11.87	8.11	4.94	-15	12.30	12.32	23.94	0.56
	9:05	4.18	11.86	8.12	4.88	-18				
	9:20	3.647	11.85	8.06	4.82	-14				
	9:35	3.051	11.86	7.99	4.79	-11				
	9:50	2.228	11.86	7.80	4.76	-1	12.20	12.27	23.94	0.56
	10:05	4.568	11.89	8.10	4.64	-8				
	10:20	4.503	11.88	8.11	4.53	-9				
	10:35	4.458	11.89	8.08	4.58	-8				
	10:50	4.431	11.9	8.09	4.49	-13	12.20	12.27	23.99	0.17
	11:05	3.795	11.89	8.02	4.43	-13				
	11:20	3.281	11.88	7.97	4.40	-12				
	11:35	3.126	11.87	7.86	4.36	-8				
	11:50	4.473	11.89	8.05	4.32	-14	12.20	12.27	23.89	0.56
	12:05	0.706	11.86	6.88	4.16	25				
	12:20	0.723	11.87	6.90	4.06	23				
	12:35	0.742	11.87	7.04	4.05	17				
	12:50	0.761	11.88	7.10	4.06	16	12.20	12.37	23.94	0.58
	13:05	0.784	11.91	6.89	4.11	27				
	13:20	0.807	11.91	7.12	4.00	18				
	13:35	0.831	11.92	7.00	4.29	25				
	13:50	0.849	11.9	6.82	4.24	36	11.95	12.04	23.99	
	14:05	0.873	11.94	6.76	4.24	43				
	14:20	0.89	11.92	6.81	4.95	39				
	14:35	0.908	11.89	7.12	3.60	27				
	14:50	0.923	11.87	6.99	4.54	30	12.00	12.02	23.99	
	15:05	0.935	11.89	6.77	4.39	41				
15:20	0.959	11.87	6.80	4.58	43					
15:35	0.974	11.85	6.71	4.87	45					
15:50	0.993	11.87	7.07	4.80	28	12.00	12.02	23.99		
16:05	1.011	11.87	6.81	4.68	39					
16:20	1.02	11.92	6.71	4.58	45					
16:35	1.03	11.90	7.04	4.56	31					
16:50	0.01	12.34	6.46	4.58	81	11.90	12.12	23.99		
17:50						11.95	12.12	23.94		

**Table A21**

**BAZE - Acetate Injection - June 2005**

Date	Time	Cond. mS/cm	Temp °C	pH	DO Conc mg/L	ORP mV	Pump Flow - gpm			
							IW01	IW02	EW01	Acet. Feed
6/22/2005	6:00						12.52	12.47	23.99	---
	6:17	4.608	12.13	7.86	6.79	-37.00	12.51	12.47	23.99	---
	6:32	4.612	12.13	7.86	6.68	-29.00				
	6:47	4.664	12.15	7.85	6.75	-26.00				
	7:02	4.633	12.19	7.81	6.30	-22.00	12.52	12.42	23.99	---
	7:17	4.317	12.18	7.82	6.19	-21.00				
	7:45	3.994	12.25	7.81	6.01	-17.00				
	8:00	3.872	12.27	7.81	5.89	-13.00	12.51	12.42	23.99	---
	8:15	3.539	12.22	7.76	5.75	-8.00				
	8:30	3.531	12.22	7.75	5.87	-6.00				
	8:45	3.572	12.24	7.74	5.73	-4.00				
	9:00	3.512	12.23	7.76	5.62	-5.00	12.32	12.41	24.04	---
	9:15	3.495	12.24	7.72	6.13	-3.00				
	9:30	3.548	12.24	7.66	5.57	1.00				
	9:45	3.561	12.26	7.63	5.37	2.00				
	10:00	3.519	12.27	7.62	5.40	4.00	12.31	12.42	23.99	---
	10:15	3.556	12.27	7.6	5.26	5.00				
	10:30	3.209	12.25	7.54	5.10	6.00				
	10:45	2.589	12.2	7.5	5.09	8.00				
	11:00	2.298	12.16	7.37	5.00	10.00	12.31	12.42	23.99	---
	11:15	0.629	11.93	6.78	5.04	45.00				
	11:30	0.648	11.91	6.75	5.51	48.00				
	11:45	0.664	11.91	6.77	5.03	50.00				
	12:00	0.686	11.89	6.77	4.96	46.00	12.20	12.02	24.14	
	12:15	0.702	11.95	6.85	5.30	47.00				
	12:30	0.724	11.97	6.89	4.86	48.00				
	12:45	0.739	12.02	6.92	5.21	54.00				
	13:00	0.755	12.03	6.92	4.72	59.00	12.20	12.07	24.14	
	13:15	0.767	12.05	6.93	4.68	61.00				
	13:30	0.778	12.05	6.94	4.83	62.00				
	13:45	0.796	12.06	6.94	4.67	63.00				
	14:00	0.81	12.06	6.94	4.70	63.00	12.20	12.07	24.14	
	14:15	0.83	12.06	6.95	4.66	61.00				
14:30	0.847	12.06	6.95	4.70	60.00					
14:45	0.855	12.07	6.97	4.81	53.00					
15:00	0.878	12.05	6.95	4.61	43.00	12.20	12.07	24.19		
15:15	0.893	12.06	6.93	4.66	43.00					
15:30	0.9	12.03	6.94	4.68	40.00					
15:45	0.911	11.99	6.86	4.65	39.00					
16:00	0.916	11.98	6.89	4.58	43.00	12.20	12.07	24.19		
16:15	0.92	12.03	6.96	4.65	51.00					
16:30	0.929	12.02	6.91	4.60	51.00					
16:45	0.929	11.99	6.86	4.78	50.00					
17:00	0.931	11.96	6.89	4.80	47.00	12.15	12.12	24.14		
17:15	0.941	11.99	7.09	4.49	32.00					
	17:30	0.949	12.02	7.01	4.47	46.00				
	17:45	0.953	12.01	6.95	4.75	58.00				
	18:00	0.959	12.01	6.93	4.45	62.00	12.10	12.17	24.14	



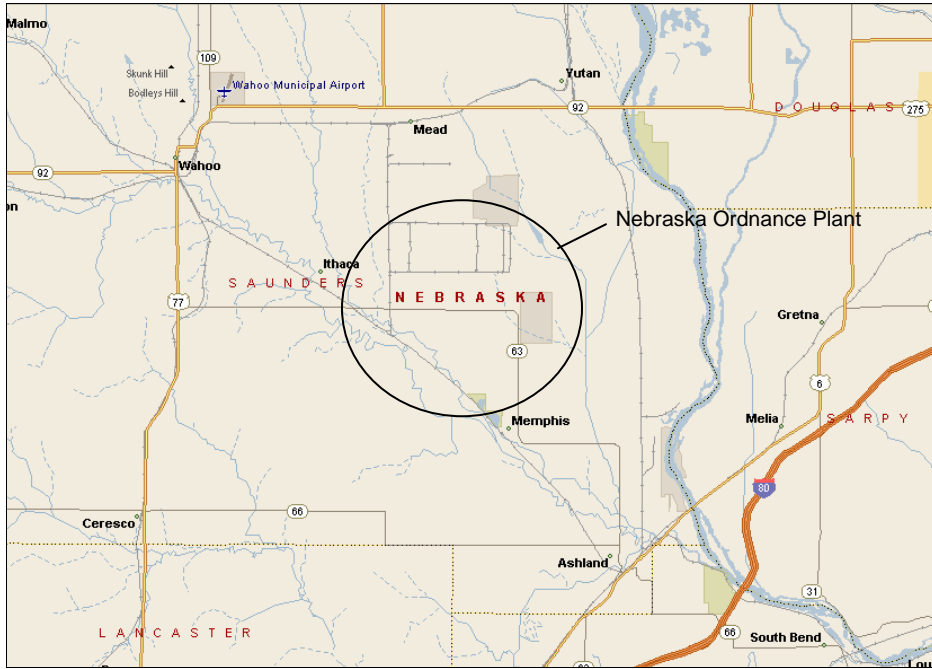


Figure 1. Site map

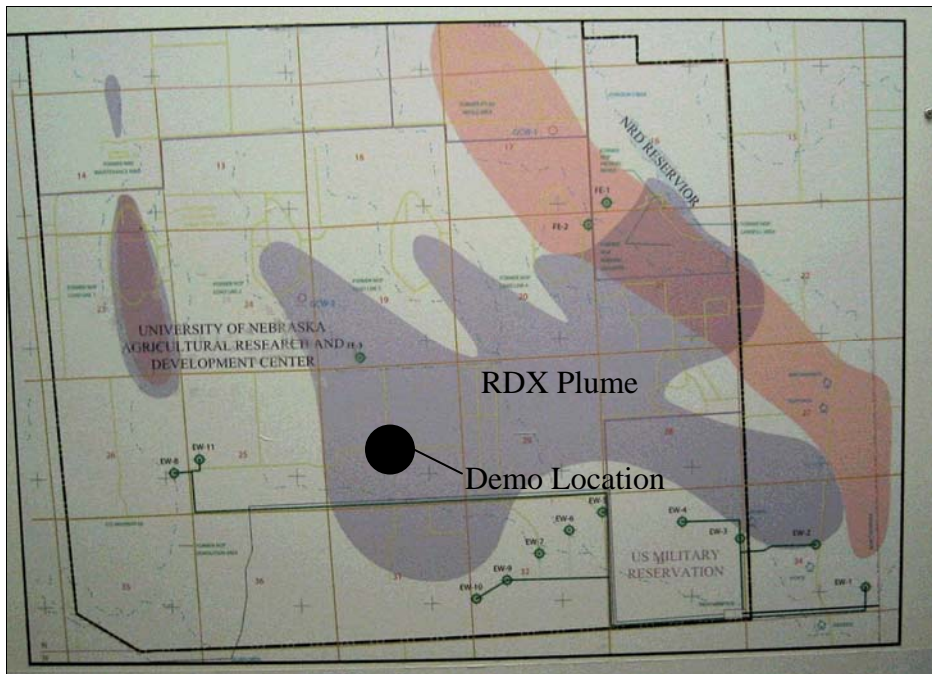


Figure 2. Plume map



Figure 3. Geoprobe operation

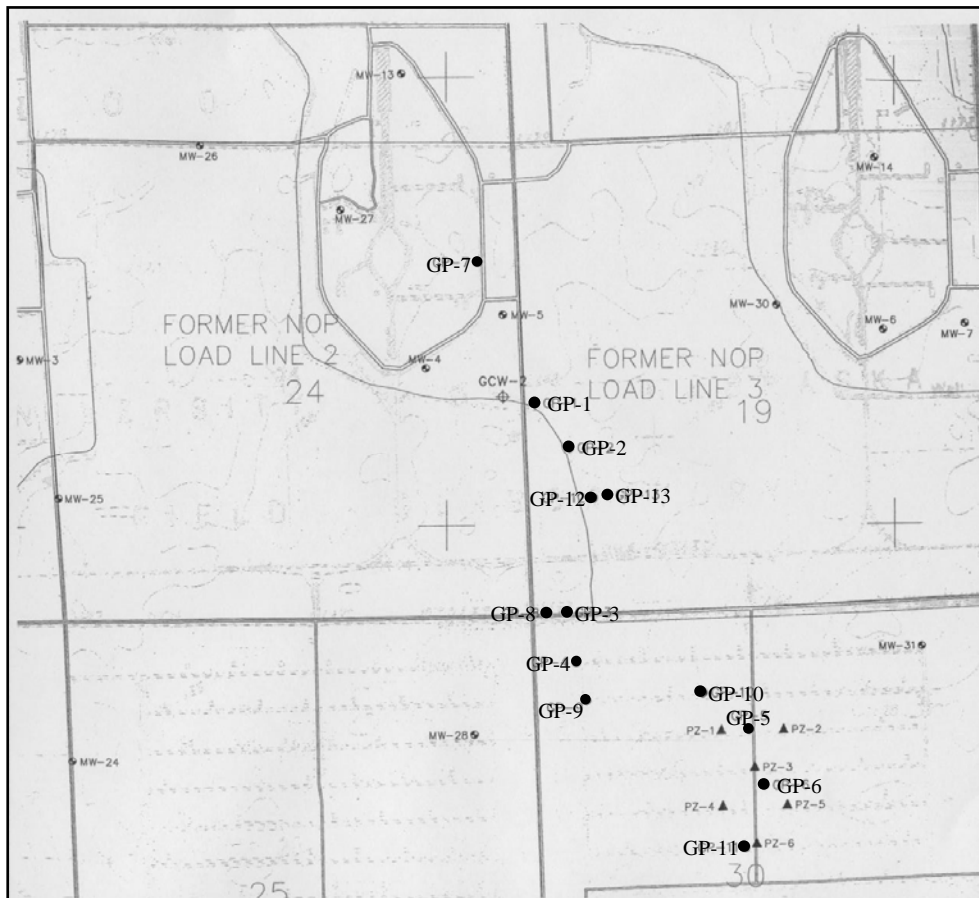


Figure 4. Geoprobe installation of 13 direct pushes.

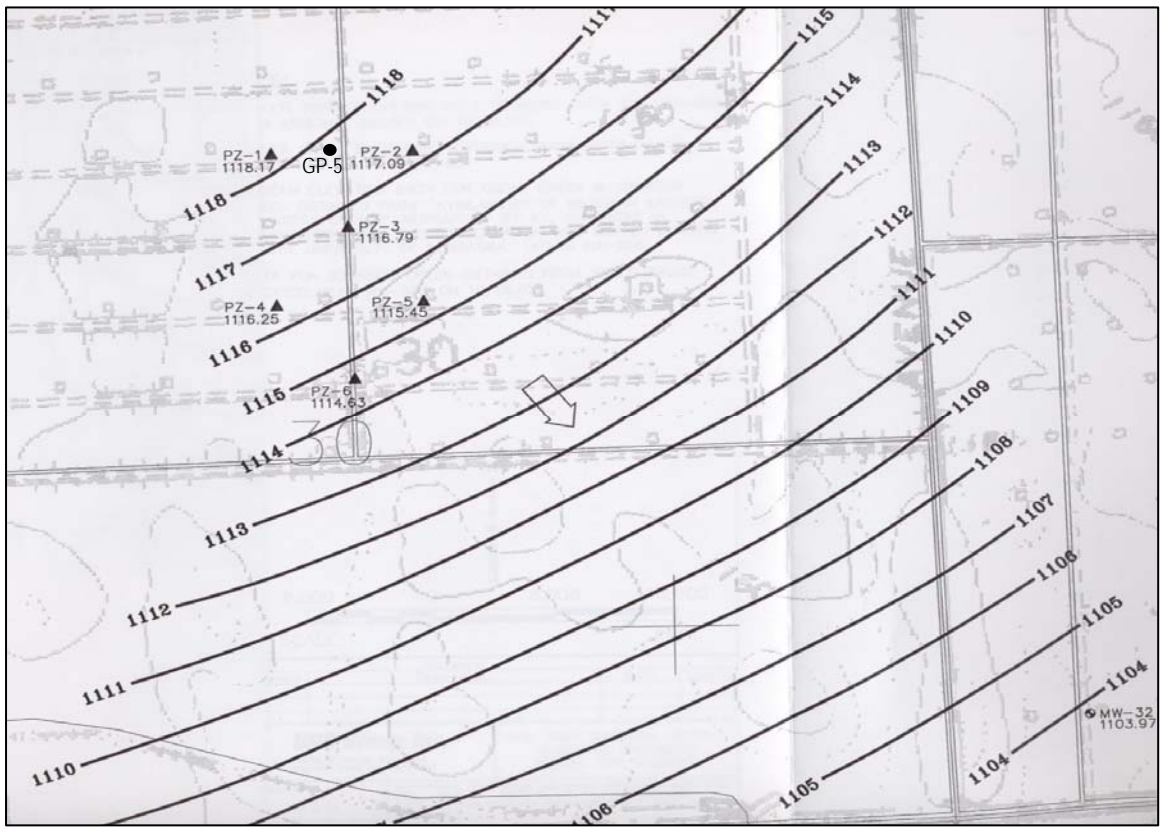


Figure 5. Temporary piezometer locations and potentiometric surface map



Figure 6. Installing extraction well (EW-01)





Figure 7. Photo of injection wells 1 & 2, extraction well 1, and monitoring well 3

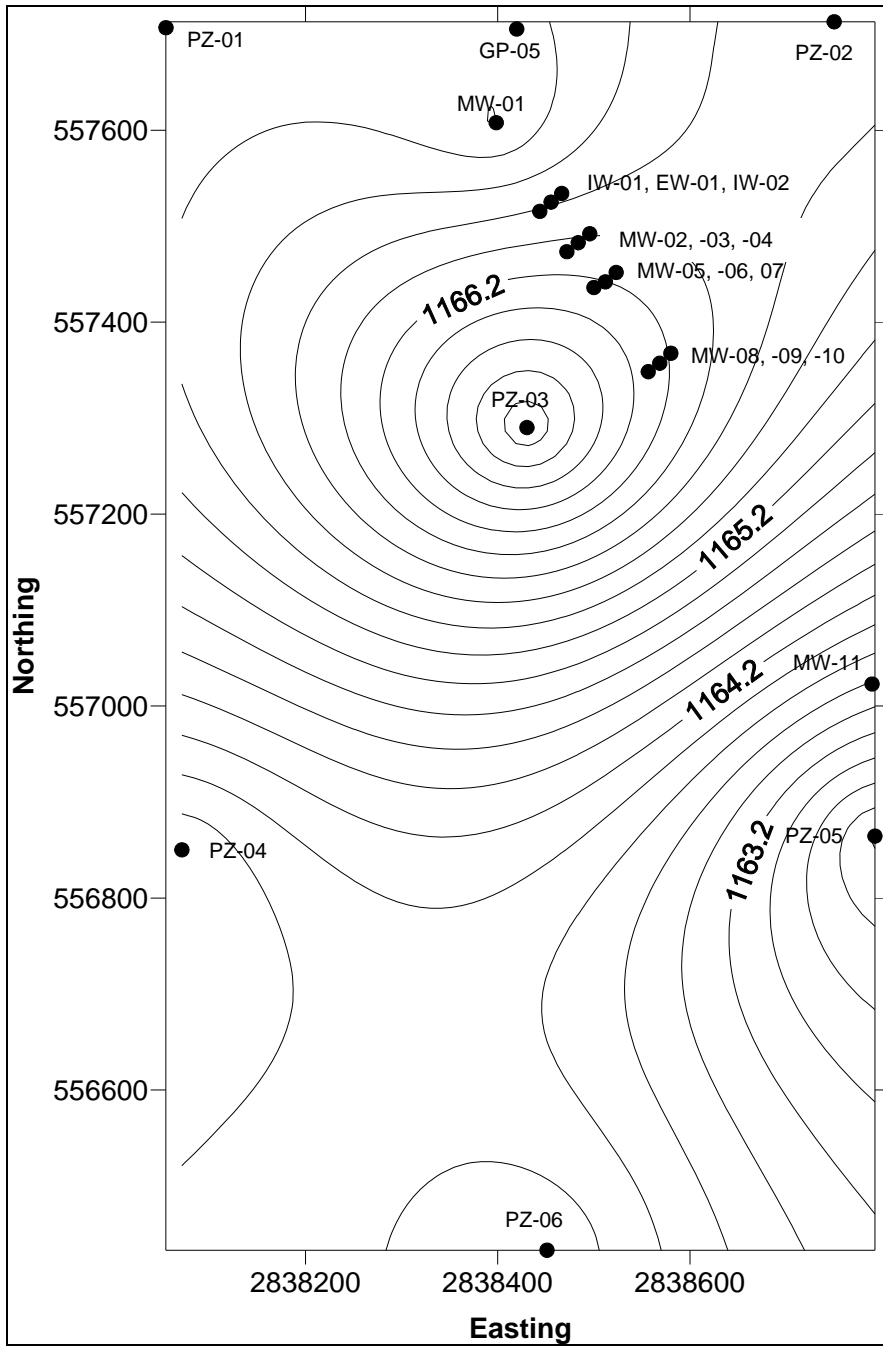


Figure 8. GP-5, piezometers, and well locations



Figure 9. Installation of MW-01

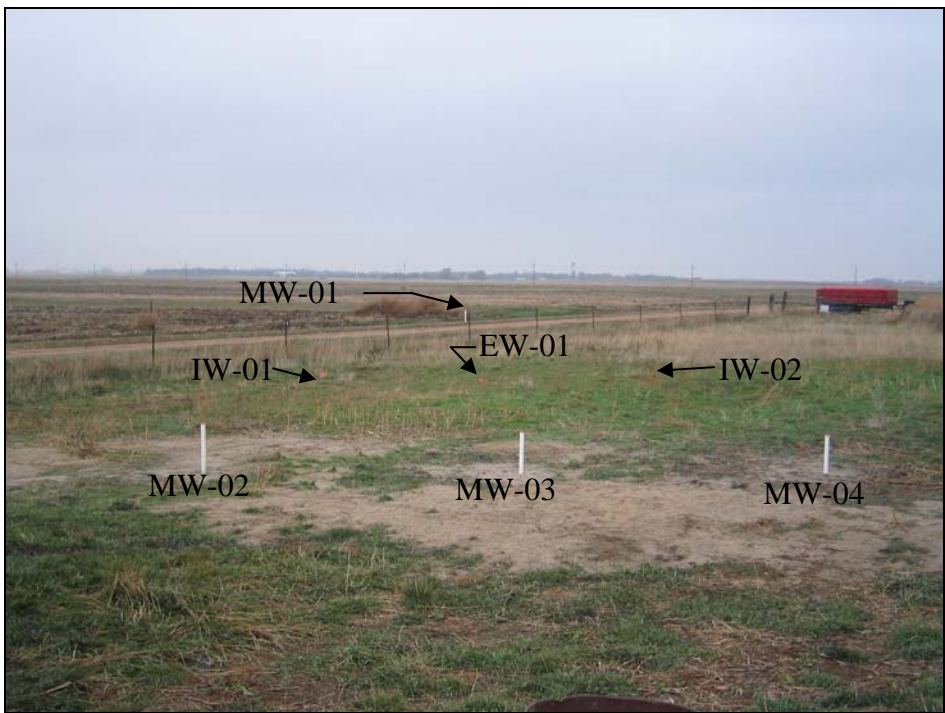


Figure 10. Photo of extraction, injection, and monitoring wells

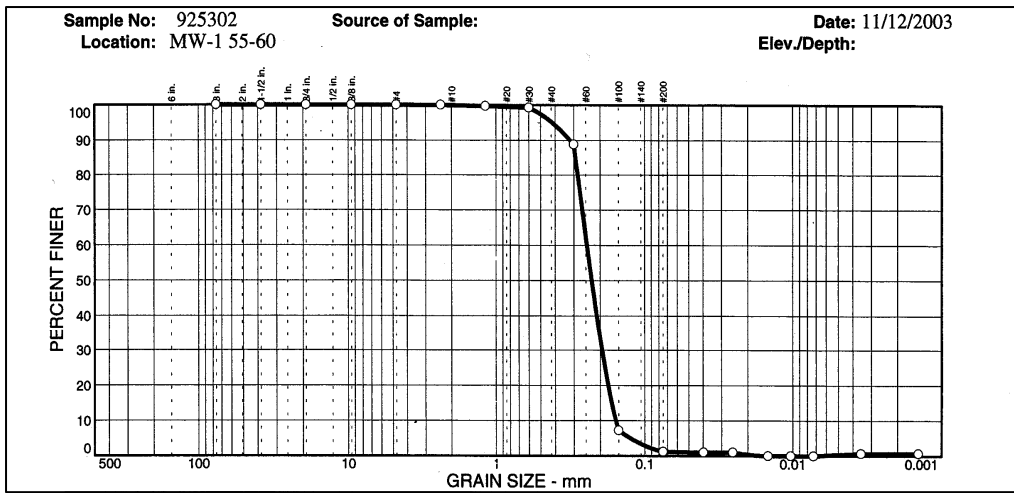


Figure 11. Particle size distribution at 55-60 ft bgs for MW-01

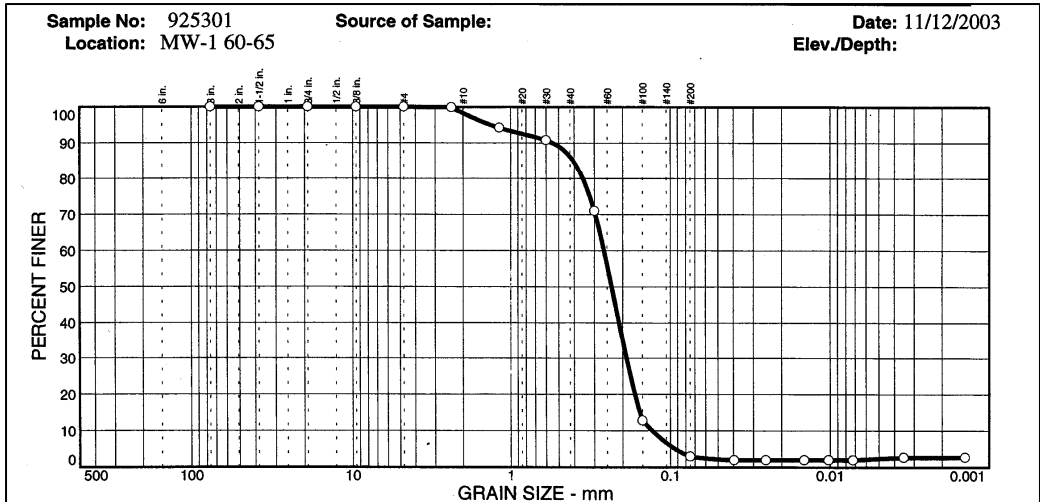


Figure 12. Particle size distribution at 60-65 ft bgs for MW-01

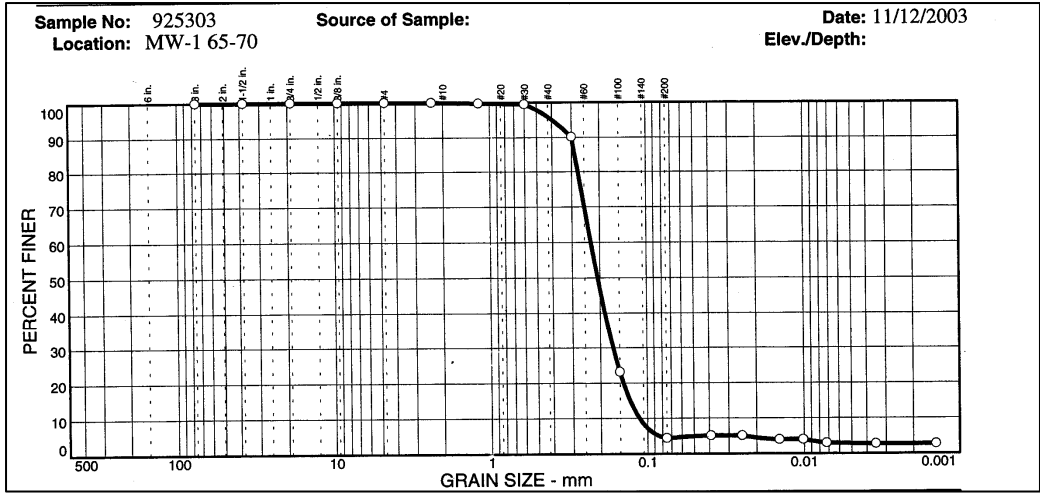


Figure 13. Particle size distribution at 65-70 ft bgs for MW-01



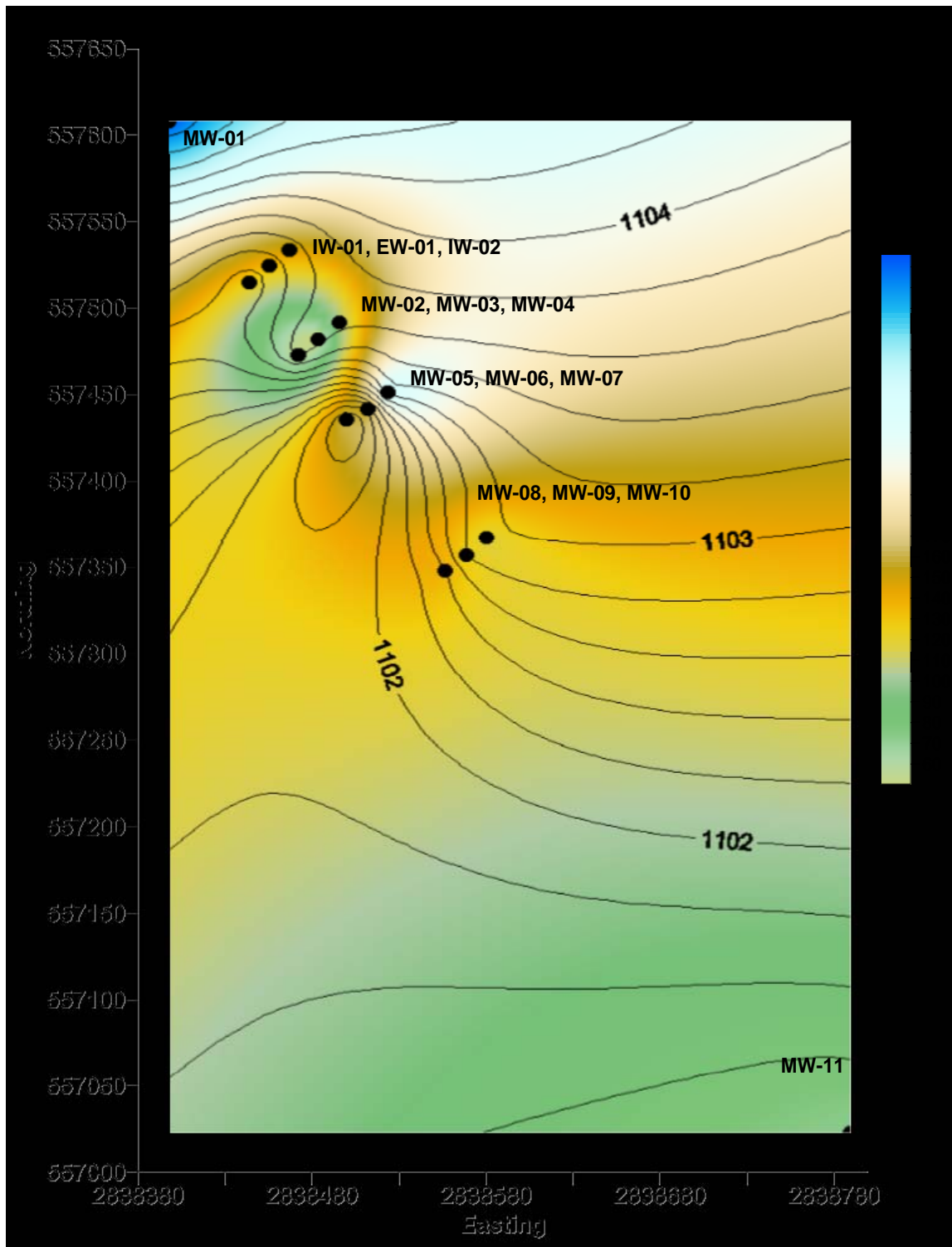


Figure 14. RDX concentration at approximately 60-ft bgs

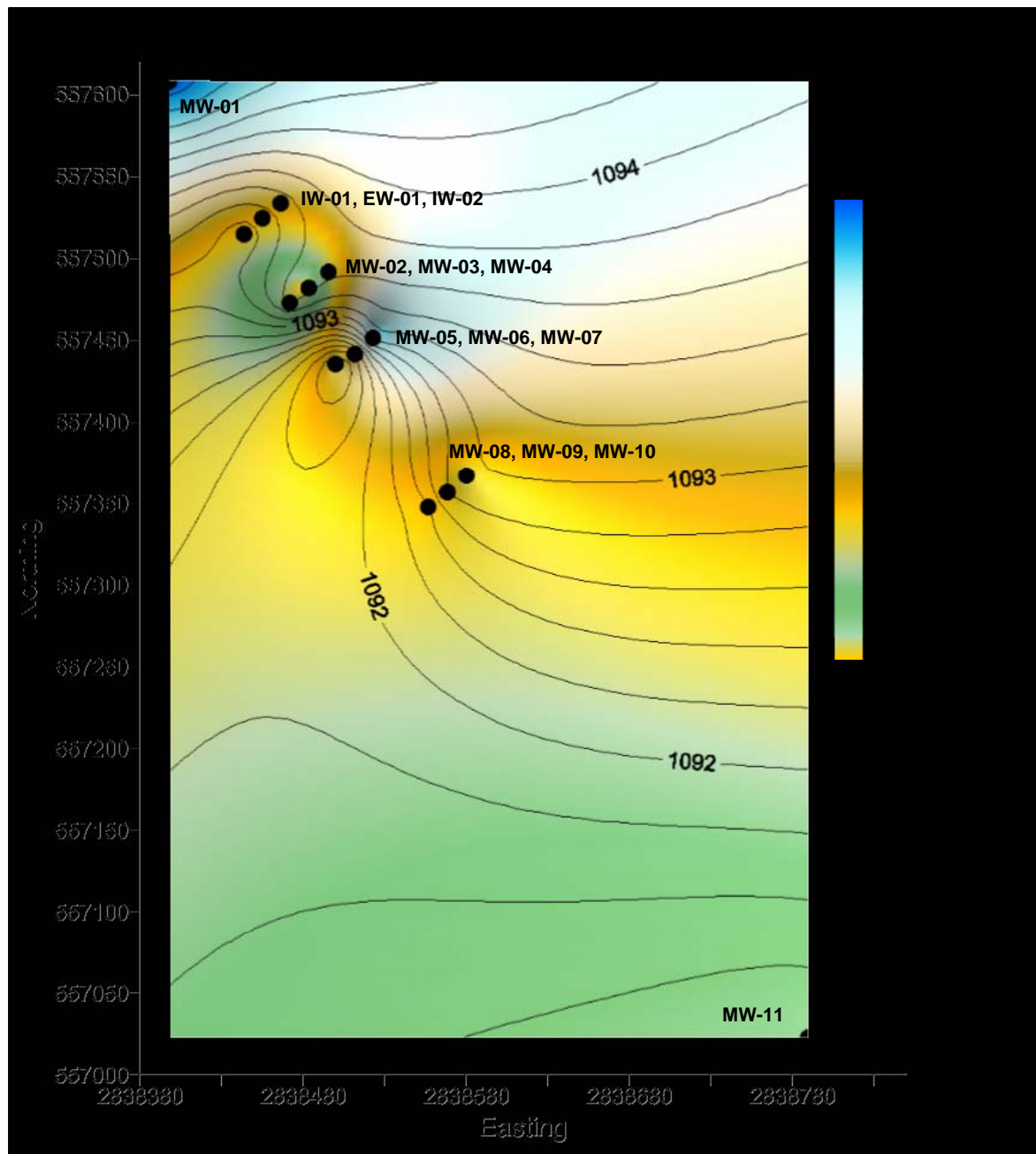


Figure 15. RDX concentration at approximately 70-ft bgs

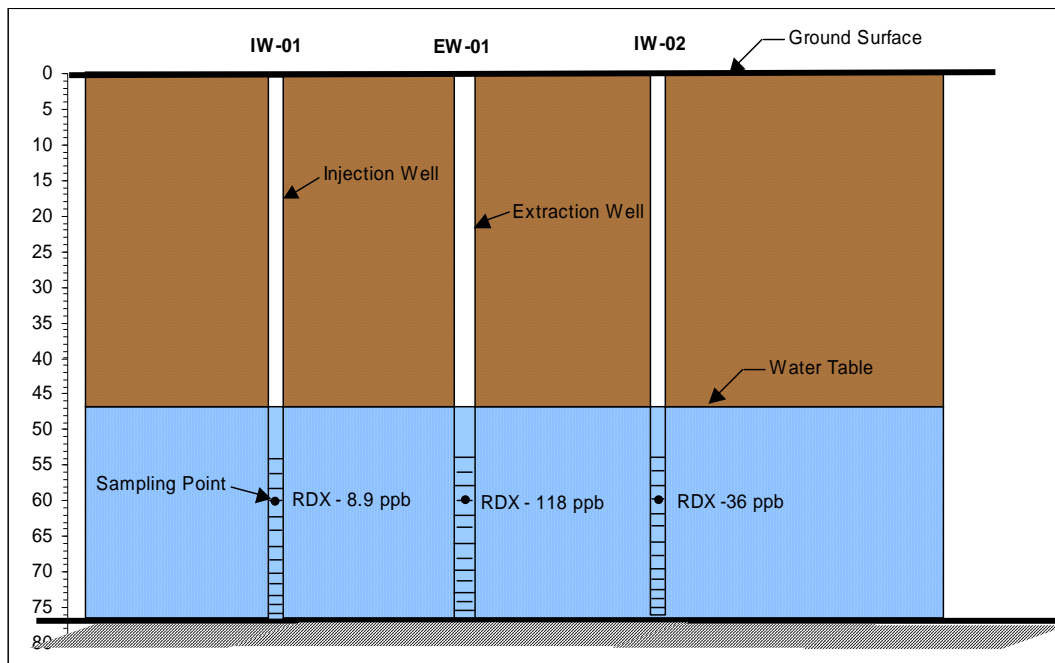


Figure 16. Injection and extraction wells cross-section showing sampling point and RDX concentration during November 2004 sampling event

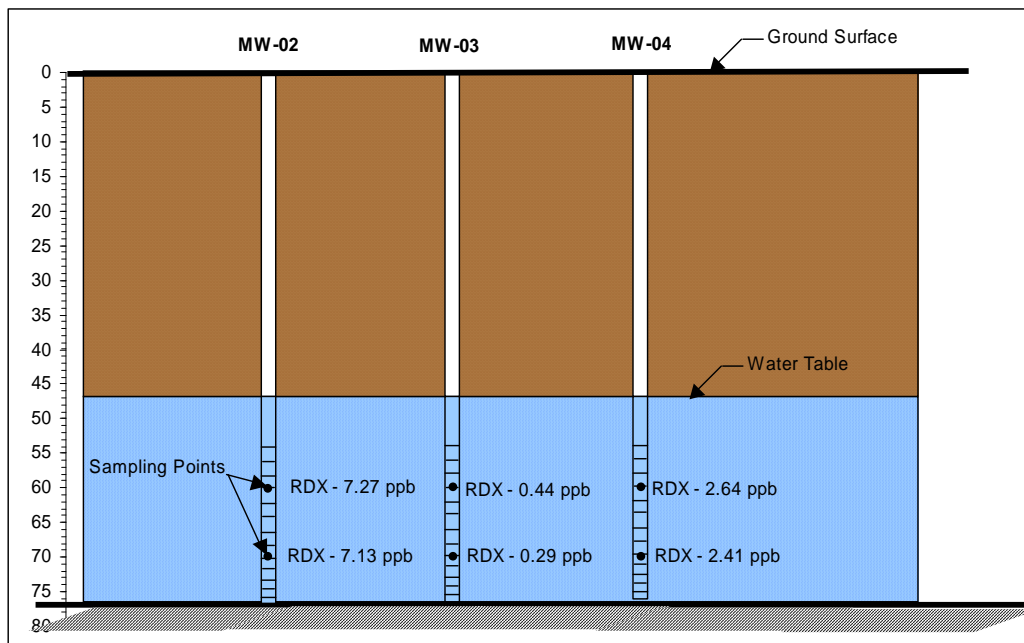


Figure 17. Monitoring wells 2-4 cross-section showing sampling point and RDX concentration during November 2004 sampling event

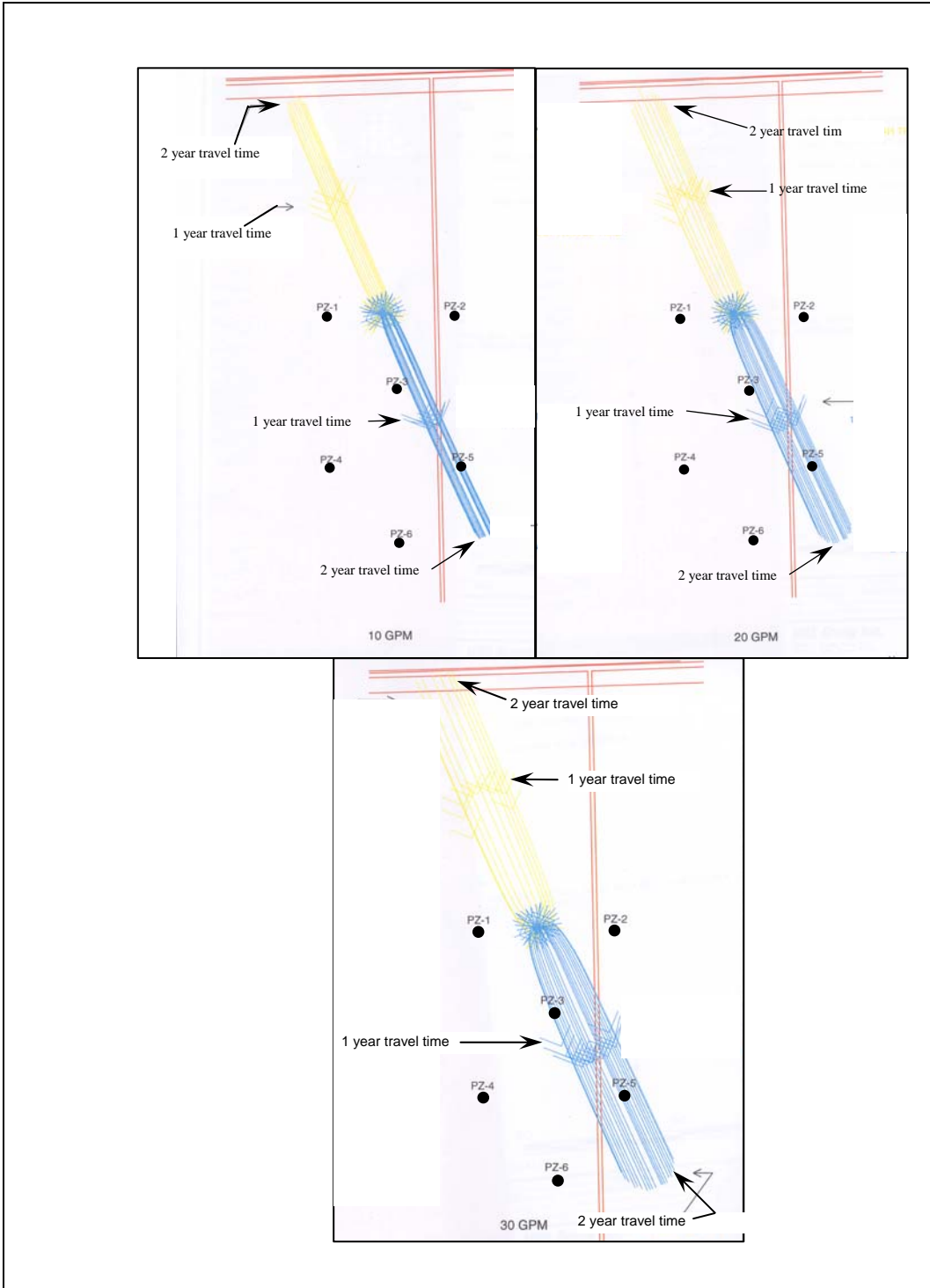


Figure 18. Model predicted capture and recharge zones for pump rates of 10, 20, & 30 gpm

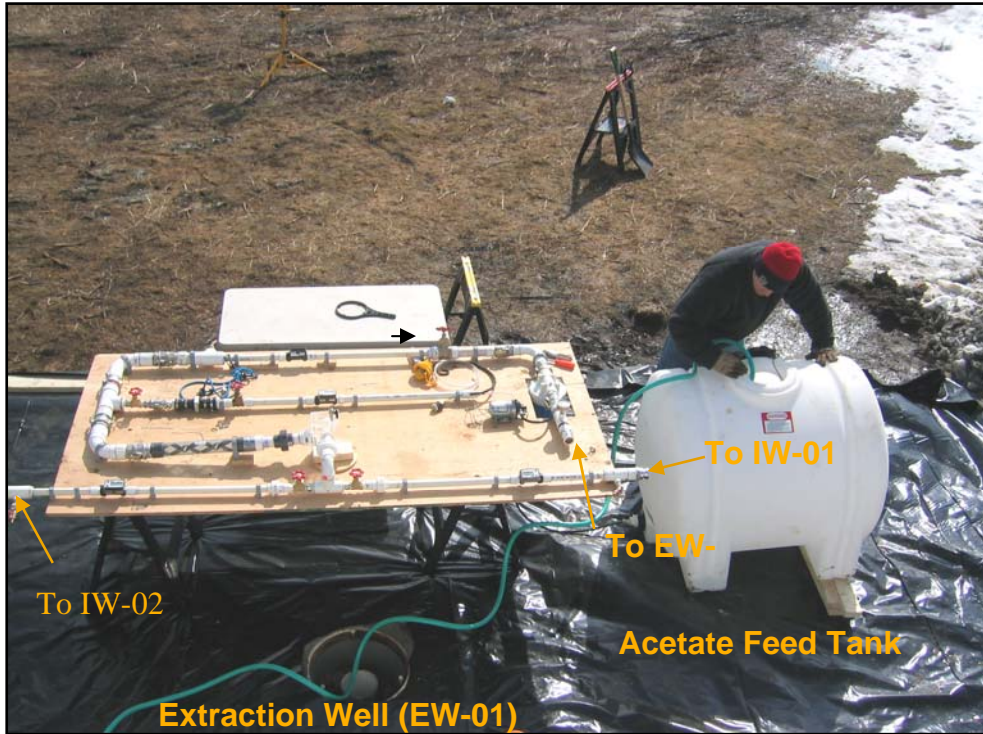


Figure 19. Acetate injection system layout

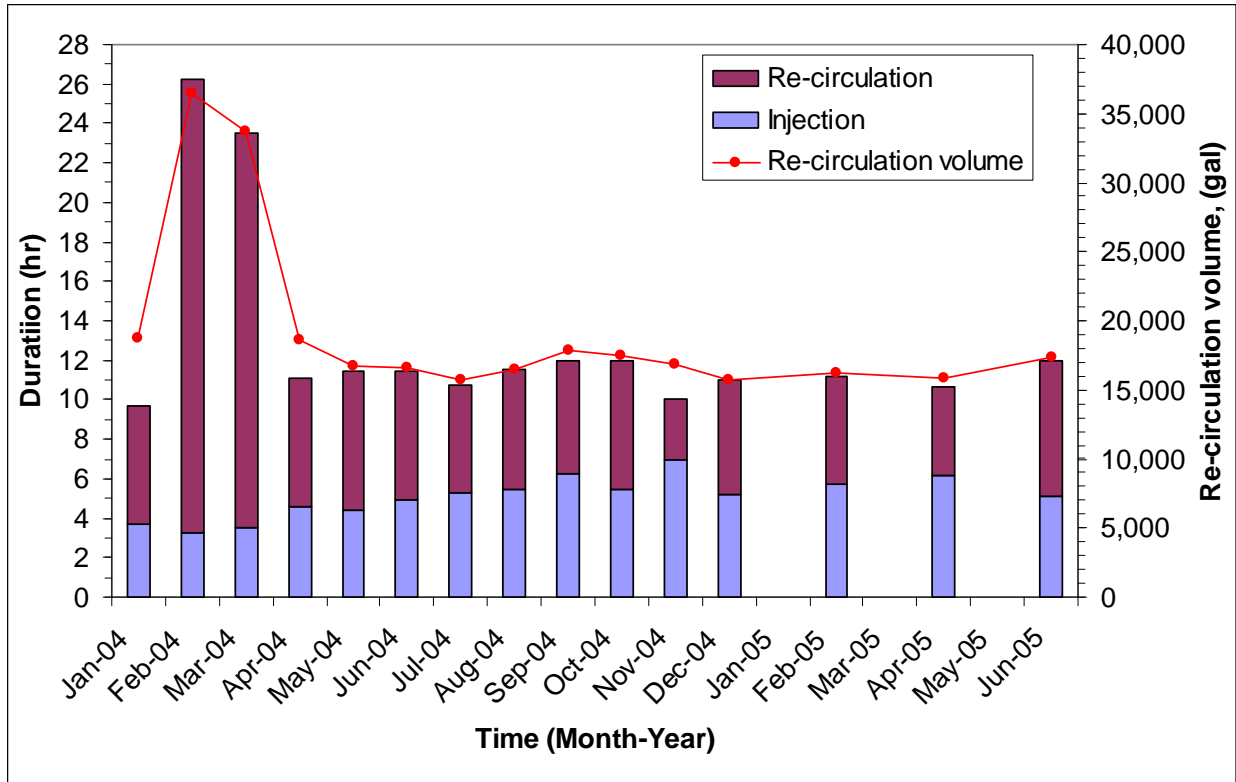


Figure 20. Acetate injection system injection and recirculation duration

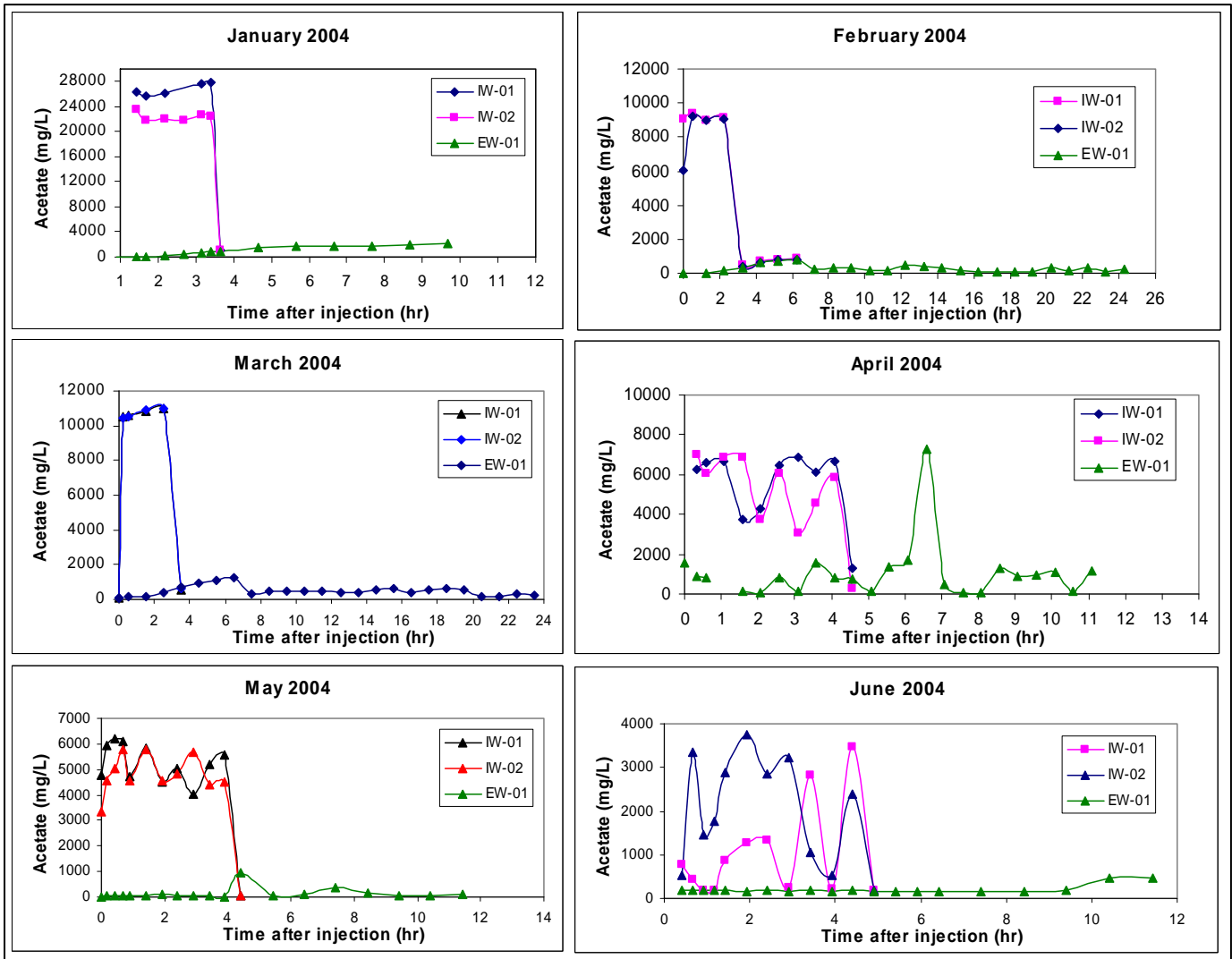


Figure 21. Acetate injection results from January to June 2004

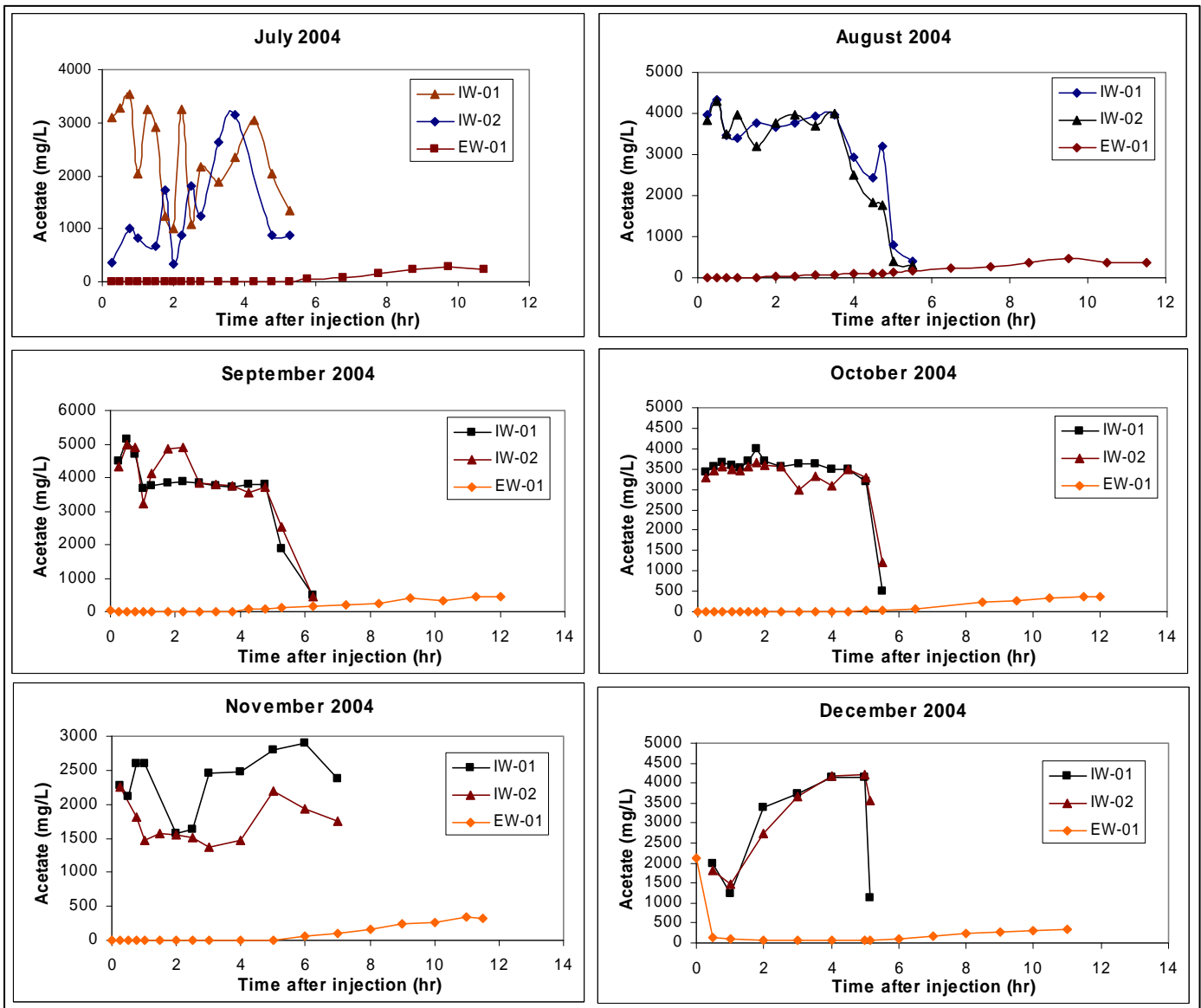


Figure 22. Acetate injection results from July to December 2004